Effects of Parasites on Food Web Structure and Dynamics: New Ways to Improve Accuracy and Ecological Realism

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Abstract:

Food webs have come to assume a central place in ecological theory; however, they often only describe a subset of interactions present in an ecosystem. Consequently, food webs have been defined as caricatures of nature, because like caricatures, a food web's representation of nature is distorted. One way to reduce this distortion is the inclusion of parasitic species. Parasitism is a significant and fundamental consumer strategy in almost all ecosystem communities. Since the 1980s there has been a large scientific plea to include parasites within food web literature. This study aims to identify new ways to include parasites within food web models and to investigate any influence that parasite species may have on the structure, function, and dynamics of a marine food web off Scotland's west coast, which covers the ICES fisheries management area 6a. The ecosystem has a high socioeconomic value through supporting an array of commercially valuable species. The study will focus on topological, energetic, and functional food webs with detailed investigation into which food web type best represents parasitic interactions. Additionally, the study will compare the changes in food web metrics with or without parasite species and with generalist parasite species compared to specialist parasite species. Finally, the study will also investigate the use of environmental DNA (eDNA) metabarcoding techniques to detect parasites to reduce the need for dissections in future parasitological studies. The poster aims to outline the project, the work completed hitherto and will show the results of the literature review, dissections, and preliminary food web designs.

Generalized impacts of man-made structures on the North Sea benthic communities

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Oil and gas extraction activities have influenced North Sea ecological communities with the installation of over 1,300 man-made structures (MMS) to offshore maritime waters. Previous studies revealed divergent impacts of individual MMS, including the colonization of epifaunal communities, facilitating larval dispersal and species connectivity, the introduction of physical disturbance during MMS construction, and possible oil-associated contamination. This study compiles benthic survey data from 1975 to 2015 across over 200 MMS in the North Sea. Generalized patterns of diversity metrics of benthic communities were identified in relation to MMS characteristics, including distance from structure, age, infrastructure type, and distribution aggregations. Preliminary results show that heterogeneity exists in benthic communities across distribution aggregations. An increase in distance from structure and age tend to yield to higher abundance and diversity level. But distance and infrastructure types explain a small portion of total variance in diversity metrics. Individually, MMS construction appears to cause a decline in total abundance and diversity in the short term but yield to higher abundance and diversity level as MMS age increases. The study aims to provide evidence for MMS effects on benthic communities which will be critical to devising sustainable management plans in light of the rapidly evolving energy infrastructure in the North Sea

Dolphin detections in the waters off Western Scotland and the coast of Northern Island

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The INTERREG VA cross-border region constitutes an important habitat for several dolphin species such as Risso's dolphins, a designated feature of interest protection in the North East Lewis Marine Protected Area, common dolphins, white-beaked dolphins or bottlenose dolphins (Hammond et al. 2017). Protected under several regional and international legislation, data on their ecology, population structure, abundance and distribution is still poorly understood. Passive acoustic monitoring data were collected between November 2017 and November 2021, all year round, to depict seasonal and diel occurrences of this species at ten sites across the cross-border region of western Scotland, Northern Ireland and Country Donegal, Republic of Ireland.

C-PODs detect and classify echolocation click trains produced by porpoises and other cetaceans, which includes various dolphin species. In this study, raw C-POD data were processed and summarized for the other cetaceans category (for simplicity, throughout this report we will refer to this classification as dolphins) in Detection Positive Minutes per hour (DPM), and Detection Positive Hours per day (DPH). Statistical models (Generalised Additive Models for big data; BAMs) were used to describe the seasonal and diel pattern in dolphin detection. Seasonal-diel plots were produced to visualize patterns occurring between seasons across years. Noise from the environment or the mooring itself might influence observed diel patterns as well as the overall rates of detection. The diel patterns observed are therefore discussed with consideration of time lost from recordings (variable
Time Lost). High proportion of Time Lost was observed in the Northern Irish sites of Middle Bank and the Outer Copelands, 3.59% and 3.95% respectively, when compared to the rest of sites (<1.5%). At Middle Bank, a four cycle diel pattern in the Time Lost would suggest a noisy tidal environment saturating the C-POD and reducing the time available for dolphin detections.

Clear variability was observed between sites in overall detections, in both the DPM per hour across the day and in the DPH per day across all seasons and years. Significant diel patterns were found for all sites, with nocturnal patterns clearly noticeable at Stanton Bank, Tolsta, Hyskeir and Shiant Isles, where higher numbers of detections were found between 8pm to 8am. Seasonality in detections was also found across all sites, with overall higher detections from September to April in Tolsta, Hyskeir, Shiant Isles, Stanton Bank and Malin. At the Malin site, a secondary peak in detections was found between April and June. Future analysis of acoustic broadband data and statistical analysis would help to confirm these patterns of occurrence and elucidate drivers for them. Acoustic broadband data will also help to distinguish between different species of delphinids.

This study highlights annual, seasonal and diel patterns in acoustic dolphin in the waters between Western Scotland and Northern Island (the Interreg VA area) and demonstrates the value of long-term PAM for species monitoring.

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Integrating genomics and modelling to predict climate change response and identify drivers of decline in the endangered freshwater pearl mussel (*Margaritifera margaritifera*)

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Under the rapid pace of climate change, we urgently need to understand the resilience and response of threatened species. Adaptation to the future climate is therefore important to estimate efficiently. Success of non-invasive DNA collection techniques and the increased affordability of whole genome sequencing offers an opportunity to test for adaptation in endangered species without prior functional knowledge. Genome scans and association analyses enable the detection of adaptive variants across a climate gradient. By integrating this genomic information with ecological modelling, we can determine the mismatch between current adaptive variation and future climate, deemed 'genomic offset'. The freshwater pearl mussel (*Margaritifera margaritifera*) is a critically endangered, keystone species distributed across environmental gradients in Scotland. Although its decline is linked to anthropogenic and climate change impacts, no study has explicitly investigated climate-associated genomic variation and vulnerability in this species. This project will use low coverage whole genome sequencing data derived from non-invasive swabs of mussels from 30 Scottish rivers to resolve fine-scale population structure, detect climate-associated genomic variation and identify populations at risk of loss under future climate change scenarios.

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Predictive biophysical models of bivalve larvae dispersal in Scotland

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1. Introduction

Molluscs, mainly bivalves, represent a significant portion of our current aquaculture production worldwide accounting for over 22% of the total global harvest (FAO, 2018).The ability of mussels to disperse and settle on suitable substrates is exploited by the aquaculture industry for the seasonal supply of seeds. However, dispersal of *Mytilus spp.* larvae at present remains largely unresolved and it is difficult to measure in situ. In this study, we use an unstructured 3D hydrodynamic model to drive a particle tracking model where prediction of larvae movement and dispersal, together with simulations of spat dispersal in designated localities help to investigate potential connectivity between sites (Adams et al., 2016). These advanced approaches help to characterise broad-scale dispersal patterns and have wide implications that can be applied to evaluate the efficiency of spatial-temporal management measures.

2. Material and Methods

The biophysical model is based on an unstructured grid approach; modelling pelagic connectivity between aquaculture sites consists of a hydrodynamic model, a particle tracking model and post-processing module to estimate the source location of the mussel larvae. The domain for this study covers the west coast of Scotland (Aleynik et al., 2016), building upon previous work using smaller domains in the same locality (Adams et al., 2012, Adams et al., 2014, Aleynik et al., 2016, Davidson et al., 2021). The hydrodynamic model applied for this study is based on the Finite Volume Coastal Ocean Model (FVCOM; Chen, 2013). Particle tracking was carried out using the model of Adams et al. (2012, 2016). This model, originally developed to predict the dispersal of sea lice, links physical processes such as water movements with biological processes such as maturation and mortality. The movement of larvae incorporates advection due to local currents and a fixed random diffusion term.
We run the model under two different scenarios. First a single day release of particles in order to assess variability in predicted dispersal patterns. And second a tidal cycle release of particles to quantify the accumulation of particles in each target location (Shellfish farms) and to detect possible source locations seeding each target location.

3. Results

We have analysed the general patterns related to the connectivity between source areas and different geographical areas. The overall overview from the single day releases shows a constant pattern between years (2017 to 2021) and different depths (2 m, 6 m, and 10 m depth). Through the tidal cycle releases, we have calculated the particle dispersal accumulation and we've been able to identify possible source locations of mussel larvae seeding our target locations (Shellfish farms located on the West Coast of Scotland) (fig.1). Results were considered in context with the relevant wind roses for the simulated periods. We have produced monthly representation of the current direction for the same period. With this study we are one step closer to help mussel farmers with their site selection process, as well as to understand the larvae movements through the flow along the complex coastline and bathymetry in fjordic coastal environments.

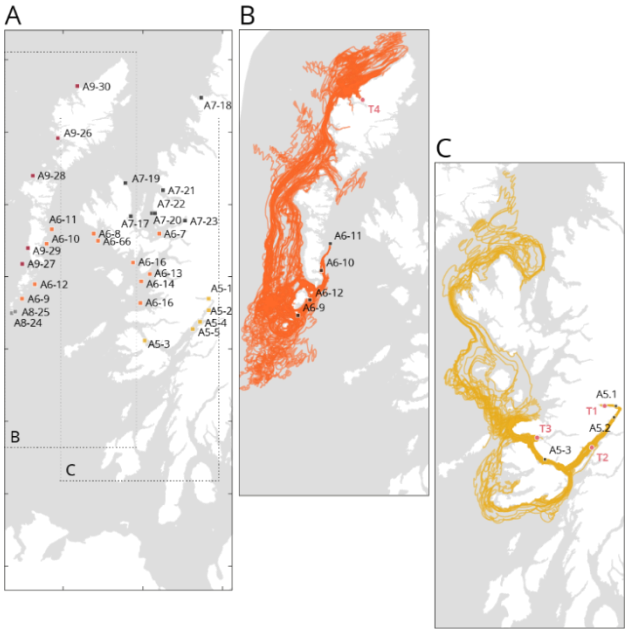

Figure 1. Details of the source locations significatively contributing to the particle accumulations at each target locations. (A) Representation of the source points; (B) Cases of self-recruitment, Loch Eil (T1), and self-recruiting and influence of external recruitment for Loch Linnhe (T2) and Loch Sunart (T3); (C) Example of external recruiting only: Loch Roag (T4). To avoid visual clutter, only the source points A6-9 to A6-12 are illustrated. Distinct colours represent different geographical areas.

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A review of the Scottish marine species and habitats data landscape – improving data availability and accessibility

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High quality, current and accessible marine species and habitat data are essential to support marine environmental policy and planning decisions. Achieving greater exchange and interoperability of data within the marine sector will help support the transformation required to meet the ambitious commitments set by Scottish Government to reach Net Zero-emissions by 2045 and tackle both the climate emergency and biodiversity loss.

NatureScot commissioned this analysis, as an adjunct to the original SBIF Review, for Scottish marine biodiversity data. The aim was to explore and determine limitations to the existing infrastructure, through engagement with key stakeholders.

Key findings: A large amount of Scottish marine data flows into the Scottish and wider UK infrastructures (e.g., databases, repositories, portals, and the Marine Environmental Data and Information Network (MEDIN)) at varying levels of efficiency; ranging from well-established automated workflows to ad-hoc or non-automatic workflows, depending on the biodiversity receptor (mammals; benthic; birds; fish) in question and the organisations contributing the data. Difficulties in identifying, accessing and using marine biodiversity data persist; it is widely recognised that current data flows could be simplified and that there are still barriers to be overcome with data sharing, spatial resolution and coverage. The existing framework and mechanisms to mobilise and access the wide range of existing marine biodiversity datasets can be labour intensive and inefficient.

Technical and cultural barriers to data sharing in particular impact on the availability, quality, and accessibility of data for collation and use by others. These relate to:

- Cultural and behavioural barriers
- Practical barriers
- Inadequate strategies and resources

The review found that relatively large quantities of data were still stored locally and not fully incorporated into the data flow network. Gaps in data availability were identified, in part, are likely to be a result of a combination of data not being properly shared, organised or due to resource driven workflow time-lags.

25 high-level recommendations, prioritised based on their impact or value and the effort or investment required to complete, aim to address these issues. They are brigaded into the six themes:

- Theme 1: Continued engagement with key stakeholders.
- Theme 2: Clarifying and streamlining data flows.
- Theme 3: Improving the quality of existing data management.
- Theme 4: Investing in infrastructure and resource (people skills and funding).
- Theme 5: Improving existing and creating new data infrastructure.
- Theme 6: Simplifying existing and creating new guidance.

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Determining the reproductive biology of the flame shell, *Limaria hians*

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Flame shells, *Limaria hians*, are a nest building bivalve mollusc that can create dense biogenic beds which support rich associated communities. Given their size and the global scarcity of this habitat, Scottish flame shell beds are of international importance, classified as a Priority Marine Feature in Scottish waters (Sloan *et al*., 2022). Understanding the physical (e.g. oceanographic conditions) and biological factors (e.g. reproductive systems, spawning phenology, larval life history characteristics) that contribute to population connectivity is crucial to the implementation of effective marine conservation and management. However, despite their ecological importance, with several flame shell beds protected by the Scottish Marine Protected Area network, relatively little is known about the species' biology.

Bivalves show extreme diversity in their reproductive systems, ranging from separate sexes to sequential and simultaneous hermaphrodites. Several members of the Limidae family have been reported to be protandrous hermaphrodites (Lodeiros & Himmelman, 1999; Järnegren *et al*., 2007**)**, meaning individuals begin their reproductive lives as males before switching to reproduce as females later in life. Preliminary work by Trigg (2009) reported a significant change in the sex-ratio of *L. hians* related to shell size, an observation consistent with it being a protandrous hermaphrodite. However, no hermaphroditic individuals were observed, and further research is needed to confirm these findings. Additionally, little is known about *L. hians* spawning phenology or behaviour. Evidence suggests that the reproductive cycle varies between regions, with Loch Creran specimens spawning in May and June whilst Clyde Sea specimens spawn between July and September (Trigg, 2009), however, there has been no research into the species' reproductive cycle.

Through macroscopic and histological characterisation, we aim to identify the reproductive system and determine the reproductive cycle and spawning phenology of *L. hians*. This research forms part of a wider investigation into the connectivity of Scottish flame shell beds. Tissue from all specimens collected for this project are being used in studies of population connectivity and determining the mode of mitochondrial inheritance in *L. hians.* Information collected on the spawning phenology of *L. hians* will be used to inform the parameterisation of bio-physical models which will resolve population connectivity through larval dispersal.

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Deep seabed mining and demersal fish

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Deep-sea mining is a developing industrial activity, with recent rapid growth in exploration for high-grade polymetallic nodule ore deposits in the Clarion-Clipperton Zone (CCZ) located in the central Pacific Ocean.

Over 21 billion tonnes of nodules are estimated to exist in the CCZ, and the CCZ reserves of nine industry critical metals (including manganese, cobalt and nickel essential for modern green technologies such as electric vehicles) exceed the entire terrestrial reserve base.

The CCZ deposit lies in international waters, and is regulated under UNCLOS by the International Seabed Authority (ISA), who have signed 19 exploration contracts for seabed mining including two with the United Kingdom. The ISA is now in an active phase of developing the legal, financial and environmental regulations for full commercial exploitation. Critical to the development of these environmental regulations is a scientific knowledge base on the physio-chemical impacts and immediate and long-term biological consequences of mining.

SMARTEX (Seabed Mining And Resilience To EXperimental impact) is a £3.2m consortium funded under the UKRI-NERC High-Light Topic programme. SMARTEX has developed seven broad hypotheses, each of which will be formally tested within a linked objective.

Part of SMARTEX's remit will be to re-visit sites in the CCZ where collector tests were carried out in 1979. The Ecotoxicology work falls under Objective 6, Ecosystem functioning and will take place in the UK-1 test mining site. Mining the seabed scars the surface and the disturbed sediment creates a plume of fine particulate matter including inorganic metals. The aim of the ecotoxicology work is to assess the impact of the exposure of demersal fish species to these plumes.

Fish were caught usingtraps baited with mackerel. They were left for 48 hours and rapidly returned to the surface and processed on board. The fish species caught included *Coraphaenoides sp., Barathrites iris* and various other Macouridea and Zoarcidae.

DNA damage was assessed using the Comet assay. Blood and gill tissue were sampled from the freshly caught fish and immersed in HBSS containing 10% DMSO as a cryoprotective agent and stored at -80ºC until further processing back in Edinburgh. Comet assay: the samples were prepared and processed as described in and analysed using Comet Assay IV (Perceptive Instruments). The first phase of the ecotoxicology work was to optimize the assays to the species of deep-sea fish. The Comet assay was performed on 2 species of deep see fish and compared to trout prepared in a similar way (frozen in 10% DMSO/HBSS).

There was no significant difference between the deepsea species and the trout. This suggests that the procedure of catching, transport to the surface and processing at sea had no additional artefactual effects that might mask any toxicological response following exposure to mining sediment plumes.

Covid-related lock-downs, disruption to laboratory access and the subsequent postponement of cruises means that only very preliminary results are available to date.

The next step will be to opitimize histopathological changes to gill epithelia and oxidative stress assays (TBARS, SOD, GSH, GPx, CAT) in preparation for the CCZ cruise in February/March 2023

Marine spatial planning- moving beyond plan making

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Since the mid-20th Century there has been a rapid expansion of marine activity, including oil and gas exploration, electricity and telecommunication cables, sand and gravel extraction, aquaculture, seaweed farming and marine renewables, as well as the creation of marine protected areas (MPAs). This is in stark contrast to the relatively limited use during the preceding millennium, where human use of the marine environment was largely confined to fisheries and seafaring. This rapid growth has led to conflict between new and existing users through competition for space and resources, as well as a range of environmental impacts. To help mediate conflicts, balance multiple objectives and move towards more sustainable decision-making, marine spatial planning (MSP) has emerged as a key management tool.

While the plan making phase can set criteria and conditions for future use and has been subject to considerable research effort, the implementation phase has been less well researched. This in part reflects that few plans have moved to statutorily adopted. In Scotland marine planning is implemented via a National Marine Plan and 11 regional marine plans. The Shetland marine plan is the most advanced of these regional marine plans and will be the first regional marine plan in Scotland which has moved to this implementation phase.

Here we present range of actions and research projects that will support delivery of the policies and objectives within the marine plan and how their effectiveness will be monitored. These findings will help to monitor impact and inform future iterations of the Shetland marine plan. While the implementation plan is Shetland focused monitoring of effectiveness of the plan and its implementation will help to inform the development of marine plans elsewhere.

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Resilience of European native oyster reefs in habitat restoration

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Biodiversity restoration has become a popular conservation practice across the UK and Europe. A common target of restoration are European native oyster reefs. These restoration efforts are often sponsored by corporate and government agencies which require evidence that their funds and resources are being used effectively. It is therefore important to assess restoration progress and understand the biodiversity outcomes of restoration activities.

In a changing climate, however, and with increasing anthropogenic pressures, coastal ecosystems are increasingly under pressure. This potentially poses a challenge to restoration initiatives, and calls into question whether restored habitats have the same resilience as naturally occurring examples.

Ecological concepts such as resilience and functional redundancy can be used to infer ecological stability and the future potential of restoration sites. Using the recovery of a naturally occurring oyster bed from fishing activity as an analogy for the restoration process, the present study compared two European native oyster reefs, one from a long-established fishery and a second from a restoration site.

The restoration site was four years old and it had been four years since the naturally occurring oyster bed had been fished. Eight five meter transects were used at each site to obtain in situ biodiversity records using SCUBA. Factors determining reef health were also recorded, including oyster size distribution, number of dead oysters and oyster shell percentage cover. Biological trait analysis was carried out to assess and compare functional redundancy between the sites.

The findings of the present study are discussed in the context of the UN Decade on Ecosystem Restoration and rapidly emerging biodiversity restoration initiatives and policies throughout the UK and Mainland Europe.

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