UK Marine Climate Change: Taking our community forward

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The UK Marine climate change impacts partnership (MCCIP) was initiated in 2006. Since then, we have worked directly with well over 300 researchers (including many MASTS members!) to provide a community view on the state of the science and consider how we can collectively address the many issues raised.

This inclusive approach has been critical to the ongoing success of MCCIP and to enable us to broaden the scope of our work into new areas.

This talk will focus on:

*Our recent publication on key challenges facing the UK marine climate change community from both research and end user perspectives. These outputs are intended to help the community plan and deliver cross-cutting work programmes, inform UK and devolved marine and climate change strategies, and support policy needs.

*Our move from printed periodic report cards to online 'rolling' evidence updates to accelerate science to policy knowledge exchange. Headlines from the first few topics to be published topics will be presented, including the 'Scottish' led aquaculture review.

*Progress on new adaptation work. Two projects are underway, one looking at fish, fisheries and aquaculture in the context of a rapidly changing policy context, and the other on coastal communities, and their health and wellbeing.
*The application of MCCIP principles and approaches to the wider world, including the UK overseas territories.

*Our efforts to engage more widely with evidence providers and users…and lessons learnt along the way!

Acknowledgements

The UK Marine climate change research community, including the MASTS community, who have contributed massively to the success of MCCIP.

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The Importance of Collaborating with Multiple Stakeholders for Translating Science into Policy: A Success Story from Brazil

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Research produces new knowledge and often unexpected innovative solutions to existing challenges, but application is frequently hindered by a disconnect and/or lack of mutual trust between academia and decision-makers. Overcoming these frustrating barriers to make a positive change through science-informed policy changes can be facilitated by taking a strategic approach whilst (co)conducting the research.

Here we present a success story from Brazil, showcasing (i) why and how an initial blue-sky study on mangrove crabs was developed into a research initiative spanning 7000 km of the country's coastline; (ii) the strategic approach, i.e. connecting with multiple stakeholders early-on and (iii) the critical final step taken to achieve the targeted long-term change of the inadequate fisheries policy that had been in force for 17 years, unnecessarily causing environmental, social and economic problems.

Acknowledgements

A big thank you to the many contributors of the REMAR initiative. The project, mostly self-funded by the academic partners, was supported by small grants from MASTS and the NERC SUPER DTP, allowing Edinburgh Napier's School of Computing Undergraduate students to help build the REMAR citizen-science mobile app and mating predictor tool.

How MEDIN supports the marine community to address Scotland's Blue Economy Vision

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Scotland's Blue Economy Vision is that by 2045 the shared stewardship of our marine environment supports ecosystem health, improved livelihoods, economic prosperity, social inclusion and wellbeing. This vision is built around 3 key pillars: environment, social and economic, and will be operationalised based on a set of principles for partnership working. One of these principles is that evidence is paramount. This presentation will reflect how The Marine Environmental Data and Information Network (MEDIN) provides a comprehensive evidence base for the environmental pillar of Scotland's Blue Economy Vision. Moreover, it will demonstrate how marine environmental data contribute directly to the economic pillar of Scotland's Blue Economy Vision.

The Marine Environmental Data and Information Network (MEDIN) is the hub for UK marine data and have been working with UK organisations since 2008 to promote good data management practices. Providing marine data guidelines, tools and an online portal, MEDIN aims to make UK marine data Findable, Accessible, Interoperable and Re-usable (FAIR). The MEDIN portal contains over 17,000 marine environmental datasets available from around the UK. This plethora of marine data provides the evidence base that allows users to make better informed decisions during projects such as when assessing ecosystem health, carrying out offshore development, and conducting marine science research. The MEDIN portal has undergone over 50 improvements in 2021 to make it easier to search for UK marine data.

In recent years, MEDIN's focus has evolved to include consideration of the economic benefits of its services as well as the marine environmental data that we provide access to. Whilst perhaps not the main focus of the economic pillar of Scotland's Blue Economy Vision, it is nevertheless a significant area to consider.

A cost benefit analysis of MEDIN conducted in 2019, showed that the benefits of MEDIN far outweigh the costs of running MEDIN with a cost benefit ratio of 8.1. One of the largest monetary benefits (saving £27.2million over 10 years) for the marine community is by using MEDIN, users can manage their own data holdings efficiently and improve their organisational data management. MEDIN users spend less time carrying out expensive surveys of the marine environment because of the accessibility and availability of other people's data from the MEDIN portal and Data Archive Centres. This saves users about £13.7million over 10 years according to the cost benefit analysis study carried out by consultants eftec and ABPmer.

The Scotland's Blue Economy Vision aligns with MEDIN principles in that both strategies aim to enable innovation and raise awareness of marine resources. The MEDIN tools and services support the Blue Economy Vision in terms of marine data accessibility and monetary benefits to the economy via the re-use of existing marine data. MEDIN provides measurable benefits to the UK economy and will increase the efficiency of gathering marine data by providing better access to data, support better decision making by increasing the quality and volume of data available and finally, adding value to UK marine data by maximising interoperability and enabling the UK to contribute to, and benefit from, global best practices in this domain. MEDIN will soon be developing a new business plan and aspects of Scotland's Blue Economy Vision report will feed into it.

Analysis of greenhouse gas emissions from Scotland's fisheries by fleet and region

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Reducing greenhouse gas emissions from activities across the Blue Economy remains a critical priority in achieving Scotland's climate target to reach net zero greenhouse gas emissions by 2045. Emissions from fisheries are estimated globally to be responsible for 4% of emissions from food productions (Parker et al., 2018). In Scotland, the fishing sector is estimated to contribute 0.3 megatonnes CO2-equivalent (MtCO2e) of the total 40.0 MtCO2e in 2020 (Scottish Government, 2021).

Based on an in depth analysis of Scotland's pelagic fishing fleet, vessel fuel consumption is the main activity contributing to these emissions (Sandison et al., 2020). Recent work by Marine Scotland and others to improve the estimation of greenhouse gas emissions for all the fleet segments of the Scottish fishing sector has shown the distribution of emissions is skewed to certain segments. This work has also highlighted that consideration of overall greenhouse gas emissions, as well as the emissions per kilogram landed should be considered carefully in decision making. These analyses have all so far focused on fuel consumption, and have not explicitly considered interaction with carbon stored in sea bed sediments and biota.

Here, we present an analysis of the greenhouse gas emissions from the entire Scottish fleet, both by fleet segment and by region. Greenhouse gas emissions for certain fleet segments are also associated with specific ports, based on the current fleet's distribution.

The results of this analysis will inform engagement between the fishing sector, ports & harbours and decision makers.

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Effects of Coasteering on Intertidal Rocky Shore Biodiversity

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As tourists are becoming progressively more aware of anthropogenic environmental impacts they are increasingly drawn to "ecotourism", which promises a more grassroots experience with a greater focus on immersion in local culture and nature (Ana, 2017). Ecotourism activities are often marketed as environmentally sustainable, but several emerging challenges are fueling debate over best practices, sustainable management, and growing demand (Micheli *et al*., 2017).

Many ecotourism experiences are focused on coastal areas due to their high biodiversity, natural beauty, and traditional tourist draw. This, coupled with the advancement of wetsuit technology and the increasing use of digital media to map and showcase locations of interest has led to increased interactions between recreational water users and marine organisms.

Negative local-scale impacts of increasing recreational water users fall into two main categories (Davenport & Davenport, 2006), increased demand on infrastructure, and impacts on local ecosystems and marine communities. The latter mainly occurs as a result of direct interactions between marine environments and recreational watersport participants within the intertidal zone. One such watersport is coasteering.

Coasteering originated in Wales around 15 years ago and is becoming increasingly popular around the UK. While coasteering participants navigate the rocky intertidal zone by swimming, climbing, jumping, and scrambling around various coastal features. This allows participants to engage with many intertidal organisms and become immersed in an environment often inaccessible to them.

Despite the increasing profile of coasteering as an ecotourism activity, it has been identified as a potential cause of damage to the rocky intertidal.

Here we demonstrate the potential negative effects of coasteering on the rocky intertidal site known as "The Delves", located in Dunbar, East Lothian. Species richness and abundance data were gathered at two sites; the "outer delves" an area regularly used for coasteering, and the "inner delves" an isolated undisturbed area. Specific emphasis was put on the measurement of features regularly used in coasteering.

We found that the disturbed sites had lower species richness with three species *Patella vulgata*, *Nucella lapillus*, and *Corallina officinalis* in particular having significantly reduced abundances in response to coasteering activities. Sessile species were found to be particularly susceptible to damage with reduced diversity and evenness observed at disturbed sites.

Repeated measurements are needed to fully understand if these negative effects persist, or possibly increase, throughout the coasteering season, and to generate strategies to mitigate these impacts.

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Temporal trends in zooplankton and demersal fish community composition on the Scotian Slope during 1982-2019

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Understanding how marine ecosystem respond to environmental variation and human activities is key to predicting the consequences of climate change. We therefore analysed time series of both zooplankton (55 taxa; from spring and fall surveys) and demersal fish and invertebrate (32 taxa; from yearly trawls) community composition on the eastern Scotian Slope during 1982–2019. The study area, off Nova Scotia, Canada, is influenced by complex oceanographic interactions between warmer, north-eastward flowing waters derived from the Gulf Stream and colder south-westward flowing waters from the Labrador Current and Gulf of St. Lawrence[1]. In addition, the study area currently sees only limited fishing but did experience intense trawling before 1993[2]. Complex multivariate statistical analyses (trajectory analysis, multivariate regression trees and dynamic factor analysis) were applied to each ecological data set to assess (1) temporal trends and (2) identify potential tipping points. Abiotic field data as well as outputs from the Bedford Institute of Oceanography North Atlantic Model (BNAM)[3] were also examined to link ecological changes identified to shifts in the oceanographic conditions experienced in the region.

Considering the zooplankton data, our statistical approach revealed a single, significant linear trend common to both seasonal datasets, in which the abundances of 18 taxa decreased after 2008. Warmer-water species such as *Oithona atlantica* became more prevalent in the later part of the time-series while colder-water species (like *Calanus glacialis* or *Spinocalanus abyssalis*) appeared to decrease in abundance. Considering the demersal fish and invertebrate dataset, our statistical analysis revealed two periods of significant change in taxon abundances. First, a sharp increase in one third of the taxa was identified between 1996 and 2000. This was, for example, observed for *Lophius americanus* (American anglerfish) and *Hippoglossoides platessoides* (American plaice). Second, there was a decrease in the abundances of eighteen fish species after 2000 (including the longfin hake, *Urophycis chesteri*, or the Atlantic halibut *Hippoglossus hippoglossus*), while a few taxa, including the squid *Illex illecebrosus*, displayed strong increases in biomass towards the end of the time series.

Studies have suggested that surface and subsurface temperatures along the Scotian Slope have increased in recent decades, as the influence of warm slope water has grown[4]. This was confirmed by the analysis of satellite derived data as well as the BNAM outputs. It is believed that this increase in temperature has contributed to the biological shifts detected in both ecological compartments. This work is part of the Horizon 2020 iAtlantic project, which aims to assess the status of deep-sea and open-ocean ecosystems across the Atlantic Ocean. Analysis of ecological time-series from other study regions are underway to identify additional drivers of change across the Atlantic bassin.

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Adapting the Marine Stewardship Council's Risk-Based Framework to assess the impact of towed bottom fishing gear on blue carbon habitats

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Area being submitted to: *1. General Science Session;*

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*This template is an example of how to prepare an abstract for the 2022 MASTS Annual Science Meeting, to be held on **8-10 November 2022 at the Technology & Innovation Centre, Glasgow**.*

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Acknowledgements

All the Authors are kindly thanked for having submitted an abstract formatted according to this template.

References

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Abstract: Wild capture fisheries are of global economic and social importance providing commercial seafood and a primary source of protein to people globally. There is a broad research base on the environmental impacts of fishing gears and the processing methods involved in wild capture fisheries yet, they are also known to contribute to the global CO_2 budget. Evaluating the risk wild capture fisheries pose to ecosystem health is vital to sustainably scale fishing practices to meet increasing global nutritional needs, whilst meeting ambitions for reaching net-zero and reducing direct and indirect GHG emissions. Ecological risk assessments, trait-based assessments, and vulnerability assessments have long supported fisheries management systems globally but do not yet provide any representation regarding the impacts that fishing gears have on the ability of the habitat to capture and store carbon. Considering the importance of accessibility and transparency in approaches necessary for fisheries sustainability certifications, this paper describes a method to integrate habitat carbon capacity attributes into the Marine Stewardship Council (MSC) Consequence and Spatial Analysis (CSA) framework. Applying the CSA carbon extension developed herein produces different CSA risk scores compared to the MSC CSA that does not account for carbon. The CSA carbon extension tool developed is the first attempt made to incorporate carbon indicators into an extant risk-based framework, which can be widely adopted to assess the UK fishery's carbon impacts.

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Salmon Parasite Interactions in Linnhe, Lorn, and Shuna: Sea lice dispersal model evaluation using an ensemble approach

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Continued growth of the blue economy requires a strong scientific evidence base underpinning relevant, timely and fair regulation, developed in consultation with stakeholders. Sea lice are ubiquitous, endemic ectoparasites of salmonids in the North Atlantic Ocean. The potential negative effects of sea lice on wild salmonid fish populations are regarded as one of the most serious limitations to sustainable growth of salmon aquaculture. Due to their planktonic larval stages, lice can be transmitted over distances of several kilometers, so management must focus at the area rather than farm level.

To understand area interactions, in order to mitigate negative effects of sea lice on aquaculture and wild salmonids, coupled biophysical models are used to calculate dispersal rates of sea lice from farms. State-of-the-art hydrodynamic models have been developed, which, when coupled with a biological model, can be used to inform on dispersal rates of sea lice. We evaluated three coupled bio-physical models, each describing sea lice dispersion in Loch Linnhe, Scotland's largest fjordic system and home to around 20 salmon aquaculture sites. We carried out physical model validation and biological inter-model comparison, through comparison with field data. We assessed use of ensemble modelling techniques to provide estimates of uncertainty within the Loch Linnhe system. Relative within-model between-scenario changes resulting from different control strategies or resource constraints in different scenarios were found. Although there were differences between the models in absolute outcomes, model comparisons with the field data provided similar results. This first use of an ensemble approach for sea lice dispersal modelling allows quantification of model uncertainty, providing management and end-user a level of confidence in predictions made by these models.

Modelling brown algae individual growth using dynamic energy budget theory under various climate change scenarios

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Seaweed forests are a significant feature of coastal ecosystems. They are not only of economic importance, but also play a role in carbon capture, primary production and in creating a structurally complex habitat that enhances biodiversity,. However, there are few models which describe the dynamics of forests.

Here we follow a dynamic energy budget (DEB) theory approach to model the individual growth trajectories of two contrasting species of brown seaweeds - *Laminaria hyperborea* and *Fucus vesiculosus*. Our DEB model tracks the pathways of carbon and nitrogen from environmental uptake thorough to storage and assimilation into new tissue and reproductive structures. Parameters for the models were determined partly from the literature, and partly by fitting the models to experimental data on individual plant growth patterns.

The parameterized models are used to predict the effect of changing environmental conditions on biomass, for both *Fucus* and *Laminaria*. The baseline results for both species are the current environmental conditions in Scotland. The results show that the model can predict the biomass of the individual, both for lifetime growth curves and seasonal fluctuations. The model runs are then repeated for future environmental conditions under the IPSS RCP8.5 emissions scenario, to show how growth and biomass will be affected by the changing conditions that we could be seeing in Scottish water in the near future.

Physiological process-based models such as the one developed here provide a mechanistic alternative to statistical models for predicting changes in species distributions in response to climate change.

Acknowledgements

This studentship has been funded under the NERC Scottish Universities Partnership for Environmental Research (SUPER) Doctoral Training Partnership (DTP) and University of Strathclyde.

Consequence of small-scale sea lice movements on their dispersion: A sensitivity study in Lower Loch Linnhe, Scotland

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Sea lice are ectoparasites causing significant problems to fish health and aquaculture costs. The high density of suitable hosts in salmon farms supports a high number of sea lice. Their planktonic larvae can be released back in the surrounding waters where they can infect wild migrating salmon smolts, making sea lice a potentially contributing factor in the decline of wild salmonids in Scotland.

In the context of a Blue Economy vision for Scotland, sustainable salmon aquaculture and conservation of wild salmon are both priorities for Scottish Government policy. This strategy requires the identification of areas of higher risk to wild salmon populations to facilitate the mitigation of sea lice impact.

Coupled hydrodynamic and particle tracking models are widely used to understand sea lice. The transport of a salmon louse is affected by physical processes and biological behaviours like vertical swimming. Parameterisation of these behaviours in particle tracking models is critical to provide a realistic picture of sea lice dispersion in the marine environment.

Here we perform a sensitivity analysis of adult sea lice residence times and distributions to vertical swimming velocity and maximum swimming depth using Loch Linnhe as a case study. In a fjordic system like Loch Linnhe, wind shear and water column stratification create a high vertical shear where vertical position of sea lice affect their horizontal trajectory. However, a review of previous sea lice studies shows no clear consensus on the implementation of these parameters for sea lice vertical movement.

While sea lice modelling has improved during the last 15 years, this study suggests that the use of numerical models for effective management of sea lice would benefit from more observational data to reduce uncertainties derived from the effect of sea lice vertical swimming behaviour.

Numerical modelling of exchange flows through sea straits and across submerged sills

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This study presents the application of ocean numerical modeling to gain understanding of the dynamics of exchange flows through sea straits and across submerged sills. The restricted density-driven exchange flows are generated in oceans, seas and coastal margins when adjacent water bodies with different densities are connected by narrow channels (i.e. straits) and/or natural topographic obstructions on the seafloor (e.g. submerged sills). Numerical model simulations, combined with scaled laboratory experiments, have proven to be a powerful tool to help understand the restricted oceanographic flow processes occurring within these complex regions.

We have conducted laboratory-scale numerical simulations using a non-hydrostatic 3-dimensional model (Bergen Ocean Model, referred to as BOM) in both non-rotating and rotating frames of reference (the latter considering Earth rotation effects through inclusion of Coriolis accelerations). These BOM simulations are shown to reproduce the main dynamic flow patterns and density structure of the large-scale exchange flows generated through an idealized trapezoidal sill-channel, with a lower layer saline intrusion (see sill-channel geometry in Figure 1).

The numerical results also show that the saline intrusion flux across the sill is initially reduced and then eventually fully blocked under increasing net-barotropic flow conditions imposed in the counterflowing upper freshwater layer (Grifoll et al., 2022). The BOM simulations are also extended to consider rotating exchange flow dynamics, and demonstrate that the inclusion of Coriolis forces increases the overall blockage of the saline intrusion layer by the upper freshwater layer flow compared to equivalent non-rotating exchange flows. Based on these rotating exchange flow simulations, the numerical results reveal a distinct secondary cross-channel circulation pattern, characterized by Ekman dynamics in the lower dense water layer and the presence of two anticlockwise circulation cells in the upper freshwater layer. The strength and coherence of these secondary flow cells are also strongly controlled in the along-channel direction by the proximity of the overspill at the end of the trapezoidal sill-channel crest, with the significant increase in the densimetric Froude number (i.e. increase in inertial factors) at this location implying a relative decrease in the influence of rotation and dominance of non-hydrostatic flow effects.

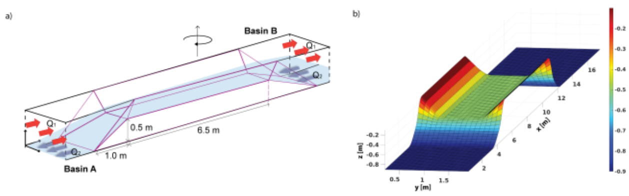

Figure 1. (a) Schematic representation of the trapezoidal channel-sill including counterflowing lower saline Q_2 and upper freshwater Q_1 layers. (b) Numerical mesh used for the BOM simulations.

Acknowledgements

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Smartrawl: a system to eliminate discards and bycatch in fisheries

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Abstract

Discards and bycatch (Fernandes *et al.*, 2011) are one of the main threats to fisheries sustainability. According to the most recent estimates (Pérez Roda, 2019), around 46% of total global annual discards (4.2 million tonnes), were from bottom trawls. In Europe, the practice is banned through the Landings Obligation, but there is no effective means of preventing it, so it continues more or less unabated (EFCA, 2019).

This presentation describes the Smartrawl, a technological solution to the problems of discards and bycatch. The system consists of a stereo camera, a computer, and an innovative gate, all of which are inserted into the trawl extension - the part of the trawl just before the cod-end (where fish are caught). The stereo camera takes images of fish passing by, and the computer, employing artificial intelligence algorithms, will then size these and identify them. Based on user selected preferences of species and size, the computer then sends a message to the gate to either close, thus catching the fish, or open, releasing the fish (or other animal) into the water, unharmed.

Crucial to the function of the system is an understanding of how quickly fish pass by. Trials have been conducted which have generated over 200,000 images which have been analysed. Fish passage rates ranged from 1 fish every 0.5 s to more typical rates of one fish every several seconds. Faster rates were associated with patches of small haddock, which are the most numerous demersal fish in the North Sea. The gate was, therefore, designed with a response time of 0.5 seconds. However, the provisional AI algorithms, by virtue of being run on the local, small PC, can take longer than that to run. The algorithms also need large numbers (several thousand per species) of high-quality images to be trained, and we also report how image quality has been improved.

The system is still in development, but most of the components have been built and tested. The presentation highlights the next steps and plans for further trials to test the system in the field.

Acknowledgements

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Current status of whitefish stocks in the Firth of Clyde (West coast of Scotland)

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The Firth of Clyde is one of the main grounds of the Scottish Nephrops (*Nephrops norvegicus*, or Norway lobster) trawl fishery. However, this fishery also catches demersal fish species such as cod, haddock and whiting. Almost 100% of fish bycaught is discarded due to trawlers not possessing licenses to land whitefish and the fish caught being below the minimum conservation reference sizes. Even though targeted fishing for whitefish ended in early 2000s [1], there are still no signs of cod and whiting recovery in the Clyde. One hypothesis is that fish discards in the trawl fishery for prawns is sufficient to maintain a high mortality rate on the stocks, thus hindering their recovery.
This study examines this hypothesis by estimating the quantities of cod, haddock and whiting discarded in the Nephrops fishery, and assessing the fishing mortality and current abundance of fish biomass.
We developed an age-structured stock assessment model that tracks annual cohorts of fish through time and uses the survey index information (as annual indices of relative abundance) and commercial catch data. The model can account for the high proportion of zero values in the data and was implemented using Bayesian inference through Markov Chain Monte Carlo algorithms for parameter estimation. The model was applied to the three main species of whitefish in the Firth of Clyde.
Results show high levels of mean fishing mortality (mean $F>1$) for all three stocks and low levels of spawning biomass (less than half of estimated catches), with a range of sensitivity tests all supporting this finding. The scale of the estimated mean fishing mortality might be unrealistically high because of migration effects out of the Clyde not accounted for in the model. Nevertheless, mean fishing mortality has decreased substantially for the three stocks within the last 10-15 years (up to 50% decrease), and is correlated, albeit weakly, with mean fishing mortality estimated by ICES [2] for adjacent stocks of the west coast of Scotland and the Irish sea. Despite this decline, it appears likely that mortality resulting from the Nephrops fishery is a significant factor in the lack of recovery of the whitefish stocks in the Firth of Clyde.

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Outer Hebrides Early Adopters and Creel Limitation Pilot Trials – A case study in inshore fisheries co-management

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In November 2020 Marine Scotland, in collaboration with the Western Isles Fishermen's Association and the Outer Hebrides Regional Inshore Fisheries Group, initiated two pilot projects to run in parallel for two years to:

1. Assess the potential to role out a low cost tracking system on 10m and under vessels (Early Adopters Pilot – EAP)
2. Introduce creel limits to reduce the increase in creeling effort (Creel Limitation Pilot – CLP)

These initiatives were linked as the 40 vessels involved in the EAP were also party to the CLP involving ~140 vessels.

The development of CLP was founded on calls from fishers in the Western Isles for limits to be set on the maximum number of creels that could be deployed by a vessel of given size. The fishers recognized the significant increase in creeling effort that had been taking place and needed to formalize with Scottish Government a mechanism to limit creeling effort.

The EAP was designed to further inform Marine Scotland's intention to introduce tracking of all commercial fishing vessels of 10m and under operating in Scottish coastal waters. The objectives of the EAP were to assess the operational challenges of equipping and monitoring the fishing activities of a subset of vessels involved in the CLP, including the development of novel processes to identify fishing activity and estimate creel numbers deployed. An App was also developed to encourage reporting of catch and landings that could be linked to fishing track.

The EAP and CLP have taken place against the backdrop of major political, economic and social challenge including EU Exit, the COVID-19 pandemic and now the cost of living crisis. Teasing out the, impacts, costs and benefits of the EAP and CLP within the context of such perturbations is challenging. The need to inform future policy in this area requires that we do so.

We will report on the progress of the EAP and CLP which is due to end in November 2022 and explore some of the lessons learned with respect to the development of co-management approaches in the context of the inshore fishery.

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Essential spawning grounds of Scottish herring: current knowledge, challenges and ongoing research

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Atlantic herring (*Clupea harengus*) helped to generate local income, identity, and societal change in Scotland for centuries. Their numbers on the west coast of Scotland have been in steady decline since the 1980s, but in spring 2018/2019, large herring shoals were observed on the west coast for the first time in decades, at a formerly important spawning ground. This highlighted the importance of maintaining suitable benthic spawning grounds, which these fish rely upon for egg deposition. However, information on exact location, characteristics, and status of historic and contemporary spawning grounds, if existing, is not easily accessible. We therefore performed an exhaustive literature search, dating as far back as 1884, using scientific databases, grey literature, a query for automated search of comprehensive historical reports, and fisher interviews (Frost and Diele 2022). We present current knowledge on Scottish herring spawning grounds and discuss challenges arising from methods currently used to recognize these grounds. Knowledge gaps regarding spawning season, as well as the location and environmental status of spawning grounds, particularly relevant for Scotland's west coast, are also identified.

Based on the importance of specific environmental variables for herring reproductive success, protection of herring spawning grounds should be, but currently is not, incorporated into marine management plans. This would require additional data on spawning grounds, including local ecological knowledge rarely considered. These knowledge gaps are now being addressed through the collaborative Edinburgh Napier University-led "West of Scotland Herring Hunt" (WOSHH) project, which seeks to identify and produce evidence for the conservation and potential restoration of herring spawning habitat on the west coast of Scotland. In addition to conducting interviews and collaborative field work along the Scottish west coast, WOSHH will shortly provide a new citizen-science 'herring hunt' web-app to help collect signs of spawning herring and aid the identification (and evaluation) of spawning grounds.

Healthy (and abundant) spawning grounds would increase the chance for herring to rebuild inshore populations (where and when possible), with potential positive social and economic impacts, as well as improve general biodiversity. A more inclusive and ecosystem-based approach to herring management, encompassing targeted actions to protect essential spawning habitat, would contribute towards Scotland's Blue Economy vision and Nature Positive commitments.

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Biomass and the Large Fish Indicator in a changing North Sea Ecosystem

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Recently, fish species richness in the North Sea has increased, driven by increased occurrence of species with an affinity for warmer waters (Lusitanian). This process is known as tropicalization, an increase in richness caused by movement of species from warmer and more diverse waters into historically cooler, less diverse waters. Evidence for this in coastal regions and in the North Sea is strong, though trends in abundance of Lusitanian species at the haul level has not been published previously. Therefore, it is important to investigate whether abundance of Lusitanian species has also increased alongside richness as this will likely have a greater impact on the ecosystem. Equally, little research has focused on how these changes may affect ecosystem health and current quality objectives. One such quality objective is the Large Fish Indicator (LFI). This is the proportion of fish above a specific length (50cm in the North Sea) within the total community. This has declined from historic baselines in the North Sea but has been recovering in recent years. Lusitanian species often grow faster, mature earlier, and reach smaller sizes compared with species from cooler waters. Since typically the North Sea was dominated by species from cooler waters (Boreal) the increase in occurrence of Lusitanian species has the potential to negatively impact LFI recovery and may mask recovery seen in Boreal species.

This paper looks to further investigate whether the recent increases in Lusitanian richness have also led to an increase in abundance (using biomass) and what impact, if any, this may have on the LFI. Data was taken from the International Bottom Trawl Survey for the North Sea between 1983 and 2020. Haul data was converted from number at length data into using weight-length relationships as reported in Fung et al. 2012. Biomass density was then calculated by dividing the calculated biomass by the reported swept-area (downloaded from ICES-DATRAS) as per the method used by OSPAR. Boreal (cold water) and Lusitanian (warm water) species were analysed separately to investigate how shifts in thermal affinity may impact these measures as the ecosystem changes.

Though biomass of both Lusitanian and Boreal species fluctuated between years, there was no clear increase in Lusitanian biomass over the study period. A slight declining trend was observed in Boreal biomass, though this is difficult to state definitively due to the fluctuating nature of the data. These fluctuations were largely driven by key commercial species such as whiting (Lusitanian) and haddock (Boreal). The beginnings of a recovery in the LFI was reported by OSPAR in 2017. Interestingly, this increase in the LFI after 2000 was seen in both Lusitanian and Boreal species. However, Lusitanian LFI was much lower overall than Boreal LFI (0.1 compared to 0.2 for Boreal).

This study suggests that increases in Lusitanian biomass have not been observed despite the increases seen in Lusitanian richness. However, the difference in the LFI between Boreal and Lusitanian species highlights the potential impact an increase in Lusitanian biomass could have on the overall LFI in the North Sea if this is observed in the future. The general utility of the LFI as a measure for fish community health in a changing North Sea is also discussed.

Acknowledgements

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Integrated system to improve inference of fishing activity from geospatial data

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Geospatial data obtained from vessel tracks is an important source of information with fisheries management and marine planning applications. These analyses can provide information on fishing grounds (Mendo et al., 2019) as well important measures of fishing effort. These data can improve the resilience of fishing industry by providing objective metrics by which to assess the impacts of management measures and spatial squeeze resulting from offshore renewable energy developments for example. Whilst (Mendo et al., 2019) use spatial data to reliably identify hauling events, identifying when gear is shot is more problematic as vessel spatial data provides few characteristics synonymous with this event. This makes it more difficult to calculate, for example, the time that the gear was in the water, which is important to understand fishing effort (Lifentseva, 2022).
In order to improve the prediction of the exact location of both hauling and shooting events an integrated system has been designed and is currently being tested on an inshore vessel deploying pots. The integrated system for inferring fishing activity consists of a tracking device, an Inertial Movement Unit (IMU) and two active Radio Frequency Identification (aRFID) tags. The tracking device provides GNSS position, speed and track. The IMU records the movement of the vessel in the 6 Degrees Of Freedom (DOF: linear surge, sway and heave; rotational roll, pitch and yaw) by measuring the acceleration with an accelerometer, the rotation speed with a gyroscope and the true heading with respect to magnetic north. The aRFID tags are placed inside the first and last creels in a string and communicate with the tracking device via Bluetooth indicating their presence whilst on board the vessel. Details are summarized in Table 1.

Table 1. Description of the elements within the ISIFA

Unit	Sensor	Data
Tracker	GNSS+GSM	Lat-Lon + speed ($m \cdot s^{-1}$)
	Accelerometer	ms^{-2}
IMU	GNSS+GSM	Lat-Lon
	Magnetometer	nanotesla
	Accelerometer	$m \cdot s^{-2}$
	Gyroscope	$rad \cdot s^{-1}$
aRFID	Bluetooth	Presence/Absence

As an example, Figure 1 plots the georeferenced points obtained during a fishing trip with the tracker (orange stars), and the IMU (black circles). Based on previous work, (Mujal-Colilles et al., 2022), tracker position reporting for these static gear vessels has been optimized to record location every 30 seconds which explains the differences in point density within Figure 1. Nevertheless, both the IMU and the Tracker yield similar geo-positional data.

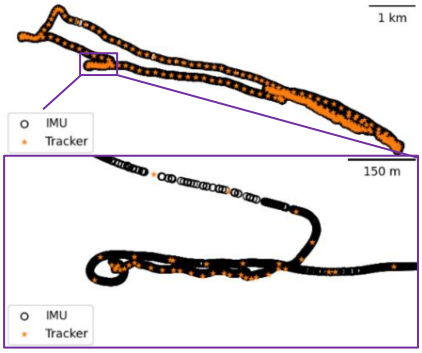

Figure 1. Comparison of the lat-lon points obtained by the two devices fixed at the vessel

Figure 2 is an analysis of the associated IMU data showing high resolution movement data. The grey section shows data associated with the fishing trip. During the hauling process, the magnetometer data has a specific pattern. By analyzing a combination of track and IMU data, with the time and position of hauling and shooting being validated through the aRFID tags, we hope to detect signatures in vessel movement that can be more reliably used to infer the deployment of fishing gear.

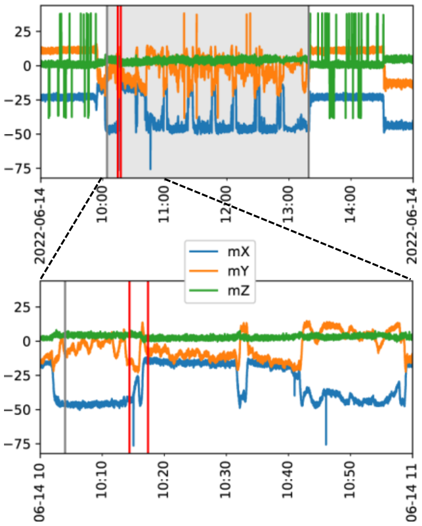

Figure 2. Three-component magnetometer data. Red lines indicate the presence of the aRFID onboard.

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Supply of sympagic organic material to the Barents Sea benthos strongly linked to sea ice seasonality

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The benthos plays a key role in carbon flow through Arctic ecosystems, being both an endpoint for much of the overlying production and an important food source for higher trophic levels. On Arctic shelves, primary production occurs in both pelagic and sympagic (ice-associated) habitats, by phytoplankton and ice algae respectively. Organic matter (OM) from both sources has been traced through benthic food webs using biomarkers, highlighting regional variability in the quantity of sympagic and pelagic OM utilised by benthos.

In an increasingly ice-free Arctic, it is important to understand the potential change in contribution of sympagic OM to benthos caused by primary production regimes shifting due to reduced ice cover. As the Barents Sea – located in the Atlantic Arctic, north of Norway – is the region with the most rapidly retreating sea ice of the whole Arctic Ocean, but also a site of important fisheries and industrial activities, it is a vital area to understand for better future management. We therefore aimed to quantify the relative contributions of sympagic *vs* pelagic OM in the Barents Sea shelf (200 - 400 metres deep) megabenthos across different seasons and durations of seasonal ice cover.

Megabenthos were collected with trawls in the summer and winter of 2018 and 2019 from 10 stations in the Barents Sea seasonal ice zone, where ice duration ranged from 0 to 245 days per year. The organisms were categorised into feeding guilds: surface deposit feeders, subsurface deposit feeders, suspension feeders, carnivores/scavengers, and facultative suspension/surface deposit feeders. We used highly branched isoprenoids – lipid biomarkers produced with distinct structures in sea ice and the water column – to estimate ratios of sympagic-to-pelagic OM in megabenthos. These biomarkers are particularly useful as they are source-specific, resistant to degradation, and produced by diatoms found in pan-Arctic algal communities.

Of 110 samples analysed, we found that the proportion of sympagic OM assimilated ranged from 0.4% to 96% and correlated strongly (r^2=0.59) with the duration of ice cover. This trend was observed for all feeding guilds other than suspension feeders. A longer period of ice cover provides a longer period for sympagic production, which is reflected in the OM utilised by the benthos. There was an estimated 9% decrease in the proportion of sympagic OM assimilated from summer to winter. This is likely due to the lower availability of sympagic OM in the winter as most ice algal production takes place in spring. Our data show that sympagic production can be an important source of OM for benthos in the Barents Sea, even though it only accounts for around 25% of annual primary production in the northern seasonal ice zone. These results are comparable to similar studies conducted on benthos in the Pacific Arctic, suggesting that the role of sympagic OM in benthic food webs is similar in both systems. Both of these are Arctic inflow shelves, which are most at risk of all Arctic seas of losing ice cover due to inflowing boreal water masses. However, the high variability of sympagic OM within benthos, and high proportion of pelagic OM at lower latitudes, suggests that in a future, ice-free scenario, the benthos could be adaptable and feed on pelagic OM.

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Oceanographic conditions and variability in Loch Ewe based on sustained observations at different spatial and temporal scales

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Abstract

High-resolution in-situ measurements and multi-decadal time series of data, in the context of wider scale observations, are required to detect any long term changes in coastal ecosystems above the pattern of short term variability which characterises such systems. Marine Scotland Science has been conducting environmental monitoring in Loch Ewe, a sea loch on the west coast of Scotland, since 1999. A range of oceanographic, atmospheric and biological parameters are measured as part of the Scottish Coastal Observatory monitoring programme and INTERREG VA COMPASS project, including physical water properties (temperature, salinity, current speed and direction, and wave characteristics), meteorological conditions, carbonate chemistry, nutrient concentrations and the phyto- and zooplankton community. The temporal resolution of measurements ranges from every 10 minutes to weekly.

This study characterises the oceanographic conditions of Loch Ewe, investigating how they vary spatially and temporally across the available time series and determining the forcing mechanisms behind this variability. We describe tides, residual currents, freshwater input and salinity variability within the loch system. We also investigate the meteorological drivers of temperature change within the water column and to which extent wider scale phenomena such as the reported recent freshening of the subpolar North Atlantic (Holliday et al., 2020; Wells et al., 2022) are observed in our data.

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Hydrological requirements for salt marsh habitat in Scotland

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https://www.imarest.org/membership/membership-registration/upgrade-your-membership/student-member-simarest

Salt marsh habitats require tidal inundation but are generally limited at the seaward edge to elevations above the Mean High Water of Neap Tide (MHWN) mark. Prolonged or too frequent tidal inundation will lead to salt marsh being replaced by unvegetated intertidal flats or seagrass habitats. With the potential threat to salt marshes due to sea-level rise and an increasing interest in restoring and creating salt marsh for their societal benefits it is crucial to be able to accurately assess the hydrological conditions that allow salt marsh to form and persist. Using a combination of water level sensors and novel Mini Buoy sensors, we present a summary of monitored hydrological conditions at a number of Scottish salt marsh – tidal flat transitions. The data reveal that only very few of the monitored Scottish marshes are able to tolerate inundation that is characteristic of MHWN elevations. Moreover, tidal inundation at the mean high water mark is markedly seasonal in Scotland. We will further demonstrate how the Mini Buoy can be used to assess tidal exchange, for example at a managed realignment site post breach, to inform future adaptive management. We will discuss how low-cost hydrologic and hydrodynamic monitoring approaches with the Mini Buoy can help to improve intertidal habitat restoration success.

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Greenhouse gases in the urban Clyde estuary: Physical estuarine processes and nutrient loading impact greenhouse gas generation

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Biologically productive regions such as estuaries, even though they only cover a small percentage of the world's oceans, contribute significantly to methane and nitrous oxide emissions. This paper synthesises greenhouse gas (GHG) and nutrient data measured in the Clyde estuary to determine the main physical and biogeochemical mechanisms that influence GHG sources and sinks, and ultimately lead to high GHG evasion.

The Clyde estuary, a temperate, urban mesotidal system, is often highly stratified with reduced mixing with a high loading of nutrients. The physical processes within the estuary are strongly influenced by river flow and tide. Nitrous oxide (N_2O) concentrations can be predicted in both the upper fresh and lower saline layers primarily by consideration of: the total dissolved nitrogen concentration, dissolved oxygen saturation and conductivity, with denitrification triggered by the lower oxygen conditions, which occur frequently in the lower saline layer. The apparent rapid response of N_2O production to increases in dissolved nitrogen concentration implies that most nitrogen processing is occurring in the water column despite the low turbidity within this estuary. Methane (CH_4) concentrations are more variable and show clear differences between the upper fresh and lower saline layers. The initial significant increase in methane concentration in the surface layer, after the transition from river to estuary, confirms that CH_4 generation occurs within the estuary rather than being passed from the river. Methane concentrations within the lower saline layer are significantly higher than in the surface layer suggesting generation within the bed with the peak CH_4 generation occurring where salinities are consistently below 10psu. The prolonged low river levels that occurred between June and September 2021, with the resulting saline intrusion into the inner estuary, caused a significant suppression of this CH_4 generation.

Understanding these dynamics helps to improve our knowledge of estuarine environments and their potential for GHG release to atmosphere.

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Industrial soundscapes: evaluation of operational sounds from Scottish salmon farms

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Noise, defined as unwanted or disturbing sound, is increasing in the marine environment due to anthropogenic activity within the oceans. The impacts of such noise on species can be multi-faceted, and may include masking of biologically relevant sounds, physiological stress, and even injury (Rako-Gospić & Picciulin, 2019). To date, few studies have examined noise emitted by the aquaculture industry, particularly within the Atlantic salmon (*Salmo salar*) farming sector. Preliminary research suggests that typical industry activities can emit noise, yet these have yet to be fully characterised (Radford & Slater, 2019).

In Scotland, Atlantic salmon farming is an expanding industry mainly located on the west coast and among the northern and western isles, which also host some of the highest densities of harbour porpoise (*Phocoena phocoena*) in Europe (Booth et al., 2013). The region's importance for the species is recognised by the Inner Hebrides and the Minches Special Area of Conservation (SAC).

To record salmon farm soundscapes on the Scottish west coast, characterise the sector's noise emissions and establish its relevance to the harbour porpoise, Passive Acoustic Monitoring (PAM) was conducted from seven farm feeding barges from 2018-2020. It was found that stocked salmon farms produce a broad range of sounds, many of which can be ascribed to specific activities carried out as part of normal farm maintenance operations. Spectral analyses revealed the distinctive acoustic characteristics of various activities, including air-driven fish feeder systems, electricity generators, acoustic deterrent devices (ADDs), vessel use, net cleaning activities, equipment use and even staff movement upon the feeding barges. Several of the identified activities created signals with ultrasonic components that may be perceived by harbour porpoises. Long-time average (LTA) spectrograms were also produced to examine the distribution of noise energy across multiple frequency bands. These analyses revealed differences between fallow and stocked farm soundscapes, and identified that some operations dominated certain frequency bands across time. In particular, generator use, feeder systems, and ADDs produced consistent noise emissions when examined over longer time periods.

Overall, the present study offers the first description of underwater noise associated with typical operational salmon farms in Scottish inshore waters. Signals from the described activities contained frequency components and intensities likely to be detectable by harbour porpoises, indicating animals interacting with these environments have the capacity to be both aware of, and exposed to, this diverse and temporally variable industrial soundscape.

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What's in a whistle? Towards accurate species classification of UK delphinid whistles

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Abstract
Passive acoustic monitoring (PAM) is a cost-effective and non-invasive tool for surveying delphinid presence but is hindered by the current lack of a reliable method for acoustically distinguishing between (or classifying) species. The challenge of acoustically classifying delphinid species is significant, mainly due to the high intra-specific variability in their vocalizations. Narrowband tonal whistles are a common type of vocalization produced by delphinids, known to exhibit high variability at the individual level and thus making species classification of whistles difficult. Developing accurate algorithms for identifying delphinid species by their whistles would greatly benefit acoustic monitoring by allowing reliable estimates of species abundance and distribution from sound recordings alone. Despite a recent surge in interest toward acoustic monitoring in the UK, there has been no attempt to date to develop an acoustic classifier for the seven delphinid species *(Tursiops truncatus*, *Delphinus delphis, Grampus griseus, Orcinus orca, Lagenorhynchus albirostris, Lagenorhynchus acutus, and Globicephala melas)* common to UK waters.
This study attempted to classify these species by their whistles using random forest (RF) and discriminant (LD) analyses. Fifty-six frequency-time variables were measured from manually traced frequency contours of 1319 whistles detected in towed hydrophone recordings in Scottish waters. Preliminary classification of individual whistles showed average accuracies of 15.8% and 10.5% higher than classification by random chance using RF and LD analyses, respectively. Interestingly, accuracy improved when classifying average measurements across pairs of randomly selected whistles. Using this technique, RF analysis classified with an accuracy 34.2% higher than random chance whilst LD analysis showed an accuracy 17.1% higher than chance. Finally, encounters (all whistles from a single species encounter) were classified to the species with the highest proportion of individual whistle classifications. This technique showed further improvements, increasing the average accuracy of RF classification by 11.3% and that of LD classification by 9.2%. The first RF classifier will soon be publicly available for use in the ROCCA (Real-time Odontocete Call Classification Algorithm) module in the open-source software PAMGuard. We will continuously improve this classifier by adding contextual variables, other types of vocalizations such as echolocation clicks, and alternative approaches in machine learning such as deep learning. These improvements will be implemented in ROCCA as new classifier releases as soon as they become available. Development of acoustic species classifiers not only provides new tools for passive acoustic surveys, but also advances our understanding of differences in vocal repertoires between species. To our knowledge, this is the most comprehensive attempt at acoustic species classification of UK delphinids to date. This work will serve as an important base for comparison as we continue to collect more data and develop alternative methods in machine learning.

Acknowledgments
I would like to thank the Hebridean Whale & Dolphin Trust and Prof. Phil Hammond for contributing a large amount of pre-existing acoustic data to this project. I would also like to thank the SUPER DTP community and Dr. Ewan Edwards for providing additional support and supervision during the first year of my PhD.

Reconstructing abundance trends of humpback whales at an oceanic migratory stopover

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We re-constructed annual abundance of a migratory baleen whale at an oceanic stopover to elucidate temporal changes in the increasingly busy waters around Bermuda. The annual abundance of North Atlantic humpback whales visiting Bermuda between 2011 and 2020 was estimated using photo-identification capture-recapture data for 1,204 whales. Owing to a sparse data set, we combined a Cormack-Jolly-Seber (CJS) model, fit through maximum likelihood estimation, with a Horvitz-Thompson estimator to calculate abundance and used stratified bootstrap resampling to derive 95% confidence intervals (CI). We accounted for temporal heterogeneity in detection and sighting rates via a catch-effort model and, guided by goodness-of-fit testing, considered models that accounted for transience. A model incorporating modified sighting effort and time-varying transience was selected using (corrected) Akaike's Information Criterion (AICc). The survival probability of non-transient animals was 0.97 (CI 0.91-0.98), which is comparable with other studies. The rate of transience increased gradually from 2011 to 2018, before a large drop in 2019. Abundance varied from 786 individuals (CI 593-964) in 2016 to 1,434 (CI 924-1,908) in 2020, with a non-significant linear increase across the period and interannual fluctuations. These abundance estimates confirm the importance of Bermuda for migrating North Atlantic humpback whales and should encourage a review of cetacean conservation measures in Bermudian waters, including area-based management tools. Moreover, in line with the time series presented here, regional abundance estimates should be updated across the North Atlantic to facilitate population monitoring over the entire migratory range.

Acknowledgements

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Predator-prey interactions: modelling the multi-species functional response of grey and harbour seals in the North Sea

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1. Resource uptake is the fundamental process that links trophic levels through predator-prey interactions. The critical component that describes how consumption rate of a predator varies in relation to prey density is the functional response and is crucial to understand trophic interactions, predation pressure, prey preference and population dynamics.

2. This study modelled the multi-species functional response (MSFR) of grey (Halichoerus grypus) and harbour seals (Phoca vitulina) in the North Sea to describe how consumption will vary dynamically depending on the availability of multiple prey species. Bayesian methodology was employed to estimate MSFR parameters and to incorporate uncertainties in diet and prey availability estimates. Diet composition was based on information from seal faecal samples. Prey availability estimation was based on combining prey distributions, estimated from fish survey data, with predictions of the geographical area that was accessible to the predator, given food passage time, from telemetry data.

3. Results indicated that both seal species have a type III functional response. Sandeels are important but more strongly preferred by grey seals. While harbour and grey seals are sympatric and consume similar prey species, results also suggested that they might be functionally distinct predators, with harbour seals having a more diverse diet and exhibiting a more sigmoidal response that may indicate a greater tendency to switch prey. Depending on what kind of prey is available and their associated profitability (i.e. obtained energy divided by costs of acquiring that prey) could lead to circumstances that are unfavourable for harbour seal populations.

Simulating the distribution of beached litter on the northwest coast of Scotland

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It is estimated that between 4.8 - 12.7 million tons of plastic waste enter the ocean globally per year, contributing to at least 5.25 trillion plastic particles floating on the ocean surface. Marine litter can enter the open ocean directly, or via coastal waters, and then through numerous hydrological processes is transported to the open ocean, and potentially dispersed vast distances. The spatial and temporal variability of plastic marine litter is complex due to the interaction between differential characteristics, hydrological processes, and coastal morphology. Various field methods have been used globally in an attempt to understand and quantify plastic pollution. However, the sparse population of the Atlantic coast of Scotland, combined with the complex coastline of numerous islands, sea lochs and headlands, has resulted in limited field data from this region. Hydrodynamic modelling offers a mechanism to explore such areas, and the interaction of marine litter with physical forces arising from ocean currents, and windage, coupled with particle tracking models, can predict the trajectories and fate of simulated particles over space and time.

Our research focussed on the Clyde Sea, the most populated and industrialised region on the west coast of Scotland and considered a potential source of plastic litter to the less populated northwest. This study first presents an analysis of Marine Conservation Society (MCS) citizen-science beach-clean data, from 1994 to 2019, revealing spatial patterns between beach-clean sites on the west coast of Scotland. Plastic litter items were further categorised into land, marine and unknown sources, with the most common items in these categories being crisp packets, fishing rope and fragments, respectively. It was calculated that on the west coast of Scotland there are on average 380.31 ± 419.92 plastic items per 100 m of coast, with the site average number of items recovered ranging from 1-2355 per 100 m of coast. The hydrodynamic model used in this study is West Scotland Coastal Ocean Modelling System (WeStCOMS), an unstructured grid model developed specifically for the region.

To simulate marine plastic litter movement from the Clyde Sea, WeStCOMS was coupled with a particle tracking model subject to currents, diffusion, and wind. Three coastal boundary conditions were used to compare transport paths: with or without particle resuspension, and, for the resuspending cases, with or without a distinction between coastal type (retentive beaches versus reflective rocky coasts) to predict landing points. After a one-year model run, out of the total particles released, 37.2% - 99.5% had beached depending on the coastal boundary condition. The Clyde Sea was found to be a potential source of beached plastic litter to the north, as on average, 6.1% (range: 3.1% - 12.2%) of particles exited the Clyde Sea, crossed a defined northern boundary, and beached on the northwest coast. Both hydrodynamic and particle tracking models were tested, and the varying boundary conditions were compared to investigate holistic methodologies to better understand plastic pollution.

Genomic analysis of Flame Shells (*Limaria hians*) to inform nature conservation

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Flame shells (*Limaria hians*) are a species of bivalve present across the northeast Atlantic. They have high ecological importance due to the dense beds that they form; they use byssal threads to bring together debris, raising and stabilising the sea floor and thus creating habitat for hundreds of species. Increasingly more of these beds are being discovered off the west coast of Scotland, and elsewhere. Little is known about the biology of flame shells.

I am using a genomic approach to understand population connectivity and design a set of genetic tools that can be used to inform flame shell management throughout their range. I used RAD-seq to assay genomic variation across 6 populations from Scotland and the Republic of Ireland. Results revealed little genetic differentiation among the populations sampled in Scotland, but clear differentiation between Scottish and Irish populations. I am using the RAD dataset to develop targeted genotyping-by-sequencing assays for a subset of SNPs, with the aim of including more populations into this study and potential for use in future research. With this knowledge we can begin to understand flame shell populations' potential for recovery, and we can consider MPA design for the future of this species.

Population genetics of Scottish maerl beds informing the need for targeted conservation management

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Maerl, free-living red coralline algae, that form reef-like ecosystems (maerl beds) which support high biodiversity including many rare, endemic and commercially important species, are found throughout the world's coastal oceans. Listed as 'Vulnerable' or 'Endangered' on the IUCN Habitats Red List, Scotland is a European hotspot for maerl beds but they face an uncertain future because of destructive human activities and climate change.

Current understanding of Scottish maerl bed distribution relies on limited data and morphological species identification. There is little understanding of factors that control apparent distribution patterns, and knowledge of genetic diversity and species assemblages is almost non-existent. Here, we use a whole genome genotyping approach to explore the population genomics of maerl across Scotland.

We present data that doubles the number of maerl species previously thought to be in Scotland and identify the extent of genetic connectivity both within and between maerl beds at a local to national scale. Coupled with species distribution modelling, we project how maerl species may be differentially affected by climate change over the coming century. Using this information, we provide recommendations for their targeted conservation management, such as identifying which species are at most risk from climate change, and identification of priority conservation areas for genetic refuge.

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A brief history of Scottish blue carbon science and the Scottish Blue Carbon Forum: Where next ?

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Before the term "blue carbon" was coined by Nellerman et al. in 2009[1], there had already been significant studies of related topics in Scotland. The geology of our shelf sea sediments and seabed habitats had been extensively mapped in the 1970s and 80s, partly in support of the growing offshore oil and gas industry. Through the 1990s and 2000s, carbon, as a principal building block of life, had been tracked and quantified as it flows through marine ecosystems, and there had been significant studies of the carbonate cycle of our shelf seas. However, with the growing realisation of the impact of CO_2-induced climate change and the imperative to stop the increase of this greenhouse gas in the atmosphere at the turn of the millennium, the understanding of the flux and storage of carbon in marine habitats took on a new urgency.

"Blue carbon" science in Scotland has undergone a similar evolution as that globally, moving from basic descriptive inventories of carbon stores, to studies of sequestration rates and processes, studies of threats and pressures and their impacts, studies of restoration and protection measures, and investigations of the potential use of "blue carbon" habitats in an emerging carbon trading market.

A notable first inventory of Scottish blue carbon across all marine habitats was published by Mike Burrows and co-authors in 2014[2], commissioned by NatureScot (then SNH). In 2018, the Scottish Blue Carbon Forum (SBCF) was formed in collaboration with the Scottish Government, to coordinate blue carbon science in Scotland. Since then specific areas of focus of Scottish research have been sea loch carbon stores (e.g., detailed inventories of sea loch carbon stocks by Craig Smeaton and the lead author here [BA] from 2016 onwards[3]), saltmarshes (from a first national habitat survey published in 2016 by Haynes[4] and NatureScot, to a recent complex assessment of carbon stocks and sequestration rates by the St Andrews team[5]), and seabed sedimentary carbon stores (from simple stock assessments using national seabed geological records through to a recent assessment of the vulnerability of seabed carbon to bottom trawling by Kirsty Black and co-authors[6]).

The threat to seabed blue carbon from fishing recently made global media headlines following the publication of a paper in Nature by Enric Sala and co-workers in 2021[7], and the fallout from this work is still reverberating around blue carbon science. Alongside the headline-grabbing papers, Scottish scientists have made great efforts to explain blue carbon science to policy makers, stakeholders and the public through a series of events, publications and infographics (e.g., the SPiCE review, SBCF infographics). A major international conference was hosted alongside COP26 by Marine Scotland and the SBCF, which aimed to move blue carbon science forward to studies "beyond the inventory". Additionally the SBCF has recently launched an International Policy Challenge to further bring together policy makers and blue carbon scientists and the SBCF has become a member of the IPBC and is now leading on the UN Decade Programme for Blue Carbon (GO-BC) to support the UN SDGs.

Today blue carbon scientific focus is moving on to providing the evidence to include saltmarshes in the UK greenhouse gas inventory; providing advice for the development of Highly Protected Marine Areas that consider the protection of blue carbon; developing a full understanding of the impact of bottom trawling on carbon stores; and developing the science needed to protect and restore all fragile coastal blue carbon habitats with a better holistic understanding of all the ecosystem services they provide.

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Trial to Validate Environmental DNA (eDNA) as a Survey Method for Fish Ecology Assessment around Offshore Wind Farms

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Ambitious UK Government targets to reach 50GW of operating offshore wind capacity by 2030, is increasing the pressure on the offshore wind farm industry. There is also a move towards demonstrating Biodiversity Net Gain (BNG) and Net Positive Impact (NPI) from marine development activities (Natural England, 2022). These pressures increase the demand for robust and scalable environmental data collection. However, many conventional environmental surveys still rely on costly and time-consuming capture-based techniques (Maiello *et al*. 2022). This is creating a supply chain bottleneck which can result in consenting and development delays. Furthermore, as a greater number of Offshore Wind Farms (OWFs) are being sited in deeper water, it can become more difficult to conduct the required environmental monitoring using existing methods.

Environmental DNA (eDNA) metabarcoding is a technique which can potentially provide an innovative solution to overcome these challenges. All living things leave traces of DNA in the environment (such as mucus, scales, and faeces from fish as they swim in the water column). Water samples for eDNA analysis can be taken without specialized staff using a non-intrusive hand-held device from a wide range of vessels, and from previously inaccessible locations, such as within turbine arrays. Once collected, eDNA can be amplified and sequenced to identify unique genetic sequences. The sequences are then compared to genetic reference databases through a process called bioinformatics to identify species and generate information on the biodiversity of the area sampled.

Natural Power is leading a research project at Blyth Offshore Demonstrator, part funded by the Offshore Wind Growth Partnership (OWGP) and in partnership with EDF Renewables and NatureMetrics. The study will compare data from eDNA sampling with fish catch data from otter trawl surveys conducted simultaneously, as well as with historic data from the site. The main aim of the study is to produce a method for fish ecology eDNA surveys around commercial sites; demonstrating that the technique provides equivalent if not better fish ecological data than the traditional method. Initial results show it also provides data on marine mammals, seabirds, and invertebrates. Should the eDNA methodology be accepted as a viable alternative it would likely lead to a reduction in development costs, delays, survey personnel and environmental impacts. It also has the potential to support ecological targets through the provision of high-quality biodiversity data to assist informed marine planning decisions at both project and regional level.

The first two of four planned surveys are complete, with initial data showing good overlap in the fish species identified, and with 70% more species from the eDNA samples, including fish, invertebrates, seabirds, and marine mammals. The formal results of this study will be published in 2023, however the initial results indicate the potentially important role eDNA may play in future environmental assessment.

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Scotland's changing coastal environment: how time series support the Blue Economy Vision

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The Scottish Coastal Observatory (SCObs) has been measuring environmental and biological variables at multiple locations around the Scottish Coast for over 25 years. A combination of temperature, salinity, nutrients, carbonate chemistry, dissolved oxygen, pigments, and plankton communities are collected weekly at selected sites. Two metocean buoys have recently been added to the programme, collecting high frequency meteorological, physical and chemical data which is available in near real time. SCObs data are used to fulfil the Scottish Government's statutory reporting requirement for the Marine Scotland Act (2010), the UK Marine Strategy and the Oslo/Paris Commission (OSPAR) status assessments. SCObs is providing evidence that the physical and chemical properties, and plankton communities of Scottish coastal waters are changing. These changes which have the potential to impact industries that are part of the Blue Economy include; i) a change in the diversity and abundance of plankton life forms with the potential to impact food webs, ii) a decreasing trend in salinity coincident with a catastrophic decline in zooplankton abundance observed at the Loch Ewe site, iii) an increase in the abundance of the shellfish toxin producing diatom *Pseudo-nitzschia* observed in Scalloway, increasing the risk of shellfish harvesting closures, iv) a mismatch between the timing of zooplankton and fish larvae potentially influencing recruitment, and v) dissolution of the shells of shellfish larvae associated with carbonate chemistry. The SCObs dataset also highlights the regional variability of Scotland's coastal environment and how this can impact local marine industries. The conditions of Scotland's marine waters are predicted to change over the coming decades due to multiple pressures such as climate change, ocean acidification and natural variability over yearly to multi-decadal time scales. Time series such as SCObs which identify environmental changes that can impact sustainable use of the marine environment provide important support to the Blue Economy Vision.

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The SCObs programme relies on a number of dedicated citizen scientists, volunteers, contractors and Marine Scotland Science staff, to collect water samples and lower instruments in the sea each week in all weathers. Their input is gratefully acknowledged; Millport: Field Studies Council, Mallaig: Hugh Cameron, Loch Maddy: John Macdonald, Loch Ewe: Loch Ewe Shellfish, Scapa: Orkney Islands Harbour Council, Scalloway: North Atlantic Fisheries College, Fair Isle: David Parnaby, Cromarty: Robert Bashford, Stonehaven: The Stonehaven Sampling Team, St. Abbs: St Abbs Marine Station, St. Kilda: National Trust for Scotland.

Bipolar contrast in phytoplankton size structure revealed from deep learning

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Abstract

Phytoplankton size plays an important role in regulating primary production, carbon cycling, and sustaining upper trophic levels in the global ocean. However, it is still under debate how phytoplankton size structure is affected by environmental factors such as temperature (Marañón et al. 2012, 2015; López-Urrutia et al. 2015). While Ward (2015) suggested that the temperature effect was only pronounced in polar waters, a number of studies showed that small phytoplankton dominated in Arctic waters (e.g., Zhang et al. 2015). In addition, although size fractionation of chlorophyll *a* is one of the most widely used method to quantify phytoplankton size structure due to its ease of sampling, we still lack a global dataset and associated statistical model to predict global phytoplankton size structure based on these measurements.

Here we assembled the largest ever dataset on size-fractionated chlorophyll *a* measurements in the global ocean and analyzed the relationships between multiple environmental factors, including temperature, nitrate, mixed layer depth, dissolved iron etc., and phytoplankton size using a deep-learning algorithm by taking advantage of the *keras* package in the R programming environment. Our results suggest that at the same temperature, the fraction of small phytoplankton increases significantly with ambient nitrate concentration. Our work contributes to solving the long-lasting debate in phytoplankton ecology as to how temperature affects phytoplankton size and highlight the difference in phytoplankton size structure between Arctic and Antarctica waters due to contrasting nutrient supply.

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Simple and accessible machine learning for automatic classification of broad-benthic habitats

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Area being submitted to (delete as appropriate): *3. Artificial Intelligence*

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Identification of benthic habitats from imagery is fundamental to marine spatial planning. Automation through Machine Learning, particularly transfer learning, has proved to be a powerful way to overcome time and resource limitations. Here, pre-trained and general convolutional neural networks (CNNs) are used with an additional domain-specific tuning step. However, these techniques are complex. They are often left inaccessible to a non-specialist, as they require large investments in time (for comprehension by the user and for training) and computational resources.

We demonstrate that we can use transfer learning, for classifying benthic habitats, in a much simpler framework. Specifically, we take an 'off-the-shelf' CNN (VGG16) (Simonyan & Zisserman, 2015) and use it to extract features from benthic images (without further training) (Razavian et al,. 2014, Yosinski et al., 2014). The default outputs of VGG16 are then fed in to a Support Vector Machine (SVM), a classical and simpler method than deep nets. We explore the discriminative power of our VGG16+SVM classifier on three benthic datasets (574-8353 images) from Norwegian waters; each using a unique imaging platform. Benthic habitats are broadly classified as soft substrates (sands, muds), hard substrates (gravels, cobbles and boulders) and reef (*Desmophyllum pertusum*). Each dataset was split into 80\% training and 20\% testing and SVM hyperparameters tuned using 5-fold cross validation of the training set. For comparison, we also train the remaining classification layers of VGG16, a more complex approach.

Final training time of the SVM classifier ranged from 0.57-15.6 minutes; around half the time of the CNN classifier (1.7-35.5 minutes). Both approaches performed well, however the simpler of the two (SVM) performed best with test accuracy ranging from 0.86-0.96 (average= 0.9 (±0.05)). Whereas test accuracy with the CNN classifier ranged from 0.82-0.95 (average=0.87 (±0.06). Performance in both cases increased with dataset size. Average recall and precision results were also good across datasets, with 0.82 (±0.09) and 0.87 (±0.08) for the SVM and 0.8 (±0.12) and 0.83 (±0.1) for the CNN, respectively.

This framework is simple, fast and consistent. It's usage is particularly suited for offshore use; offering near real-time decision making, development of sampling protocols, triaging data collection and providing quick, albeit crude, insights into habitat presence. It can also support automation by grouping images into similar categories, for annotation or model selection, and be used to screen old-datasets.

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From data to decisions: innovations to support the Blue Economy Vision

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Area being submitted to: *Artificial Intelligence;* **Preferred presentation medium**: oral

We may have one of the e-poster sessions as part of a wine reception on Tue 8th Nov. Would you be available for this? Yes. **Are you a student?**: No.

At a high level, the Scottish Blue Economy vision, (incorporating the Scottish Aquaculture vision), is an easy sign-up: it is consistent with "A marine environment, which is clean, healthy, safe, productive and biologically diverse, managed to meet the long-term needs of nature and people"(1). Who could argue with that!? Looking in more detail, though, raises issues of scale and perspective; there is a growing awareness to consider the 'system' as a whole: "negative impacts on marine ecosystems [should be] minimized and, where possible, reversed" (2).

Addressing ecosystem-scale questions benefits from ecosystem-scale sampling and that has posed challenges to previous generations of scientists. However, we live in an age where the decreasing cost of getting data is being matched by the amount of data gathered. Whilst generating data from the marine environment is getting easier, interpreting, and acting on those data, remain a challenge, partly because decision making frameworks are variously based on 'previous' technologies.

Two technologies that are revolutionizing the way we assess our environment are DNA-based 'omics' and image analysis. These technologies, which are reliant on machine learning (ML) and artificial intelligence (AI), give insights into assemblage structure and function, covering all organismal scales (viruses to whales), and can be utilized at virtually any scale in any ecosystem. The power of these systems includes their capacity for highly efficient scale-up including robotization in both data acquisition (sampling), sample processing (e.g., wet-lab robots) and number crunching. Machine-based data-crunching (interpretation) offers society a wealth of potential advantages, including consistency, accuracy, speed, and low cost. Within the same budget, data intensity (sampling effort) can increase giving us a much higher resolution, in space and time, at relevant ecosystem scales. Surely, then, we are on the road to delivering the 'vision'?

Possibly, but there is a slightly unnerving aspect to ML and AI– and that is we don't fully understand how they work. Random forests (RF), for example, are an increasingly ubiquitous ML tool utilized to great effect to classify samples (e.g, a sediment is degraded/not-degraded), based on its 'big-data' characteristics which can include thousands of attributes (predictors). Furthermore, the RF algorithm will tell you which of those thousands of predictors are the most important, information that, you'd hope, enables you to interpret the observed data, linking cause and effect. However, even while the RF delivers on predictions, by its very 'random' nature it varies in the identification of those key predictors between iterations with the same data – we know it works, we are less sure how. The RF algorithm is, conceptually, much simpler than the convolutional neural nets (CNNs) that underpin many of the best computer vision algorithms. CNN training involves the machine creating a complex architecture of millions of inter-connected 'neurons', and the setting of billions of parameters ('axons') connecting them all; again, the output is often remarkable, but we don't understand the detail of how a particular machine (algorithm) works. Assigning confidence in our ML/AI predictions is also quite a different process when compared to model-based predictions (e.g. around linear-regression).

Does this matter? I'm not sure, after all, I don't know how my phone works, let alone my own eyes and I still make decisions based on what I hear and see. If we do accept machines into data generation and interpretation, we are faced with the next challenge, which is societal and cultural as much as scientific. As our capacity to monitor impacts is enhanced, we will need to focus more on what it is we want from our ecosystem and how much change or 'damage' we are willing to live with – defining that 'vision' might be more challenging.

Acknowledgments

My thanks to Thorsten Stoeck, John Halpin, Joe Marlow, Shraveena Venkatesh, Victoria Ashley-Wheeler and many more for their thoughtful insights into these concepts.

References

(1) and (2) https://www.gov.scot/publications/blue-economy-vision-scotland/pages/5/ and page 6 respectively.

Smartrawl "Eye": a vision-based technique for fish detection and species identification

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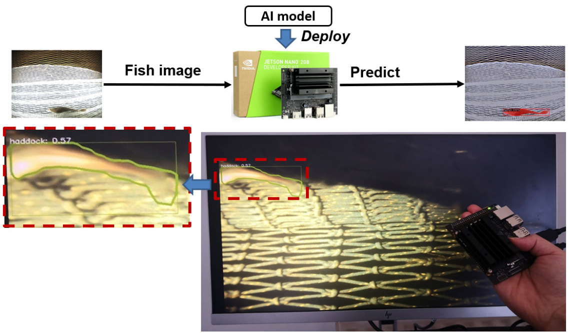
I would prefer to deliver a talk.

Are you a student? (Delete as appropriate): No.

Tweetable abstract

The Smartrawl eye is a vision-based AI technique fitted to fishing trawls, enabling the detection and identification of fish species. Combined with other elements of the Smartrawl, this "eye" can contribute to eliminate discards and bycatch, which are a global problem threatening fisheries sustainability. #MASTSasm2022 @DeweiYi @PaulFer13180972.



Abstract

Two of the leading causes of unsustainable fishing are bycatch and discards (Fernandes *et al.*, 2011), where unwanted marine life and fish, respectively, are caught in commercial fishing trawls and thrown back, dead, to the sea. To help tackle this global issue, we propose a novel vision-based technique to enhance the performance of detecting and identifying fishes prior to capture in the fishing apparatus. In particular, our developed technique can improve both the generalisation ability and stability for detecting fish and identifying their species.

This presentation describes a technological solution for accurate fish detection and species identification, which is a key component of Smartrawl system. That is, the developed technique gives an "eye" to our Smartrawl system[1]. Due to compelling progress in the success of deep learning in computer vision, it is now possible to monitor marine fauna automatically by camera images (Yi *et al.*, 2022). To achieve fish detection and species identification, an advanced object detection and recognition method (Yi *et al.*, 2021) is introduced and developed in our technique. To evaluate the performance this technique in a comprehensive way, our method is evaluated on various underwater scenarios. Experimental results indicate that our method is promising for fish detection and species identification in terms of accuracy and generalisation performance. The method paves the way for only wanted fish to be selected and caught, whilst other fish and marine life can be released in-situ unharmed.

The technique has been deployed and tested in the Jetson Nano[2] platform, a low-cost and small form factor computing unit. The presentation highlights the next steps and plans for further trials to test the system in the field.

Acknowledgements

The Smartrawl project has been funded by Fisheries Innovation Scotland, through their membership organisations, chief amongst which was Marine Scotland: all of their support is gratefully acknowledged. The vision-based technique was developed with the assistance of Yiren Li and Sean Flinn (University of Aberdeen). Shaun Fraser (UHI) is thanked for running field trials and data collection.

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[1] https://fiscot.org/fis-projects/in-water-improvements-in-selectivity-fis024/

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The effects of stressor dominance at environmentally relevant levels on the freshwater gastropod, *Lymnaea stagnalis*

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Area being submitted to (delete as appropriate): *2. Multiple aquatic stressors*

Preferred presentation medium (delete as appropriate): (i) oral

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Human activity is driving biodiversity loss at an alarming rate and multiple interacting stressors are recognised as driving many of these declines. However, due to the practical limitations associated with multifactorial experimental designs, a new approach to investigate the effects of environmental stressors is needed. Here we assess combined effects of three ubiquitous environmental stressors (pollutant mixture, invasive predator and global warming) utilising a novel testing paradigm based on the 'dominance' theory. The central tenet of this theory is that when one or more stressors are present at sufficiently high levels, this drives the observed effects. Under this scenario, the addition of co-stressors at lower levels will have little impact on the level of response. In order to test this theory, using previously collected single stressor data in our test system, stressors were combined with each stressor at a 'dominant – EC30' level, either alone or in combination with additional stressors at 'negligible – EC10' levels. The pollutant mixture consisted of 13 components at environmentally relevant concentrations (EC10: 0.015 µg/L, EC30: 0.041 µg/L), a temperature-controlled approach was implemented for the global warming exposure (EC10: 20.2 °C, EC30: 22.0 °C) and the predator cue dilutions were prepared from the invasive signal crayfish, Pacifastacus leniusculus (EC10: 10%, EC30: 57.5%). Exposure occurred starting from embryos < 24 hours old (n = 10 per replicate, 5 replicates) until adults (~ 5 months). Snails were maintained in artificial freshwater with a 16:8 photoperiod. Water changes (50 %) were carried out three times per week. Endpoints measured were survival (hatching, post-hatch mortality), growth (total biomass, shell length), reproduction (fecundity, onset of egg laying, embryo viability) and avoidance behaviour. Upon single stressor exposure at the 'dominant' EC30 exposure level, negative effects on reproduction (embryo viability) were observed in response to pollution, avoidance behaviour was observed in response to predator cue and stimulatory effects on reproduction (accelerated egg production) was observed in response to higher temperature. Supporting our 'dominance' hypothesis, there were no differences for these endpoints when compared with the co-exposure scenarios where the remaining two stressors were present at negligible EC10 levels. However, negating our 'dominance' hypothesis, additional endpoints were impacted for all stressors under the multiple stressor exposure scenario (EC30+EC10+EC10) when compared with their respective single EC30 exposure. Therefore, additional stressors at low levels elicited additional effects on measured endpoints. Interestingly, observed effects were similar between the different multiple stressor exposure scenarios, and therefore, the overall stressor levels appeared to have more importance than the individual stressor identities. This could be due to a general stress response leading to changes in energy budget allocations. Findings from this study will provide crucial information on how combinations of stressors interact to affect aquatic organisms, reflecting how human activities are contributing to biodiversity loss within natural systems.

Acknowledgements: We thank Sarah Dalesman (Aberystwyth University) for providing snails to start a breeding colony at the University of the West of Scotland, the Galloway Fisheries Trust for help in obtaining signal crayfish. This research was funded internally by the University of the West of Scotland.

Occurrence of alkylphenols and alkylphenol ethoxylates in North Sea sediment samples collected across oil and gas fields

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Area being submitted to: *2. Multiple aquatic stressors*

Preferred presentation medium: (i) oral.

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Are you a student?: No.

Alkylphenol ethoxylates (APEs) have been used in several offshore oil and gas production applications including as emulsifiers in drilling mud formulations, which may have resulted in their disposal to sea. Both NP, OP and their ethoxylates are toxic to aquatic organisms and are endocrine disrupters due to their ability to mimic natural hormones. Nonylphenol and octylphenol are listed by the Oslo and Paris Commission (OSPAR) (2009) as chemicals for priority action and concerns over the endocrine disruption potential led to the replacement of these compounds with less toxic products for offshore drilling and production in the North Sea (Neff, 2005). Despite concern over the endocrine disrupting potential of their alkylphenol (AP) degradation products, information on the presence of AP/APEs in marine sediments in the vicinity of oil and gas production facilities is scarce.

The concentrations of nonylphenol, octylphenol and their mono- and diethoxylates were determined in marine sediment from 29 environmental surveys carried out in the North Sea between 2011 and 2020. Relationships between the concentrations of AP/APEs with total hydrocarbon content, drilling fluid type present and infrastructure age were examined.

The environmental risk of nonylphenol and octylphenol was assessed by a comparison to relevant environmental threshold criteria and trends in the concentrations of APs/APEs examined using linear mixed modelling techniques.

The concentrations of octylphenol, nonylphenol and their ethoxylates near offshore installations were broadly comparable to, or higher than those of coastal and estuarine point source discharges. When compared to environmental assessment criteria, the Norwegian Pollution Control Authority Class V (extensive toxic effects) threshold values for octylphenol and nonylphenol were exceeded within 100 m and 500 m of infrastructure respectively. Predicted no effect concentration values were exceeded for nonylphenol and octylphenol up to 5000 m from infrastructure, suggesting that a potential increased risk to biota was present at a considerable distance from point source inputs.

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Effects of concurrent temperature and nitrate gradients on diatom multitrait phenotypes over two timescales

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Area being submitted to (delete as appropriate): *2. Multiple aquatic stressors;*

Preferred presentation medium (delete as appropriate): (i) oral

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Two hallmarks of environmental change in oceans is that first, many aspects of the environment change concurrently. For example, while oceans will warm, the nutrients available for phytoplankton growth in many regions will drop. Second, projections of future environments carry high uncertainty. For example, projections of global average sea surface temperature changes in the coming decades span ~4°C, with uncertainties in local projections being even higher. Because of these two characteristics of ocean change, our understanding of organismal responses to it must be applicable over a wide range of multidriver environments. I will present experimental results of the plastic (short term) and evolutionary (long term) growth of a model diatom in 20-25 different temperature x nitrate environments, with each driver present as a gradient at each level of the other driver, also known as a fully factorial experiment. We show that the ability to respond to warming on all time scales is a function of nitrate availability, with the optimum temperature for growth (T_{opt}) being a saturating function of nitrate availability in the short term. In the longer term, the ability to adapt to high temperatures by increasing growth and shifting T_{opt} upwards depends on nitrate availability, and we identify the critical concentration of nitrate needed for adaptation to warming in otherwise ideal environments. Finally, we demonstrate that adaptation is linked to changes in common markers of stress, such as internal pools of reactive oxygen. We also discuss trends in changes in ecologically-important traits such as cell size across the full range of multidriver environments. The resourcing and logistics of fully-factorial multidriver experiments can appear substantial, but we strongly advocate for doing them where possible. Because of this, I will go over the advantages and limitations of laboratory experiments with enough environments to generate “response surfaces” relative to experiments that use a smaller number of environmental scenarios, with the aim of dispelling some of the myths around carrying out experiments that generate response surfaces.

Acknowledgements: This project is funded through a Gordon and Betty Moore Foundation MMI grant to SC, MD and NL. SC and MKTs collaboration is facilitated by the SCOR project “Changing Oceans Biological Systems”.

The abstract should be submitted to masts@st-andrews.ac.uk, in an editable format, by 16:00 Friday 19th August 2022.

Aqueous Exposure to Benzo[a]Pyrene (BaP) Induced Behavioural Ecotoxicity in a Model Marine Amphipod, *Parhyale hawaiensis*

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Area being submitted to (delete as appropriate): *Multiple aquatic stressors*

Preferred presentation medium (delete as appropriate): (i) oral

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Are you a student? (Delete as appropriate): Yes

IMarEST Student Membership Name and Number: Ibrahim Lawan, 8102496

Abstract
Marine and intertidal benthic organisms can be exposed to chemicals released from oil and gas-related activities, negatively affecting their survival. Among these substances are polycyclic aromatic hydrocarbons (PAHs) that include Benzo[a]Pyrene (BaP), which is neurotoxic and can affect aquatic organism behaviour. The objective of this ecotoxicity study was to assess the effects of chronic-aqueous exposure to BaP in the circumtropical marine amphipod, *Parhyale hawaiensis*. This amphipod is especially environmentally relevant in marine and estuarine ecosystems vulnerable to pollution and has emerged as a prominent model organism with considerable information on genomics, development, and physiology to support ecotoxicology investigations. Adult male and female *P. hawaiensis* (total carapace length 5-9 mm) were selected and exposed to 500µg/L BaP for 21 d to assess effects on feeding rate, precopula pairing, geotaxis and phototaxis, and locomotory response to food presence. These behavioural responses to BaP exposure were also investigated according to the amphipod gender. Relative to unexposed controls, the feeding rate, moulting frequency, and geotaxis activities were reduced by more than 50% in BaP-treated *P. hawaiensis*. No mortality was recorded, but both males and females presented significant differences ($p \leq 0.05$) in feeding rate and moulting frequency. A significant difference was also observed in the geotaxis and phototaxis activities of male but not female amphipods. Ongoing investigations include assessment of PAH exposure on changes in target gene expression profiles, haematology, and pathophysiology. Many tropical marine and estuarine ecosystems are vulnerable to anthropogenic pollution. Thus, developing ecotoxicology methods and understanding *P. hawaiensis* responses to oil-related pollutants will assist in protecting these critical ecosystems.

Tweetable abstract (Tweeter handle: @ibnlawan2010)

Our ecotoxicity work sponsored by @PTDF_Nigeria and presented at #MASTSasm2022, Glasgow, shows how aqueous exposure to an #oil_pollutant, Benzo[a]Pyrene, affects the behaviour of a marine model organism, #*Parhyale hawaiensis*, in ways that could contribute to population decline.

Acknowledgements
We want to thank Petroleum Technology Development Fund (PTDF) Nigeria for providing the funding to conduct this study. We also thank Robert Rennie for improvising the cylindrical moulds plate for preparing the experimental feeds, John Fox, Sean McMenamy, Dominique Anderson and other Institute of Life and Earth Sciences members for their help and advice.

Predicting changes in the spatial distribution of UK grey and harbour seals using a random forest algorithm and climate model projections

Hannah M.E. Wyles[1], Debbie J.F. Russell[1,2], Matt I.D. Carter[1] and Lars Boehme[1]

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Area being submitted to (delete as appropriate): *2. Multiple Aquatic Stressors*

Preferred presentation medium (delete as appropriate): (i) oral

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The North Sea is entering a period of unprecedented change in the seascape with installation of windfarms and removal of oil and gas. During this period, sea surface temperatures are set to increase with climate change impacting primary productivity, which will in turn affect marine top predators. Thus, predicting the impacts of the changing seascape on top predators and associated effective marine management is predicated on incorporating the potential impacts of climate change. Here we quantify the current at-sea thermal envelope of the two UK seal species and predict which areas will remain within that envelope in the next 30 years.

Specifically, this study investigates the suitable thermal at-sea habitat and foraging areas for grey and harbour seals in the western North Sea and the potential impacts of climate change on their spatial distribution using a machine learning algorithm, random forests. Random forest models have been shown to be one of the best performing species distribution model approaches and to be particularly useful when comparing the effects of multiple environmental variables on species distribution.

We use GPS tracking data from grey and harbour seals tagged on the east coast of the UK and the northern coast of France, sea surface temperature data, along with static covariates to characterise areas which seals inhabit. We also use Hidden Markov Models to identify foraging areas to enable characterization of the suitable thermal foraging habitat for both species. To predict suitable thermal habitat for seals in the future, both for presence and for foraging, climate model predictions for sea surface temperature data are obtained from the Met Office HadGEM3 model and incorporated into the random forest model.

Here, we present our findings from the random forest modelling and highlight the changes in at-sea spatial distribution of seals that may occur due to climate change. This thermal habitat suitability modelling will provide valuable information on the species environment relationship for two important marine mammal species in the UK.

PREDICT: Predicting locations and seasons of top predator interactions with offshore wind farms

Natalie Isaksson[1], Georgina Hunt[2], Marilou Jourdain de Thieulloy[1], David Bould[3], Emma Ahart[3], Kaitlin Eames[3], Beth Scott[2], and Benjamin Williamson[1]

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With the increase of planned large-scale offshore wind developments in the North Sea, there is a growing need to understand where top-predator distributions will have heightened probability of interaction with windfarms. The seasonal distributions of top predators such as seabirds and marine mammals are driven by the movements of their principal prey, fish. The daily, weekly, and annual migration patterns of fish result in highly predictable seasonal changes in foraging and spawning grounds that are driven by environmental variables [1]. Characterising the environmental predictors of fish aggregations between seasons and years could enable calibration and validation of regional models, thereby providing robust forecasts of top predator distributions, which in turn can inform siting and operations of offshore windfarms.

The PREDICT project is a multi-disciplinary collaboration between the University of the Highlands and Islands, the University of Aberdeen, and industry partner Ørsted that aims to improve understanding of fish migration patterns and the environmental drivers of these in the North Sea throughout the annual cycle. The project will identify years, regions, oceanographic and finer-scale features (e.g. frontal and highly stratified areas) to predict mechanisms driving variability in annual fish migrations that are the most likely cause of high variation in seabird and marine mammal distributions [2]. Appropriate low-carbon and low-cost technologies will also be determined, including combinations of novel sensors and platforms, to facilitate simultaneous collection of data on fish and environmental drivers. The design and development of processing techniques for the temporal and spatial data generated from such instrumentation will likewise be conducted [3]. The bottom-up approach employed in this study will add to the evidence base, thereby helping to address knowledge gaps in regional offshore wind environmental characterisation while simultaneously providing a vision for next-generation monitoring techniques to reduce variance and uncertainty in assessments of top predator distributions.

Acknowledgements

PREDICT is a three-year project funded by Ørsted, working with the University of the Highlands and Islands and the University of Aberdeen.

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Hydrodynamic drivers fish school behavior in high energy tidal sites

Ana Couto[1], Benjamin Williamson[2], Shaun Fraser[3], Ian Davies[4] and Beth Scott[5]

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Tidal stream environments are areas characterised by extremely fast currents and a range of turbulent features that vary considerably over short temporal and spatial scales and are known foraging hotspots for highly mobile marine predators due to increased prey availability. On the other hand, such areas are ideal for marine renewable energy extraction, introducing the potential for conflict, due to planned increases in the use of coastal seas for the extraction of renewable energy. For this reason, there is an urgency to understand the effects of tidal devices on seabirds' behaviour, both direct and indirect, through changes in their prey behaviour and availability.

Using fish school and hydrodynamic data collected simultaneously in a tidal stream area and a mediation analysis framework, this study aimed to characterise the drivers behind prey availability in tidal stream areas. Specifically, we focused on characterising the direct and/or indirect effect of velocity and turbulent kinetic energy (TKE) on fish school depth and cohesion, to test the hypothesis that fish schools are closer to the surface and less cohesive in the water column during periods of fast velocities and therefore more accessible to foraging seabirds.

Results showed that fish schools moved closer to the surface and became less cohesive as velocity increased, thus more accessible to foraging seabirds. However, as TKE increased, so did fish school cohesion, suggesting that velocity and TKE have opposite effects on fish school cohesion. Given that the effect of velocity on fish school cohesion is higher than the effect of TKE, during baseline conditions with high velocity and high TKE, we would likely observe a decrease in school cohesion. However, as other studies have shown, TKE is likely to increase downstream of tidal devices while velocity decreases. Under this scenario, an increase in school cohesion is expected downstream of devices, consequently affecting predator foraging behaviour.

This study brings us a step further to identifying the underlying mechanisms which can influence seabird foraging, as well as other marine predators targeting similar prey species.

PELAgIO: Physics-to-Ecosystem Level Assessment of Impacts of Offshore Wind Farms

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By 2050 it's estimated >400 GW of energy will be gathered by offshore wind in the North Sea alone. How will this increased anthropogenic use of our coastal seas impact already stressed marine ecosystems? And how will that same production of renewable energy offset risks of extreme climate change that, left unchecked, will increase the risk of biodiversity declines. There are many complex changes to ecosystems linked to Offshore Wind Farms (OWFs) that we need to understand, so that the extent of increasing wind energy extraction further offshore is managed in the most sustainable way. An important effect of large wind energy extraction will be to reduce the amount of energy that would normally go into local ocean currents via surface stress, altering sea state and mixing. Conversely, there will be local increases in turbulence around turbine structures and seabed scouring near fixed foundations. Any change in ocean mixing may change the timing, distribution and diversity of phytoplankton primary production, the base of the food chain for marine ecosystems, to some degree. This has knock-on-effects on the diversity, health and locations of pelagic fish that are critical prey species of commercial fish, seabirds and marine mammals. Observed changes caused by operational OWFs in the southern North Sea include local surface temperature rise and the displacement of seabirds and fishing fleets from the OWF footprint, whereas seals often appear to be feeding near turbines. All of these changes have a linked component, important prey fish species, which are likely to aggregate near structures (as seen at other offshore platforms). Seabirds and fishing fleets subsequently have less space to hunt, with potentially increased competition for fish. However, if OWFs are also de facto marine protected areas and so positively affect local primary production, they may provide good habitat for fish population growth.

So, what are the cumulative effects of current OWF developments and the thousands of additional planned structures? Do the physical, biogeochemical and ecosystem changes exacerbate or mitigate those resulting from climate change? As OWFs migrate further offshore as floating structures, how can current knowledge based on shallow, coastal fixed turbines be suitably extrapolated to understand the impacts on ecosystems dependent on seasonal cycles that are typical of deeper waters?

The new PELAgIO project will address all of these questions through an inter-disciplinary, multi-scale observation and modelling framework that spans physical mixing through to plankton production, on to the response of fish and whole ecosystems. We will present how we will collect fine-scale data using the latest multi-instrumented acoustic platforms set beside and away from OWFs, complemented by autonomous submarine robots. The new approach to capture continuous and coincident data from physics to fish, over multiple scales and seasons will allow understanding of the changes to mixing and wind deficit impacts and what is 'different' inside an OWF as well as the size of its footprint. This bottom-up, comprehensive approach will enable true calibration and validation of 3D ocean-biogeochemical modelling systems, from the scale of turbine foundations up to the regional and even cross-shelf scales. These new data will also help to understand and quantify how OWF expansion might change prey fish availability to seabirds and mammals with the identified changes integrated into Bayesian ecosystem models. The outcomes of these models, run under different scenarios chosen by stakeholders, will enable the cumulative effects of ecological, social and economic trade-offs of different policy approaches for OWFs to be quantifiably assessed for present day conditions, during extreme events and under climate change.

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The potential of wind farms to affect primary production

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The rapid growth of renewable energy development in the shelf seas has raised the need to assess the direct and indirect impacts of these new infrastructures on the marine ecosystem. Very large-scale windfarms (fixed and floating) are going to be deployed in Scottish shelf seas (Scottish Government, 2022) under different hydrodynamic conditions (Leeuwen et al., 2015) where will change physical and biological processes (Carpenter et al., 2016). The extent in space and time of these variations are partially unknown and are likely to affect the trophic layers relying upon primary producers and physical drivers.

To investigate the possible effects of wind energy extraction, we need to start exploring areas with good long-term baseline data. The region of Firth of Forth and Tay Bay (Scotland, UK) has extensive wildlife and physical surveys and exemplifies an ecological and economic area of interest for top predators (seabirds, mammals) and the fishing industry. The area is targeted for future floating and static wind farm deployments. Seasonal variations occurring at and around wind farms were investigated by comparing two modelled scenarios, with and without windfarms, using FVCOM coupled to ERSEM. A first parametrization of the effects of wind farms on primary production is applied in this region following Christiansen et al. (2022).

Comparing the two models from March to July 2003 showed an overall decrease in primary production before the bloom, with a daily maximum decrease of up to 6% after wind farm deployments. Variations in Chl-a higher than 0.2 mg/m^3 at the depth of maximum concentration were recorded up to 80 km away from the wind farms. The size and location of each wind farm appeared correlated to the spatial extension of their effects. Shallow and highly concentrated patches develop in coastal waters (< 25 km), while the primary productivity changed over time close to the wind farms (< 20 km). The resulting change in the vertical distribution of food resources is likely to affect the distribution of upper trophic layers, influencing their vulnerability or sensitivity to turbines (e.g. seabirds and fish).

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Cumulative Effects of Offshore Renewables: from pragmatic policies to holistic marine spatial planning tools

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To alleviate climate change consequences, UK governments are pioneering offshore energy developments (ORE) at an ever-increasing pace. The North Sea is a dynamic ecosystem with strong bottom-up/top-down natural and anthropogenic drivers facing rapid climate change impacts. Therefore, to ensure the compatibility of such large-scale developments with nature conservation obligations, cumulative effects need to be evaluated through cumulative impact assessments (CIA). However, by excluding climate change impacts, the CIA lacks spatio-temporal appropriate baselines linking oceanic ecosystem indicators to population dynamics, leading to uncertain predictions at populations levels. At a European level, the CIA is currently required under both the Strategic Environmental Assessment (SEA, Directive 2001/42/EC) and the amended Environmental Impact Assessment (EIA, Directive 2014/52/EU). The Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) also requires the assessment of the main cumulative and synergetic effects based on its ecosystem approach. At the UK level, CIA requirements and MSFD are mirrored within the Marine and Coastal Access Act, the UK Marine Policy Statement, and the UK National Policy Statement.

This study presents an overview of the CIA policy framework, enabling an ecosystem-based approach linking lower ecosystem components to top-predator populations using the UK as a case study. Firstly, we show how CIA and MSFD requirements are integrated into the UK licensing and maritime planning frameworks. Secondly, we provide policy pathways embedding the MSFD as a baseline for CIA at the European and UK levels. Thirdly we propose tools such as a shared monitoring effort and a modelling approach with connections to current online databases. Finally, we highlight how Contracts for Difference policy could be used as an integrative tool to enhance a holistic and pragmatic ecosystem-based framework for an inter-disciplinary CIA approach fit for a rapid expansion of ORE.

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Nuances of Nature Based Development

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As part of supporting the Blue Economy Vision there is a need to ensure sustainable development and solutions that bring biodiversity net gain.

In this talk we present some of Mott MacDonalds experience in sustainable development to date and the challenges encountered with using nature-based solutions. Projects covered include coastal defence programs, touching on handling managed realignment and wastewater treatment solution with accompanying habitat creation. The question of compensatory habitats and current understanding of what, where, when and how these can be undertaken is raised.

We also seek to provide insight on some of the policy and evidence-based challenges that occur, and the current gaps in knowledge experienced. This includes recent programs to map stakeholders and link associated environmental processes to enable a holistic view on impacts and cumulative aspects to be taken. This holistic view on processes is often missed and is a particular concern to properly assess outcomes of projects.

Communication of these challenges and their resolution is key to enhancing the uptake of blue economy within Scottish waters. As such, this talk seeks to encourage the development of partnerships, summarise lessons learned and identify potential opportunities for future research to deliver measurable impacts.

Improving understanding of vessel activity in Scotland’s coastal waterways: implications for wildlife and policy

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Understanding, and then subsequently monitoring and managing human activities in the marine environment is inherently challenging. Challenges include inadequate data, a limited understanding of environmental interactions within marine ecosystems, and the inherent complexities of managing species and activities that traverse multiple jurisdictions. To assess and understand the degree of impact or potential risk an activity poses, we first must know where and when that activity is taking place. For many ‘static’ actions, this information is relatively simple to obtain and characterise, but this is not true for all uses, especially ‘mobile’ activities. For example, vessel activity is highly mobile, and so understanding the potential risk posed in space and time can be challenging. This is, in part, because the vessel tracking system known as ‘Automatic Identification System’ (AIS) is only legally required to be broadcast by vessels over a certain tonnage or length, working commercially, or carrying a certain number of passengers. This means that without targeted data collection there is only a limited understanding of the presence and distribution of non-AIS vessels, such as small fishing boats, recreational vessels, and jet skis, despite non-AIS vessels constituting a significant portion of maritime traffic. This has important conservation management and policy implications, as these types of (more commonly non-AIS) vessel are associated with several potential impacts to marine wildlife, including underwater noise exposure, strike, and behavioural disturbance.

To address this, the Scottish Vessel Project is a collaborative initiative exploring several data collection approaches to build a more holistic overview of vessel traffic in coastal Scottish waters. The project utilises land-based watch data (through Whale and Dolphin Conservation’s (WDC) Shorewatch and the Orkney Marine Mammal Research Initiative), collects and analyses AIS and time-lapse camera data (in collaboration with FleetMon.com and ECCC), and explores the utility of ship noise models to predict minimum underwater noise contributions from AIS vessels in an urbanised waterway (in collaboration with FleetMon.com and Styles Group Acoustics). This project provides a fundamental step towards improving our understanding of the total volume/presence of vessels, and their potential associated impacts, in Scotland’s coastal seas. This understanding is imperative to provide managers and decision-makers the information to support the sustainable management of our coastal spaces.

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Assessing faunal diversity and status of European flat oyster beds through analysis of soundscapes, eDNA and visual surveys

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European flat oyster beds(EFOBs) improve water quality, increase overall biodiversity and store carbon [1,2].Overfishing in the early 1900's vastly reduced their numbers and extent, and today only trace populations remain[3].Many native oyster restoration projects have recently been implemented across Europe, but time/cost effective methods for evaluating their ecological status are lacking. This PhD project will apply, develop ,and compare different methods and metrics, i.e. soundscapes, environmental(e)DNA and visual surveys, for assessing diversity of fauna associated with EFOBs at varying states of development/recovery, as an indicator for ecosystem complexity and status. The first ever systematic EFOB soundscape recordings were generated in Scottish and Swedish remnant habitats(summer 2022),by deploying passive acoustic monitoring units over ~2 weeks(Sweden) and 6 weeks (Scotland). Soundscape recordings, to be analysed using e.g. machine learning, will be compared with eDNA results derived from water and sediment samples, and with visual biodiversity survey data. Forthcoming results will demonstrate whether the applied methods, individually or combined, can be used as time and cost-effective tools to adequately assess/monitor ecosystem complexity and status, and inform EFOB conservation and restoration efforts. This research is timely, given recent national and international emphasis on restoring degraded habitats.

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