ROPES TO REEFS

UK Seafood Fund: Fisheries Industry Science Partnerships scheme (FISP)

PROJECT REPORT

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Executive Summary

This report describes the Ropes to Reef FISP project. It provides a preliminary assessment of the surveys and data gathered in Lyme Bay including the offshore longline mussel farm, Offshore Shellfish Ltd (OSL), the scallop farm, Scallop Ranch Ltd (SR), the seaweed farm, Biome Algae Ltd (BA) and the Lyme Bay Marine Protected Area (MPA) carried out by the University of Plymouth.

Ropes to Reef brings together farmers, fishers, scientists, government, regulators and industry at a critically important time for the UK aquaculture industry. Utilising, novel, innovative approaches and an invaluable 8-year ecological dataset, the aim of the project was to provide hard evidence on essential data gaps on the habitat and fish stock benefits of offshore aquaculture to inform future management and policy. Communication and dissemination were at the core of the Ropes to Reefs project to convey the outcomes of the project to a wide range of audiences and public and improve stakeholder's understanding of the wide ecosystem benefits of the industry, while increasing manager's and regulator's insight into the environmental impacts of the industry to aid and streamline future licensing and consenting applications. The impact of the project's communication and dissemination has reached over eight million people, including MPs in Parliament and BBC Radio 4 listeners as well as Fishing News readers.

This multi-method approach included ecological videos, acoustic fish biomass (EK80), a Multibeam Echosounder (MBES) bathymetry and backscatter surveys, and the deployment of an acoustic telemetry receiver network, distributed across the Ropes to Reefs partner aquaculture sites (OSL, SR, BA) and the MPA where a range of fish and crustaceans were tagged (lesser spotted catshark, *Scyliorhinus canicular*; thornback rays, *Raja clavata*; thicklip grey mullet, *Chelon labrosus*; black bream, *Spondyliosoma cantharus*; and European lobster, *Homarus gammarus*).

The project has produced the first Ecosystem Service Assessment (ESA) of the offshore shellfish aquaculture sector based on the UoP's long-term monitoring of the mussel farm, providing crucial evidence for government, managers and the industry. We have also written a Policy Brief presented to MPs and published a scientific peer-review journal article on how the mussel farm has created a biogenic reef where there was once damaged seabed ecosystem due to decades of bottom fishing. Results from the surveys have produced a map of the substrate displaying the creation of Essential Fish Habitat (EFH - biogenic reef) and its extent. Although further analysis are needed, preliminary data exploration shows that fish biomass was higher where most of the biogenic reef and courser sediment is found, indicating EFH use. Species such as lobsters display resident behaviour within the farm while dogfish behaviours suggest this species feed within the mussel farm. Results show there is species connectivity between the farm and the Lyme Bay MPA with fish aggregating within the mussel farm in higher abundance at certain times of the year which could be due to food availability. Species such as thornback ray have been tracked to move between the MPA and the mussel farm and certain species such as lobsters, show spillover from the farm into surrounding fishing grounds.

Once fully assessed, the evidence gathered will support the industry meet Fisheries objectives under the Fisheries Act 2020 and White Paper and support sustainable development goals (SDG2 - food security and zero hunger; SDG14 - conservation and sustainable development), the IFCA's Mariculture Strategy, Defra's Marine Spatial Prioritisation strategy towards more sustainable industry, while achieving Net Zero and Good Environmental Status (GES). This evidence is also key to develop the role of offshore aquaculture as nature-based solution (Blue Economy) and its function as part of the UK's Biodiversity Net Gain plans.

Keywords: Aquaculture, BRUV, ecology, ecosystem service assessment, essential fish habitat, FAD effect, fish biomass, fisheries acoustic, food supply, MPA, mussel farm, offshore, PelagiCam, policy brief, ROV, scallop farm, seaweed farm, telemetry, towed video.

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The data and analyses presented are subject to further review and will be published through peer-reviewed scientific journals in due course.

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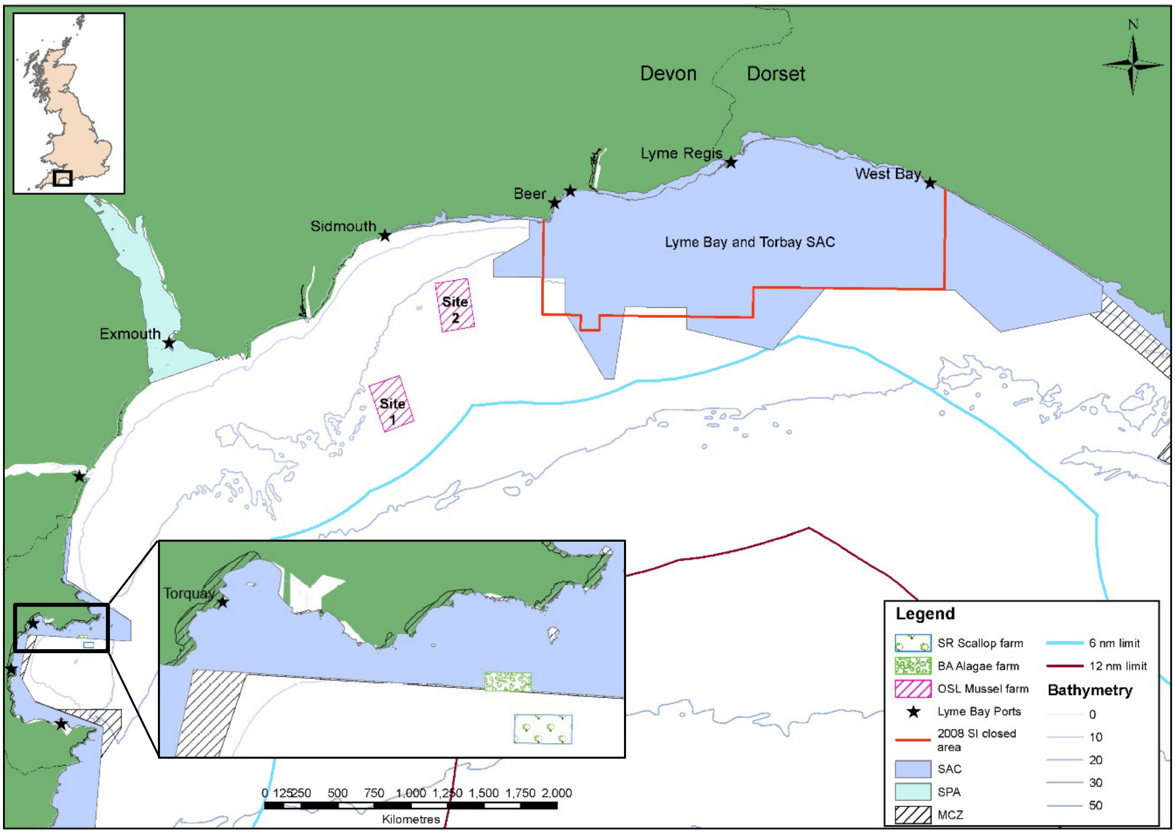

Figure 1.1 Map of Lyme Bay including location of the three farms under (OSL, BA and SR) study as well as the Lyme Bay and Torbay MPA.

1 Introduction

1.1 Offshore Shellfish mussel farm

The UK's first large scale offshore, longline rope cultured mussel farm, operated by Offshore Shellfish Ltd. (OSL), is a suspended rope type of mussel aquaculture located in an exposed area between about 3 and 10 km offshore of Sidmouth and Seaton in depths of between 20 and 30 m relative to chart datum, in Lyme Bay, South Devon (Figure 1.2). The farm leased 15 km^2 of seabed from the Crown Estate to deploy a specially designed technology of suspended longline ropes to cultivate the native blue mussel *Mytilus edulis*. When fully operational, these three sites will cover a total area of 15.4 km² and produce up to 10,000 tonnes of mussels per year. The mussel farmers first deployed pilot mussel lines in Sites 1 and 2 in November 2013. Most of the development is now

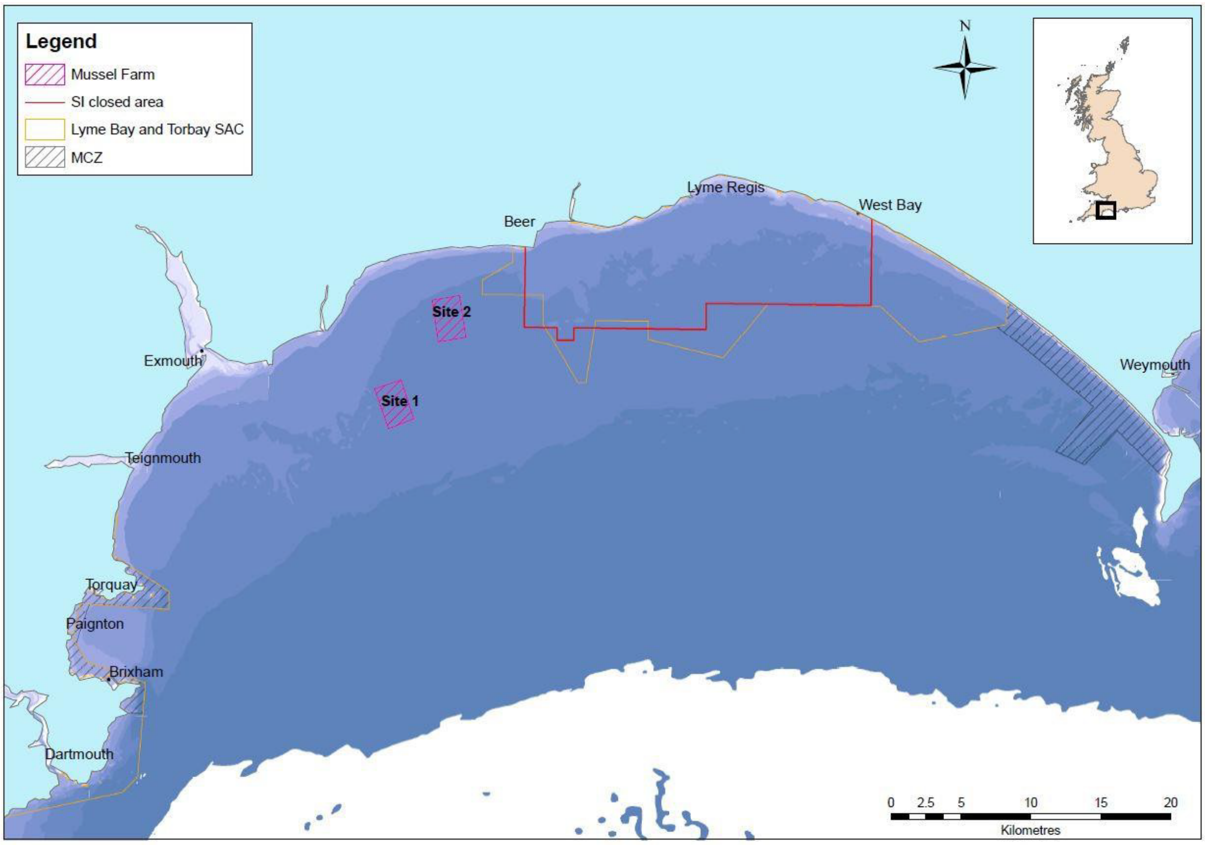

Figure 1.2 OSL location in Lyme Bay.

focused on Site 2, the area under study. The competent authority considered the farm to be ‘offshore’ as the central point of all three sites lie at least 5 km from the shore.

Each 150 m long mussel headline is moored to the seabed with a pair of screw anchors. The headlines are suspended 3 m below the surface from a series of tubular buoys at regular intervals to keep the structure floating. From the headline a series of ‘dropper’ loop ropes extend a further 10 m down, upon which the mussels are attached (Figure 1.3a). As far as possible, headlines are placed following the bathymetry of the area and parallel to each other at 50 m intervals (Figure 1.3c). Headlines along the same bathymetry line are separated between each other by a 250 m gap (Figure 1.3b). This arrangement ensures the dropper lines are suitably damped against wave action(Cefas, 2015) (Cefas, 2015).

Based in Brixham, Offshore Shellfish Ltd are now producing high quality rope grown mussels in a fully offshore marine environment. In 2018 it obtained the Best Aquaculture Practices (BAP) certification by the Global Aquaculture Alliance, being the first mussel farm in Europe to earn such distinction.

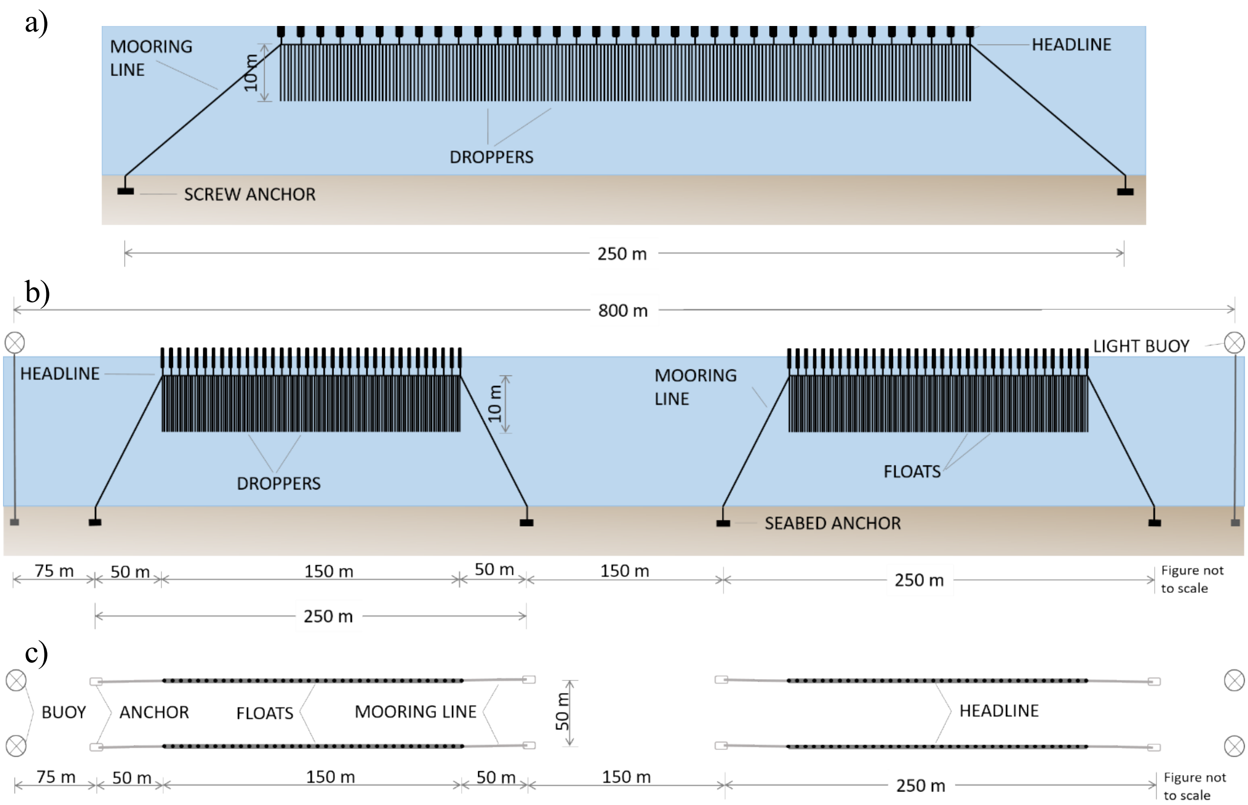

Figure 1.3 Schematic representation of the suspended longline mussel farm showing a) elevation view of a single longline; b) elevation view of a double longline; c) plan view of a double longline.

1.2 Biome Algae farm

Biome Algae Ltd. (BA) is a seaweed farm and processing site in Devon and Cornwall, UK. Operating since 2020, BA have grown over multiple farming seasons. BA Devon is located in Torquay, Torbay (Figure 1.4). The farm has eight lines that are West/East in orientation producing approximately 7kg of yield per metre of single-seeded line. With approximately, 11,428 meters of line on the Torbay site, BA has a potential maximum yield of 80,000 kg however. The site is predominantly single-seeded line however, 2.5 lines are double-seeded and 1/28th of the farm is direct seeding and it also includes areas for secondary species and designated as test lines locations (Figure 1.5).

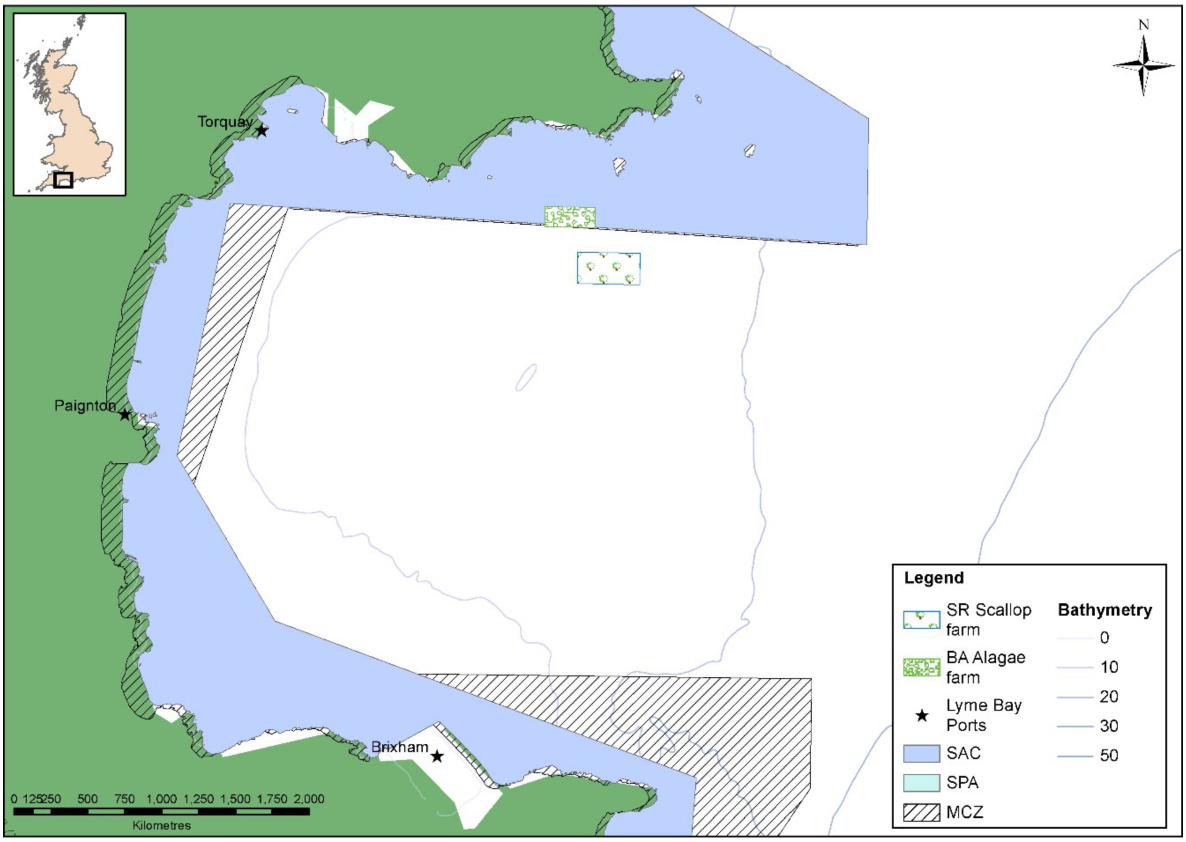

Figure 1.4 Location of Biome Algae Ltd and Scallop Ranch Ltd in Torbay.

BA has won a range of awards which include the 2022 Green Start-Up (Southwest) and Overall Start-Up (Southwest), the 2023 St James Place Community Award and the 2023 Game-changing Innovation MARINEi award.

1.3 Scallop Ranch farm

Scallop Ranch Ltd. (SR) is a scallop farm located in Torquay, Torbay (Figure 1.4), operating since 2015 when the first lantern nets with scallops with shell width >30 mm were established on 2 x 150m lines (Figure 1.6). The lantern nets were constructed with 15mm mesh netting separated into 25 compartments each 20 cm high and with a diameter of 50 cm. The total length of each lantern net was 5 m and they were suspended 3 m beneath the sea surface. By 2016, only a small number of lines in the farm had lantern nets but that increased in 2017 and 2018.

Figure 1.6 Schematic representation of the Biome Algae Ltd seaweed farm.

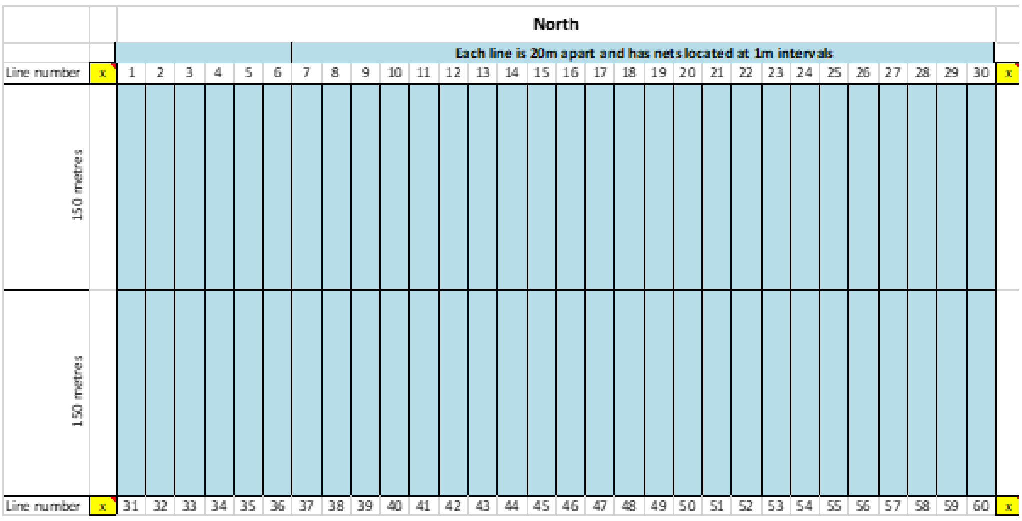

Figure 1.5 Schematic representation of the Scallop Ranch Ltd scallop farm.

1.4 Lyme Bay MPA

Situated in the Southwest of England within the counties of Devon and Dorset (Figure 1.7), in the English Channel, Lyme Bay is a large, open embayment with a moderate slope from the intertidal zone to up to 50m depth in the central outer reaches. Most of the Bay is backed by cliffs with a number of watercourses draining into it (Cefas, 2015). Lyme Bay has been identified as a "marine biodiversity hotspot", holding particularly high species richness making it one of England's most important areas for marine biodiversity (Fleming and Jones, 2012; JNCC, 2010; Rees *et al.*, 2016; Sheehan *et al.*, 2021, 2013; Singer and Jones, 2018). The Bay contains a mosaic of substrates including sand, mud, gravel, rock and mixed ground (Rees *et al.*, 2016). The area protects UK Biodiversity Action Plan (BAP) species and habitats such as the pink sea fan (*Eunicella verrucosa*), seagrass beds (Eelgrass) and honeycomb worm (*Sabellaria alveolata*) reefs (NE, 2010). These are important in terms of ecology, conservation and socio-economics (Sheehan *et al.*, 2016) as they

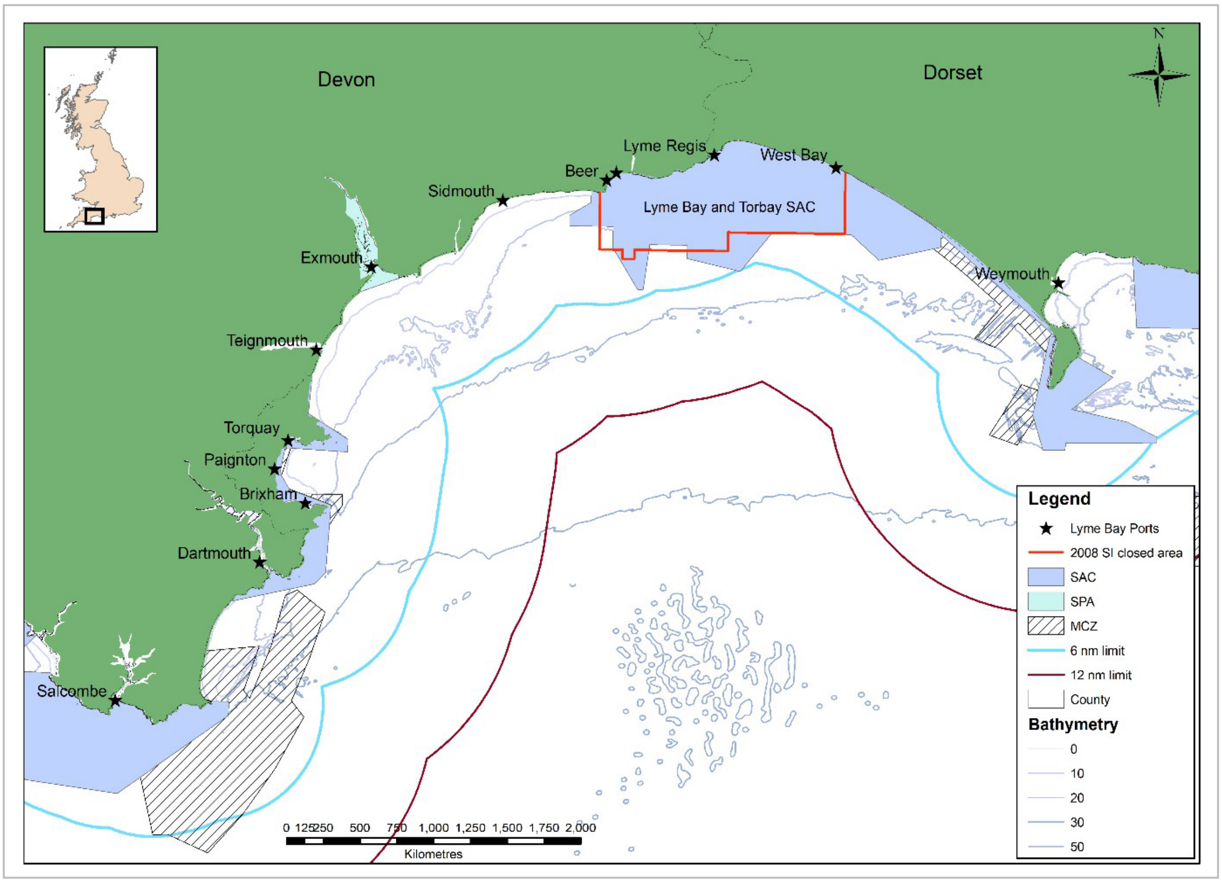

Figure 1.7 Lyme Bay MPA designations.

interact to support the delivery of several ecosystem processes (i.e. primary and secondary production) and ecosystem services (i.e. fish for food) (Rees *et al.*, 2016).

Lyme Bay is home to important fishing grounds where different fishing methods are used contributing 12% of the SW England Gross Value Added (GVA) in 2016 (Sheehan *et al.*, 2016; Singer and Jones, 2018). Traditionally, fishermen towing bottom-fishing gear (otter trawls, beam trawls, scallop dredging) avoid the rocky areas and fish on the mixed sediment areas (sands, gravels, cobbles). Static gear fishermen place pots in the rocky areas to catch crabs and lobster. The Bay also supports a large number of recreational users, including sea anglers and dive charters operate around the reefs and wrecks of Lyme Bay, significantly contributing to the local community (Rees *et al.*, 2016; Sheehan *et* *al.*, 2016; Singer and Jones, 2018). Wildlife watching boats also operate in the Bay, taking marine mammal and birdwatching trips (Rees *et al.*, 2016).

Lyme Bay is home to several areas of national and international conservation importance, holding different marine protected areas (MPA) designated with various levels of spatial management (Figure 1.7): four areas closed to towed demersal fishing gear under voluntary agreements in 2001 and expanded in 2006; the voluntary areas developed into The Lyme Bay Designated Area (Fishing Restrictions) Order, a Statutory Instrument (SI) excluding bottom-towed fishing gear from a 206 km2 area (Defra, 2008); new byelaws implemented by the Southern Inshore Fisheries and Conservation Authority (IFCA) and Devon and Severn IFCA protected 236km^2 of Habitats Directive 92/43/EEC Annex I reef features within a 312km Site of Community Interest (SCI) to conserve the reef and associated reef species; the SCI developed into the Lyme Bay and Torbay Special Area of Conservation (SCI/cSAC: NE, 2010; SAC: Defra, 2011); Torbay Marine Conservation Zone (MCZ), Chesil Beach and Stennis Ledges MCZ, East of Start Point MCZ, South of Portland MCZ and Skerries Bank and Surround MCZ (Rees *et al.*, 2016; Stevens *et al.*, 2014).

1.5 Ropes to Reefs aims and objectives

Project Aims:

- Assess the ecosystem services and benefits of the UK's first large-scale, offshore mussel farm that has been the focus of a comprehensive long-term ecological research monitoring programme.
- Assess the biodiversity and extent of essential fish habitat (EFH) that has been restored as a result of the farm, and the associated mobile species of both conservation and commercial value and its connectivity with a nearby MPA and two other low-trophic aquaculture developments.
- Deliver essential evidence regarding the role of offshore aquaculture as a nature-based solution and inform Fisheries Management Plans, the Mariculture Strategy, Biodiversity Net Gain, Sustainable Development Goals and Global Ocean Alliance targets.
- Disseminate and communicate the project's research and findings to a wide range of audiences.

Project objectives:

- Produce the first Ecosystem Service Assessment (ESA) of the offshore mussel farm industry.
- Produce a Policy Brief.

- Use cutting edge, cost-effective and non-destructive remote sampling techniques: fish echosounder (seasonal survey), multibeam, and ground truthing cameras deployed from local fishing boats to produce high resolution data on the presence, biodiversity and extent of EFH (mussel reef on seabed and water column) and associated mobile species.
- Track fishes and crustaceans using acoustic tags via the world's first multi-farm (mussel, scallop, and seaweed) aquaculture telemetry network and the wider FISH INTEL network.
- Prepare and deliver a project Webinar.
- Produce an animation video.
- Dissemination of the project through various social media outlets and channels and through a wide range of conferences and meetings.

2 Offshore mussel farm long-term assessment of environmental interactions

Data gathered during the long-term assessment of environmental interactions of the Lyme Bay offshore mussel farm is being used to produced and Ecosystem Service Assessment (ESA) and a Policy Brief to inform managers and industry for the sustainable development of aquaculture. The long-term environmental assessment data has been included within the benthic habitat restoration analysis (section 2.3).

2.1 Ecosystem Service Assessment (ESA) study

The first Ecosystem Service Assessment (ESA) of the offshore shellfish aquaculture sector based on qualitative and quantitative data from UoP's long-term ecological (benthic and pelagic) and oceanographic data. This thorough ESA study provides evidence for government, managers and the industry to inform future aquaculture license applications and the sustainable management of the marine environment. The ESA report has been delivered separately.

2.2 Policy Brief

We have produced a Policy Brief accompanied by a 3-minute video on the environmental interactions of offshore shellfish aquaculture. Both the Policy Brief and 3-minute video were presented to MPs and peers in Parliament (Table 2.1) during the Sense about Science Evidence Week on 25th and 26th June. The Policy Brief has now been distributed and shared with the Ropes to Reefs partners as well as stakeholders, managers, government and the wider public.

Restorative Offshore Aquaculture Policy Brief

Table 2.1 List of MPs and peers spoken to and presented the Policy Brief in Parliament during Evidence Week.

MP/Lord/Peer	Role
Patrick Vollmer	Director of Library Services and Librarian at UK House of Lords
Dr David Halpern	What Works National Adviser, Chief Executive Officer of the Behavioural Insights Team
Jeremy Williams	Senior Researcher to Leonie Cooper AM (London Assembly)
Chi Onwurah	Labour MP for Newcastle upon Tyne Central and West
Lord Patrick Vallance	Minister of State for Science, Research and Innovation
Ben Goodall	Scientific Advisor, Plant Health Evidence & Analysis. DEFRA
Luke Pollard	Labour (Co-op) MP for Plymouth Sutton and Devonport and Parliamentary Under-Secretary of State in the Ministry of Defence
Jonathan Wentworth	Environment Adviser, Parliamentary Office of Science and Technology at House of Commons. POST
Jonathan Davies	Labour MP for Mid Derbyshire
Alison Hume	Labour MP for Scarborough and Whitby
Michela Barbieri	Researcher to Baroness Bull (member of the House of Lords)
Clare Young	Liberal Democrat MP for Thornbury and Yate
Oliver Bennett MBE	Head of POST
George Freeman	Conservative MP for Mid Norfolk and former Minister of State in the Department for Science, Innovation and Technology
Theo Brown	PA to Martyn Wringley MP (Liberal Democrat MP for Newton Abbot)
Deborah Cohen	Journalist - ITV news
Iqbal Mohamed	Independent MP for Dewsbury and Batley
Liz Twist	Labour MP for Blaydon and Consett

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The MI has identified five research themes to help address the unprecedented number of global environmental challenges: Towards net zero, Sustainable blue economy, Safe seas, Healthy oceans, Digital ocean. Within each theme, we are developing and optimising positive interventions and training leaders of the future.

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POLICY BRIEFING FOR PARLIAMENTARY EVIDENCE WEEK 2024/25

30,000 TONNES OF MUSSELS

What is required to reach the UK government target?

EXECUTIVE SUMMARY

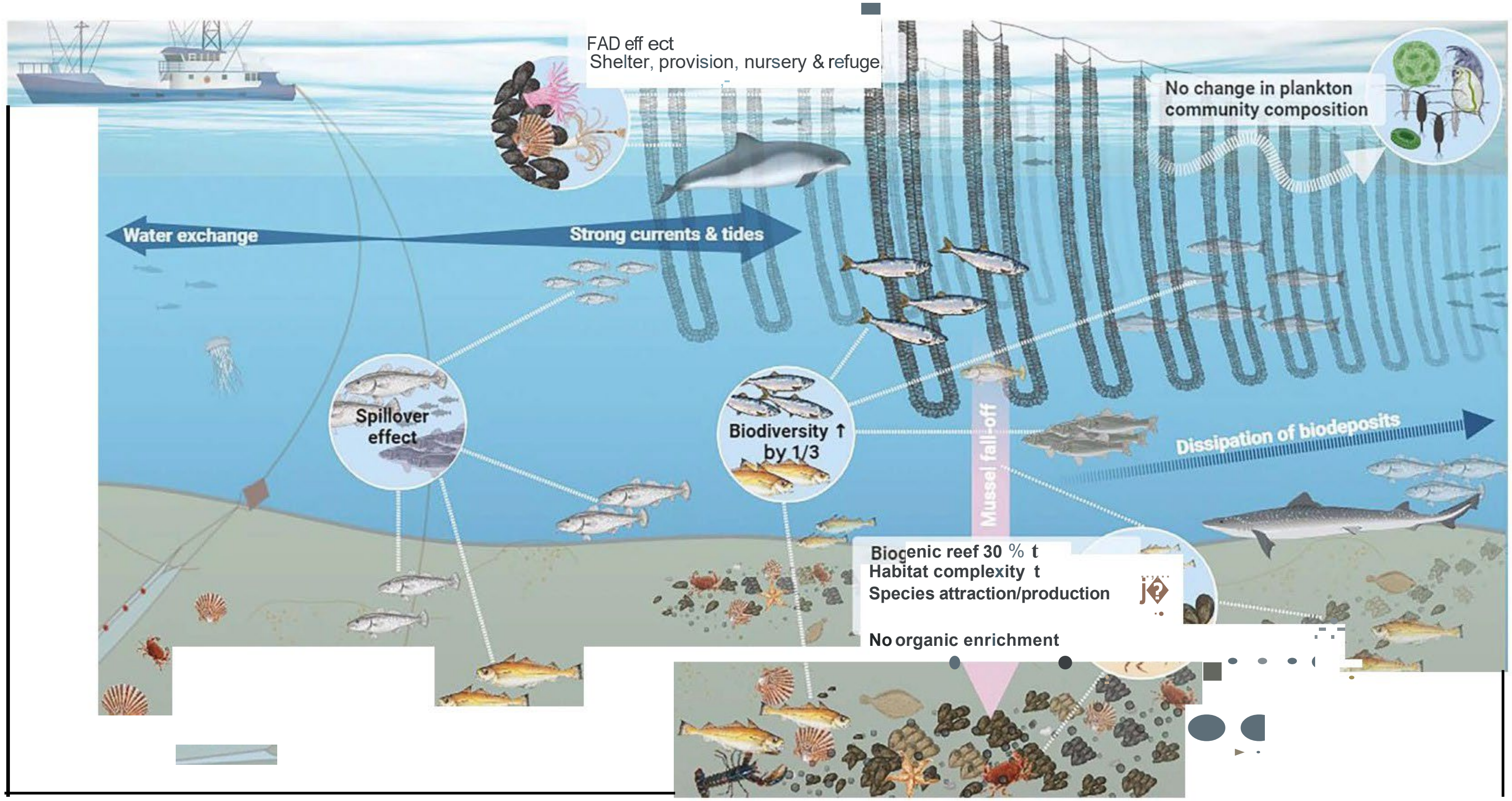
Dr Llucia Mascorda-Cabre and Dr Emma Sheehan

Growth aspirations for English aquaculture predict **30,197 tonnes of mussels by 2040.'** The UK's first offshore mussel farm, Offshore Shellfish Ltd. (OSL), annually contributes >£2.5 million to the economy. The farm currently produces a net total of>1,000T of high-quality marine protein.

Theoffshore industry can deliver **benefits to the UK:** food security, economic resilience, enhancing the seafood industry, and contributing to marine conservation as a **Biodiversity Net** Gain (BNG). Major obstacles face its expansion: competition for space, licensing constraints, negative public perception, and lack of secure access to export markets.

OSL increases diversity and abundance of **commercial fishes** that **spillover** into adjacent fishing grounds. The farm increases biodiversty and creates **biogenic reef, restoring seabed** degraded by destructive fishing, and acts as a *de facto* **marine** protected area **(MPA).**

Results support the government on sustainable fisheries management, under the **Fisheries Act 2020,** and demonstrate the industry's role as a **nature-based solution** and Biodiversity Net Gain as part of the **Blue Growth Agenda,** while supporting marine conservation and helping to deliver **sustainable development goals (SOGs).**



KEY MESSAGES

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RPstor.1tivP offshorP aquaculture to reach the UK govPrnnwnt's targPt:

Growth asp·rafons for Engl sh aquaculture pred'ct 30,197T of mussels, 5,141T of oysters, 776T of scallops, SOT of lobsters anda total of 13,067T of macroalgae by 2040, w·tha total grown by rope andl ne culture of 37,523T.

OSL·s sgnl cant ly contrbufng £2.5 m on per year to the economy, provd ng susta·nahle,ohs for 24 people

OSL currently produces a tota net of> 1,C0OT of ed hie, natural y grown, sust.:J°nable h"gh-qu al"ty mar·ne p rote·n every year Th s equates to 5,000 average beef cattle, 44,000 sheep, 600,000 salmon or 400,000 ch ckens.

POLICY CONTEXT

Strategic efforts aim to **expand** the **UK aquaculture** sector by fostering sustainable, resource-efficient, innovative, competitive and evidence-based aquaculture to support the **Blue Growth Agenda** and support **Biodiversity Net Gain, SDGs, food security** and economic resilience.

There is a critical need for evidence on the environmental effects of the industry[1] to avoid impacts and precautionary measures[2] that risk the future of the UK's food security. The industry can support the UK's **Blue Economy** which can be applied to other **Blue Industries** and help inform **DEFRA's Marine Spatial** Prioritisation strategy.

Offshore mussel farms like OSL can **act as de facto MPAs** with the potential to contribute to the **UK marine conservation strategy** as part of an **integrated ecosystem-based approach**, supporting **Net Zero** and **Good Environmental Status (GES)** with the prospective to be considered as 'other effective area-based conservation measures' (OECMs).

POLICY IMPLICATIONS

Support the growth of the industry as a sustainable source of marine protein.

Support secure access to export and UK markets.

Improve licensing procedures and develop monitoring guidance to evaluate environmental impacts.

Influence public perception on restorative aquaculture.

The ofTshore shellfish aquaculture industry as a nature-based solution. can deliver benefits to the UK: food security, economic resilience. enhanceing the seafood industry. and contribute to marine conservation as a Biodiversity Net Gain

RESEARCH AIMS

Fill knowledge gaps on ecosystem interactions of offshore aquaculture farms.

Study the fami's seabed restoration potential, enhancement of ecosystem services, fisheries, and spillover.

Study the first account of biogenic reef creation.

Provide evidence based on the environmental interactions of restorative offshore aquaculture to inform policy, management, and marine conservation efforts.

OSL increases diversity and abundance of commercial fishes that spillover into adjacent fishing grounds. The fann increases biodiversity and creates biogenic reef. restoring degraded seabed and suppo1 1ing the govenunent on sustainable fisheries management

RESEARCH FINDINGS

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2.3 Biogenic reef creation below the UK's first large scale offshore mussel farm

As part of the long-term data assessment of the ecological interaction of the UK's first large scale offshore mussel farm, a scientific article was produced and published in Ecological Indicators. Over eight years, this research presents the results of a BACI (Before-After Control-Impact) approach to evaluate the temporal and spatial effects of the farm on benthic habitat and epibenthic species assemblages. Situated in historical fishing ground, the farm is located on a degraded seabed ecosystem dominated by soft sediment. For this article, Dr Llúcia Mascorda-Cabré produced a graphic abstract summarising the findings which has been widely used (including the Policy Brief) to explain the long-term ecosystem interactions of the offshore mussel farm (Figure 2.1).

The study investigates the creation of biogenic reefs under the mussel farm, in an area damaged by years of bottom fishing practices, and how it is enhancing biodiversity. The study showed how the accumulation of mussel shells and associated organisms led to the development of a biogenic reef (30 % increase). This reef structure enhanced habitat complexity, benefiting both sessile and mobile marine species. This led to an enhancement of the local biodiversity, supporting higher diversity of species compared to adjacent areas. The abundance and diversity of commercial species increased compared to far control sites and certain commercial species were exclusively recorded beneath the mussel headlines: *Cancer pagurus*, *Maja squinado* and *Necora puber*. This increase was attributed to the complex structures provided by the mussel beds, which offer shelter and feeding opportunities for various organisms

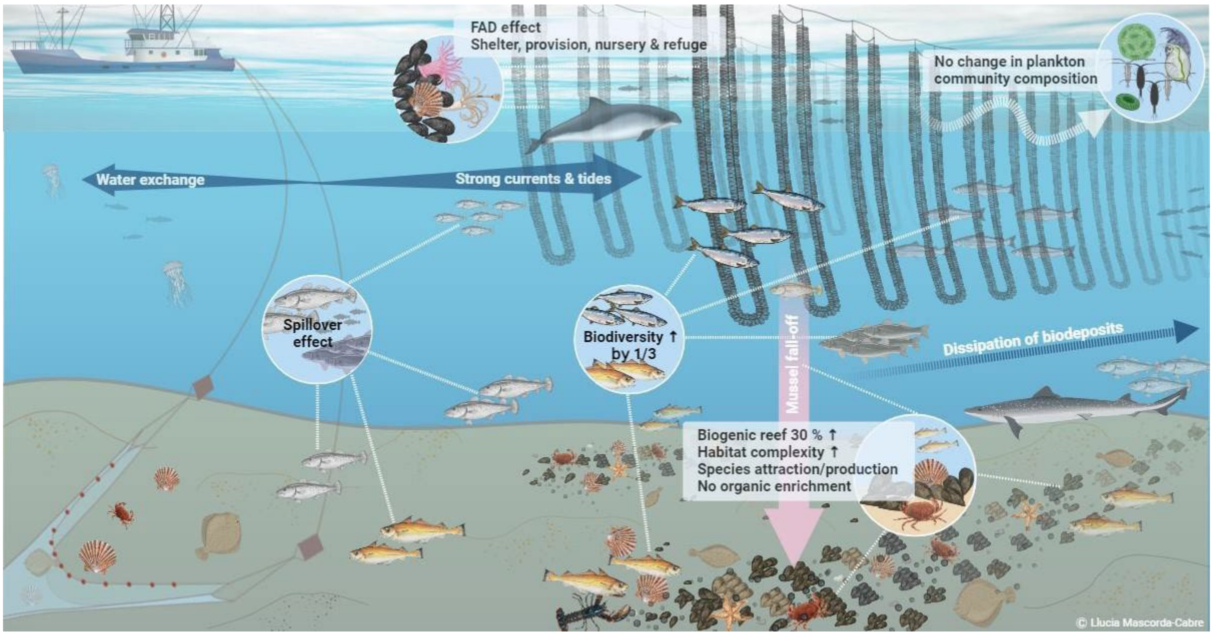

Figure 2.1 Infographic displaying the ecosystem interactions of the UK's first offshore mussel farm and it biogenic reef creation.

Results from this study are crucial to support policymakers develop a sustainable offshore industry as part of the blue economy that can both produce sustainable protein and contribute to marine conservation objectives. This study reports how low-trophic farming can support nature restoration and recovery. This dual role underscores the potential of integrating aquaculture with conservation efforts.

Biogenic reef creation below the UK's first large scale offshore mussel farm

3 Multibeam bathymetry and backscatter study – seabed mapping

Seabed survey data was collected to support the assessment of ecosystem services and impacts of offshore mussel farming, which include restoration potential to the surrounding habitat. Multibeam echosounders provide both detailed bathymetry (depths and shape of the seabed surface) and backscatter data (hardness and roughness of the seabed) through the use of sophisticated sonar technology.

The survey conducted at the Offshore Shellfish mussel farm in Lyme Bay, collected multibeam echosounder bathymetric and backscatter data to gain insight into seabed characteristics to support assessment of the farm's impacts on the seabed. Specifically, this report examines the morphological and textural changes of the seabed over the past decade since the farms installation and provides new observations of seabed substrate and habitat distributions within and outside the farm extent through the use of multispectral acoustic backscatter data.

3.1 Survey design and methodology

A hydrographic survey of Site 2 of the Offshore Shellfish mussel farm in Lyme Bay was conducted from the 20th to the 25th of May 2024 on board the University of Plymouth's research vessel Wavedancer. RV Wavedancer is a South Cat 11-meter MK11 catamaran, equipped with a pole-mounted R2Sonic 2024 Multibeam Echosounder (MBES). The MBES data was collected in multispectral mode using frequencies 170, 280 and 400 kHz (low, medium, and high) at 100 us pulse length. MBES acoustic swathe was set at 135˚ enabling footprint overlap underneath the mussel ropes (while missing the ropes themselves) throughout the tide, meaning full seafloor coverage was achieved. Primary positioning and motion were provided by an Applanix POSMV system receiving RTK GNSS corrections via NTRIP (over 4G) from a newly established base station (static baseline processing against OSNet station in Exmouth) <20 km from the survey site. Sound velocity calibration data was collected using the Valeport Swift SVP profiler (48 profiles were taken).

3.1.1 Survey Design

The bathymetric survey of the Lyme Bay mussel farm covered the entire farm area (average of 14 acoustic soundings per 1 m^2), plus an additional zone extending 500 m to 1 km beyond the farm's western and eastern boundaries. Survey lines were run between the ropes within the farm (running E-W) at 5 kts. Figure 3.1 illustrates survey coverage. The survey region also covered control areas associated with University of Plymouth long-term benthic monitoring programme.

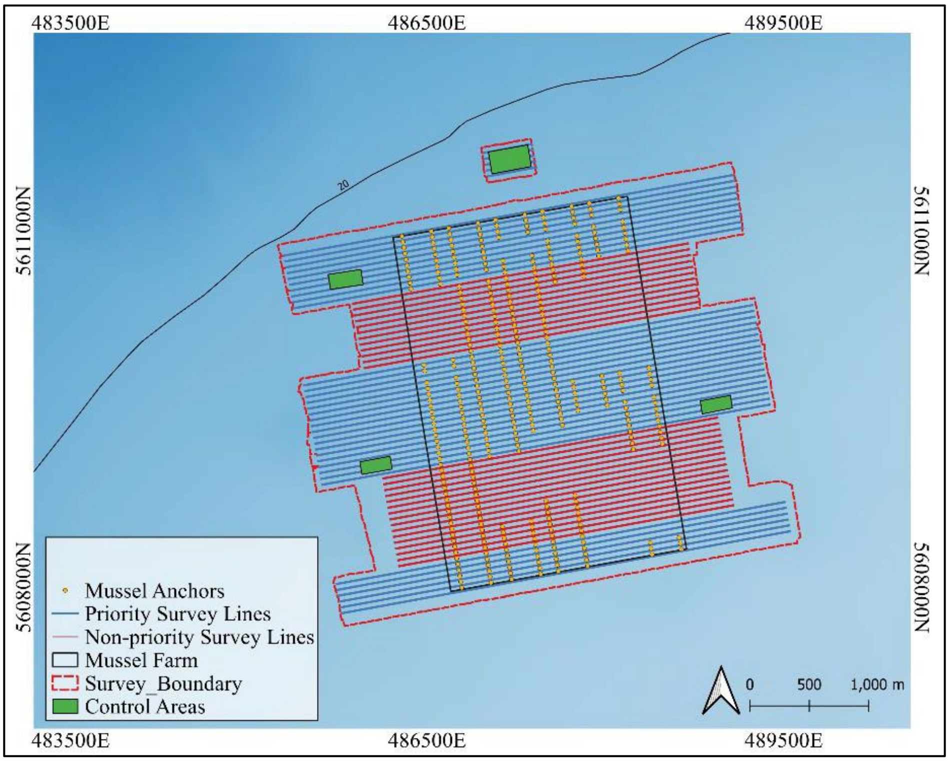

Figure 3.1 Intended line plan highlighting priority survey lines in blue, covering control areas (green) and non-priority survey lines in red. Also displayed is the boundary of the final survey surrounding the farm (dashed red line), the mussel farm and anchor layout.

To allow for a comparison of seabed change due to the farm, a buffer region up to 1 km either side of the farm was surveyed providing coverage of unaffected seabed surrounding the farm. The collected data was validated through ground-truthing samples of both underwater images (towed and ROV) and sediment grab samples provided by the Ropes to Reefs project. Furthermore, an assessment on the morphological changes of the farm over the past decade will be addressed through comparison of previously collected bathymetric data (provided by the UKHO).

3.1.2 Data analysis

MBES bathymetric data was processed using QPS Qimera software (v2.6.3). Initially, a MBES calibration was conducted over a ridge feature in the SE corner of the survey region. Resulting roll, pitch and heading misalignments corrections were applied (Figure 3.2). Major outliers and ropes occurring in the point cloud data were cleaned manually, then a spline filter applied to the surface data to reduce noise. Data were then gridded at 1 m using CUBE (Combined Uncertainty and Bathymetric Estimator), an error-model based, direct DTM generator that estimates the depth plus a confidence interval directly on each node point of a bathymetric grid (Calder and Mayer, 2003). The soundings were reduced to Admiralty Chart Datum using the VORF separation model (ETRS89-CD) and a cross-check analysis completed over a surveyed reference surface (Figure 3.2). This validation confirmed that measurement uncertainties met IHO S-44 6th Edition Exclusive Order (most stringent), with cross-check computed vertical uncertainty of 0.11 m (95% confidence level). Additionally, .gsf files and a bathymetric reference surface (1-m gridded) were extracted from the sonar data for backscatter analysis in FMGT.

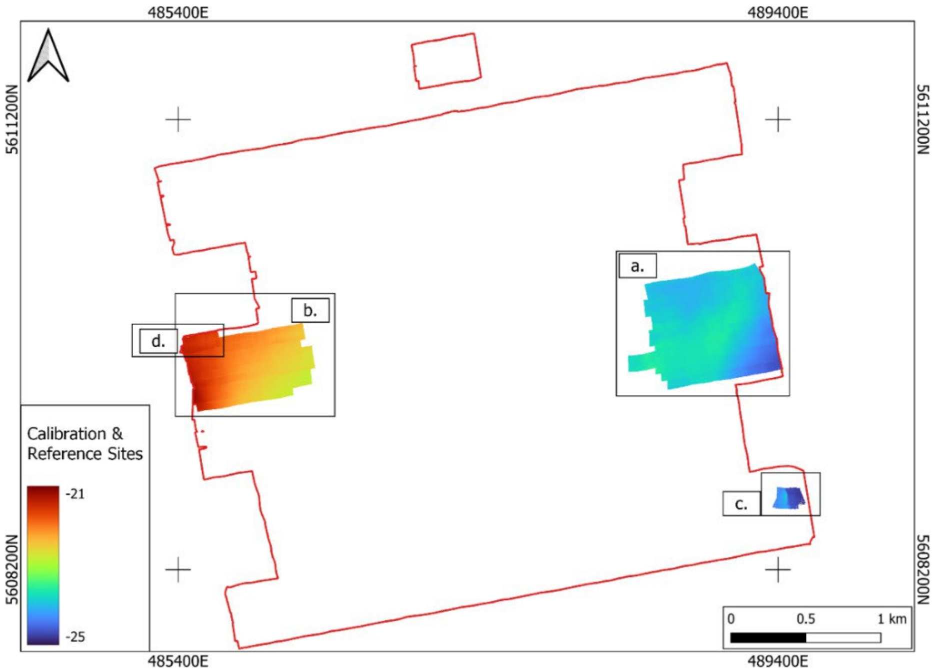

Figure 3.2 Locations of the reference and calibration surfaces used for the cross-check (a & b) and calibration /patch test (c & d)).

The MBES multispectral backscatter data were processed using QPS FMGT (Fledermaus Geocoder Toolbox v7.11.1) to produce individual and multispectral backscatter mosaics. FMGT allows for frequency-specific pings to be extracted from the multibeam data, with separate backscatter mosaics generated for each operating frequency (170 kHz, 280 kHz, and 400 kHz) and a multispectral RGB false colour composite image. A detailed description of the steps involved with backscatter data processing are described by Schimel *et al*. (2018). A bathymetric reference grid and processed point .gsf files, output from QPS Qimera, are used in FMGT for raw data decoding, georeferencing, applying radiometric corrections, angle dependence removal, and mosaicking. Angle Range Analysis (ARA) was conducted, fitting physical models (Jackson model) to angular response curves from the backscattered intensity across the swathe to determine estimates of substrate type (phi grain size in this case). Model fitting was validated by ground truth data. Further to ARA, an angular dependence correction or Angle Varying Gain (AVG) is applied to the data to compensate for the varying backscatter strength relative to the incidence angle of the sound wave at the seafloor, by normalising the backscatter levels across the different angles of the swathe. The angular dependence of backscatter was normalised to 45°, producing a homogenous seafloor mosaic (Schimel *et al.*, 2018). Backscatter mosaics were produced at each operational frequency and finally a multispectral RGB image was created where each frequency was assigned a colour (170 kHz = red; 280 kHz = green; 400 kHz = blue).

In order to interpret ARA and backscatter mosaics, ground truth data of the seabed substrate is required for validation of the varying acoustic backscatter signatures observed across the surveyed region. Data collected by the Ropes to Reefs project team, and made available for this analysis, consisted of both sediment grab data and video footage of the seabed at various locations in and around the farm (Figure 3.3). Sediment grab samples were collected during summer surveys using a Van Veen Grab, over the course of multiple years spanning 2013 - 2020. The most recent Video footage from May/June 2024 is used and analysed. Epibenthic and demersal communities have been monitored yearly since 2008 using a Towed Underwater Video System (TUVS), a video system used to collect benthic video footage between mussel ropes (Sheehan *et al.*, 2021), a method that has been well established (Sheehan *et al.*, 2010). Supplementing this, are video files from a Remotely Operated Vehicle (ROV), which are used to capture footage from underneath the ropes. Each system is mounted with high-definition cameras, LED lights and two green lasers separated by a known distance to allow for scaling (Bridger *et al.*, 2022; Mascorda-Cabre *et al.*, 2024).

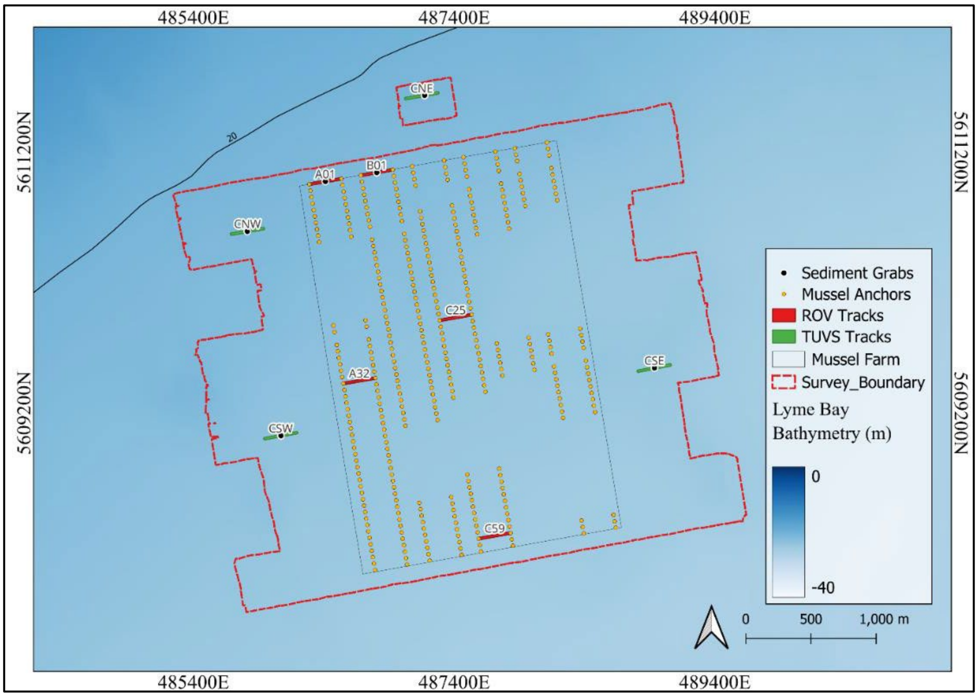

Figure 3.3 Locations of Sediment grab sample (Black), ROV (Red) and TUVS (Green) video recording sites.

The sediment grab data consists of Organic Matter (OM), Sand, Mud and Gravel percentages at different sampling locations across the years. Based on the percentage ratios of sand, mud and gravel, the data were classified a modified Folk sediment classification (following EMODnet). Positional information for the grab samples are coarse, with only a location of a specific rope available. This was rationalised by taking the midpoint between the two anchor coordinates. Video screen grabs from the highest quality frames at equal intervals throughout the videos were visually classified. 5 images were taken from each video transect. Observations of sediment type, colour, organisms, shell abundance and anything notable were recorded from each frame and dominant sediment type distinguished. Sediment grab samples were used as an additional source of information to support image classification.

The stills, alongside observations of benthic fauna, organic material and the past sediment grab data were classified to MHCBI (Marine Habitat Classification for Britain and Ireland) Level 4. Classification to level 5 requires expert knowledge on benthic fauna, where identification must be at species level. Classification was not taken to Level 5 but a simpler bespoke classification was added which identifies shell density cover on the seabed. This simple categorisation can be applied by any layman and without a need for in-depth knowledge. The scale is three-fold, 1 = Little to no shell cover, 2 = Partially shell covered and 3 = Almost fully covered with shells. This simple addition to the Level 4 HMCBI classification scheme allows for another level of discrimination between very similar or the same dominant sediment types. This is particularly useful when observing backscatter information where different returns can appear on the same sediment type.

3.2 Results

3.2.1 Bathymetry and backscatter datasets

Figure 4 shows the fully processed, 1-m gridded bathymetric surface of the study site, revealing a depth range of approximately -21 m to -25.5 m CD. The seabed is predominantly flat, with the exception of a rocky outcrop in the southeast corner utilized for sonar calibration. Some horizontal banding visible throughout the survey area, these are due to sound velocity where variable sound velocities are not fully captured by the SVP profiling. The sound velocity environment was particularly challenging within the farm as vertical water column oceanography changed dramatically spatially due to the ropes.

The collected backscatter data, displayed as single frequency mosaics and a RGB false colour composite multifrequency image, reveal distinct seafloor characteristics (Figure 3.4). Variation in return signal intensity, represented as bright and dark colours, highlight the variation of seabed substrate. White vertical banding patterns can be observed across all frequencies, which occur within the mussel anchors where mussel ropes have been deployed. Broad scale natural seabed features can also be seen to vary across the survey region. Backscatter differences across the three frequencies reveal more detail. Higher frequencies are known to detect finer detail on the superficial level, while the lower frequencies are penetrate deeper into the sediment and revealing very shallow subsurface characteristics (Schulze *et al.*, 2022).

The observed banding occurs directly beneath where the mussel farm ropes are located, strongly suggesting that the concentrated reflective material beneath the ropes is a direct consequence of their presence. These banding features are also blue-white in the multispectral composite, suggesting they have a more dominant high frequency response which is linked to the surface properties of the seabed, as opposed to some of the brighter regions outside the roped regions which are red dominant, suggestion possible subsurface properties more dominant in the low frequency response. These observations underscore the potential influence of mussel farm infrastructure on the surface seabed environment, altering its physical properties and creating distinct backscatter signatures and surface roughness.

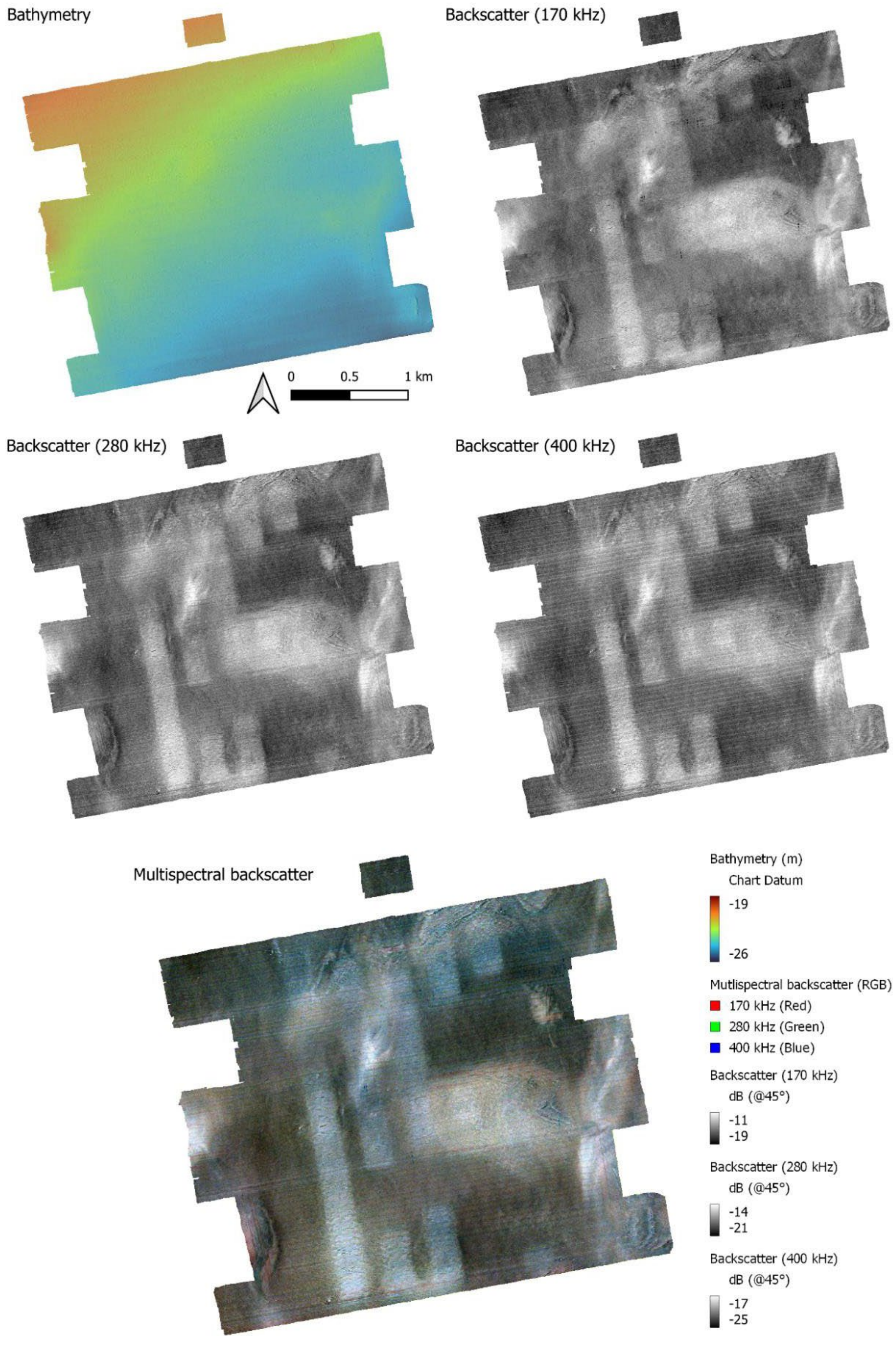

Figure 3.4 Summary figure of collected bathymetry (a), and backscatter at 170 kHz (b), 280 kHz (c), 400 kHz (d) and the multifrequency RGB false colour composite image (e) sites.

3.2.2 Geomorphological change – biogenic reef development

The surface morphology of the farm region and surrounding area is very flat and featureless with a bathymetric slope of 1 m per 1 km. There were no broad-scale significant (beyond measurement uncertainty) detectable changes in morphology across the survey region (2015-2024), which is interpreted to be a region that is naturally bathymetrically stable. In contrast, when analysing morphological change at a local feature scale, there were some clearly identifiable morphological features that where nearly exclusively observed beneath the mussel ropes (between anchor locations). Examples of which are highlighted in Figure 3.5. These features occur in regions associated with high intensity backscatter (rough/hard) and align with the bright vertical banding that has been linked to the presence of the mussel ropes. These features typical morphological expression is a long thin mound aligned with the mussel ropes, with lengths and widths of approximately 20-150 m and 10 m, respectively. Heights of the features range from 0.05-0.1 m. While mild in vertical expression, these features are clearly distinguishable as new and not present in previous bathymetric survey (2015). The validation of these features and the backscatter is addressed in the next section.

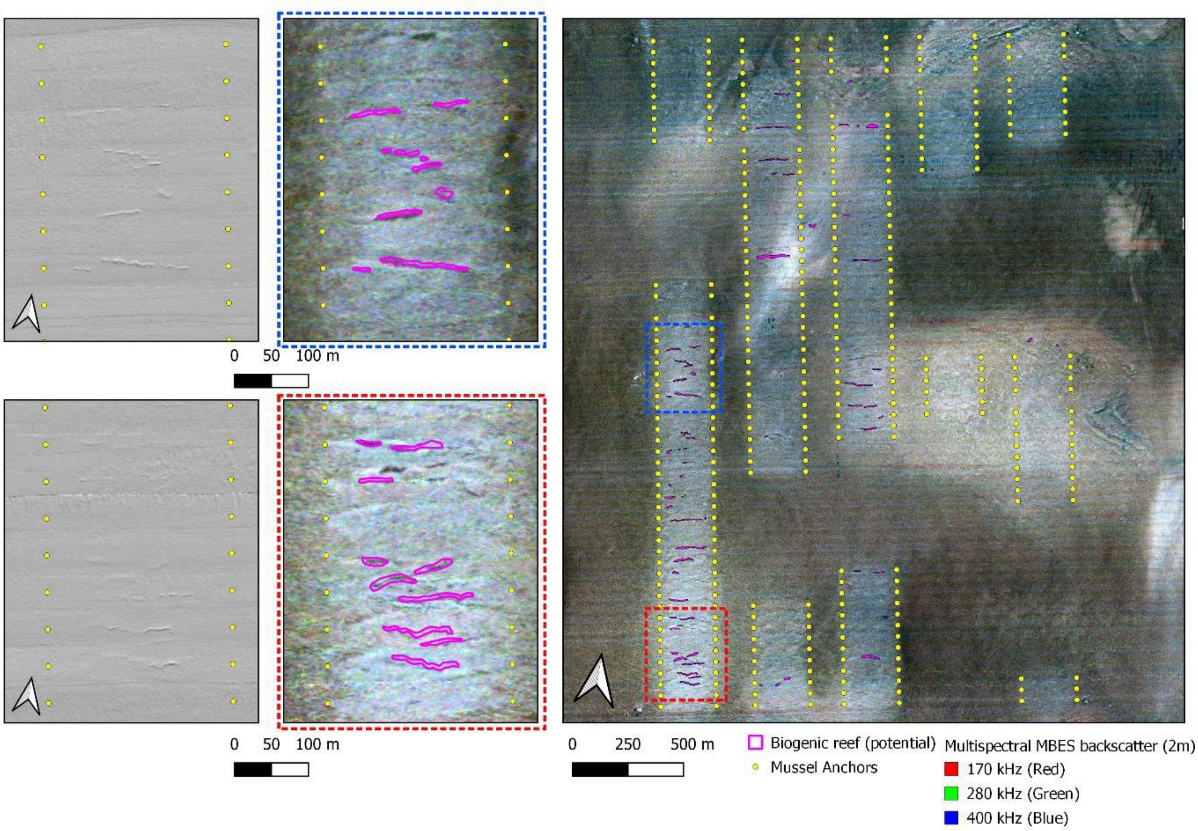

Figure 3.5 Identified geomorphic change that is interpreted as new biogenic reef. (left) Examples of geomorphic features not present in original MBES data (2015) occurring within the mussel farm anchor locations (hillshade of bathymetric survey 2024). (middle) Examples of classified features that show significant morphological expression (pink) overlain on multispectral backscatter image. (right) Farm scale distribution of significant morphological change (potential new biogenic reef; pink) mostly occurring within the mussel rope regions, multispectral backscatter basemap.

3.2.3 Substrate textural change

The backscatter mosaics and the identification of localised new morphological features provide evidence of the impact of the farm on the seabed. ARA analysis of the 400 kHz backscatter data was performed to characterise the grain size characteristics of the seabed (Figure 3.6). The grain size characteristics from ARA and backscatter mosaics validate well against sediment grabs (Table 3.1), demonstrated by Figure 3.7 where there is clear differentiation between ground control substrate classes at each frequency (

Table 3.2). The ARA analysis clearly highlights regions where the coarser surface substrate is located. These areas in Figure 3.6 are predominantly within the roped regions with some patches outside the farm extents to the west and east. These areas of higher grain size outside the farm could be associated with emerged/submerged natural or pre-existing biogenic reef habitats.

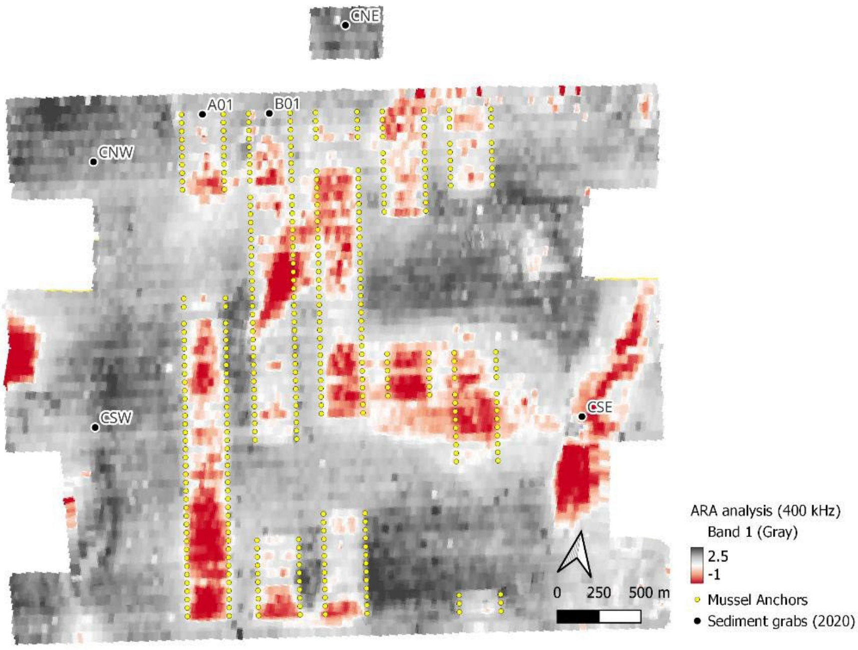

Figure 3.6 Results from Angular Range Analysis (ARA) of multibeam backscatter (400 kHz). Colours show estimated mean grain size (phi) from model fitting with red = sand/gravel and dark grey = fine sand.

Table 3.1 Sediment grab sample gravel, sand and mud proportions, with USGS (2019) classification.

Site	Year	Gravel %	Sand %	Mud %	Classification
A01	2020	10.77	46.13	43.1	Mixed Sediment (Mix)
B01	2020	10.17	59.67	30.2	Mixed Sediment (Mix)
C25	2019	6.43	60.17	33.4	Mixed Sediment (Mix)
CNW	2020	4.07	48.57	47.33	Muddy Sand (MS)
CNE	2020	10.43	44.37	45.23	Mixed Sediment (Mix)
CSW	2020	4.13	59.43	36.4	Muddy Sand (mS)
CSE	2020	13.2	72.17	14.63	Mixed Sediment (Mix)

Table 3.2 Samples sites categories by Class type with modified EUNIS codes.

Class 1	A32, C59	Sublittoral mussel beds on sediment 3	A5.62_3
Class 2	A01, B01, C25	Sublittoral mussel beds on sediment 2	A5.62_2
Class 4	CNE, CSE	Circalittoral mixed sediment 1	A5.44 _1
Class 3	CNW, CSW	Circalittoral muddy sand 1	A5.26_1

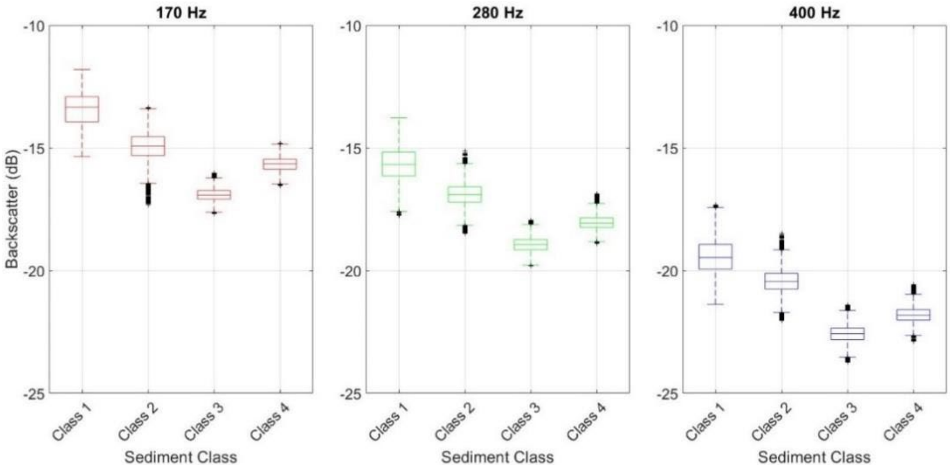

Figure 3.7 Backscatter statistics for ground control regions.

While the ARA analysis provides support for the impact of the ropes on the seabed surface at 400 kHz, a closer inspection of the 170 kHz backscatter data, which can also detect more reflective material beneath shallow fine sediment, shows that there is significant spatial variation in substrate across the survey region (Figure 3.7), suggesting possible emerged/submerged biogenic reef. Figure 3.8 shows a supervised classification map of the 170 kHz backscatter mosaic computed using a GMM (Gaussian Mixed Model). Classes relate to

Table 3.2 and areas determined to be impacted by the farm (regions between the rope anchor locations) are masked out.

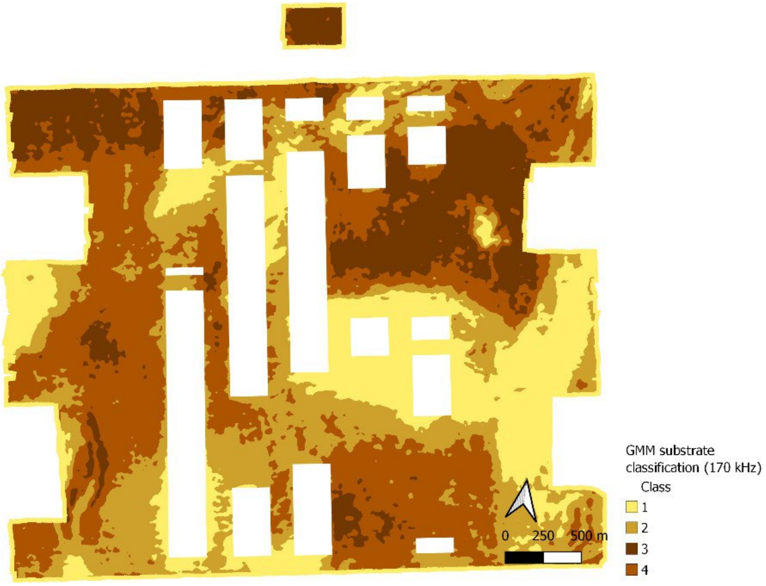

Figure 3.8 Gaussian Mixture Model classification trained on ground truthing (TUV/ROV/grab samples). The class map shown is generated from the 170 kHz backscatter (class number relates to Table 2). White rectangular regions mask out area within rope anchors where most of the modified substrate exists. Map therefore indicates the background condition.

3.2.4 Spillover analysis

In order to quantify the extent of the impact of the farm activities beyond the active roped areas as highlighted previously, an assessment of spillover was made using the backscatter data. A section of the survey region where there was minimal natural spatial variability in background substrate type was selected which included part of the buffer region to the SW and one column of ropes (red box, Figure 3.9). Within this region, the mean backscatter intensities were analysed as a function of the distance from the outer rope anchor positions (Figure 3.9). This analysis showed that the maximum backscatter intensity occurs in in the middle of the ropes and begins to drop off ~50 m before the anchor locations. Around the anchor location and just outside the ropes the backscatter intensity drops rapidly until ~100 m beyond the anchors, where it begins to level out (interpreted as reaching non-impacted background level of buffer zone). This suggests the impact of the ropes on the substrate are mostly linked to the areas within the anchors with a narrow spillover region.

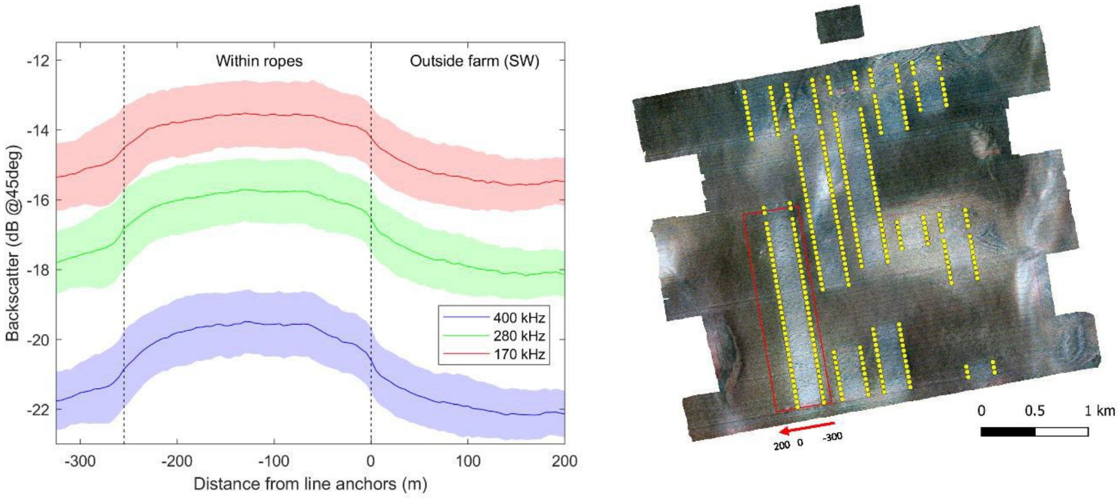

Figure 3.9 Spillover analysis visualising mean (bold line) and standard deviation (transparent band) of backscatter intensity (dB) throughout a cross-section extending across a roped region to outside farm extends (see red box).

4 Benthic habitat restoration and pelagic fish study

The influence of offshore large structures on the surrounding environment and the current regimes of the area can influence various ecosystem processes which can result in a range of direct and cascading effects on the surrounding ecosystem (Figure 4.1). For instance, by adding physical structure to the environment both through the introduction of hard infrastructure, which contributes to ocean sprawl (Firth et al., 2016; Heery et al., 2017) and the organisms themselves, which in turn can modify hydro-sedimentary processes as they modify currents, increase local sedimentation and biodeposits (Kumar and Cripps, 2012; Landmann *et al.*, 2019) or create new habitats for benthic assemblages (Mckindsey *et al.*, 2011; Sheehan *et al.*, 2019). Hard-bottom associated species that may otherwise not be there due to a lack of suitable habitat (e.g., offshore muddy bottoms or deep waters) or as a consequence of years of dredging and towing for commercial fisheries, can now colonise these structures and the surrounding ecosystem forming communities that are functionally similar to hard-bottom habitats, having a knock on effect on the complexity of the habitat (Figure 4.1).

Benthic video surveys provide HD video footage of the seabed macrofauna and seabed characteristics (ROV, Towed) and benthic and demersal mobile species (BRUV). Pelagic surveys provide HD video footage of pelagic fishes (PelagiCam). All video footage and frames are analysed, and taxa are recorded and identified to the lowest taxonomic level possible. Quantitative data is extracted from the videos and frames. These data are pooled to give relative abundance (mean min^{-1}) per taxa per replicate. This method ensures that individuals swimming in and out of the field of view multiple times are not over-represented. Statistical analysis is performed to compare change overtime, differences inside the farm with control areas and the MPA, and correlations between mobile species and % mussel cover using R©, MatLab© and PRIMER v7 (Anderson, 2001; Clarke and Warwick, 2001). This study will support the Essential Fish Habitat restoration as part of WP2 and support the assessment of the farm's footprint. Outputs from the different video techniques will provide a thorough species list including abundance and diversity.

This section describes the ecological surveys performed to date: benthic epifauna; pelagic epifauna (FAD effect).

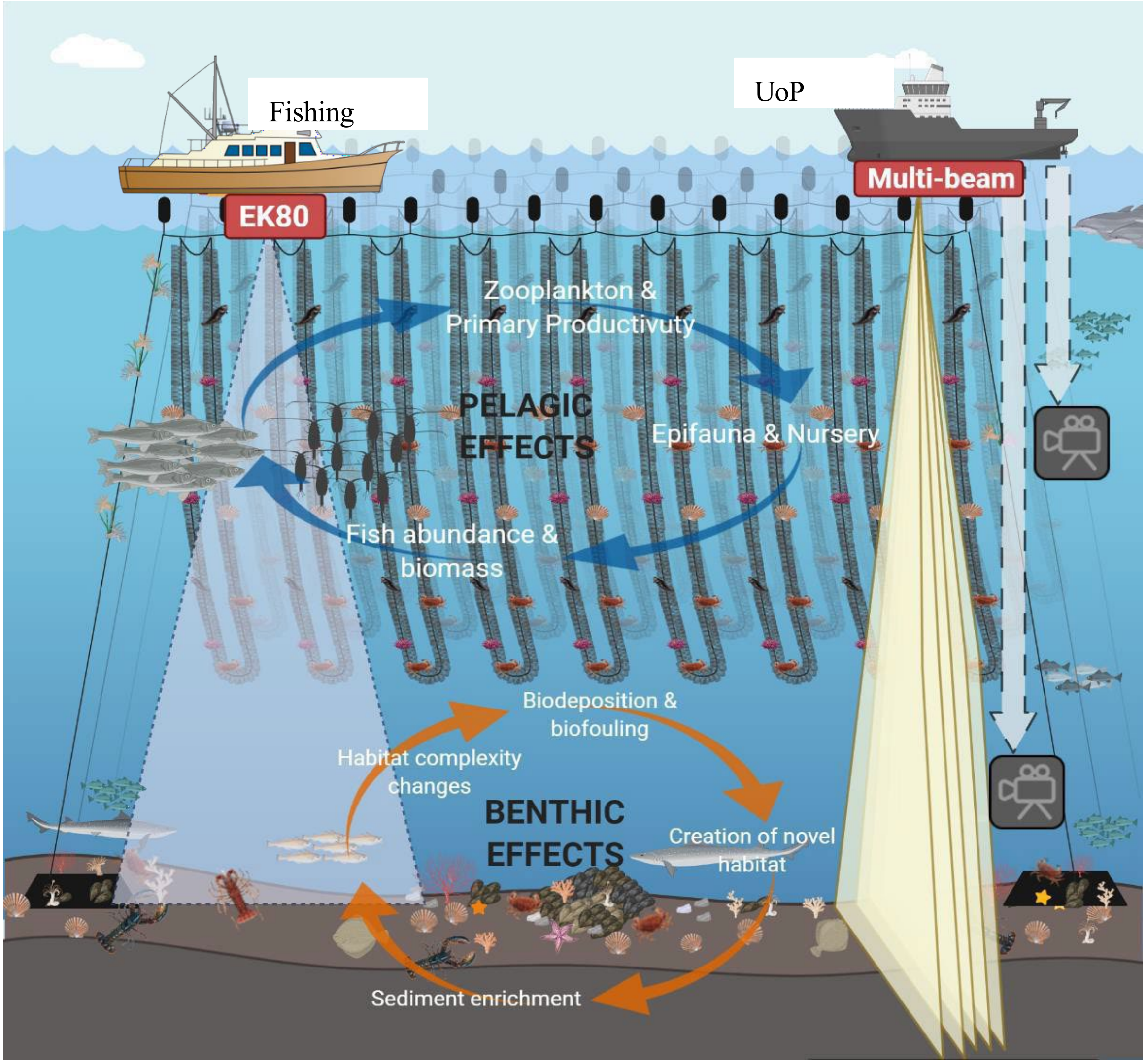

Figure 4.1 Ropes to Reefs survey methodology to define and assess extent and biodiversity of restored essential fish habitat (biogenic mussel reef), and the abundance, diversity and biomass of associated mobile species within and surrounding the Lyme Bay Offshore Mussel Farm (Mascorda- Cabre 2022).

4.1 Survey design and methodology

The ecological surveys included the study of the benthic and pelagic habitats and fishes within and around the mussel farm. The area surveyed included two spat ropes (NW of the site – A01 and B01), four ropes within the farm (A29, A59, B11 and C16), four control sites (NW, SW, NE and SE) and two far control sites (FCW and FCE) located 4 km to the west and northeast of the Site (Figure 4.2).

Marine benthic epifauna are sampled using high-definition cameras. Sessile and sedentary epifauna are recorded using a camera mounted on a towed flying array (Sheehan *et al.*, 2010; Stevens *et al.*, 2014) and mobile epifauna are recorded using baited remote underwater video (BRUV) cameras. A remotely operated vehicle (ROV) is used to record the species assemblages directly beneath the mussel ropes (sessile and sedentary). Towed and BRUV sampling began in 2013, whereas ROV sampling began in 2014.

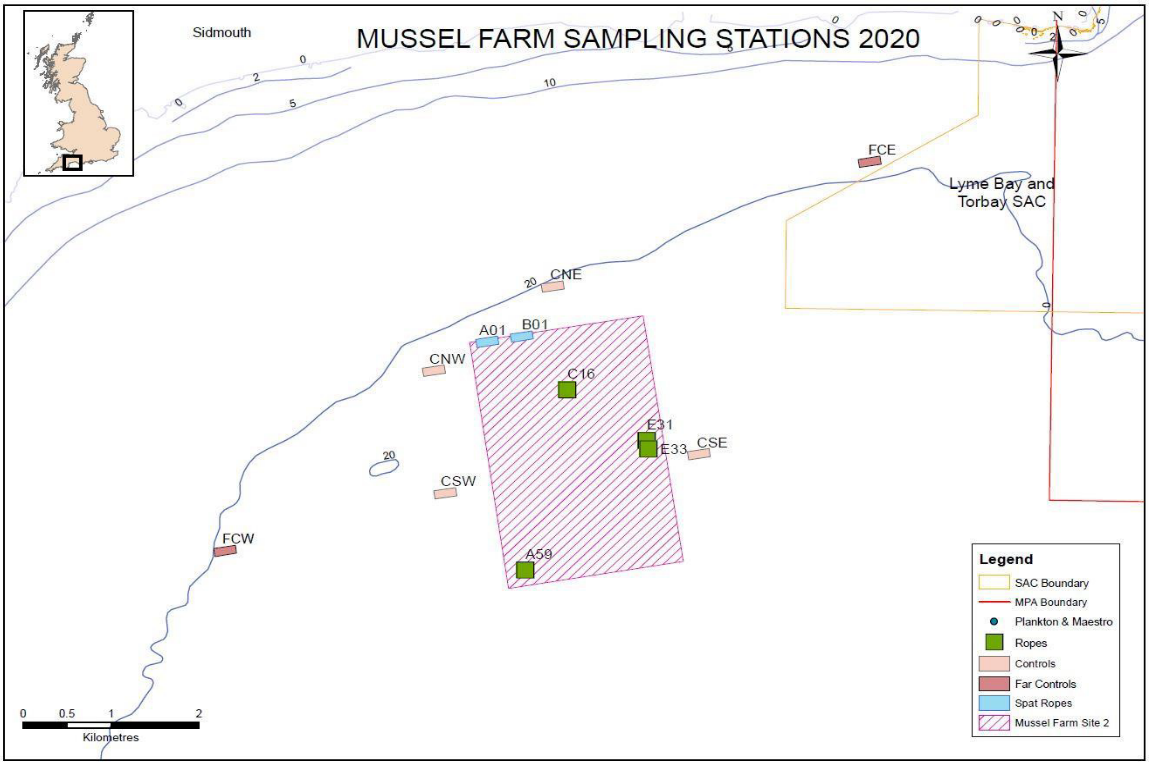

Figure 4.2 Example of sampling stations surveyed during the summer season 2020.

4.1.1 Quantification of benthic epifauna

4.1.1.1 Sessile and sedentary epifauna - Towed HD video array

This method is used to quantify sessile and sedentary benthic epifauna. As described in Sheehan *et al.* (2010), the array is flown over the seabed for 200 m at a slow speed (0.3-0.5 knots) close enough to identify the species present. Three replicate transects are positioned to cover the extent of each area being sampled. All sites apart from rope sites were sampled (rope sites are surveyed with an ROV).

The HD video system comprises a camera (Surveyor-HD-J12 colour zoom titanium camera, 6000 m depth rated, 720p) positioned at a 45˚ angle to the seabed, three LED lights (Bowtech Products limited, LED-1600-13, 1600 Lumen underwater LED) fixed to the array in front of the camera to provide improved image definition and colour and two laser pointers (wavelength 532 nm Green) set 30 cm apart (Figure 4.3). The umbilical is connected topside to a Bowtech System power supply/control unit. This allows control of the camera, focus, zoom and aperture, and intensity of the lights. The camera system is mounted on a towed flying array to glide the camera over the seabed (Sheehan *et al.*, 2010). This method has been chosen as it allows large areas of seabed to be filmed relatively quickly, making it a cost-effective survey method as well as being relatively low impact with minimal disturbance caused.

Figure 4.3 Towed array (left) and image of what can be seen while recording the seabed with the

4.1.1.1.1 Video data processing

Frame grabs are extracted at five second intervals from each towed video transect and overlaid with a calibrated grid using 3Dive Frame Extractor software (Cybertronix). Each frame is viewed and those that do not meet the following criteria are deleted, leaving only those suitable for analysis: image well focussed, lasers within acceptable margins on the grid overlay and image clear of anything obstructing the benthos. 30 frame grabs are then haphazardly selected from the suitable ones, following Stevens et al. (2014) who determined that 30 frames from a 200 m long transect gave equivalent results to sampling all frames. Taxa are recorded and identified to the lowest taxonomic level possible. Where species level identification was not possible, some alternative groupings were used. For example, goby species were grouped due to the difficulties in positively identifying them from the video and the spider crabs *Inachus spp*. and *Macropodia spp*. were identified to genus level as the species are taxonomically similar.

1.1.1.1. Sessile and sedentary epifauna underneath the ropes - Remote Operated Video camera (ROV)

As a previous baseline assessment found that fallen mussel clumps had settled and were often hosting starfish, hermit crabs and tube building serpulid worms, additional quantification of sessile and sedentary epifauna targeting directly beneath the mussel ropes was studied. The ROV is a Videoray accompanied with a ventrally mounted GoPro to provide HD footage of transects directly beneath the mussel ropes (Figure 4.4). Three transects under each rope are filmed, starting from both anchor points and travelling in the direction of the mussel headline towards the middle. This method is designed to complement the footage from the towed array as the ROV can target its position to travel directly beneath the ropes where the towed array cannot be used (entanglement risk).

Figure 4.4 ROV Videoray (left) and image of what can be seen while recording the seabed underneath the mussel farm ropes (right).

4.1.1.1.2 Video data processing

Frame grabs are extracted from the video, selected and taxa recorded and identified as per Towed methodology. The presence and abundance of mussel clumps and mussel beds is also recorded.

4.1.1.2 Mobile epifauna - Baited Remote Underwater Video cameras (BRUV)

This method is used to quantify mobile epifauna with the use of a bait to attract mobile species. Custom made submersible rigs are built by Greenaway Marine Ltd., each housing a camera (Panasonic HDC-SD60 Full HD Video) and accompanied by a LED light mounted on a housing. A pole and bait box containing 100 g of mackerel bait are attached to the housing and weights are fixed to the bottom to pull the camera to the seabed (Figure 4.5). The cameras are deployed up to 30 m apart using a system of numbered buoys to indicate replicate numbers. This method is used to film nekton not captured by the towed array, such as fishes and large mobile invertebrates. Three replicates per site.

Figure 4.5 BRUV array (left) and image of what can be seen while recording the seabed with a bait (right).

4.1.1.2.1 Video data processing

Quantitative data are extracted from the BRUV samples by identifying and counting the number of mobile individuals in the field of view within one-minute slices of video for 30 minutes. These data are pooled to give relative abundance (mean min^{-1}) per taxa per replicate. This method ensures that individuals swimming in and out of the field of view multiple times are not over-represented. To provide adequate settling time and to standardize the approach, video analysis begins five minutes after the camera reaches the seabed for each replicate.

4.1.2 Quantification of pelagic epifauna (FAD effect)

Nonbaited midwater video or PelagiCam systems are used to sample pelagic fauna to provide an insight into differences in prey levels around the mussel lines and whether they are acting as FADs.

4.1.2.1 Mobile pelagic species - PelagiCam

Pelagic fauna is quantified at each site using three PelagiCam systems, developed by UoP (Sheehan *et al.*, 2020). To ensure that the video is always pointing towards the ropes regardless of position or tidal flow, three video cameras (GoPro HD Hero4 with housings) are fixed in a circle, facing outwards, 120° from each other on an anodised stainless steel circular plate (400 mm diameter) with a vane (200 mm (L) x 185 mm (W)). GoPros are secured in place by bolt GoPro mounts. A hollow pole (425 mm (L), 30 mm (diameter) is positioned through the centre of the plate so that the rope can be passed through it. A stainless-steel cage is welded onto the main rig to protect the cameras and torches from abrasive contact with mussel ropes (Figure 4.6). The PelagiCam systems are deployed at 6 m depth from a surface marker buoy and moored with a 30 kg drop weight. To stabilise the system, dive weights are secured directly beneath the PelagiCam.

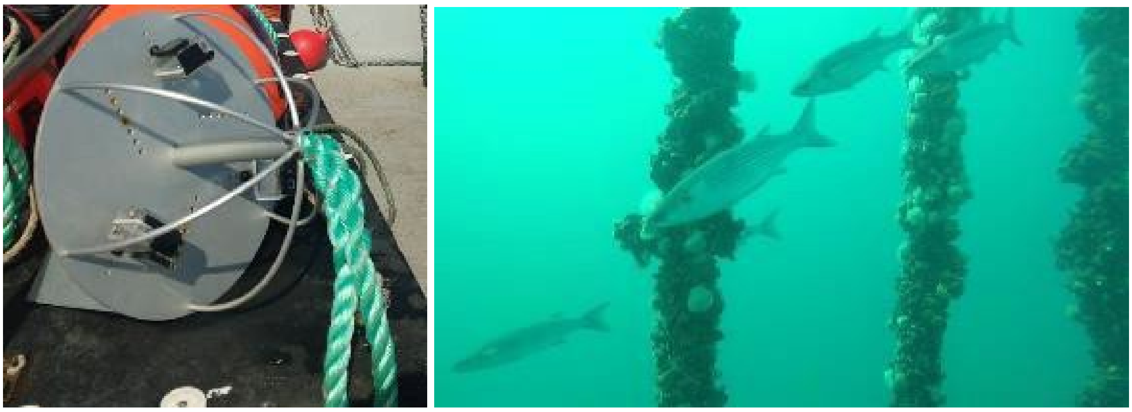

Figure 4.6 PelagiCam (left) and still of what is being recorded within the mussel farm ropes at midwater (6m) depth (right).

4.1.2.1.1 Video data processing

Quantitative data is extracted from the PelagiCam videos by identifying and counting the number of pelagic mobile individuals in the field of view within one-minute slices of video for 60 minutes. Data is then pooled to give relative abundance (mean min^{-1}) per taxa per replicate. This method ensures that individuals swimming in and out of the field of view multiple times are not over-represented. To provide adequate settling time and to standardize the approach, video analysis begins 5 minutes after the PelagiCam rig is placed in the water.

4.2 Data analysis

Abundance and other ecological descriptors will be obtained. Statistical analysis was performed with R©, PRIMER v7© and PERMANOVA©. Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson, 2001) from software package PRIMER v7 (Anderson, 2001; Clarke and Warwick, 2001) will be used to test for differences between univariate and multivariate variables. Multivariate Assemblage composition data were log(x-1) transformed and analyses based on Bray Curtis similarity indices. Data was averaged for each Site and Treatment, and the means and standard errors presented. Significant differences for any interactions will be further interpreted using SIMPER and Pairwise tests in PERMANOVA.

4.3 Results

To date the authors have been able to analyse 2023 Towed and ROV video data. Preliminary results are shown below.

4.3.1 Mussel clumps and mussel beds

Mussel clumps within the farm were observed within the first year of development and continued to be detected throughout the years exclusively within the farm boundaries (Figure 4.7 and Figure 4.8). Clump abundance increased over time ($p<0.0001$) with greater abundance observed under the ropes ($p<0.0001$) (Table 4.1). No clumps were detected within any control site. Mussel clump sizes varied from small to large throughout the farm with small sizes being the most abundant followed by medium and large.

Figure 4.7 Mussel bed (left) and large mussel clump (right) recorded under mussel farm ropes.

Mussel beds were started to be detected in 2017 (year 4 since deployment) (Figure 4.7 and Figure 4.8). Beds were divided as young and established due to the obvious visual differences in mussel size when performing video analysis. Since 2017, the total area covered with ROV surveys was 554.5 m^{-2}, of which 61.5 m^{-2} were covered with mussel bed thus mussel beds accounted for 11 % of the total area surveyed.

The overall abundance of established and young mussel bed cover increased over time ($p < 0.05$) (Table 4.1) from a total of 3.4 m^{-2} of mussel beds in 2017 to a total of 4.4 m^{-2} in 2023. In 2017, the total area surveyed was 72 m^{-2} while in 2023, a total of 119 m^{-2} was surveyed accounting for a total of 4.7% and 3.7 % of total area surveyed respectively. It must be noted that in 2020, from a total of 111 m^{-2} of area surveyed, 33.9 m^{-2} were mussel beds, accounting for 30.4 % of the total area surveyed (Figure 4.8). Time and treatment difference of established beds were driven by higher abundances under rope sites ($p < 0.005$), while no significant difference was observed between rope and spat transects for young beds. Overall, there was an increase of mussel bed cover within the farm over time ($p < 0.05$).

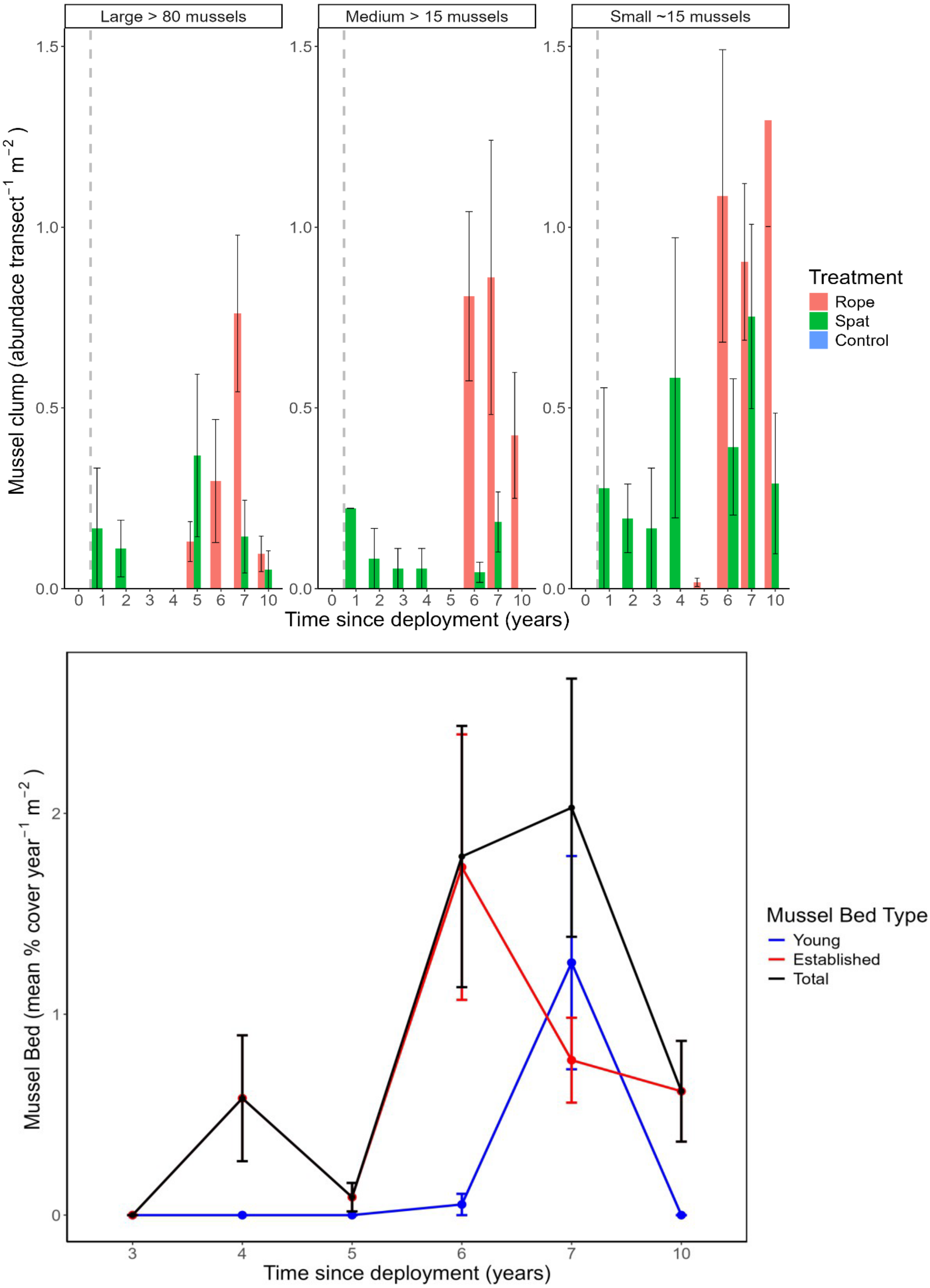

Figure 4.8 Comparison of mussel clump abundance and mussel bed cover between the farm and control sites over time (no mussel clumps or beds were found outside the farm's boundaries).

Table 4.1 Results of three factor two-way analyses of variance (ANOVA) testing the effect of Time, Treatment and Site and their interactions on the abundance of mussel clumps and mussel beds. Significant values (p<0.1) in bold.

Response	Terms	Df	Sum Sq	Mean Sq	F value	Pr(>F)
MUSSEL CLUMPS						
Large						
	Time	8	1.458	0.1823	5.050	**< 0.0001*******
	Treatment	2	2.102	1.0508	29.109	**< 0.0001*******
	Site	15	1.854	0.1236	3.423	**< 0.0001*******
	TimexTreatment	10	1.483	0.1483	4.107	**< 0.0001*******
	Residuals	173	6.245	0.0361		
Medium						
	Time	8	3.837	0.4796	7.590	**< 0.0001*******
	Treatment	2	4.969	2.4843	39.311	**< 0.0001*******
	Site	15	4.829	0.3220	5.094	**< 0.0001*******
	TimexTreatment	10	3.481	0.3481	5.508	**< 0.0001*******
	Residuals	173	10.933	0.0632		
Small						
	Time	8	10.991	1.374	10.676	**< 0.0001*******
	Treatment	2	13.820	6.910	53.696	**< 0.0001*******
	Site	15	15.296	1.020	7.924	**< 0.0001*******
	TimexTreatment	10	2.423	0.242	1.883	**0.05 ***
	Residuals	173	22.263	0.129		
MUSSEL BEDS						
Established						
	Time	5	20.07	4.014	3.483	**< 0.05***
	Treatment	1	10.40	10.395	9.018	**< 0.01****
	Site	9	3.68	0.409	0.355	0.94943
	TimexTreatment	3	15.30	5.100	4.425	**< 0.01****
	Residuals	40	46.11	1.153		
Young						
	Time	5	17.30	3.459	3.280	**< 0.05***
	Treatment	1	0.57	0.574	0.544	0.4649
	Site	9	16.16	1.795	1.702	0.1205
	TimexTreatment	3	0.63	0.21	0.199	0.8961
	Residuals	40	42.18	1.055		
Total						
	Time	5	40.87	8.175	3.018	**< 0.05***
	Treatment	1	6.08	6.083	2.246	0.142
	Site	9	19.41	2.156	0.796	0.622
	TimexTreatment	3	17.18	5.726	2.114	0.114
	Residuals	40	108.35	2.709		

Bold values denote significant P/t values (< 0.05) and asterisk's define level of significance: p/t < 0.0001 = '****'; p/t < 0.001 = '***'; p/t < 0.01 = '**' ; p/t < 0.05 = '*'; p/t < 0.1 = '.' .

4.3.2 Sessile and sedentary epifauna – Towed and ROV

To date, 2023 Towed and ROV video data has been analysed. The total number of species observed across all of the videos was 32 (Table 4.2), 25 for each survey technique, a Shannon Diversity Index of 1.839 and 2.930 for Towed and ROV respectively and a Pielou's Index of Diversity (evenness) of 0.723 and 0.825 for Towed and ROV respectively (Figure 4.9). Most of these species belonged to the phyla Chordata or Arthropoda, with a total of 19 species between these two phyla. The other represented phyla were Echinodermata and Mollusca with 5 species each phyla. The most commonly seen species in Towed videos were *Ophiura ophiura, Pagurus* spp. and *Asterias rubens*, and in ROV videos were *Pagurus* spp., *Ophiura ophiura, Turritella communis* and *Asterias rubens*, all of which were observed in over 50 % of the videos.

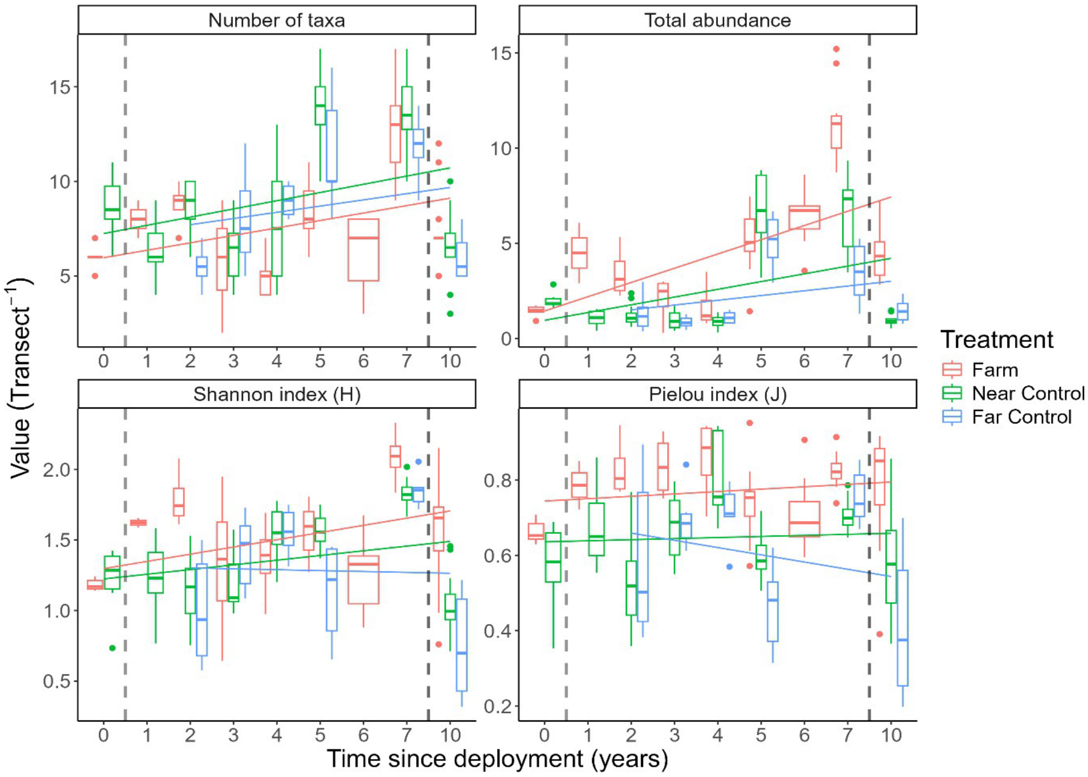

Figure 4.9 Boxplot showing temporal change in sessile and sedentary species taxa, abundance and diversity indexes (Shannon and Pielou's) over time (0-10) and treatments (farm-red, near control-green and far control-blue).

The number of sessile and sedentary taxa increased over time ($p<0.0001$) being significantly different between treatments ($p<0.01$) with ropes showing the greatest increase over time (Figure 4.10 and Table 4.3). Total abundance increased over Time since deployment ($p<0.0001$) showing significant differences between treatments, with the greatest difference between the farm and control sites over time ($p<0.0001$). Although there was an increase in the Shannon diversity index (H) over time, this was not significant however, there was a significant difference between time and treatment ($p<0.0001$) between the ropes, the spat and both control sites.

Table 4.2 Species list observed across Towed and ROV 2023 videos and biodiversity indexes.

Phylum	Species	Common Name	Towed	ROV
Arthropoda	*Cancer pagurus**	Brown crab	✓	
Arthropoda	*Goneplax rhomboides*	Angular crab	✓	✓
Arthropoda	*Inachus spp.*	Grouped scorpion spider crabs	✓	✓
Arthropoda	*Liocarcinus spp.*	Grouped swimming crabs	✓	✓
Arthropoda	*Macropodia spp.*	Grouped long-legged spider crabs		✓
Arthropoda	*Maja squinado**	Common spider crab	✓	✓
Arthropoda	*Necora puber*	Velvet swimming crab	✓	
Arthropoda	*Pagurus spp.*	Grouped hermit crabs	✓	✓
Chordata	*Callionymus lyra*	Common dragonet	✓	✓
Chordata	*Chelidonichthys cuculus*	Red Gurnard	✓	
Chordata	*Goby spp.*	Grouped goby species	✓	✓
Chordata	*Limanda limanda**	Dab	✓	
Chordata	*Pleuronectes platessa**	European Plaice	✓	✓
Chordata	*Raja clavata**	Thornback ray		✓
Chordata	*Scyliorhinus canicular*	Small-spotted catshark		✓
Chordata	*Solea solea**	Sole		✓
Chordata	*Syngnathus acus*	Greater Pipefish		✓
Chordata	*Trisopterus luscus**	Pouting	✓	✓
Chordata	*Trisopterus minutus**	Poor cod	✓	✓
Crustacea	*Atelecyclus rotundatus*	Circular crab	✓	
Crustacea	*Crab*	Unidentified crab	✓	✓
Crustacea	*Homarus gammarus**	Common lobster	✓	
Echinodermata	*Astropecten irregularis*	Sand sea star	✓	✓
Echinodermata	*Asterias rubens*	Common starfish	✓	✓
Echinodermata	*Luidia cilaris*	Seven armed starfish	✓	
Echinodermata	*Ophiothrix fragilis*	Common brittle star	✓	✓
Echinodermata	*Ophiura ophiura*	Serpent star	✓	✓
Mollusca	*Aequipecten opercularis**	Queen scallop	✓	✓
Mollusca	*Buccinum undatum**	Common whelk		✓
Mollusca	*Pecten maximus**	King scallop	✓	✓
Mollusca	*Sepia officinalis**	Common cuttlefish		✓
Mollusca	*Turritella communis*	Common tower shell	✓	✓
Species Richness				25
Total Abundance				2141
Shannon Index of Diversity				1.839
Pielou's Index of Diversity				0.723

* denotes commercially valuable species

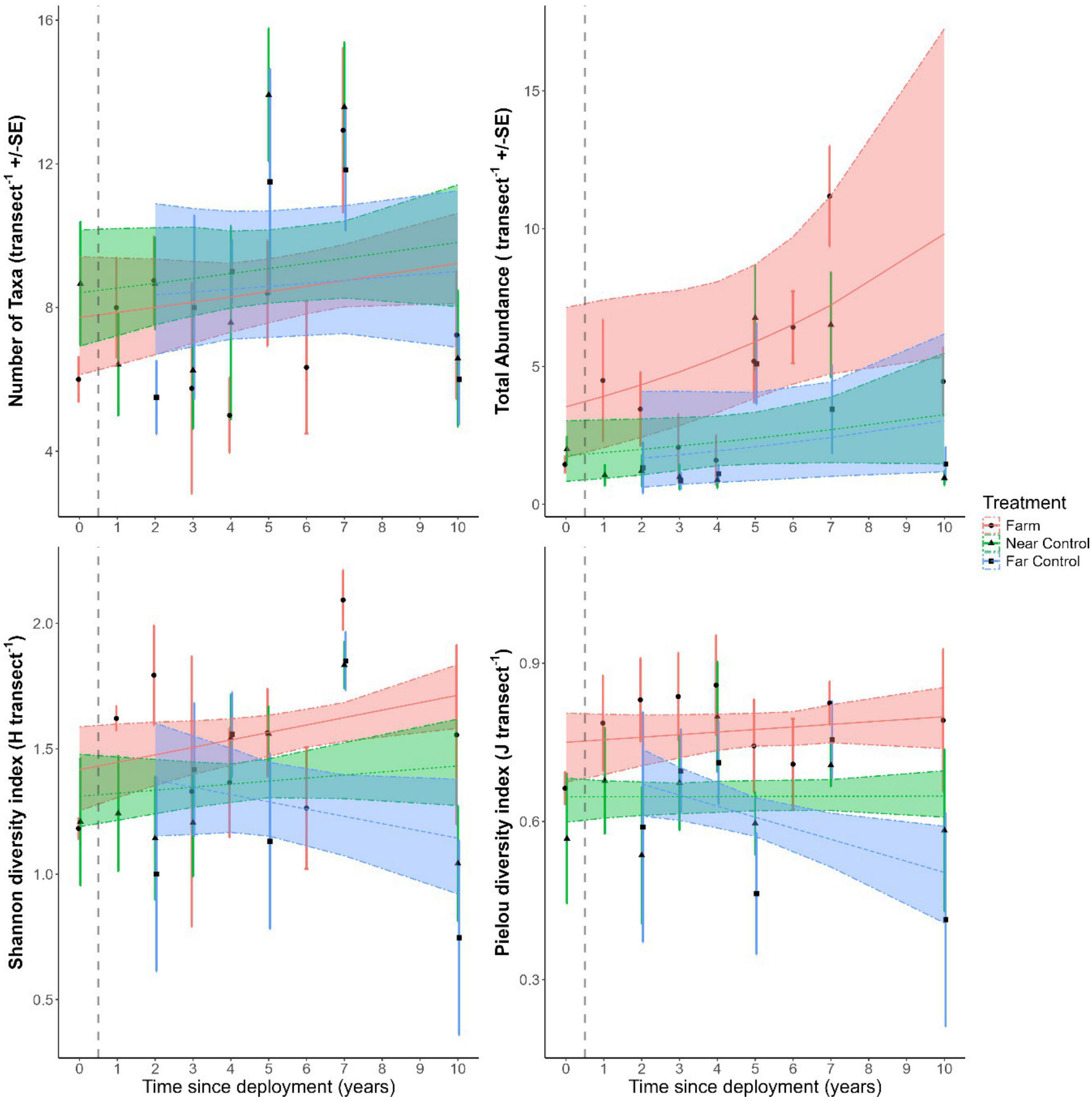

Figure 4.10 Temporal change (Years 0-10) in mobile species number of taxa, abundance and diversity indexes (Shannon and Pielou's evenness) derived from video analysis of Towed and ROV video surveys from farm-red, near control-green and far control-blue locations. Lines show model estimates with shading and dotted lines indication 95% confidence intervals. Symbols with error bars show raw mean values and 95% confidence intervals.

Table 4.3 Generalised Linear Mixed Effect model outputs for the Number of Taxa (species richness) and Total Abundance and Linear Mixed model outputs for Shannon and Pielou's Diversity Indexes derived from sessile and sedentary epibenthic survey video analysis as a function of Time and Treatment with Site as a random factor.

Response	Terms	Estimate	Std. Error	p/t value
Number of Taxa	Intercept	0.384	0.4500	0.39
	Time	0.338	0.0715	<0.0001****
	Treatmentxspat	1.380	0.4650	< 0.01 **
	TreatmentxNearControl	1.440	0.4560	< 0.01 **
	TreatmentxFarControl	1.240	0.4800	< 0.01 **
	TimexTreatmentxspat	-0.245	0.0756	< 0.01 **
	TimexTreatmentxNearControl	-0.225	0.0735	< 0.01 **
	TimexTreatmentxFarControl	-0.204	0.0792	0.01*
Total Abundance	Intercept			
	Time	-0.5310	1.170	<0.0001****
	Treatmentxspat	0.5110	0.190	2.7
	TreatmentxNearControl	1.8500	1.200	1.5
	TreatmentxFarControl	0.7620	1.190	0.64
	TimexTreatmentxspat	0.0382	1.230	0.031*
	TimexTreatmentxNearControl	-0.2950	0.194	<0.0001****
	TimexTreatmentxFarControl	-0.3140	0.193	<0.0001****
Shannon diversity index	Intercept			
	Time			
	Treatmentxspat	0.0324	0.4050	0.08
	TreatmentxNearControl	0.3150	0.0669	4.7
	TreatmentxFarControl	1.2300	0.4140	3
	TimexTreatmentxspat	1.0200	0.4100	2.5
	TimexTreatmentxNearControl	0.8270	0.4280	1.9
	TimexTreatmentxFarControl	-0.2240	0.0697	<0.0001****
Pielou diversity index	Intercept			
	Time	0.6370	0.1670	3.8
	Treatmentxspat	0.0283	0.0276	1
	TreatmentxNearControl	0.0931	0.1710	0.54
	TreatmentxFarControl	-0.0300	0.1690	<0.0001****
	TimexTreatmentxspat	-0.0542	0.1770	<0.0001****
	TimexTreatmentxNearControl	-0.0121	0.0288	<0.0001****
	TimexTreatmentxFarControl	-0.0136	0.0283	<0.0001****

Bold values denote significant P/t values (< 0.05) and asterisk's define level of significance: p/t < 0.0001 = '****'; p/t < 0.001 = '***'; p/t < 0.01 = '**' ; p/t < 0.05 = '*'; p/t < 0.1 = '.' . Std Error defines standard error.

5 Acoustic fish biomass, abundance, and diversity study

Fisheries echosounders transmit pulses of sound to ensonify the water column allowing the detection of pelagic fish. This form of data provides vital information on the distribution and behaviour of pelagic fish on a larger scale than what can be achieved with video cameras. The pulses of sound emitted from the echosounder reflect off fish in unique patterns depending on the acoustic settings, species, orientation, and behaviour of fish providing a large volume of detailed information (Simmonds and MacLennan, 2005). Acoustics surveys are common when assessing pelagic fish stocks however, their use around mussel farms is limited, despite having the ability to unlock new information about the dynamics of pelagic fish and their relationship to the shellfish aquaculture sector. Measuring the relationship between pelagic fish and the ropes of the mussel farm is essential for understanding how mussel farms create and support essential fish habitat.

The EK80 fish echosounder data will produce relative estimates of pelagic fish biomass, abundance, diversity and fish schooling behaviour which will allow us to generate an estimate of fish stocks within the farm, trawled controls and the MPA to assess the spillover effect of the mussel farm and its connectivity with the surrounding ecosystem including the MPA and fishing grounds.

5.1 Survey design and methodology

5.1.1 Data collection

A fisheries acoustic surveys were conducted at Site 2 of the Offshore Shellfish mussel farm in Lyme Bay MPA in Lyme Bay throughout different seasons in 2024 (Figure 5.1; Table 5.1). Three different types of survey were conducted to research the biological differences at multiple scales- these consisted of a fine scale and broadscale mussel farm survey and a broadscale MPA survey (Table 5.1). The fine-scale survey was conducted within the confines of the mussel farm's Site 2 transiting parallel to the mussel ropes. In comparison, the broad scale mussel farm survey extended beyond the limits of Site 2 by 1 km to the East and West of the Site. The broadscale MPA survey involved transects between the MPA and Site 2.

A Simrad EK80 split-beam echosounder, emitting at 38 and 120 kHz was pole mounted to the vessel whilst conducting transects of the survey area (Table 5.2). Data was acquired using the Simrad EK80 acquisition software with Global Navigational Satellite System (GNSS) data input from a Navilock 2.0 USB GPS. Validation of the acoustic targets was undertaken using a towed video camera with three GoPro Hero 10 cameras and a 250 mm frame plankton net to determine the source of backscatter observed on the echograms. Oceanographic properties (temperature, salinity and chlorophyll) were measured using a Valeport Swift SVP plus to determine the oceanographic regime at the mussel farm and allow for the calibration of the EK80.

Standard calibration procedures were followed to collect and process the EK80 calibration with multiple calibrations conducted to account for the different surveys (Demer *et al.*, 2015; Foote, K. G. *et al.*, 1987).

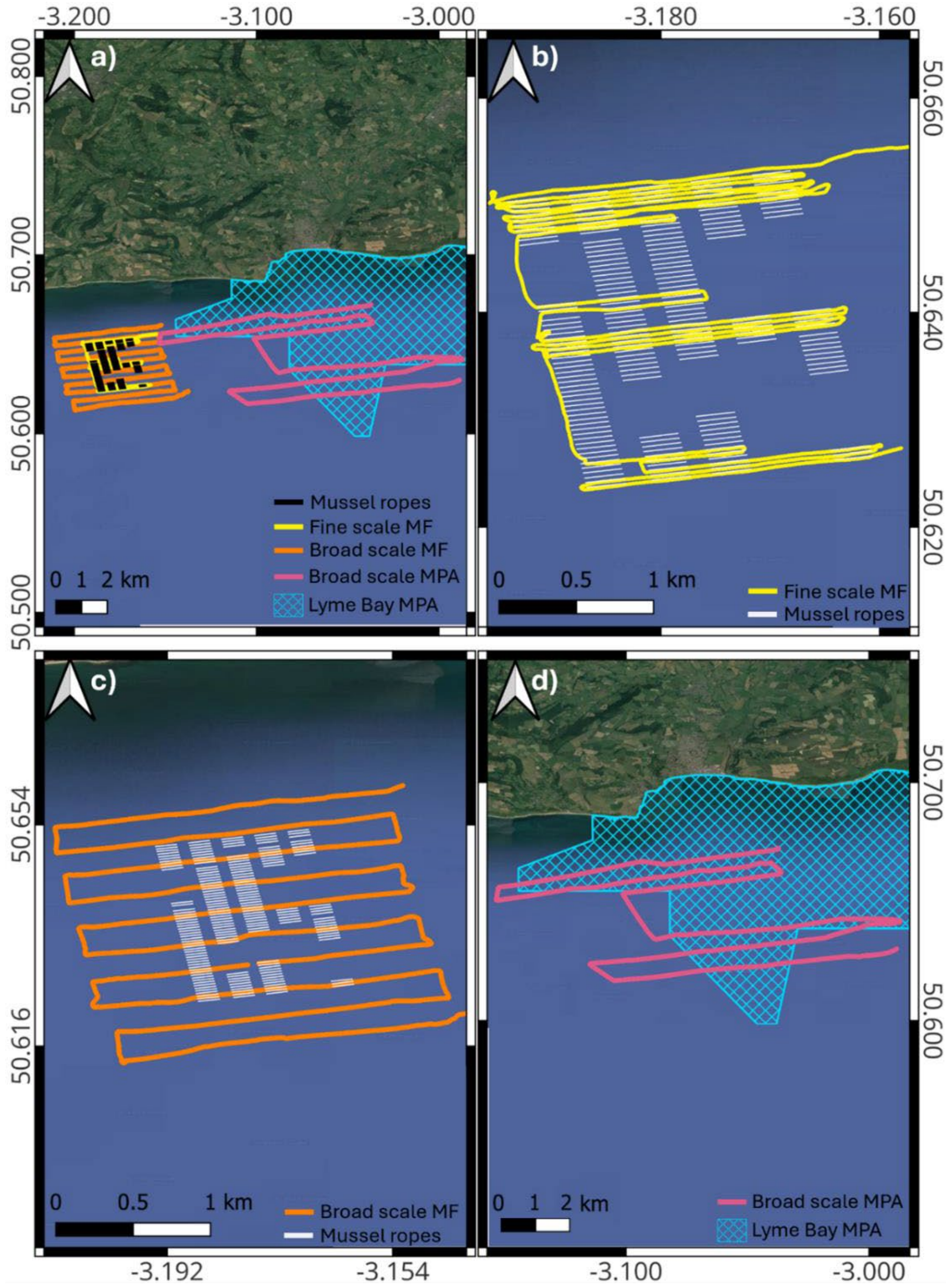

Figure 5.1 Map of a) mussel farm Site 2and Lyme Bay MPA with survey transects, b) fine scale mussel farm survey transect, c) broad scale mussel farm survey transect, and d) broad scale MPA survey transect.

Table 5.1 Summary of all EK80 surveys conducted throughout the project with validation methods.

Date	Survey name	Location	Validation methods	Vessel
21/03/2024	March- Fine scale	Site 2, Offshore Shellfish mussel farm	Video CTD	Miss Piggy
16/05/2024	May- Broad scale MF	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
17/05/2024	May- Fine scale	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
23/05/2024	May- Broad scale MPA	Lyme Bay MPA	Video CTD	Blue Turtle
24/05/2024	Calibration	50° 42.4989, 2° 57.2849	CTD	Blue Turtle
11/07/2024	July- Fine scale	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
16/07/2024	July- Broad scale MF	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
18/07/2024	Calibration	50° 42.4989, 2° 57.2849	CTD	Blue Turtle
19/07/2024	July- Broad scale MPA	Lyme Bay MPA	Video CTD Plankton	Blue Turtle
05/11/2024	November- Broad scale MF	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
06/11/2024	November- Broad scale MPA	Lyme Bay MPA	Video CTD Plankton	Blue Turtle
11/11/2024	November- Fine scale	Site 2, Offshore Shellfish mussel farm	Video CTD Plankton	Blue Turtle
15/11/2024	Calibration	Lyme Bay MPA	CTD	Blue Turtle

Table 5.2 Acoustic settings used by the Simrad EK80 echosounder for the surveys.

Transducer	Pulse type	Frequency range (kHz)	Pulse duration (ms)	Power (W)	Ramping	Beamwidth (°)
ES38	Wideband	35-45	1.024	300	Slow	18
ES120	Wideband	90-160	1.024	300	Slow	18

5.1.2 Data processing

The EK80 was imported into Echoview (v.14) for processing where GNSS offsets were applied along with a 4.5 m and 1.5 m exclusion zone for the surface and bottom waters respectively. Impulse, attenuated, transient and background noise filters were applied to clean both the backscatter (Sv) and target strength (TS) data before a -56 dB threshold was applied to the Sv data to aid the detection of pelagic fish schools (De Robertis and Higginbottom, 2007; Ryan *et al.*, 2015). Throughout the data artefacts from the farm infrastructure were observed in the data which biased the relative biomass estimates. These were removed from the dataset before further processing using visual identification. The SHAPE (Barange, 1994; Coetzee, 2000; Diner, 2001) school detection algorithm was applied to the data using fish school parameters chosen based on previous studies and evaluation of the data resolution: minimum total school height of 1 m, minimum candidate length of 0.20m, minimum candidate height of 0.20 m, maximum vertical linking distance of 1.00 m, maximum horizontal linking distance of 1.00 m and minimum total school length of 4.00 m (Aronica *et al.*, 2019; Campanella and Taylor, 2016; Fernandes, 2009). The single target wideband detection algorithm was applied to the TS data before running the fish track detection algorithm using the parameters: Minimum number of single targets in a track of 3, minimum number of pings in a track of 3, maximum gap between single targets of 5. Data was exported in 1 minute by 1 m bins for cleaning in MatLab© (v. 2022b) and analysis in R© (v. 4.3.1) and QGIS© (v. 3.3.2).

Separate processing was conducted on targets categorised as infrastructure. These were first split into two categories based on their visual appearance mussel droppers (ropes) and anchor lines. A region bitmap was applied to the processed dataset to exclude all biological targets allowing the infrastructure region to be exported by a 1 minute by 1 m grid.

Generalised Additive Models (GAMs) were used to analyse the Nautical Area Scattering Coefficient (NASC) of fish against the depth and position of the biota within the mussel farm. NASC values were further averaged across the entire water column to get a single value for each 1-minute bin which was log-transformed within the models. Variables included in the model were determined using forward stepwise selection and constrained by four knots with a Gaussian distribution. Kruskal Wallis tests were used to model NASC against the age of mussels throughout the farm.

Fish tracks and schools were bin-averaged by depth (5-9 m; 10-14 m; 15-19 m; 20-24 m; >25 m) and broadscale data was bin-averaged by longitude to aid visualisation. Results were compared using two-way analysis of variance (ANOVA) with Depth (fixed: depth bins) and Distance (fixed: longitude bins) as factors. Significant differences for any interactions were further interpreted using Pairwise analysis for comparison.

5.2 Results

5.2.1 Environmental conditions

Water properties were very different between the four different EK80 surveys (Figure 5.2). Temperature throughout the water column in March and November was homogenous at 13.4 and 14.5 °C respectively. A shallow thermocline was observed in May with with a surface maximum of 16.5 °C before reducing to 13.1° C at 15 m depth. A weaker thermocline was observed in July with a maximum temperature of 16.5 °C before decreasing to 16.0 °C at 5 m depth and 15.5 °C at 15 m.

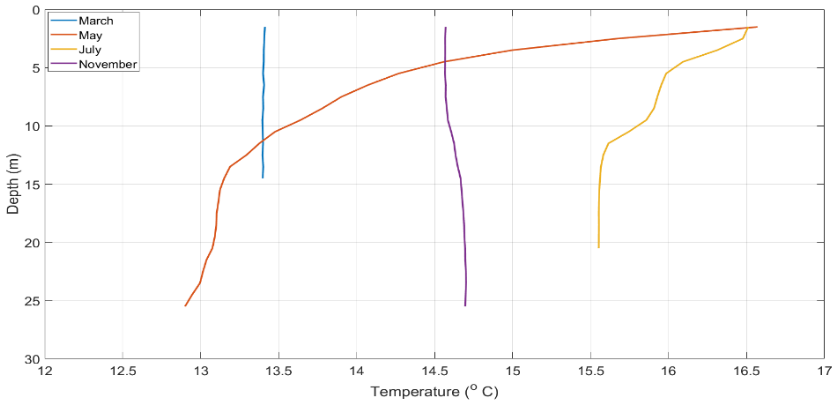

Figure 5.2 Temperature profiles throughout the water column during the different EK80 survey seasons.

5.2.2 Fish biomass

Individual fish were detected throughout the surveys, along with fish schools, demonstrating the effectiveness of the EK80 in measuring biological targets around mussel farms (Figure 5.3). Farm infrastructure was also detected by the EK80 which was validated through camera drops.

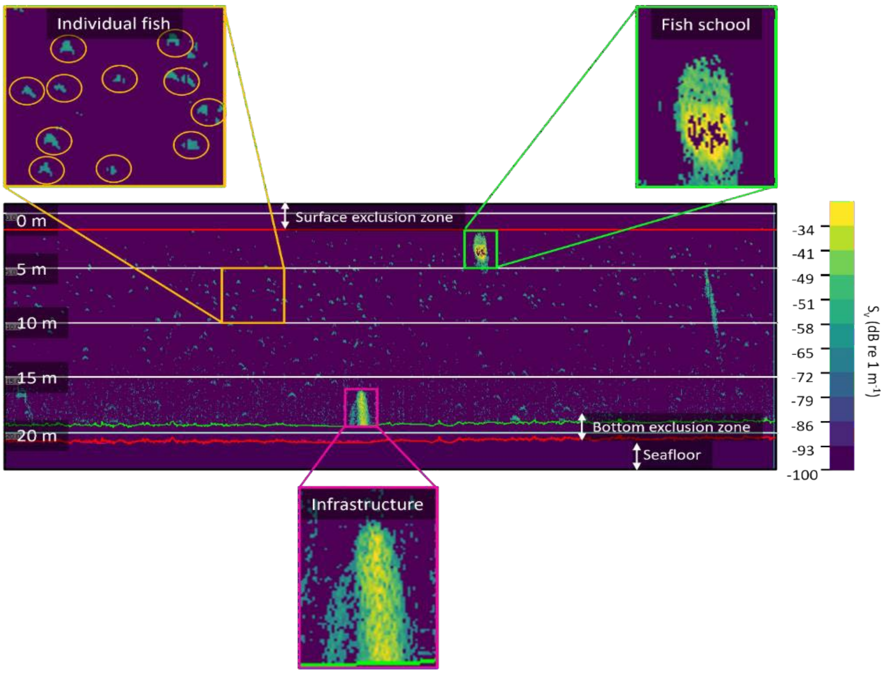

Figure 5.3 EK80 echogram at 38 kHz showing the different sources of backscatter throughout the survey: individual fish; Fish schools; and Infrastructure.

5.2.2.1 Fine scale survey

The final scale survey focused its efforts on gathering data within the mussel farm, performing transects close to the mussel headlines while avoiding mussel dropper disturbance.

5.2.2.1.1 Total Biomass

NASC, a proxy for biomass, represents the behaviour of fish combining factors such as size and density into one parameter. When interpolated over the area of the mussel farm, data from the first winter survey, showed higher NASC values (representing higher fish biomass) on the northern edge of the farm and throughout the centre of the farm (Figure 5.4). Statistical models showed no significant relationship between NASC and the age of the mussels on the ropes (W = 0.65, N = 200, p = 0.72). However, when the EK80 and mussel age data were overlaid, there was visual correlation between higher NASC values and the ropes with juvenile and 1 year old mussels on showing possible trends (Figure 5.4).

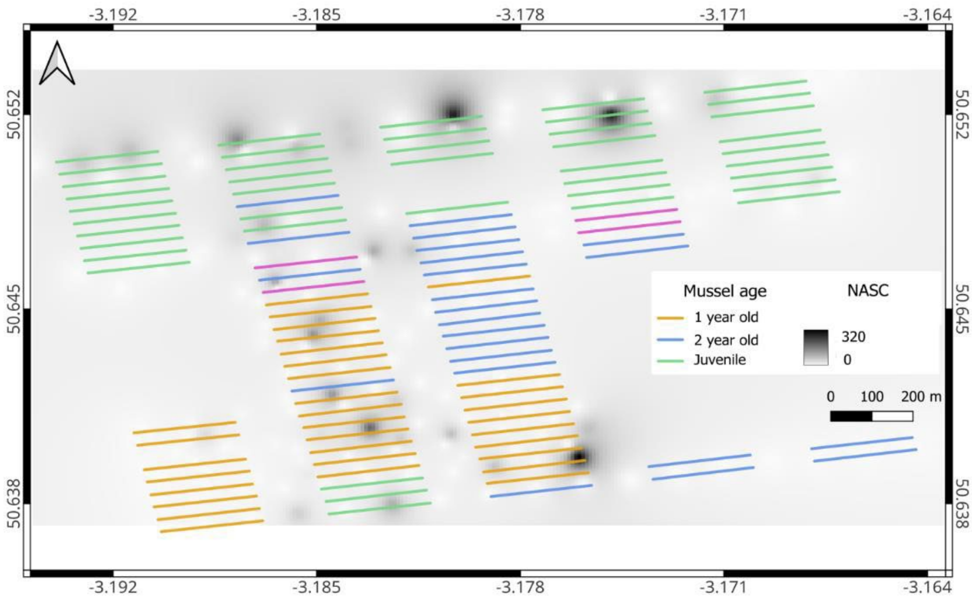

Figure 5.4 Interpolated EK80 data at 38 kHz showing the NASC values of biota with higher values (black) representing higher fish relative biomass overlaid with the age of mussels and locations of the ropes. Pink lines represent headlines that were surveyed but contained no mussels.

During the first winter survey, the depth of fish, latitude, and longitude were significant ($p<0.001$, dev. explained= 11.3%) in explaining NASC when modelled using GAMs. NASC decreased with depth with the lowest backscatter found at 8 m and the highest at 20 m (Figure 5.6a). When modelled, longitude displayed higher NASC values on the western side of the farm (Figure 5.6b). Minimal variation was observed with latitude however a small peak northward was modelled (Figure 5.6c).

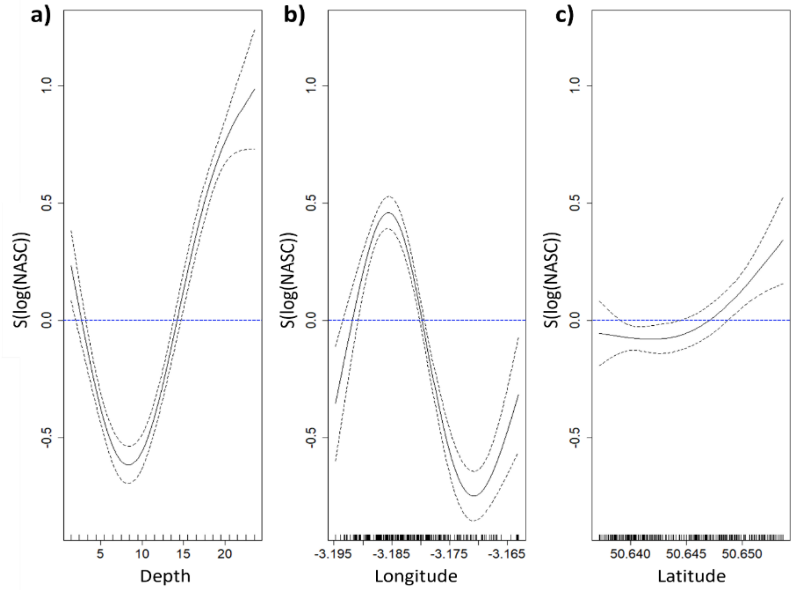

Figure 5.6 Generalised additive models showing the relationship between the log of NASC and a) depth, b) longitude and c) latitude. The blue line represents Y=0.

During the spring survey, total biomass was found to predominantly be at the south end of the farm with higher biomass levels below the mussel ropes at depths of more than 15 m (Figure 5.5).

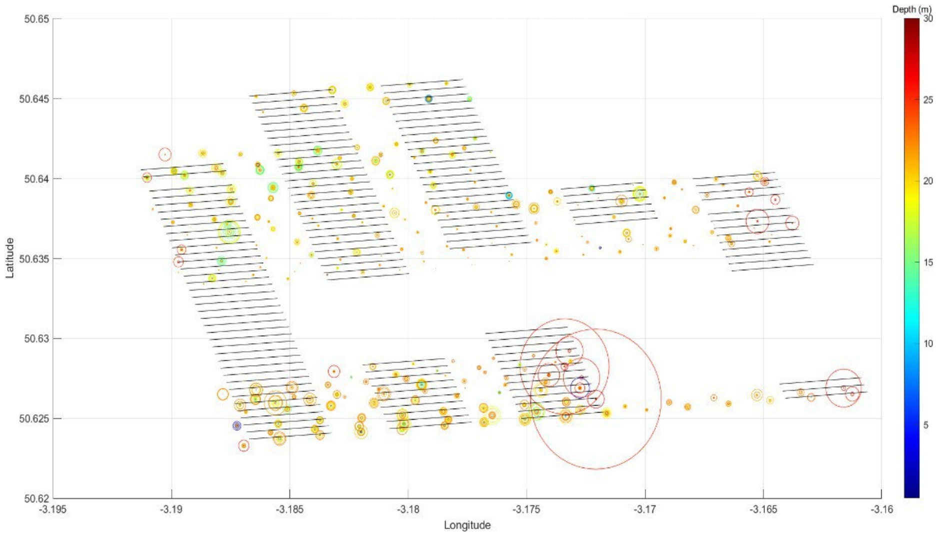

Figure 5.5 Total Biomass (NASC) over latitude and longitude with depth during the fine scale mussel farm spring survey.

5.2.2.1.2 Fish Tracks

Fish tracks were detected along the headlines during the mussel farm surveys throughout the water column as seen in Figure 5.8. However, the overall distribution within the water column changed over time (Figure 5.7).

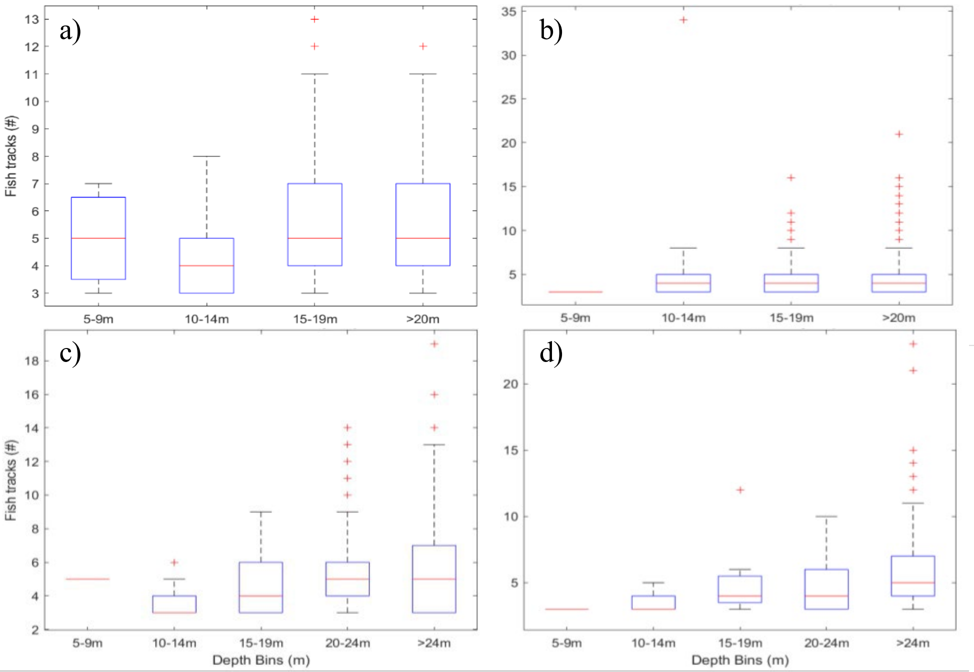

Figure 5.7 Fish tracks distribution by depth during the a) first winter; b) spring; c) summer; and d) second winter surveys.

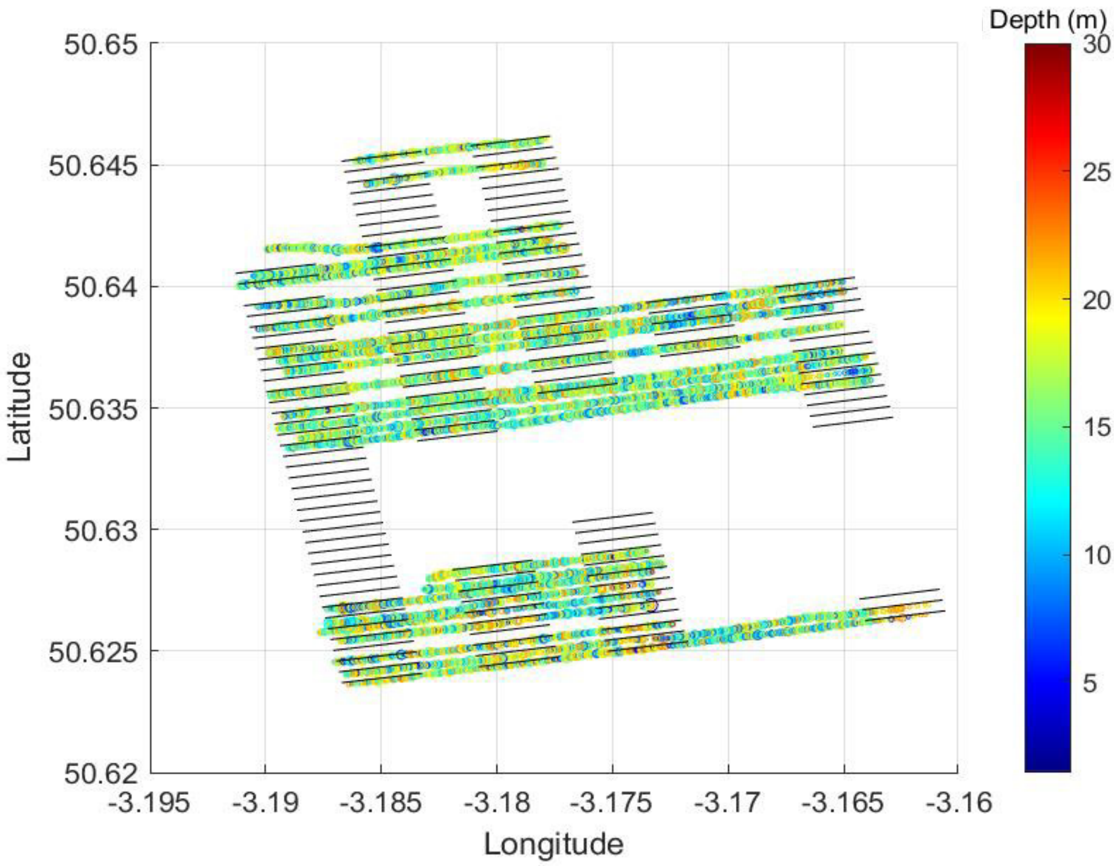

Figure 5.8 Fish track distribution over latitude and longitude with depth during the mussel farm fine scale spring survey.

During the first winter survey, fish tracks were evenly distributed throughout the water column while in the following surveys, distribution was skewed towards depths below the mussel droppers (>15 m) (Figure 5.7).

5.2.2.1.3 Fish Schools

Schooling fish were detected all throughout the mussel farm during the fine scale surveys (Figure 5.10). In the case of the spring survey, fish schools were more abundant at depth below the mussel farm droppers (>15 m). The spring and second winter surveys showed the greatest NASC values (a proxy for relative biomass), mainly detected where 1- and 2-year old mussel ropes were (Figure 5.9).

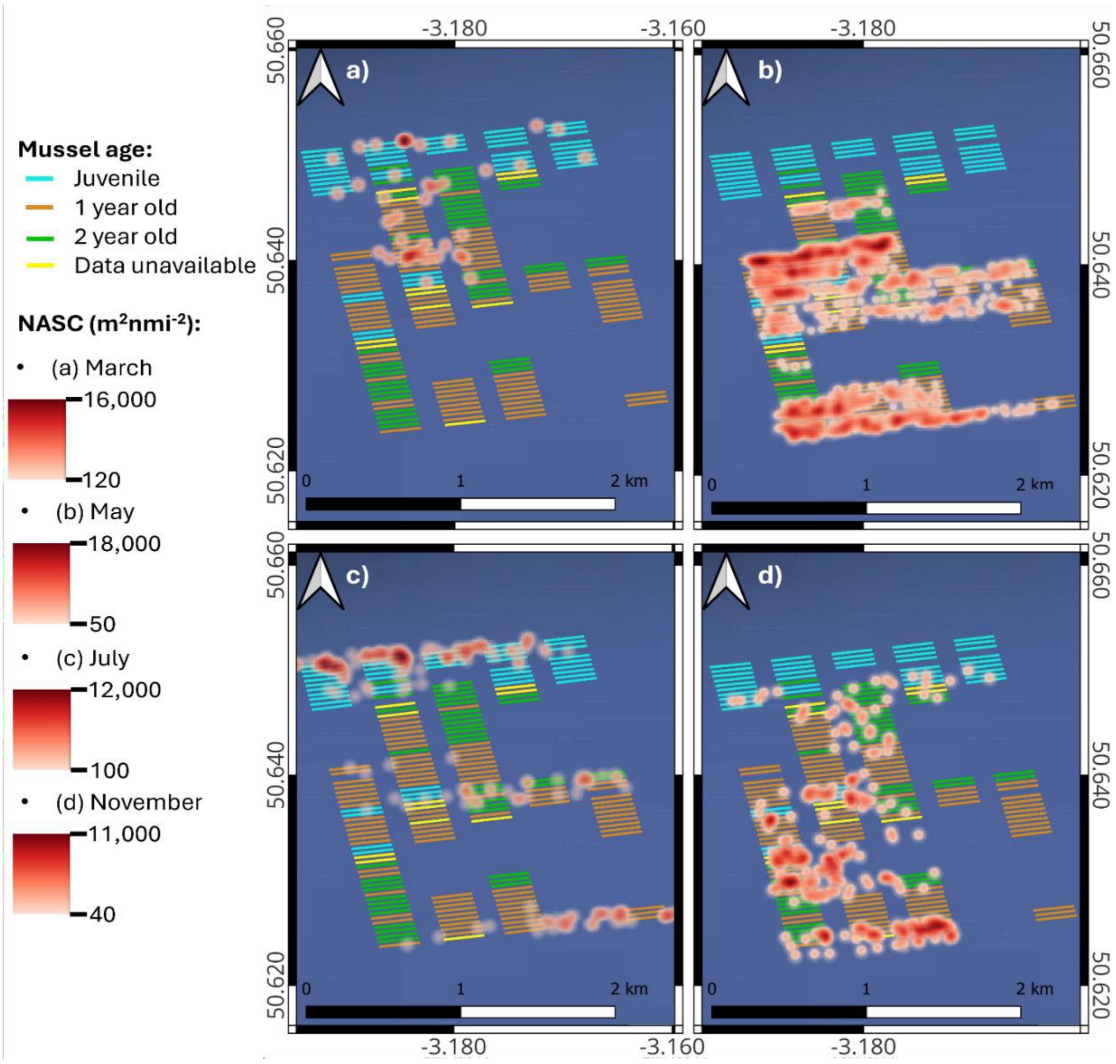

Figure 5.9 Map of Offshore Shellfish mussel farm Site 2 during the fine scale survey showing the age and location of mussels overlaid with the NASC of pelagic fish schools detected at 38 kHz during a) first winter; b) spring; c) summer; and d) second winter surveys.

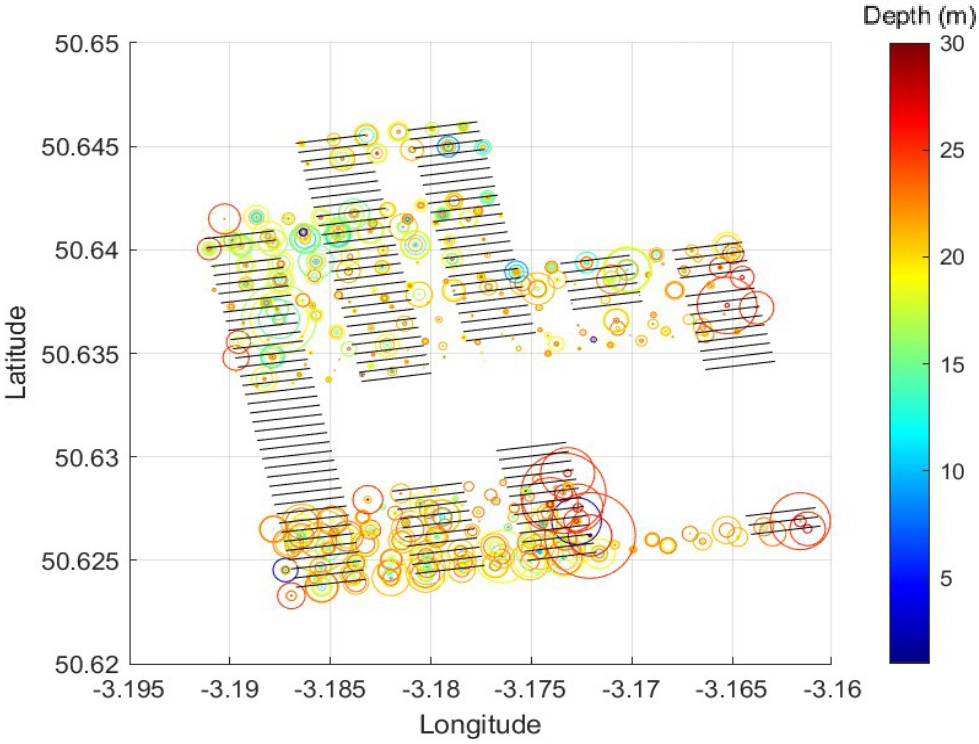

Figure 5.10 Fish Schools distribution over latitude and longitude with depth during the mussel farm fine scale spring survey.

5.2.2.2 Broad scale survey

During the broad scale survey, data was gathered within the mussel farm and its surroundings, performing transects along a subset of headlines while avoiding mussel dropper disturbance and surveying the Lyme Bay MPA. It must be noted that due to very difficult weather conditions during the winter of 2023/2024, the broadscale survey was not performed.

5.2.2.2.1 Total Biomass

Throughout the broad scale survey of the mussel farm, similar relative biomass was observed both within and outside of the mussel farm (Figure 5.11). However, throughout the seasons the spatial coverage of NASC decreased, with the highest values observed during the spring survey and the lowest coverage of NASC during the second winter survey (Figure 5.11). No distinct patterns were observed in the distribution of pelagic fish schools during the broad scale surveys between Lyme Bay MPA and Site 2 of the mussel farm (Figure 5.12).

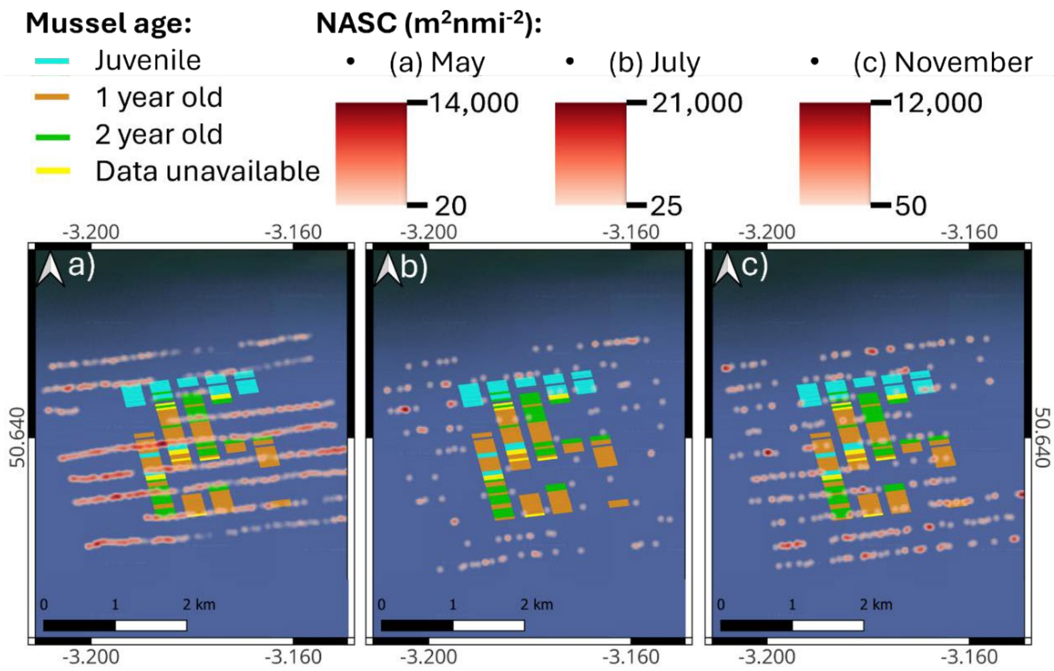

Figure 5.11 Map of Offshore Shellfish mussel farm Site 2 during the broad scale survey showing the age and location of mussels overlaid with the NASC of pelagic fish schools detected at 38 kHz during a) spring; b) summer; and c) winter surveys.

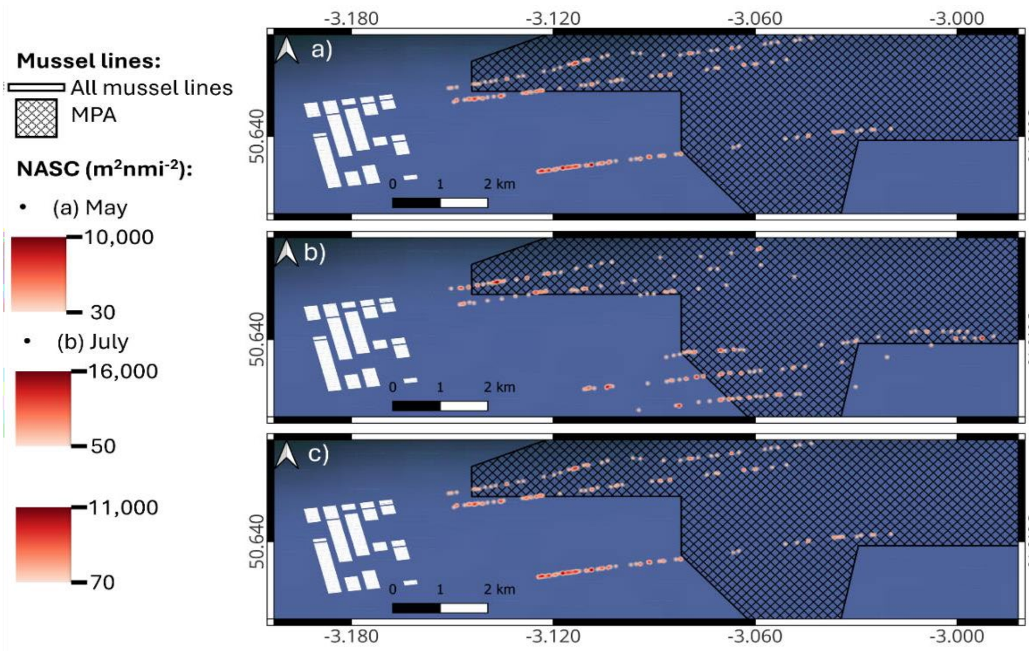

Figure 5.12 Map of Offshore Shellfish mussel farm Site 2 during the broad scale survey showing the location of mussels and the MPA overlaid with the NASC of pelagic fish schools detected at 38 kHz during a) spring; b) summer; and c) winter surveys.

When looked at the distribution of total fish biomass across the mussel farm and MPA during the surveys (Figure 5.13), it can be appreciated that higher NASC values are found during the spring survey (Figure 5.13a). Biomass distributions changes across the farm and MPA over the seasons, being higher within the farm compared to the MPA in spring (Figure 5.13a), more evenly distributed during the winter survey (Figure 5.13c), and higher biomass between the farm and the MPA in summer (Figure 5.13b). Fish biomass distribution within the water column changed seasonally (Figure 5.13). During the spring survey, biomass was found on shallower depths (5-9 m), especially within the MPA, however, that was minimum during the summer and winter surveys.

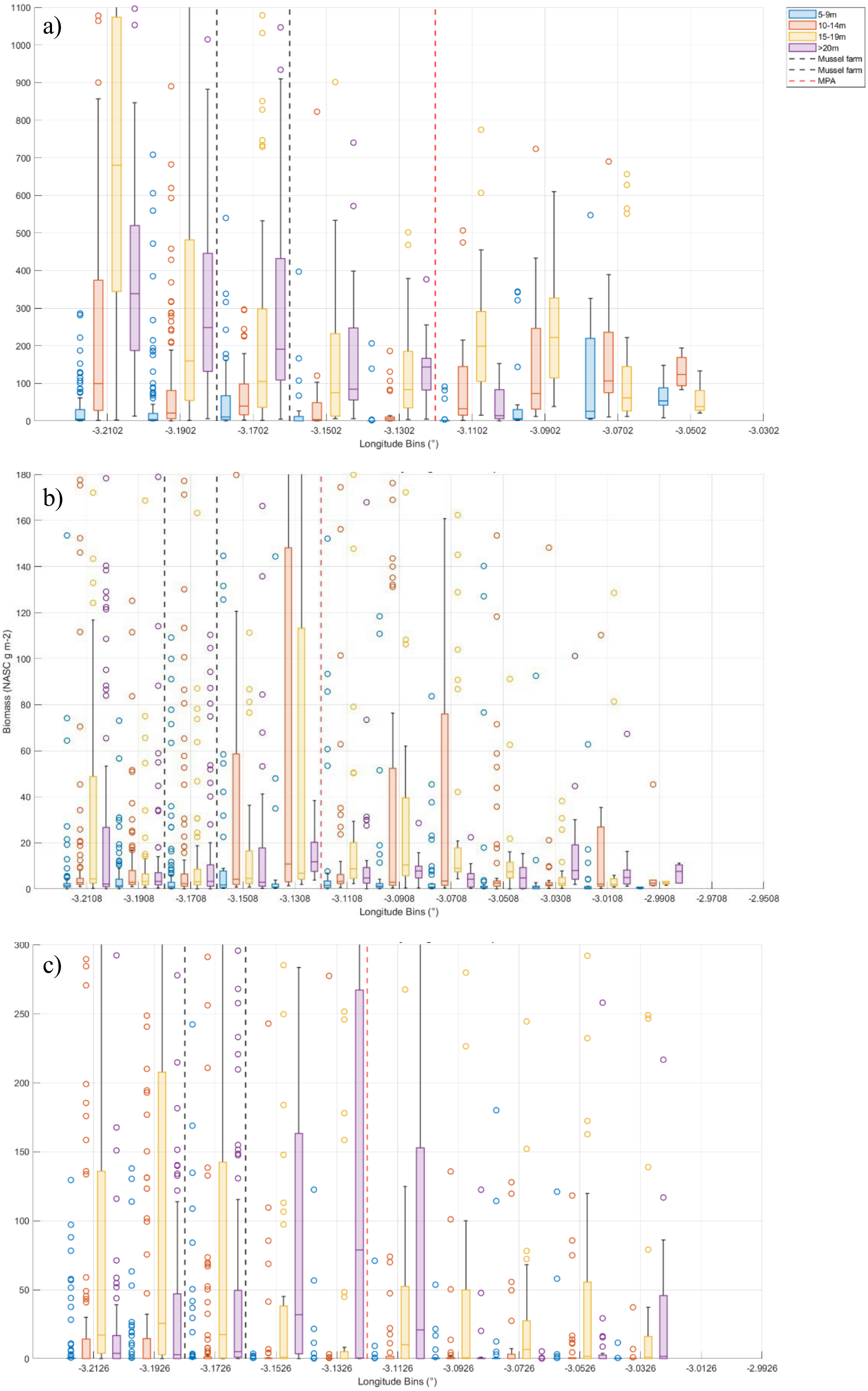

Figure 5.13 Total biomass distribution across the mussel farm and MPA during the a) spring; b) summer; and c) winter surveys.

5.2.2.2.2 *Fish Tracks*

Fish tracks distribution across the mussel farm and MPA during the spring, summer and winter surveys showed similar abundance with no spatial statistical differences (Figure 5.14). However, during the spring, and to a lesser extent the winter survey (Figure 5.14a and c), there was higher number of fish tracks within the farm compared to the MPA.

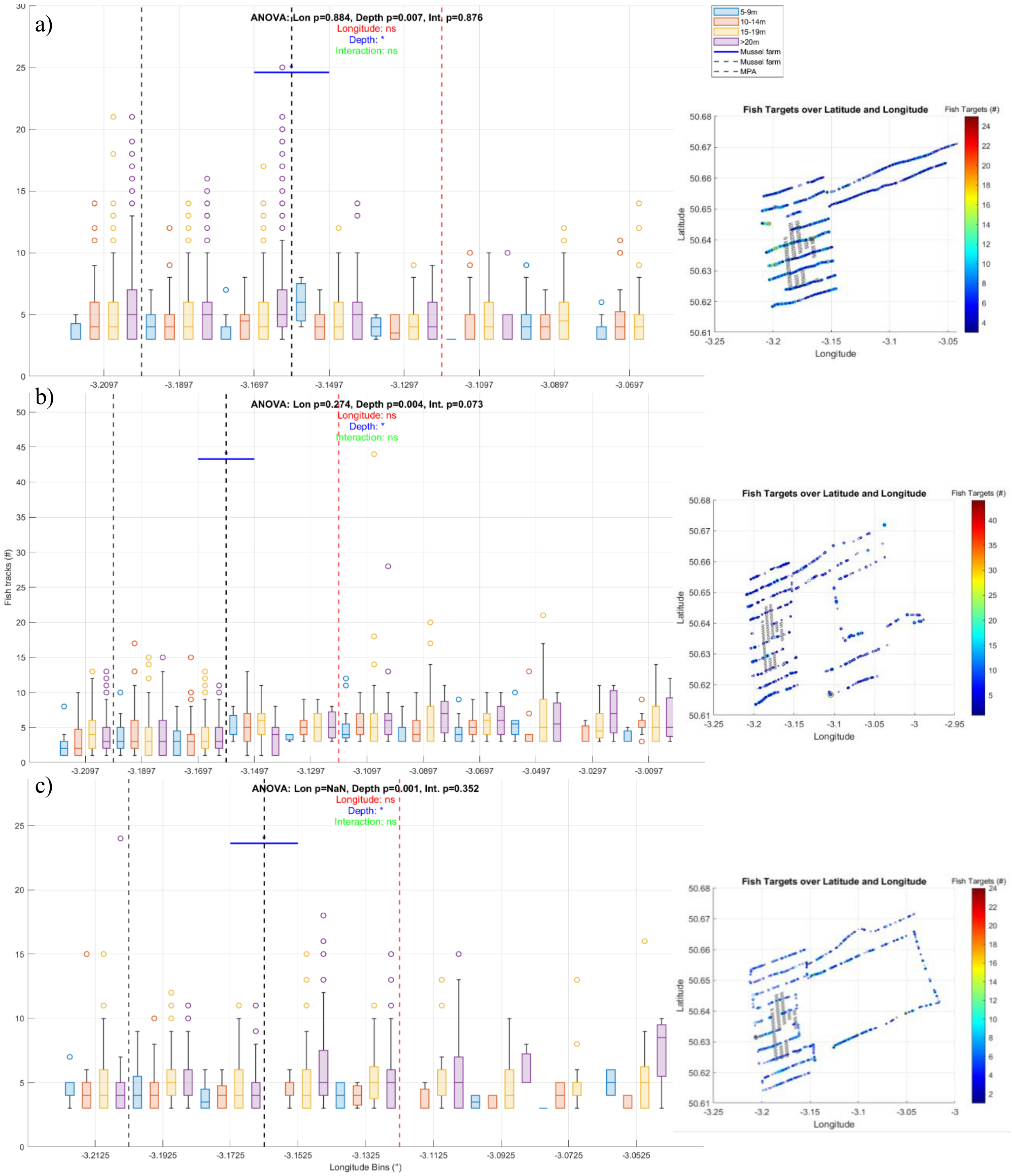

Figure 5.14 Fish tracks distribution by longitude and depth across the mussel farm and MPA during the a) spring; b) summer; and c) winter surveys.

When analysing the averaged depth-bins, fish track distribution was very similar along the transects with lower fish track abundance at shallower depths (5-9 m) (Figure 5.14). Overall, fish track abundance across depth-bins was less homogeneous within the MPA compared to the farm and its surroundings, where most fish was detected at deeper depths (>15 m), especially during winter (Figure 5.14c). An average depth-bin statistical difference was detected on the east side of the farm compared to the area adjacent to the farm's boundaries.

5.2.2.2.3 Fish Schools

Schooling fish biomass distribution by longitude and depth across the mussel farm and MPA during the spring, summer and winter surveys was separated by fish schools with signals of >56 dB and fish schools with signals of <56 dB (Figure 5.15). Fish schools with signals of >56 dB were higher by more than two orders of magnitude throughout.

Fish schools with signals of >56 dB were most abundant in summer, followed by winter and spring while fish schools with signals of <56 dB were most abundant in winter (Figure 5.15). There was no statistical difference between the farm and the MPA however, fish schools were overall more abundant within the farm and its surroundings. Fish schools were found across the entire water column with overall higher abundances between 10-14 m for fish with signal >56 dB, and between 5-9 m for fish with signal <56 dB.

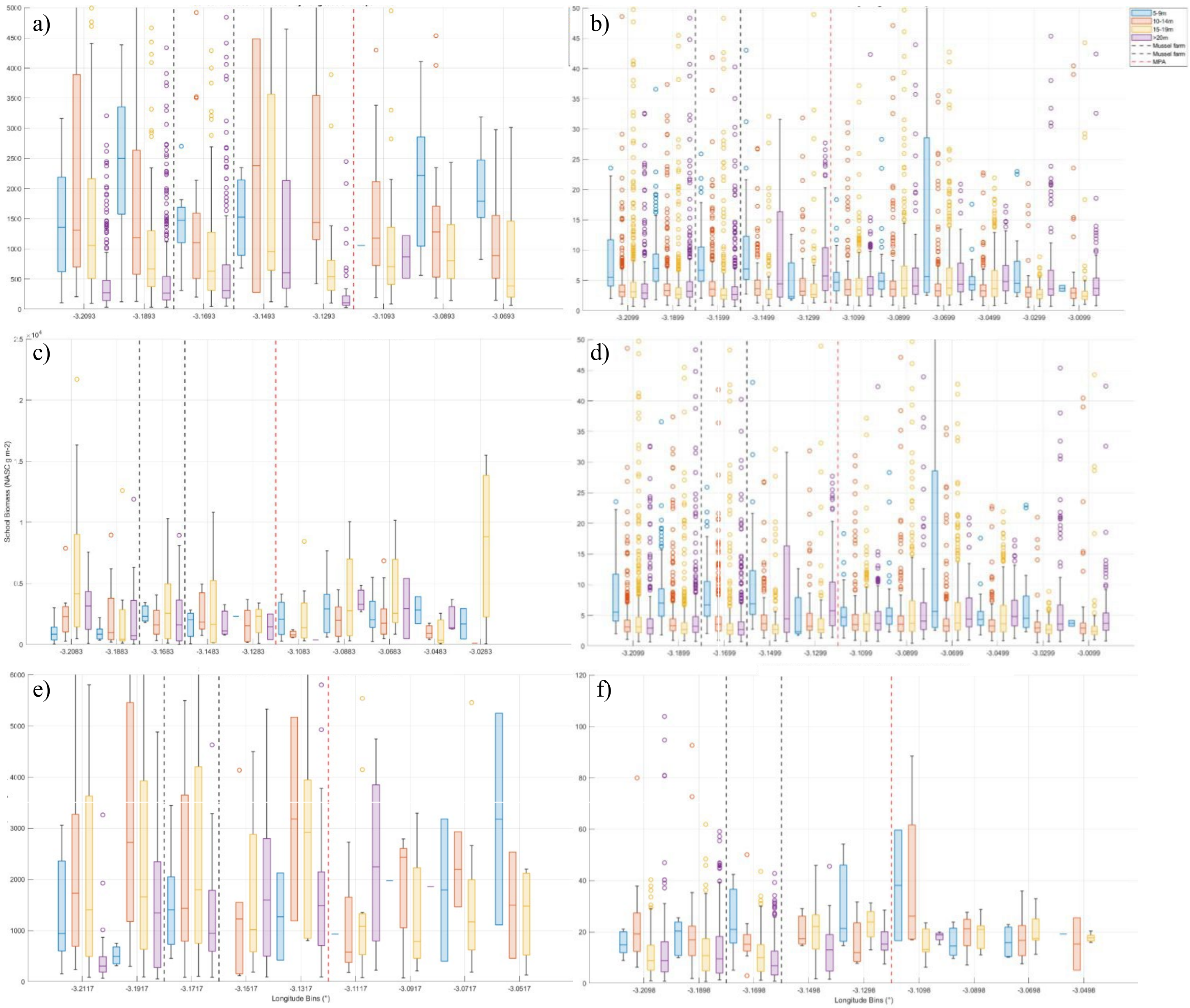

Figure 5.15 Schooling fish biomass distribution by longitude and depth across the mussel farm and MPA during a) spring for fish with >56 dB; b) spring for fish with <56 dB; c) summer for fish with >56 dB; d) summer for fish with <56 dB; e) winter for fish with >56 dB; and f) winter for fish with <56 dB.

5.2.3 Infrastructure analysis

Infrastructure artefacts were visually identified in Echoview using validation footage from the towed video to differentiate between biological and infrastructure regions. Infrastructure targets were divided into two categories based on their appearance: mussel ropes (droppers) and anchor ropes (Figure 5.16). The infrastructure targets were exported by regions and then analysed to determine if the infrastructure target detection could be automated by looking at the backscattering properties compared to that of biological targets.

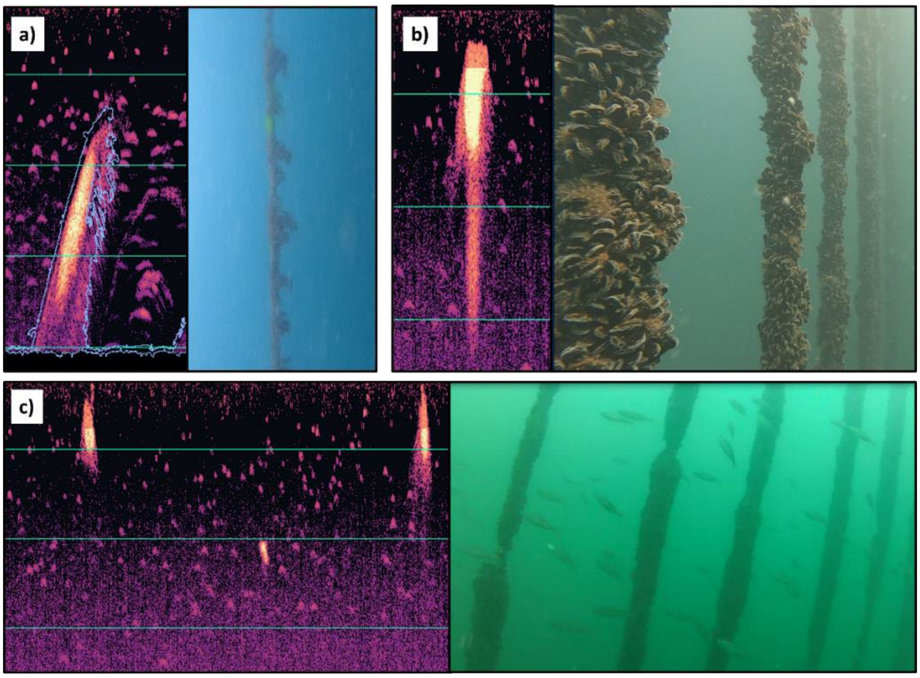

Figure 5.16 Images depicting the echogram targets with the video validation of the actual targets showing a) anchor ropes, b) and c) mussel ropes.

Principal Component Analysis (PCA) was used to reduce the number of behavioural characteristics of backscatter to key principal components (Embling et al. 2013; Table 5.3). PCA was only completed on the 38 kHz data due to stronger backscatter returns of infrastructure targets. Data for the behavioural components was normalised with the first two principal components (PCs) cumulatively explaining over 80 % of the variance. K-means clustering was used to assess the similarity in behavioural characteristics between infrastructure and fish school clusters.

Table 5.3 Behavioural characteristics exported from Echoview that describe the school and infrastructure regions.

Behavioural characteristic	Description
NASC	The Nautical Area Scattering Coefficient of a region (m^2nmi^{-2}).
Depth	The depth of the region (m).
Length	The length of the region (m).
Perimeter	The perimeter of the region (m).

5.2.3.1 4.2.3 Farm infrastructure

Infrastructure was detected at both 38 and 120 kHz throughout the mussel farm showing how effective these frequencies are for identifying infrastructure features such as those typical of a mussel farm development (Figure 5.17).

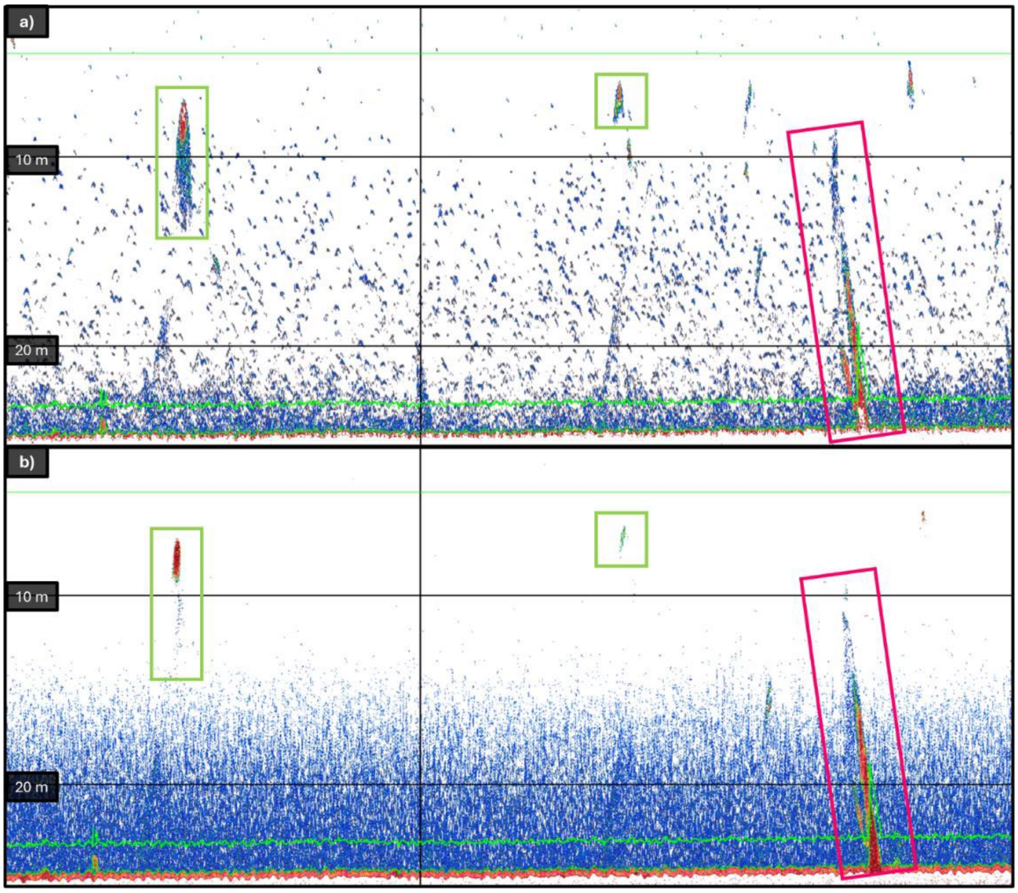

Figure 5.17 Echograms showing a) 38 kHz data and b) 120 kHz data displaying the difference between mussel ropes (green) and anchor ropes (pink).

The first two PC's of the 38 kHz analysis accounted for 80 % of the variance. The first component for the 38 kHz data described length and perimeter as the most importance descriptors of target origin (e.g. schools or infrastructure; Table 5.4). The second component at 38 kHz represented NASC and depth.

Table 5.4 PCA results from 38 kHz data showing the most important descriptors (in bold) of each PC.

Behavioural component	PC1	PC2
NASC	-0.178	**0.738**
Depth	-0.269	**-0.666**
Length	**-0.671**	0.103
Perimeter	**-0.668**	-0.0324

K-means clustering grouped the data based on PCs with the clusters showing no similarity between origin (Figure 5.18). Each cluster consisted of a mixture of schooling fish, anchor ropes and mussel ropes suggesting that without more data on the backscattering properties of infrastructure it cannot be distinguished from biological data using only it's backscattering properties.

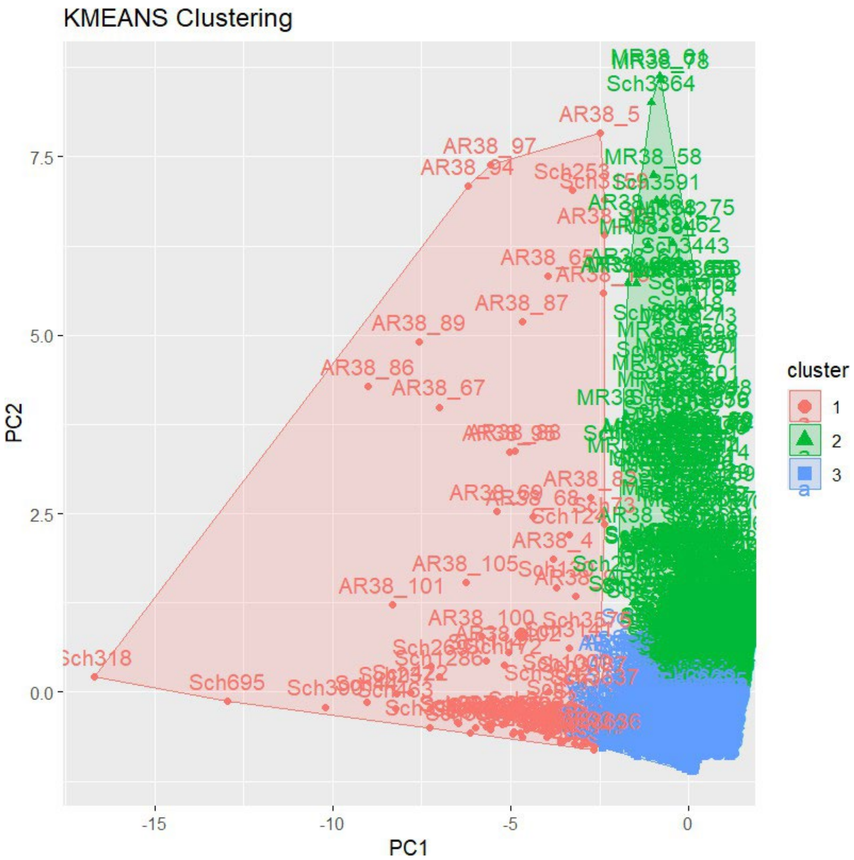

Figure 5.18 K-means cluster showing three different clusters based on the first two PC's from the PCA analysis. Point labels beginning with 'Sch' represents fish schools, 'AR' stands for Anchor ropes and 'MR' is mussel ropes.

6 Fish and crustacean telemetry study

Ropes to Reefs built the first aquaculture telemetry network to assess connectivity between the three different farms (OSL mussel farm, BA seaweed farm and, SR scallop farm). The network is also utilising the UoP's led FISH INTEL telemetry network to assess value of the farms to wider fisheries by tracking tagged animals between Ropes to Reefs project partner's farms across Lyme Bay and adjacent fishing grounds and MPAs.

A dedicated receiver network has been set-up allowing to track Ropes to Reefs tagged species along the south coast of England providing the first multi aquaculture telemetry network (mussels, scallops and seaweed). Animal tagging and tracking was conducted to define; 1) how wild animals interacted with aquaculture sites; 2) connectivity with surrounding natural environment; 3) and spillover from aquaculture sites to surrounding commercial fisheries. Each fish was tagged with a 2-year battery life transmitter and released which will continuously emit a uniquely coded "ping" detected when within range of a "receiver". The species included within the study were selected based on their abundance within the local area and/or commercial interest:

Cat shark: The lesser spotted catshark (*Scyliorhinus canicula*), is a small and widely distributed benthic shark species. This species inhabits continental shelves and slopes at depths ranging from 10 to 400 meters (Compagno, 1984; Ellis *et al.*, 2005). Despite its widespread distribution, relatively few research studies have investigated this species spatial ecology. Furthermore, the species is a target for commercial fisheries where it is often used as bait for further fisheries. Highlighting the need for continued research into its population dynamics and conservation status (ICES, 2020).

Thornback ray: Thornback rays (*Raja clavata*) are widely distributed around the UK and the most common skate observed in the UK. They are socially and commercially important, representing a key recreational angling target. Meanwhile, they are caught in all main UK fisheries and dominate skate landings in the Irish Sea, North Sea and eastern English Channel. Due to intense fishing pressure, *R. clavata* abundance and range has reduced in UK waters and the species is currently assessed by the IUCN as exhibiting a decreasing global population trend (Ellis *et al.*, 2005).

Grey Mullet: The thicklip grey mullet (*Chelon labrosus*), a member of the family Mugilidae, is a euryhaline fish species commonly found in coastal waters, estuaries, and lagoons across the northeastern Atlantic Ocean (Harrison and Senou, 1999; Whitfield, 2023). Thicklip grey mullet are omnivorous, feeding primarily on detritus, algae, and small invertebrates, which contributes to nutrient cycling in coastal habitats (De Silva, 1980). Due to their ecological importance and commercial value, *C. labrosus* has been the focus of studies on aquaculture potential, particularly in polyculture systems, as well as their role as bioindicators of environmental health (Lasserre and

Gallis, 1975; Whitfield, 2023). However, habitat degradation and overfishing pose significant threats to their populations, underscoring the need for sustainable management practices (Cardona, 2006).

Black Bream: The black bream *(Spondyliosoma cantharus)* is a distributed across the eastern Atlantic. Black bream have specific habitat requirements for spawning, where they make nests in gravel and sand over bedrock. Black seabream holds significant fishery importance due to its ecological and economic values in various coastal regions to both commercial and recreational fishers. In the UK, four Marine Conservation Zones (MCZ) have been designated to protect black seabream: Kingmere MCZ in Sussex, and Poole Rocks MCZ, Southbourne Rough MCZ, and Purbeck Coast MCZ in Dorset. Currently however, relatively little is known on this species spatial ecology, or wider movements outside of the spawning sites.

European lobster: European lobster (*Homarus gammarus*) are commercially important crustaceans in the UK and wider European shelf seas (Rees *et al.*, 2021). In the Southwest UK these species are particularly important for small inshore vessels (typically <10 m; Rees et al., 2021), which support an estimated 65 % of the direct employment for the commercial fishing sector (Stamp *et al.,* 2022). Continuing from Stamp *et al.* (2024), further work is required to define how lobsters interact with aquaculture facilities.

Wider UK and EU tracking will be conducted via tag detections on other receivers within the UoP management FISH INTEL network, two other FISP funded projects led by PI-ES and the agreed industry partnership tracking project between OSL, SRL and BAL (Figure 6.1).

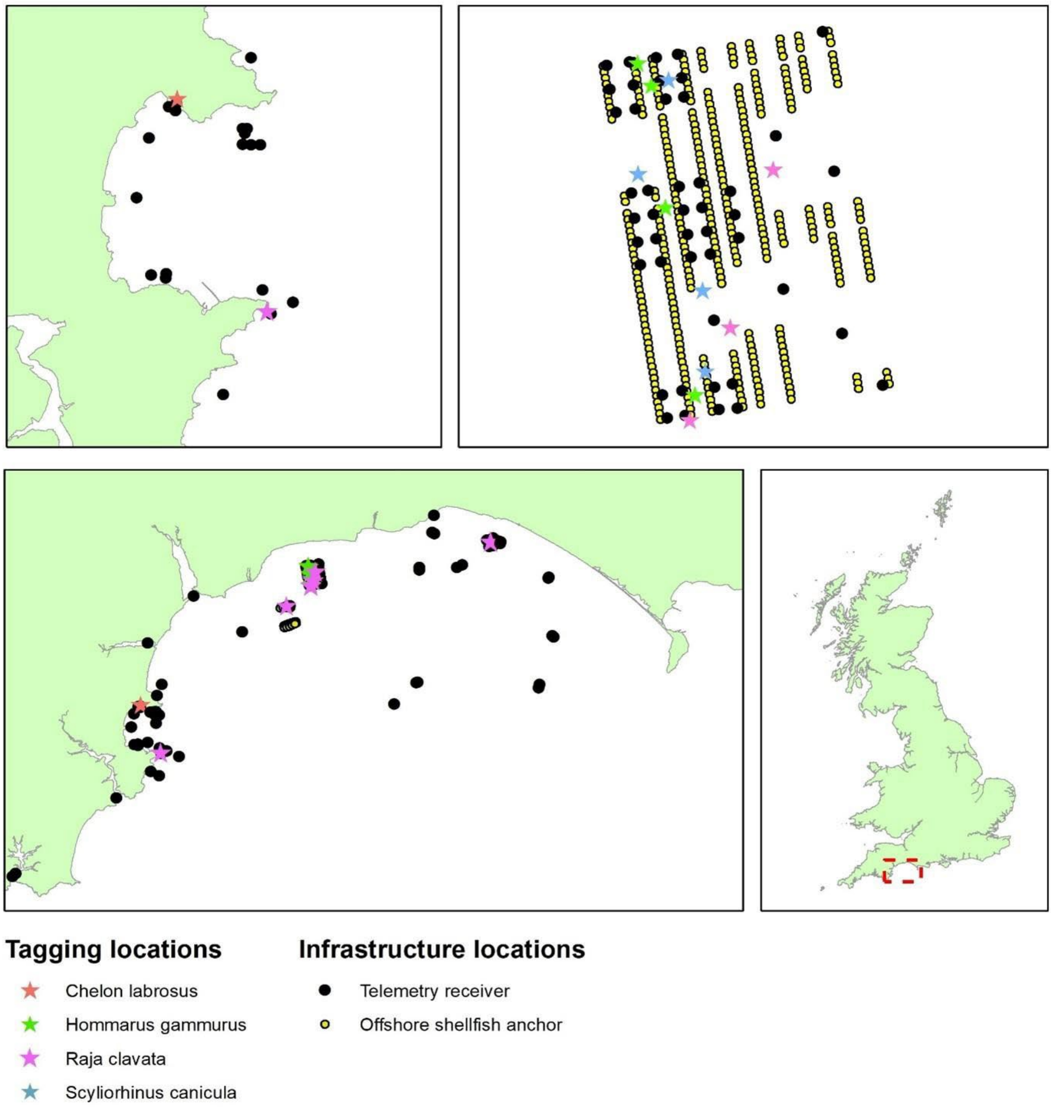

Figure 6.1 Map showing animal capture and release locations (stars) and receiver deployment locations (black dots) across Lyme bay.

6.1 Survey design and methodology

Acoustic telemetry was used to monitor how the tagged species interacted with the habitat created by the aquaculture installations, and wider marine environment. This technology relies on two components, 1) an acoustic receiver which can detect and decode the acoustic transmissions from tagged animals; 2) an acoustic transmitter which is attached or implanted within a host animal and emits a uniquely coded ping caught by the receiver.

6.1.1 Receiver deployment

By deploying a network of acoustic receivers in different configurations movement data from tagged animals can be generated at different resolutions.

To assess fine scale behaviour of tagged animals at a resolution of <10 m, a "fine scale" receiver array was deployed at Offshore Shellfish Ltd. Site 2. This includes deploying receivers in a gridded formation, where the detection range of receivers overlap (Figure 6.1). Using time differences in the detections of tagged animals from receivers with overlapping detections ranges, positions of animals at high resolution can be generated. Allowing assessment of how tagged animals interacted with the wider environment/habitat. To assess broader scale behaviour individual receivers were deployed at the Scallop Ranch Ltd., Biome Algae Ltd. and marine farm services mussel farm in Torbay. This was combined with a broader network of receivers deployed across known shipwrecks and rocky reefs throughout the surrounding area. These receivers provide presence/absence data for each individual when it is in detection range of a receiver (~300m). The fine scale array was deployed across three distinct locations within OSL, encompassing a combined area of ~4 km^2. The wider network of receivers were deployed across 80 km of open coast.

A total of 47 receivers were allocated across all aquaculture sites: 41 OSL, 3 BAL, 3SRL. Some additional receivers were also deployed to provide better coverage across Torbay: 3 Torbay harbour authority seasonal marks, 3 Marine Farm Services Mussel Farm.

6.1.2 Animal tagging

Receiver deployment was paired with an extensive animal tagging campaign. In order to assess how animal behaviour may differ between the aquaculture sites, and better define connectivity with wider natural habitats animal tagging was split across the various aquaculture sites and at rocky reef sites within Lyme Bay (Figure 6.1).

6.2 Results

A total of 29 lobster, 30 thornback ray and 2 Thicklip grey mullet were captured and tagged in 2024. Several unsuccessful black bream fishing trips were conducted across the wider area. As a result of no Black bream being captured, a decision was made to switch this tagging tagged effort onto catsharks, and as a result 31 catsharks were captured and tagged.

All receivers were successfully downloaded in October 2024, providing ~4/5months of continuous tracking data across the aquaculture sites and surrounding natural habitat. Over this timeframe the project generated 3,639,472 detections and 94.5% of the tagged animals were re-detected (n=89) (Figure 6.2).

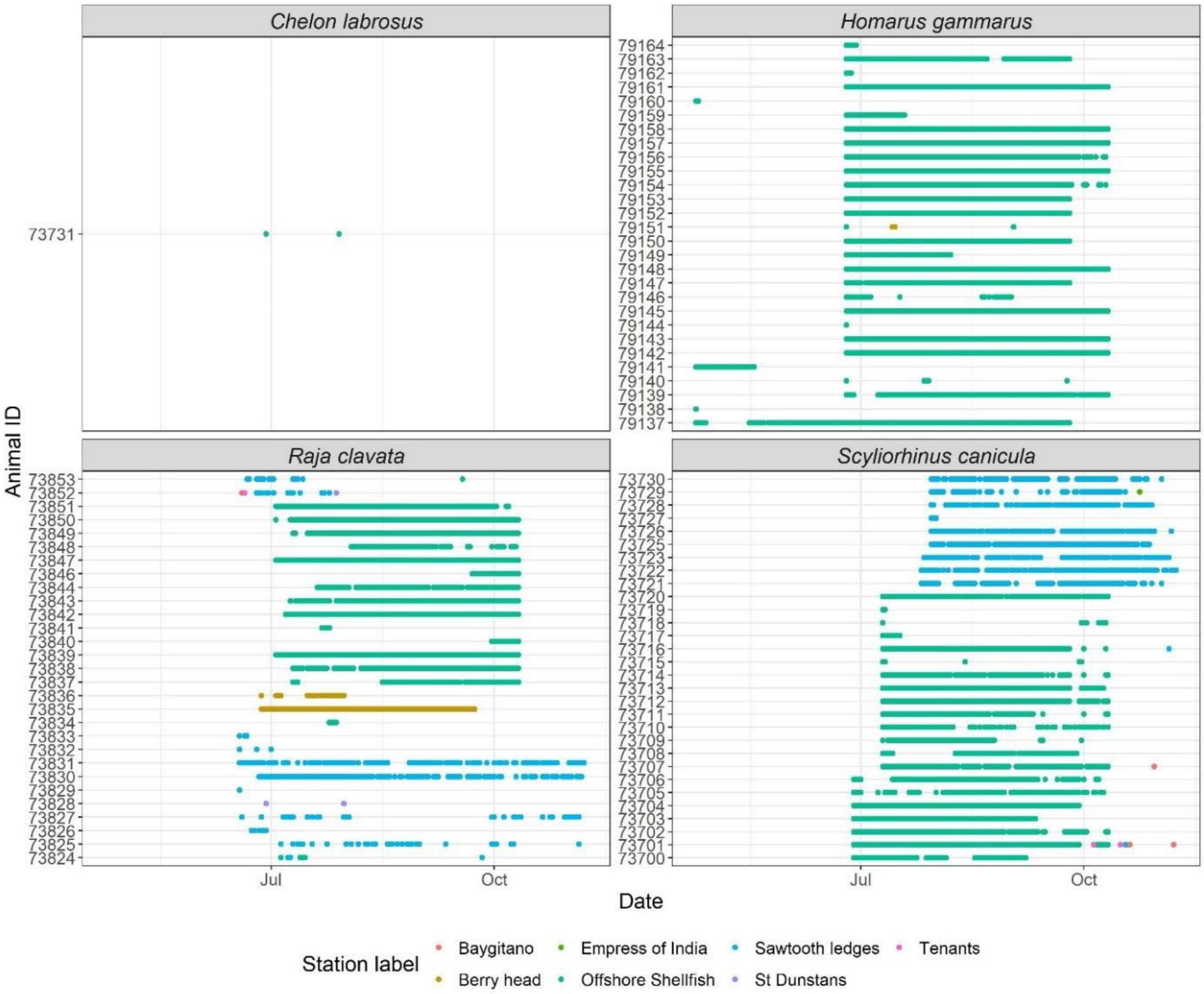

Figure 6.2 Abacus plot displaying presence absence of all tagged animals across different sites within Lyme bay. Points are colour coded by the location the acoustic receiver was deployed.

6.2.1.1 Lobsters

Across all the receivers 1,377,945 detections were generated from 29 individuals (100% tagged animals). Of the 29 lobsters tagged, they were all detected within the mussel farm, some individuals were tracked for less than a week, whereas others over a four-to-five-month period. The spread of tagged individual was relatively even between the sexes with 15 males and 14 females being tagged, as well as a diverse spread of lobster sizes ranging from 500g-1500g. Of the 29 lobsters tagged, 18 lobsters were tracked within the mussel farm for over one month (Figure 6.2).

6.2.1.2 Thornback Ray

Across all the receivers 691,294 detections were generated from 29 individuals (96% tagged animals). Generally, all tagged rays showed highly resident behaviour within both the offshore shellfish site and natural habitats, though gaps in detections were recorded suggesting intermittent movement away from release locations. Two individuals tagged within the Lyme Bay protected area, were detected within the Offshore Shellfish site 2.

6.2.1.3 Catshark

Across all the receivers 1,570,222 detections were generated from 30 individuals (96% tagged animals). Movement data suggested this species is highly sedentary and does not swim continuously but rather moves in limited bursts. As a result, animals detected in both the offshore shellfish site and Lyme Bay MPA showed highly resident behaviour, with almost continuous detections over the study.

6.2.1.4 Thicklip mullet

Across all the receivers 15 detections were generated from 2 individual (100% tagged animals). Due to logistical difficulties in capturing this species in deep water, these animals were captured in a shallow water location adjacent to the Scallop Ranch, Seaweed farm and inshore Mussel farm. These animals were detected in Torbay harbour for a two-week period after released, during which all detections were from receivers deployed in the seaweed farm. After this, 1 individual was detected on the Eastward side of Torbay, then not detected for the remainder of the project.

6.2.2 Fine scale behaviour at Offshore Shellfish site

6.2.2.1 Lobsters

From the individuals that remained within the bounds of the mussel farm for the entire monitoring duration, we see they have varying sized home ranges, with a preference to aggregating in and around the anchor pins that make up the mussel farms infer structure (Figure 6.3). Further work is being

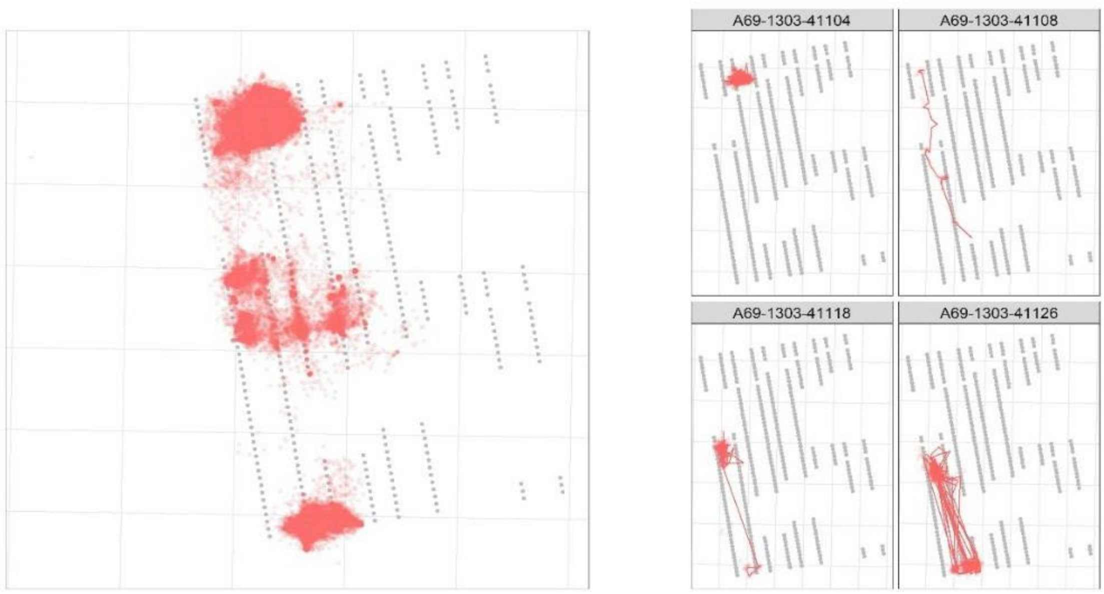

Figure 6.3 All fine scale positions for tagged lobsters within OSL Site 2 (left). Example movement tracks for four individual lobsters (right).

conducted to define how tagged animals interacted with the farm infrastructure. This includes define core territories and feeding areas within the mussel farm (Figure 6.4).

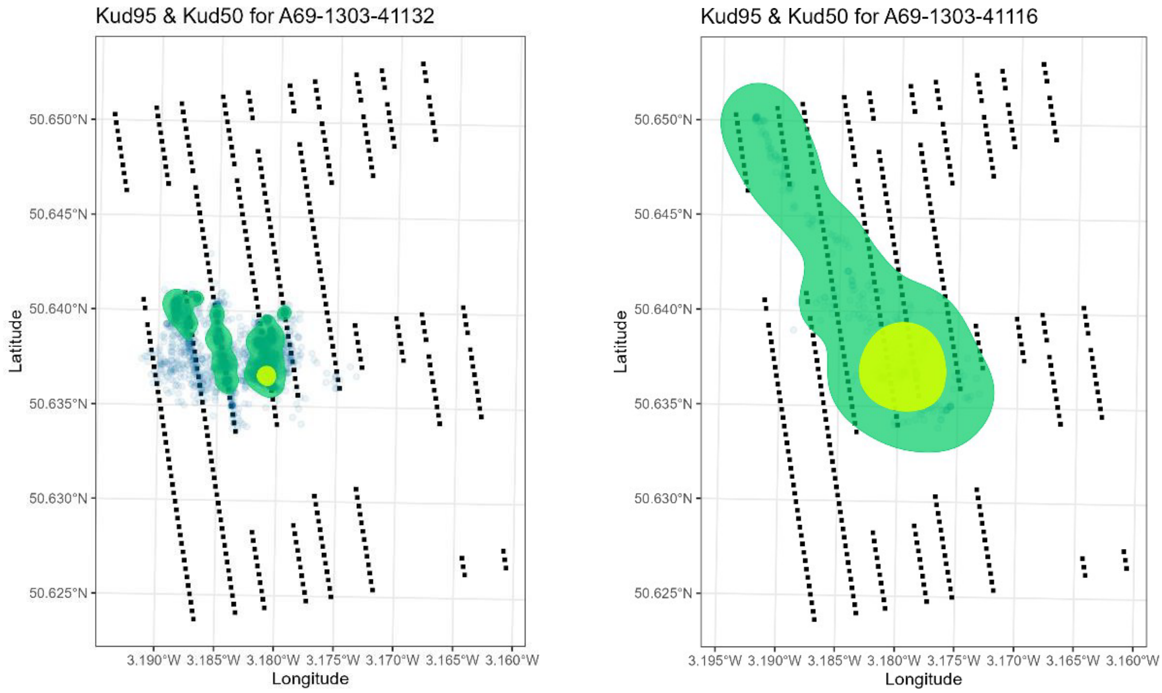

Figure 6.4 Example core activity (light green) total utilization area (dark green) for two individual lobsters within OSL Site 2.

6.2.2.2 Thornback Ray

For the individuals that were tracked within the mussel farm, the majority were detected within the central section of the mussel farm. Individual movement patterns were however not focussed on particular infrastructure. Instead, animals displayed irregular movement throughout various sections of the farm. Further analysis is required to link movement patterns and the underlying habitat (Figure 6.5).

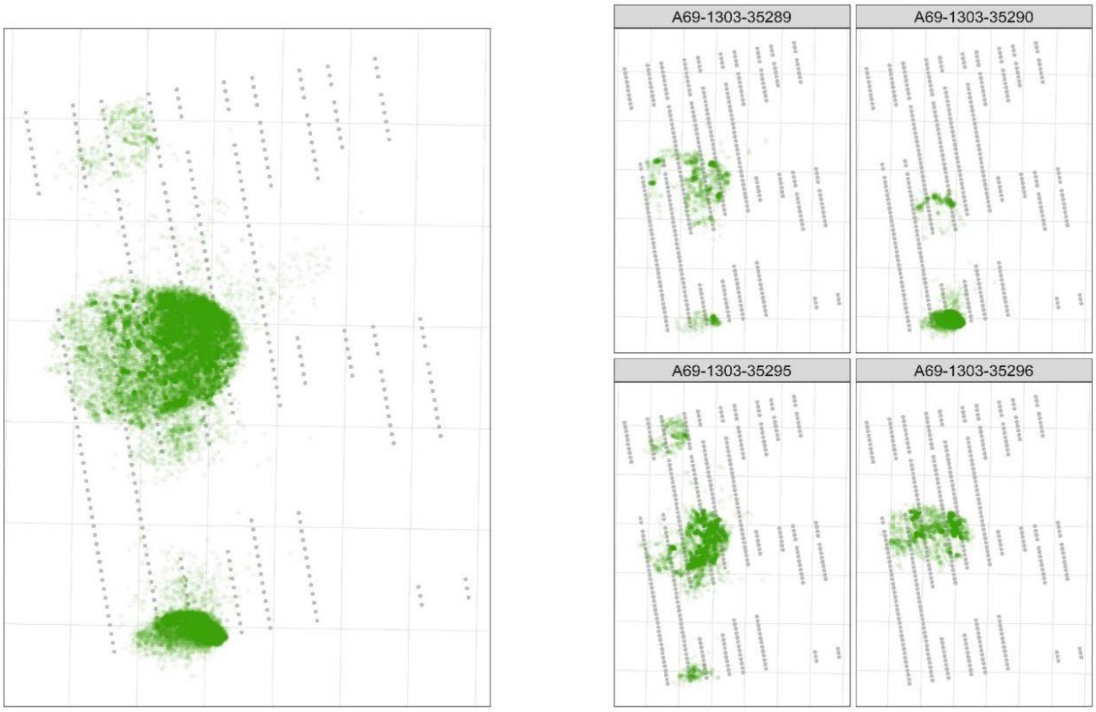

Figure 6.5 All fine scale positions for tagged thornback rays within OSL Site 2 (left). Example movement tracks for four individual thornback rays (right).

6.2.2.3 Catshark

For the individuals that were tracked within the mussel farm, there was no clear movement patterns or visually distinctive linkage to the farm infrastructure. Further analysis is required to link movement patterns and the underlying habitat (Figure 6.6).

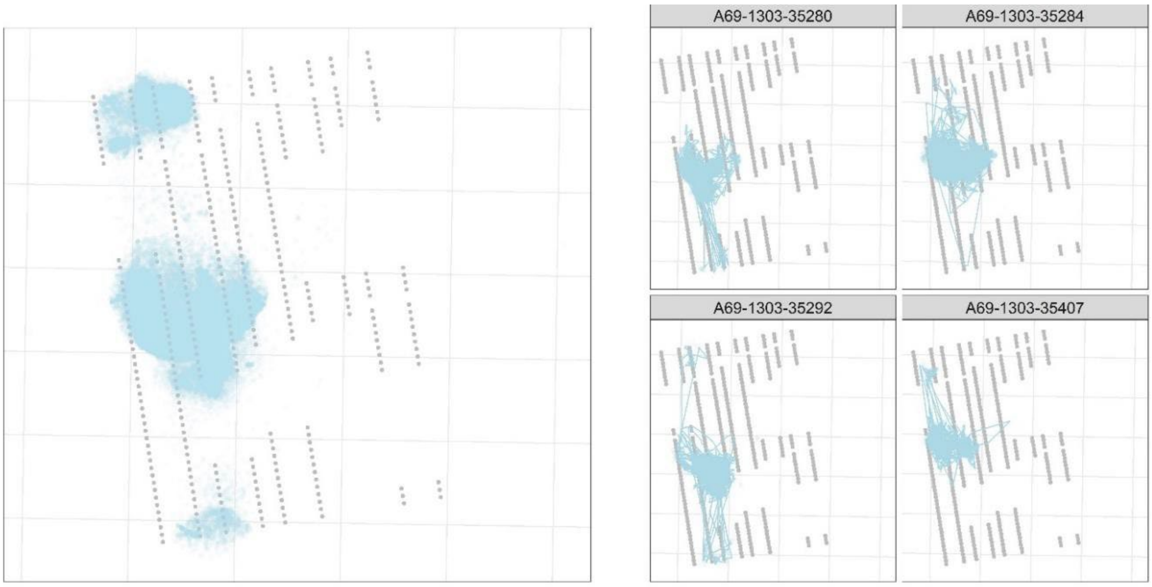

Figure 6.6 All fine scale positions for tagged Catsharks within OSL Site 2 (left). Example movement tracks for four individual Catsharks (right).

6.2.3 Broadscale movement and connectivity

6.2.3.1 Lobsters

One female lobster was tagged at 10:32am on the 25th of June 2024, and left the mussel farm at 13:59 on the same day. This same individual was later potted by a local fisherman from Beer on the 22nd of July 2025 ~13km away from the mussel farm (Figure 6.7).

6.2.3.2 Thornback Ray

Two individual rays were detected moving from the release site in Lyme bay and moving to OSL Site 2. This was equivalent to a distance of 30 km. No movement of animals tagged in the mussel farm to other receivers in the region was detected (Figure 6.7).

6.2.3.3 Catshark

Catsharks that were tagged in the Lyme Bay MPA were detected at several surrounding reef and shipwreck locations. No movement from the mussel farm to surrounding natural sites was detected (Figure 6.7).

Figure 6.7 Large scale connective movements of tagged animals across Lyme bay. Red arrows indicate movements conducted by lobster. Green indicates Thornback ray. Blue indicates catshark. Yellow indicates Thicklip Mullet.

6.2.4 Additional species

Over the study period animals that were tagged outside of the project were detected within the OSL Site 2. This included; 1) European bass, originally captured in Devon; One Smooth hound tagged in Hampshire; Three Twaite Shad, One of which was originally captured in the Severn Estuary and two individuals that originated from the Scheldt estuary (Belgium); Two Black Bream that were tagged in Hampshire (Figure 6.8).

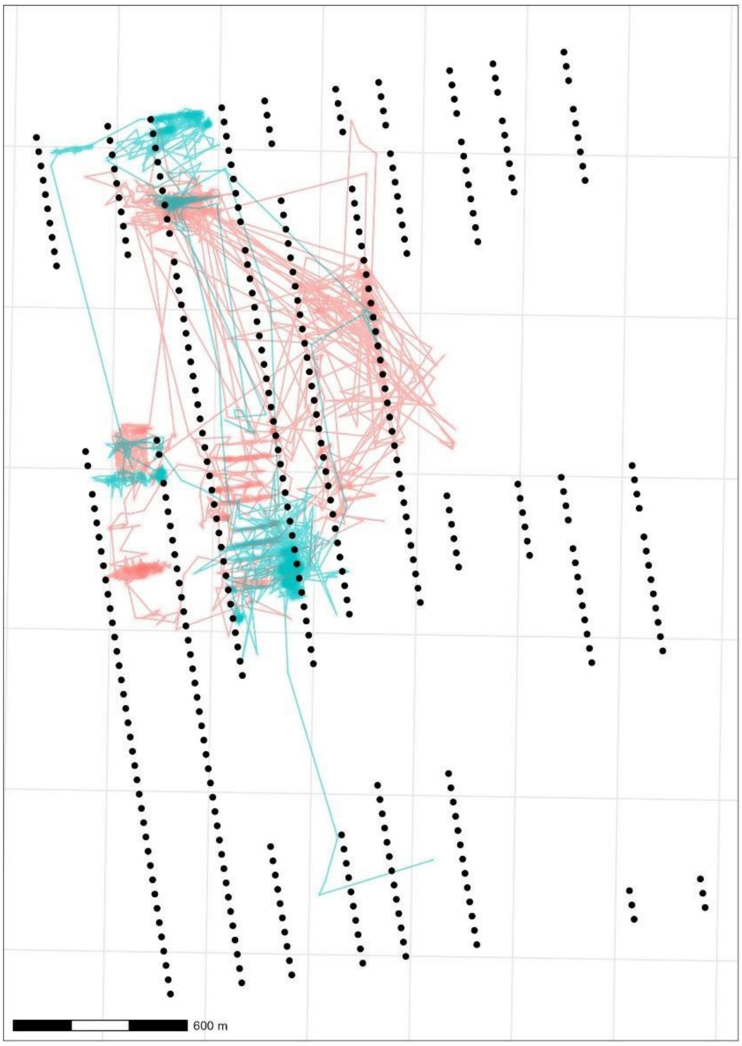

Figure 6.8 Movement of Black Bream within the offshore shellfish site 2. Each colour represents the different individuals.

7 Data validation

All data gathered within this project has been validated and submitted to the appropriate repository (ie MEDIN and ETN) (Figure 7.1) with supporting metadata (Table 7.1). This data has been organised in accordance with the repository guidelines ensuring the data is accessible for future use. All submissions have been reviewed by the managing bodies to that data submitted adheres to the specific guidelines. All data produced throughout this project can be found through MEDIN under the title ‘University of Plymouth Ropes to Reefs Project 2023_24’.

Figure 7.1 Example of Ropes to Reefs data export into MEDIN.

Table 7.1 Summary of project data stored in repositories with details of data evaluation and custodian details.

Data title	Data Standard Guideline	MEDIN Discipline	Reviewed by	Data Custodian
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey March_CTD	Oceanographic vertical profile	Physical oceanography	BODC	BODC
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey March	Side scan sonar	Marine geology	BGS	BGS
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey March_Video Groundtruthing	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey May_Plankton	Net, pot and trap data	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey May_Video Groundtruthing	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey May_CTD	Oceanographic vertical profile	Physical oceanography	BODC	BODC
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey May	Side scan sonar	Marine geology	BGS	BGS
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey July_CTD	Oceanographic vertical profile	Physical oceanography	BODC	BODC
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey July_Plankton	Net, pot and trap data	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey July	Side scan sonar	Marine geology	BGS	BGS
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey July_Video Groundtruthing	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey November_CTD	Oceanographic vertical profile	Physical oceanography	BODC	BODC
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey November_Video Groundtruthing	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey November_Plankton	Net, pot and trap data	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project EK80 Fish Biomass Survey November	Side scan sonar	Marine geology	BGS	BGS

2024 University of Plymouth Ropes to Reefs Project Pelagic Survey Lyme Bay Mussel Farm PelagiCam Midwater System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Farm Remotely Operated Vehicle (ROV)	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Farm Towed Underwater Video System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2024 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Farm Baited Remote Underwater Video (BRUV) System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2023 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Farm Remotely Operated Vehicle (ROV)	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2023 University of Plymouth Ropes to Reefs Project Pelagic Survey Lyme Bay Mussel Farm PelagiCam Midwater System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2023 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Farm Towed Underwater Video System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
2023 University of Plymouth Ropes to Reefs Project Benthic Survey Lyme Bay Mussel Baited Remote Underwater Video (BRUV) System	Video surveys of species and benthos	Marine biodiversity	DASSH	DASSH
UniversityOfPlymouth_RopesToReefsProject_MBES_LymeBay_Mussel_Farm_March24	Bathymetry	Bathymetry and Seafloor topography	UKHO	UKHO
FISP: Fisheries Industry Science Partnership	Telemetry	Marine biodiversity	ETN	ETN

8 Discussion of results

The Ropes to Reefs FISP project was a fisher, farmer, scientist collaboration to evidence fish stock and habitat benefits of offshore aquaculture to inform future management and policy and the potential ecosystem benefits of the industry. The multi-method approach (MBES, acoustic, telemetry) of the Ropes to Reefs project included a novel methodology to assess the whole ecosystem through multibeam, acoustic fisheries and telemetry provided us with a large amount of data and the possibility to understand the full picture of substrate changes, benthic and pelagic ecosystem in terms of the interactions of the offshore mussel farm with its surroundings, especially its interactions and connectivity with the Lyme Bay MPA and nearby aquaculture farms (scallop and seaweed). Thanks to this novel approach, we are now able to better understand species interactions and movements with the farm and its surroundings. This in conjunction with the previous eight years of data gathered, which includes the pre-development baseline study and seven annual monitoring studies, have provided the information we needed to fulfil the aims and objectives of the project.

Results from the long-term monitoring of the Lyme Bay offshore mussel farm had found that the farm was increasing pelagic and benthic biodiversity as well as infauna biodiversity while improving its overall functional diversity. Unlike its counterparts found in sheltered conditions, there was no impact on the plankton community or detrimental effects to sediment and water quality. On the contrary, the farm was shifting the benthic ecosystem from a homogeneous habitat typical of damaged ecosystems to a more heterogeneous habitat, promoting its recovery and the establishment of a biogenic reef. However, the effects of the farm on Essential Fish Habitat (EFH), and the potential of spillover to commercial fisheries remained to be fully assessed and evidenced.

8.1 Ecosystem Service Assessment

The ESA has joined and assessed all the data gathered to date into one single document reviewing any improvements or reductions in ecosystem services. This is the first of its kind and we are certain that it will be very useful to both industry and regulators.

Offshore bivalve aquaculture, particularly mussel farming, provides multiple ecosystem services, including provisioning of food, habitat creation, water quality regulation, and sediment recovery. These services offer significant ecological and economic benefits, with potential to restore degraded habitats and enhance local fisheries. The reviewed literature emphasizes the restorative and sustainable nature of offshore mussel farms, making them valuable tools for enhancing marine ecosystem health and resilience while contributing to sustainable blue economy goals. Its main findings are:

- Multiple ecosystem services: provisioning of food, habitat creation, water quality regulation, and sediment recovery.
- Offer significant ecological and economic benefits, with potential to restore degraded habitats and enhance local fisheries.
- Emphasizes the restorative and sustainable nature of offshore mussel farms
- Valuable tools for enhancing marine ecosystem health and resilience while contributing to sustainable blue economy goals.

These benefits are highly dependent on sustainable management, and stakeholder engagement to ensure that the flow of services is maximized and maintained over the long term.

- Data Availability: Some ecosystem services may require extensive datasets for accurate assessment (e.g., climate regulation, water purification).
- Uncertainty: Model outcomes and valuation may include uncertainties. Acknowledge and communicate these limitations.
- Spatial and Temporal Scales: Consider the appropriate scale for analysis, as services may vary across landscapes and time periods.

The structured approach of an ESA ensures that the benefits ecosystems provide are considered in decision-making processes, fostering sustainable management and conservation efforts.

8.2 Assessing the restoration of essential fish habitat (EFH)

This project has produced a map of the characteristics of substrate under farm and surroundings. Comparable to previous data gathered, we can clearly see the creation of EFH and its extent. Results from the MBES study clearly show the biogenic reef creation and a shift from homogeneous seabed towards a more complex substrate developing reef-like structures. However, changes are very localised to the substrate directly beneath the ropes. This is supported by data from the benthic video surveys showing increase in mussel clump abundance as well as recording mussel beds throughout the farm. But is this supporting biodiversity?

8.3 EFH use, MPA connectivity and spillover

Biodiversity and species abundance within the farm has increased over time. Fish biomass was found to be higher beneath the mussel farm ropes which could indicate feeding. Fish tracks and schools as well as overall fish biomass, was found at higher levels at the south end of the farm where most of the biogenic reef and courser sediment is found, indicating EFH use. Results show there is species connectivity between the farm and the Lyme Bay MPA with fish aggregating within the mussel farm in higher abundance at certain times of the year which could be due to food availability. This is supported by the movement of a thornback ray from the Lyme Bay MPA into the mussel farm highlighting the connectivity between these two areas. Seasonal variability as well as fish biomass correlation with the age of the ropes are important factors that need further study.

The results from the project have also highlighted how individuals across a range of species display resident behaviour within the farm. For instance, lobsters had high residency within the mussel farm supporting the EFH use potential of the farm. Dogfish displayed distinct behaviours suggesting this species feed within the mussel farm. Results also show spillover of some species into surrounding fisheries, for instance, lobster movement out of the farm into the adjacent commercial fishery and how one of the tagged lobsters was caught by a fisher.

8.4 Implications

The data gathered, in conjunction with the Policy Brief, webinar and animation video are providing industry, regulators and government with evidence to address current industry development issues such as licensing, impacts and public perception. The new evidence gathered will be used to inform and advice sustainable fisheries management strategies and provide regulators with evidence to underpin Ecosystem Based Fisheries Management (EBFM) as well as the sustainable development and management of the low-trophic offshore aquaculture industry.

The evidence gathered, once it has been fully assessed and published will support the industry meet Fisheries objectives under the Fisheries Act 2020 and White Paper as well as sustainable development goals (SDG2 - food security and zero hunger; SDG14 - conservation and sustainable development), the IFCA's Mariculture Strategy, Defra's Marine Spatial Prioritisation strategy towards more sustainable industry, while achieving Net Zero and Good Environmental Status (GES). This evidence is also key to develop the role of offshore aquaculture as nature-based solution (Blue Economy) and its function as part of the UK's Biodiversity Net Gain plans.

9 Impact: communication, engagement, and dissemination

A crucial part of the Ropes to Reefs FISP project is the effective communication, engagement and dissemination of the project’s different work packages, data, process, and results. The team has used a range of dissemination methods to reach stakeholders, government, and the public in the form of presentations at national (including MPs in parliament) and international conferences, workshops, webinar, videos, publications, newsletters and social media.

We have presented at 11 conferences, 9 meetings and have written 13 press articles in various outlets such as International Aquafeed and Fish Farmer. We have also been featured on BBC Radio 4 and BBC Spotlight reaching audiences of 7.5 million people (Figure 9.1, Figure 9.2, Table 9.1 and Table 9.2). Stakeholder engagement was a vital component of this project reaching audiences within the sector through our stakeholder workshops and a more public audience with our project webinar and stands at Greenman Festival. We effectively held two Ropes to Reefs FISP wider stakeholder workshops which included the project’s partners (UoP, OSL, BA, SR) as well as the wider stakeholder partners (fishers, the Fishmongers Company, MMO, IFCA and NE).

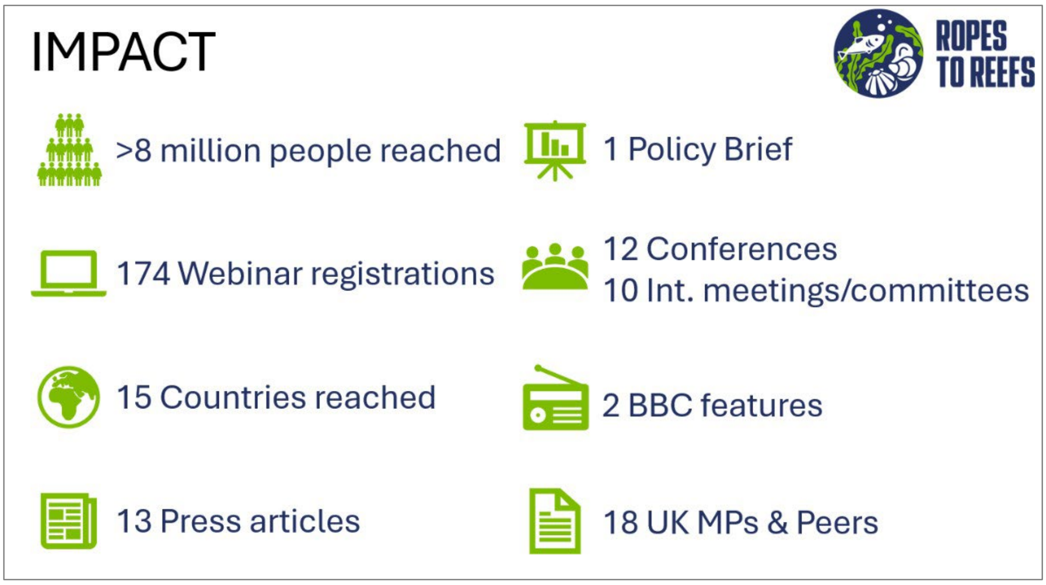

Figure 9.1 Overall Ropes to Reefs FISP project impact.

Within the wider scientific community, we have shared this research at international conferences such as the IMCC7 in Cape Town, South Africa and ICES ASC23 and ICES ASC24 which had attendance of 800 delegates each. The impact on policy was an important element of the project, speaking to MPs and peers in Parliament during Evidence Week, having a stand at Coastal Futures 2025 and presenting at the Seafood Innovation 2025 conference, sharing the project with managers, government advisors and NGOs (Figure 9.2 and Table 9.1).

Figure 9.2 Photo evidence of the Ropes to Reefs FISP project communication and dissemination outreach. From top-left clockwise: Speakers of The Fishmongers/Ropes to Reefs conference; Stakeholder workshop 1; Webinar flyer; screenshot of animation video; Dr Llúcia Mascorda-Cabre presenting at the EU AAC; Dr Emma Sheehan, Dr Llúcia Mascorda-Cabre and Amy Cartwright presenting the Ropes to Reefs Policy Brief to Luke Pollard MP. Middle: presenting the Ropes to Reefs Policy Brief to Chi Onwurah MP (top) and George Freeman (bottom).

David Jarrad, the projects experienced industry liaisons and communications officer was invaluable throughout the project disseminating the key results through press releases, meetings and conferences to Government departments, academia and the fishing industry (Table 9.1 and Table 9.2).

To encourage widescale engagement with this project multiple resources have been published to aid with the legacy of the project. Dr Llúcia Mascorda-Cabre and Dr Emma Sheehan produced a Policy Brief, prepared to be used as essential fisheries management advice. The Brief provides a framework for which impacts of current and future offshore shellfish aquaculture developments will be based.

The Policy Brief has been accompanied with a 3-minute video highlighting the findings of the long-term monitoring results of the Lyme Bay offshore mussel farm presented to MPs and peers as part of Evidence Week (Figure 9.2 and Table 9.1).

An animation video has also been produced highlighting the project methodology and results targeting a lay audience along with the project webinar that was streamed live with an open Q&A session to encourage public engagement with the project (Figure 9.2 and Table 9.1).

9.1 Presentations: Conferences, workshops and meetings

Communication of this project has gone beyond the scope of the UK with in-person presentations and meetings conducted in 8 different countries reaching a total audience of more than 8000 people (Table 9.1). Dr Emma Sheehan's presentation at BBC Spotlight on BBC Breakfast combined with a presentation at BBC Radio 4 Farming Today show gained an audience of 7.5 million people. The webinar alone gained 174 registrations from over 63 different institutions joining from 15 countries which exceeded expectations and provided an accessible method of disseminating the project. The collaboration between the UoP team and the project communications officer was pivotal in instrumenting this widescale communication to various stakeholders.

The project and ecological interactions of offshore mussel farming were effectively disseminated during the Fishmongers Ropes to Reefs conference. This was a key achievement of the project where multiple partners attended and presented to a wide range of stakeholders including government. Dr Llúcia Mascorda-Cabre presented at ICES ASC2023, Southwest Aquaculture Network AGM (SWAN) and the 8th International Shellfish Conference in the Netherlands and the EU Aquaculture Advisory Council (AAC) which generated a lot of interest, and it was received with great enthusiasm. David Jarrad presented the project at the Shellfish Aquaculture All-Party Parliamentary Group (APPG).

Table 9.1 Summary of dissemination activities completed for the Ropes to Reefs FISP project with details of the impact (number of people reached) of the event.

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
Fishmongers conference	London, UK	June 2023	**300**	Ecological impacts of farming mussels offshore: The Lyme Bay case study. Mascorda-Cabre, L., Hosegood, P., Attrill, M. and Sheehan, E.	Online presentation	Llúcia Mascorda-Cabré
				Ropes to Reefs and Lyme Bay projects presentation - Sheehan et al.	Presentation	Emma Sheehan
SAGB Mollusc Committee	London, UK	June 2023	**30**	Ropes to Reefs: a partnership to promote sustainable aquaculture that delivers ecosystem and fisheries benefits. Mascorda-Cabre, L. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
Greenman Festival	Crickhowell, Wales	August 2023	**123**	Outreach stand with SuperGEN ORE Hub	Outreach	Amy Cartwright
ICES ASC23	Bilbao, Spain	September 2023	**900**	Using ecological and oceanography techniques to evidence fish stock and habitat benefits of Offshore Aquaculture to inform future management and policy. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E	Poster	Llúcia Mascorda-Cabré
Ropes to Reefs Partner Workshop 1	Plymouth, UK	October 2023	**30**	Ropes to Reefs FISP project	Meeting	Llúcia Mascorda-Cabré
ICES WGMPA Meeting	Plymouth, UK	November 2023	**30**	Oceanographic and ecological impacts of farming mussels offshore: The Lyme Bay case study. Mascorda-Cabre, L. Hosegood, P., Attrill, M. and Sheehan, E.	Working group meeting	Emma Sheehan and Llúcia Mascorda-Cabré
SWAN AGM and Conference	Exeter, UK	September 2023	**40**	Oceanographic and ecological impacts of farming mussels offshore: The Lyme Bay	Presentation	Llúcia Mascorda-Cabré

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
				case study. Mascorda-Cabre, L. Hosegood, P., Attrill, M. and Sheehan, E.		
Crustacea Committee	Bournemouth, UK	October 2023	**30**	Ropes to Reefs FISP project	Meeting	David Jarrad
Processors Committee	London, UK	October 2023	**30**	Ropes to Reefs FISP project	Meeting	David Jarrad
Mollusc Committee	London, UK	November 2023	**30**	Ropes to Reefs FISP project	Meeting	David Jarrad
Flanders Aquaculture Symposium	Halle, Belgium	November 2023	**100**	Oceanographic and ecological impacts of farming mussels offshore: The Lyme Bay case study. Mascorda-Cabre, L. Hosegood, P., Attrill, M. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
Shellfish conference	Delta Park Neeltje Jans, The Netherlands	January 2024	**150**	Oceanographic and ecological impacts of farming mussels offshore: The Lyme Bay case study. Mascorda-Cabre, L. Hosegood, P., Attrill, M. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
University of Plymouth School of Biological and Marine Sciences Research Conference	Plymouth, UK	January 2024	**80**	Monitoring the Ecological Effects of an Experimental Scallop Ranch, South Devon UK. A.Y. Cartwright, A., Cox, D.J., Mascorda-Cabre, L., Renn, C., Attrill, M.J., Rees, S.E., Sheehan, E.	Poster	Amy Cartwright
ETN Workshop	Hull, UK	February 2024	**40**	Ropes to Reefs and Lyme Bay projects presentation - Sheehan et al.	Workshop	Emma Sheehan
University of Hull Biology Series Seminar	Hull, UK	February 2024	**100**	Ropes to Reefs and Lyme Bay projects presentation - Sheehan et al.	Presentation	Emma Sheehan
SAGB Mollusc Committee	London, UK	March 2024	**50**	Ropes to Reefs FISP project	Meeting	David Jarrad
BBC Radio 4	London, UK	March 2024	**1 million**	BBC Radio 4 Farming Today show	Radio	Emma Sheehan

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
Private conversation	Online	April 2024	**2**	Spoke to NZ colleagues re project and farm research so far	Outreach	Emma Sheehan
MBA Postgraduate Conference	Plymouth, UK	April 2024	**60**	Assessing the Ecological Effects of Experimental Scallop Farming in South-West UK. Cartwright, A., Cox, D.J., Mascorda-Cabre, L., Renn, C., Attrill, M.J., Rees, S.E., Sheehan, E.	Presentation	Amy Cartwright
University of Plymouth Faculty of Science and Engineering Post Graduate Conference	Plymouth, UK	April 2024	**80**	Assessing the Ecological Effects of Experimental Scallop Farming in South-West UK. Cartwright, A., Cox, D.J., Mascorda-Cabre, L., Renn, C., Attrill, M.J., Rees, S.E., Sheehan, E.	Presentation	Amy Cartwright
SAGB Conference	London, UK	May 2024	**75**	ROPES TO REEFS FISP PROJECT: a partnership to promote sustainable aquaculture that delivers ecosystem and fisheries benefits. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
European Union Aquaculture Advisory Council (AAC)	Brussels	June 2024	**50**	ROPES TO REEFS FISP PROJECT: a partnership to promote sustainable aquaculture that delivers ecosystem and fisheries benefits. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Online presentation	Llúcia Mascorda-Cabré
Fisheries delegation visiting from the University of Kerala	Plymouth, UK	July 2024	**6**	Oceanographic and ecological impacts of farming mussels offshore: The Lyme Bay case study. Mascorda-Cabre, L. Hosegood, P., Attrill, M. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
BBC Spotlight	UK	August 2024	**6.5 million**	BBC Spotlight on BBC Breakfast	TV feature	Emma Sheehan

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
Greenman Festival	Crickhowell, Wales	August 2024	**10**	Outreach stand with SuperGEN ORE Hub	Outreach	Amy Cartwright
ICES ASC24	Gateshead, UK	September 2024	**400**	Using echosounders, multibeam, video cameras and telemetry to evidence fish stock and habitat benefits of offshore shellfish aquaculture and its connectivity to a nearby MPA to inform future management and policy. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
				Assessing the impact of an offshore longline mussel farm on local circulation in a highly hydrodynamic energetic bay. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
				Shellfish or selfish? Does shellfish aquaculture support pelagic fish? Eager, D., Mascorda-Cabre, L., Embling, C., Hebb, J., and Sheehan, E.	Poster	Dannielle Eager
ICES WKGNSAO Meeting	Copenhagen	September 2024		Ropes to Reefs FISP project	Working group meeting	Llúcia Mascorda-Cabré
IMCC7	Cape Town, South Africa	October 2024	**300**	Using echosounders, multibeam, video cameras and telemetry to evidence fish stock and habitat benefits of offshore shellfish aquaculture and its connectivity to a nearby MPA to inform future management and policy. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
				Assessing the impact of an offshore longline mussel farm on local circulation in a highly hydrodynamic energetic bay. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
				Assessing the Ecological Effects of Experimental Scallop Farming in South-West UK. Cartwright, A., Cox, D.J., Mascorda-Cabre, L., Renn, C., Attrill, M.J., Rees, S.E., Sheehan, E.	Presentation	Amy Cartwright
				Ropes to Reefs and Lyme Bay projects presentation - Sheehan et al.	Presentation	Emma Sheehan
				Can active acoustics assess essential fish habitat at an offshore mussel farm? Eager, D., Mascorda-Cabre, L., Embling, C., Hebb, J., and Sheehan, E.	Presentation	Dannielle Eager
SAGB Mollusc Committee	London, UK	October 2024	**50**	Ropes to Reefs FISP project	Meeting	David Jarrad
Evidence Week in Parliament	London, UK	January 2025	**>1000**	Ropes to Reefs FISP project Policy Brief	Outreach	Emma Sheehan, Llúcia Mascorda-Cabré, Amy Cartwright
Ropes to Reefs Project Webinar	Plymouth, UK	January 2025	**185**	Ropes to Reefs Project Webinar. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Outreach	Emma Sheehan and Llúcia Mascorda-Cabré

Event	Location	Date	IMPACT (#people)	Citation	Format of work	Presenter
Ropes to Reefs Partner Workshop 2	Plymouth, UK	February 2025	**30**	Ropes to Reefs FISP project	Meeting	Llúcia Mascorda-Cabré
Seafood Innovation Conference	London, UK	February 2025	**150**	ROPES TO REEFS FISP PROJECT: a partnership to promote sustainable aquaculture that delivers ecosystem and fisheries benefits. Mascorda-Cabre, L., Scott, T., Embling, C., Stamp, T., Eager, D., Cartwright, A. and Sheehan, E.	Presentation	Llúcia Mascorda-Cabré
Shellfish Aquaculture All-Party Parliamentary Group (APPG)	London, UK	February 2025	**30**	Ropes to Reefs Project main results	Meeting	David Jarrad
SAGB Mollusc Committee	London, UK	March 2025	**50**	Ropes to Reefs FISP project	Meeting	David Jarrad and Llúcia Mascorda-Cabré

9.2 Publications: Social media presence and news articles

The UoP team and the project communications officer have worked very hard in order to disseminate the project's updates through a range of social media outlets, webpages, SAGB newsletter, news articles, conferences and meetings (Table 9.2). For instance, Twitter @aMER_MarineRes has generated 1000s of Ropes to Reefs FISP related impressions. The full impact of our social media presence and news articles have reached to 160000 people.

Table 9.2 Summary of written and published dissemination activities completed for the Ropes to Reefs FISP project with details of impact (number of people reached) of the event.

Type	Title	IMPACT (#people)	Date	Author	Publication
Newsletter	FoSE	**2000**	2023 - 2025	Amy Cartwright	University of Plymouth
Newsletter	Marine Conservation Research Group	**85**	2023 - 2025	Amy Cartwright	University of Plymouth
Newsletter	SAGB Monthly Newsletter	**5000**	2023 - 2025	David Jarrad, Nicky Holmyard and Amy Cartwright	Shellfish Association of Great Britain
Newsletter	SOBMS Research	**1000**	2023 - 2025	Amy Cartwright	University of Plymouth
Newsletter	Staff bulletin	**1,500**	2023 - 2025	Amy Cartwright	University of Plymouth
Magazine article	Enhancing Marine Ecosystems through Restorative Offshore Aquaculture: Insights from the University of Plymouth	**53,000**	19/07/2024	Amy Cartwright	International Aquafeed
Magazine article	Evaluating the ecological benefits of the UK's first major offshore mussel farm	**24,500**	28/03/2024	Louisa Gairn	We are Aquaculture
Magazine article	Research set to assess benefits of offshore shellfish farming	**48,000**	25/03/2024	Nicky Holmyard	Fish Farmer
Press release	Researchers connect with policy makers and advisers at Evidence Week	**>5000**	30/01/2025	Alan Williams	University of Plymouth
Press release	Lobster tagging to assess habitat restoration effects of offshore aquaculture	**>5000**	21/03/2024	Alan Williams	University of Plymouth
Press release	Project assesses wider ecological benefits of UK's first offshore mussel farm	**>5000**	20/07/2023	Alan Williams	University of Plymouth
Webpage	Ropes to Reefs FISP	**>1000**	20/07/2023	Amy Cartwright and Llucia Mascorda-Cabre	University of Plymouth
Webpage	Ropes to Reefs FISP	**>1000**	20/07/2023	Amy Cartwright and Llucia Mascorda-Cabre	aMER-applied Marine

Type	Title	IMPACT (#people)	Date	Author	Publication
					Ecosystems Research
Webpage	Ropes to Reefs Project	**5000**	20/07/2023	David Jarrad, Amy Cartwright and Llucia Mascorda-Cabre	Shellfish Association of Great Britain

9.3 Webinar

The Ropes to Reefs FISP Webinar was organised to disseminate the Ropes to Reefs project, why it was set up in terms of knowledge gaps, aims and objectives, to present the overall project results and to provide a setting for the project partners to have a Q&A session with the audience. The webinar was also a key part in the public engagement impact of this project. This is a valuable resource that is now freely available to access by anyone in the following link: Ropes to Reefs FISP WEBINAR

9.4 Policy Brief video

To accompany the Policy Brief outreach to MPs and peers, a Policy Brief short 3-minute video was produced. Written and presented by Dr Emma Sheehan and Dr Llúcia Mascorda-Cabre, this short video explains the results from the long-term monitoring and assessment of the environmental interactions of the UK's first large-scale offshore mussel farm. The has been shared with MPs and peers and is a valuable resource that is now freely available to access by anyone in the following link: Ropes to Reefs FISP Policy Brief video

9.5 Animation video

In order to reach a wider audience and share the results of the Ropes to Reefs FISP project with member of the public from all ages and backgrounds, we have produced a short animation video explaining the outcomes of the project. This is an incredibly valuable resource that is now freely available to access by anyone in the following link:

Ropes to Reefs FISP Animation Video

10 Summary and lessons learnt

Ropes to Reef brings together farmers, fishers, scientists, government, regulators and industry at a critically important time for the UK aquaculture industry. Utilising, novel, innovative approaches and an invaluable 8-year ecological dataset, essential data gaps have been filled and disseminated to improve stakeholder perception and streamline licensing and consenting applications for aquaculture. Working collaboratively, the Ropes to Reefs project partners have filled scientific data gaps and made a huge effort to communicate and disseminate the outcomes of the project.

Benthic fish are using the area as shelter from predators, as a nursery and to feed. Even though mussel fall-off is evident within the farm, these are forming reefs on the seabed, attracting biodiversity to the area. Predators are also being attracted by the amount of prey around the farm, including commercially valuable species.

The project has demonstrated the successful implementation of fisheries acoustics around the mussel farm and provided initial results that when combined with the MBES and telemetry surveys, will provide vital information on the effectiveness of shellfish aquaculture in improving fish stocks while creating essential fish habitat. The project providing novel information on the drivers of pelagic fish around the mussel farm and its 'spillover' effect. Outputs from this study help us understand the type of historical benthic substrate that once covered the area to further support the seabed recovery and restoration potential of this type of developments. This information is pivotal for the aquaculture sector that provides both economic and ecological value to UK waters.

10.1 Milestones and deliverables

As part of the FISP application, the Ropes to Reefs project was set to deliver a series of milestones (Table 10.1) and deliverables (Table 10.2 and Figure 10.1) which have all been effectively achieved and completed.

Table 10.1 Ropes to Reefs FISP project milestones.

Milestone	Description	Status
M1	Completion of first year video, acoustic and bathymetry surveys	Completed
M2	Report and Policy Brief. Analysis of long-term data to assess offshore aquaculture Ecosystem Services.	Completed
M3	Mid project presentation of results	Completed
M4	End of acoustic fish and crustacean tagging (telemetry) survey	Completed
M5	Data validation	Completed
M6	Completion of second year video, acoustic and seabed surveys	Completed
M7	Project findings dissemination including a social media video	Completed
M8	Final Scientific report	Completed

Table 10.2 Ropes to Reefs FISP project deliverables.

Delive-rable	Output	Description	Status
1	Analysis of the offshore mussel farm long-term study to assess its ecosystem services. Writing of a Policy Brief to inform managers and industry.	Use of UoP's long-term ecological (benthic and pelagic) and oceanographic data to perform a thorough Ecosystem Service Analysis of offshore mussel aquaculture to be used as evidence for government, managers and the industry to inform future aquaculture license applications and the sustainable management of the marine environment. This will be the first ESA of the sector based on qualitative and quantitative data. The long-term data set will also be used to write a Policy Brief.	Completed
2	Essential Fish Habitat Restoration	Year 1 surveys: HD video footage of benthic and pelagic ecosystem (ROV, Towed, Pelagicam, BRUVs). This study will support the Essential Fish Habitat restoration as part of WP2 and support the assessment of the farm's footprint.	Completed
3		Year 2 surveys: as above plus MBES survey that will produce a high-resolution bathymetry map showing the different morphological characteristics of the seabed within and surrounding the mussel farm that will facilitate identification biogenic reef. Video footage will be used to validate bathymetry and seabed morphology maps.	Completed
4	Fish stock assessment	Year 1 surveys: EK80 data will produce relative estimates of pelagic fish biomass and abundance within the farm, controls and the MPA to assess the spillover effect of the mussel farm and its connectivity with the surrounding ecosystem (MPA and fishing grounds). Validated with video footage.	Completed
5		Year 2 surveys: as above	Completed
6	Fish and crustacean telemetry study	Tag 30 individual fish/crustaceans and receiver deployment / Receiver data download. This will further allow us to assess EFH use and connectivity between the farms and the MPA.	Completed
7	Data validation	Translate data outputs to informing development of sustainable offshore aquaculture and upload to MEDIN	Completed
8	Engagement, dissemination and fisheries management	Dissemination of outcomes through various channels: social media, press release, webpage, conferences and meetings. One public webinar and two partner workshops. Ropes to Reefs Conference. Final project animation video.	Completed
9	Project management, data processing and reporting	Monthly UoP internal project meetings. Quarterly online project partner meetings. Semi-annual project partner in person meetings. Quarterly reports: Brief report, max. 2 pages Semi-annual reports: Detailed report, max. 5 pages Final report. Scientific publication.	Completed

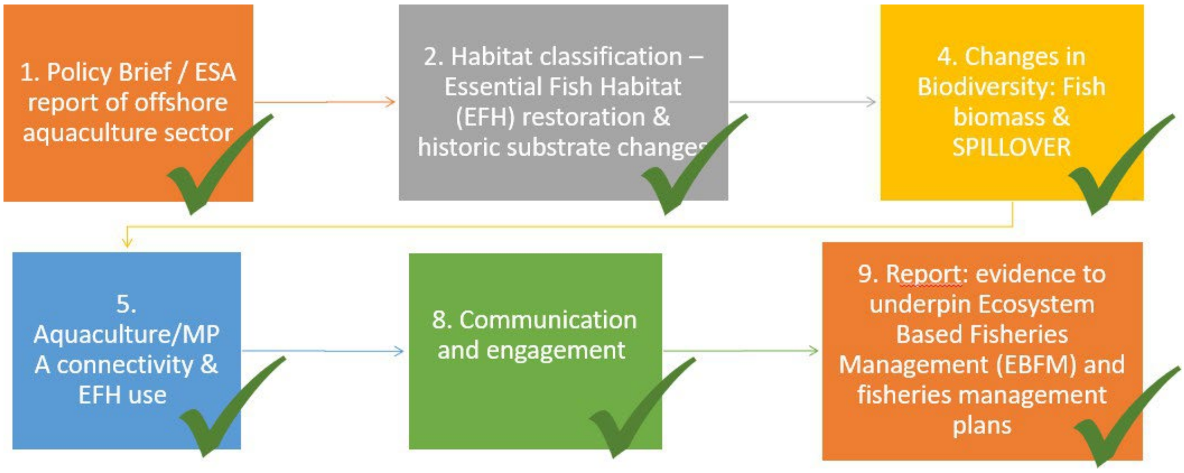

Figure 10.1 Ropes to Reefs FISP project outputs and deliverables.

10.2 Lessons learnt

The Ropes to Reefs FISP project has allowed scientist, industry and managers to work collaboratively and develop a really good model to deliver needed outputs to fill evidence gaps which are crucial for the industry and the sustainable management of the marine environment and its resources. The application of the project and its outputs and dissemination have been paramount to publicly share knowledge gaps and the results of the research performed. The Ropes to Reefs team has out a huge amount of work into the communication and dissemination of the project in order to increase its impact though a number of presentations worldwide, reaching a wide range of audiences, including MPs. The project has been an exceptional success and there has been a huge worldwide interest on this project and the outputs which will be used to inform future marine license applications and developments. This is demonstrated by the webinar attendance and various emails received afterwards.

Although we have produced an animation video, aimed to inform the general public and audiences from all backgrounds, there is a need to continue engagement with the wider public. When the outputs are published, we will make sure that they are also presented in ways that reach younger audiences and non-academics.

We have published several articles in Fishing News however, more interaction through the fishing associations and the wised fishing community is needed to get all the information across to those people that would have fears about new aquaculture developments, so they have a greater understanding.

There have been limitations in terms of timescales due to the delay in funding which has had an impact on the project's surveys and the amount of time available to gather the data and analyse it. However, the team has worked very hard to overcome this and still deliver all that was planned. There was also telemetry data limitation due to poor fish capture in the region. For instance, mullet tagging was largely unsuccessful as this is a highly understudied fish group so any insights into their spatial ecology and how or where to catch it are limited.

It was very important to develop a good logo from the onset of the project, and we are very proud of it! It has been very useful to disseminate the project and to quickly associate the logo to the project by everyone.

ROPES TO REEFS

10.3 Further work

Further work is required to continue to analyse and interpret the results and data gathered from this very comprehensive project. We now need more funding to transform all the outputs into research papers and reports to provide regulators and the industry with all the most up to date evidence on the offshore aquaculture-environment interactions.

As the regulators and industry have advised, funding is needed to continue the project, especially the evidence on the spillover to show the effects of the farm beyond its footprint. It is clear by the evidence that the farm is providing refuge, shelter, restoring damaged seabed and creating biogenic reef thus, it is paramount to continue the research on species movement and how the farm is benefiting the wider community and its surrounding, especially its spillover into recreational or commercial fisheries.

Further work is required to integrate animal movements to the underlying habitat. This will be achieved via two funded PhD at the university of Plymouth – Jake Hebb and Chloe Renn. A significant amount of the work to date has focussed on the offshore shellfish site, however receivers were also attached to Biome Algae Ltd, Scallop Ranch Ltd and an inshore mussel farm operated by marine farm services. However, data from these sites was limited to mullet that were tagged in the region. These receivers also recorded other environmental data e.g. water temperature. This data will provide invaluable insights into local hydrographic conditions across the region.

11 Quotes from our partners

11.1 Project partners

11.1.1 Dr Emma Sheehan, Project Investigator, The University of Plymouth (UoP)

This project has been a great opportunity, and we made sure that our research is valid and applied. It has been brilliant to work with a wide team of UoP scientists and industry partners. It has been a great opportunity to bring oceanographers, ecologists and acousticians together. It has provided an opportunity to learn more about the world, its biodiversity. This project has a focus on offshore aquaculture, but we have learnt so much about how species move and behave and how they use different habitats. It has been a real privilege to lead this project and learn about all these difference aspects of the sea that we wouldn't have done without the Ropes to Reefs FISP project. It is also a great educational opportunity. We now have a lot of work to bring it all together.

11.1.2 David L Jarrad, Chief Executive, The Shellfish Association of Great Britain (SAGB)

The SAGB has been delighted to be a part of and engage with the Ropes to Reef project since its inception. Whilst, worldwide, the ecosystem services of shellfish, as products, (such as carbon and nitrogen sinks, water cleansing etc) is well understood and studied, the innovative nature of this project is showing the wider beneficial role of the 'farm' as a whole.

The R2R project demonstrates, very clearly, that this is not the case and that the farm itself delivers positive biodiversity benefits to the cultivated site and the surrounding areas.

At a time when we are trying hard to demonstrate to many organisations, administrators and parliamentarians, the benefits of the sector and promote an expansion of this eco-friendly industry, the R2R project is both relevant and critically important.

Working with the excellent team of professional researchers at the University of Plymouth has been great fun, as well as very informative. We truly hope the project can be extended into the next phase.

11.1.3 John Holmyard, CEO, Offshore Shellfish Ltd. (OSL)

Offshore Shellfish has been very pleased to be a part of the Ropes to Reefs project. This complex, cross disciplinary, multi-partner research project has been well managed by the team at the University of Plymouth. Communication with partners and the wide dissemination of the results through publications and presentations has been excellent.

The project will provide long term value to planning of sustainable offshore aquaculture and forms a solid base on which to build future research

11.1.4 Greg Clifford, CEO, Scallop Ranch Ltd. (SR)

Ropes to Reefs has pulled together industry, academia and previous studies to create a project that has set the foundations to what aquaculture has the potential to achieve, over and above the food it produces. Industry has for a long time given anecdotal evidence of how beneficial sea farms are but with little valid justification. The UoP has added the scientific rigour to this and helped to rationalise what industry has been seeing. Working with UoP on the project has been a joy. There has been a real level of excitement for each workshop to hear what new data has been captured and what it shows. This project is only the start and makes way for much more data collection to build an ever-bigger picture of life on and around the farms.

11.2 Project external partners

11.2.1 Sharmin Rouf - The Fishmongers Company

The Fishmongers Company would like to convey how useful and digestible the webinar was. Having inherited this work package from Alison Freeman quite late in the game, this session has been very conclusive and clear cut in the achievements and successes of the project. The collaborative approach exemplified and embodied here is an attributing marker of your success in my books and is something I look out for with preference across project scoping exercises. I look forward to receiving the final report. All the best from Fishmongers!

11.2.2 Miranda Willis, Senior Evidence Specialist, Marine Management Organisation (MMO)

We really enjoyed hearing from the project team and stakeholders firsthand about the work they have done on Ropes to Reefs. The researchers have engaged widely on the impact of their work and provided clear and engaging materials to communicate with different groups. The project represents an important contribution to MMO’s evidence base across all our departments and we have begun discussions with colleagues on uses of the evidence.

11.2.3 Sarah Clark, Deputy Chief, Devon and Severn Inshore Fisheries Conservation Authority (D&S IFCA)

The project has demonstrated benefits of the aquaculture industry and by the offshore mussel farm. It is about the evidence that provides that will inform marine spatial prioritisation and help aquaculture business with the evidence to support future developments. Having the evidence is key. Our work as D&S IFCA we need to balance the needs for the users thus, any evidence that helps with that is great. In terms of future, we need the project to continue, we need to better understand the spillover effect, which is key. We need to bring all the resources over all the years of study into one place, one report or something that’s iterative, that can be added and a one place to go and widely disseminate.

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