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.

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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.

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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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