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Priority Marine Feature Surveys within the Small Isles MPA and surrounding Waters

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C Greathead, R E Boschen-Rose, R Langton, J Clarke, P J Wright and P Boulcott

Main Report

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In memory of Clare Greathead who worked tirelessly analysing and reviewing the imagery data from the Small Isles presented in this report. Her work as a benthic ecologist will live long in the memory, supporting as it did the conservation of marine species within Scottish waters and beyond.

Priority Marine Feature Surveys within the Small Isles MPA and surrounding Waters

Main Report

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Abstract

The Small Isles Marine Protected Area (MPA) is one of Scotland's biggest inshore MPAs, covering more than 800 km^2 and containing a complex mosaic of habitats. The six-year survey programme (2012 – 2017) conducted by Marine Scotland collected imagery of the seafloor within the Small Isles MPA: 9,374 digital images and 3,690 minutes of high definition video footage. This imagery was analysed to determine baseline abundances of eight seafloor invertebrate species with conservation importance related to Priority Marine Features. These imagery data showed that the Sound of Canna provides important habitat within the MPA. There were sufficient data to model changes in abundance over time for two species in four survey locations. The abundance of the Tall seapen (*Funiculina quadrangularis*) reduced after 2014, whilst the abundance of the Northern sea fan (*Swiftia pallida*) was stable over time. The potential impact of bottom-contacting towed fishing gear on the distribution of the Tall seapen in the wider area of the Minch, Inner Sound and Sea of Hebrides was also investigated. There was no evidence that fishing activity caused reductions in seapen abundance. However the analysis was limited by the available fishing data, which was at a broader scale (over space and time) than the abundance data. Finer scale fishing data would be needed for future studies to assess the impact of fishing activities on the abundance of seafloor invertebrate species. The results of this study provide a more extensive biological baseline of the Small Isles MPA than previously available, including more survey locations and repeat surveys over time. The Small Isles dataset strengthens the biological evidence base underpinning the Scottish MPA network by improving our understanding of where species occur and identifying important locations for different species. The abundance data can help establish management measures to support an ecologically coherent MPA network by identifying where the abundances of some species, such as the Tall seapen, have reduced. Continued surveying of the Small Isles MPA and the surrounding region is discussed with respect to monitoring changes in species abundance over space and time and assessing the effectiveness of any future management measures.

Executive summary

The Small Isles Marine Protected Area (SMI MPA) is one of Scotland's biggest inshore MPAs, covering more than 800 km^2 and containing a complex mosaic of habitats. Multiple Priority Marine Feature (PMF) shellfish and other invertebrate species, and components of PMF habitats, occur within the SMI MPA. This report focusses on eight seafloor invertebrate species that are either PMF species, components of PMF habitats, or components of MPA protected features, and provides detailed spatial and temporal information about where these occur within the SMI MPA.

The six-year survey programme (2012 – 2017) conducted by Marine Scotland, a Directorate within the Scottish Government, used a non-destructive approach that collected imagery of the seafloor. During the study period, 9,374 digital still image quadrats and 3,690 minutes of quantifiable high definition video footage were collected and analysed to determine baseline densities of the eight seafloor species. The impact that bottom-contacting towed gear may have on the distribution of the Tall seapen (*Funiculina quadrangularis*) in the wider area of the Minch, Inner Sound and Sea of Hebrides was also assessed using information on fishing vessel activity, environmental variables, and seapen abundance.

The results indicate that specific areas within the SMI MPA are important to certain PMF species or habitat components, with some species only recorded from a small number of locations. The Sound of Canna recorded some of the highest densities of the Northern seafan *Swiftia pallida*, white cluster anemone *Parazoanthus anguicomus*, and the Northern featherstar *Leptometra celtica* during the study, and this location provided the only records of the Horse mussel *Modiolus modiolus* and Fan mussel *Atrina fragilis* from within the SMI MPA during the survey period.

A few species recorded decreases in density within the SMI MPA and the wider area over the baseline study period - *F. quadrangularis, A. fragilis* and *M. modiolus* - although the latter two species were encountered rarely from a limited number of locations and were not the focus of repeated sampling. *Funiculina quadrangularis* was consistently recorded at lower densities within the SMI MPA after 2014. Statistically significant decreases in *F. quadrangularis* density between 2014 and all subsequent survey years (2015, 2016, 2017) were detected for two survey boxes in the south of the Sound of Canna. In a follow up study, the assessment of *F. quadrangularis* density and distribution across the Minch, Inner Sound, and Sea of Hebrides was unable to establish linkages between density of *F. quadrangularis* and the occurrence of towed bottom-contacting fishing.

Some species did not show any consistent patterns in density over space and time, such as the tube-dwelling anemones *Arachnanthus sarsi* and *Pachycerianthus multiplicatus* and *P. anguicomus* and *L. celtica*. There was no statistically significant change in density over time for *S. pallida* in two survey boxes in the south of the Sound of Canna (2015, 2016, 2017). Although no density changes were expected for *A. sarsi*, *P. multiplicatus*, *S. pallida*, *P. anguicomus* and *L. celtica*, their association with harder substrate patches within the SMI MPA means they were less likely to be consistently encountered during individual survey tows, thereby reducing the likelihood that any changes over space and time would be detected.

In summary, the six-year Marine Scotland survey programme presented in this report provides a biological baseline record of the SMI MPA at a spatial coverage and temporal resolution previously unavailable. The data analysed strengthens the evidence base underpinning the Scottish MPA network and can help to inform the establishment of management measures to support an ecologically coherent MPA network. The results from this study raise the following points for consideration:

- Density information for the eight seafloor invertebrate species indicates that the Sound of Canna provides important habitat within the SMI MPA. This location may benefit from tailored management measures for the conservation and recovery of the species located there with the aim of contributing to the regional health of these features.
- Continued survey of the SMI MPA and surrounding region is suggested to monitor changes in species density over space and time, and to assess the effectiveness of any future management measures. Higher spatial and temporal resolution of biological survey data, potentially using new technology, would help to determine trends in species associated with the wide range of habitats occurring within the SMI MPA.
- Where species occur in low densities, in aggregations, or are reliant on habitats with patchy distributions that are difficult to survey repeatedly over time, the resolution of the data collected may not be sufficient to detect a change or deterioration in status over time or space, thus sentinel hypothesis-based monitoring may be less effective for some species.
- Greater spatial and temporal resolution of fishing pressure data is needed to better assess the impacts of fishing activity, given that there was insufficient evidence to determine if observed decreases in species density were linked to fishing activity.

The full SMI MPA dataset is archived and stored in line with the Scottish Government’s Open Data Strategy and data relating to PMFs were provided to the Geodatabase of Marine features adjacent to Scotland (GeMS) curated by NatureScot.

Contents

Abbreviations

AF	*Atrina fragilis* individuals
AIS	Automatic Identification System
AS	*Arachnanthus sarsi* individuals
AUV	Autonomous underwater vehicle
BACI	Before After Control Impact
BF	Burrowed mud with *Funiculina quadrangularis*
BGS	British Geological Survey
BM	Burrowed mud
BP	Burrowed mud with *Pachycerianthus multiplicatus*
BS	Burrowed mud with seapens
CBR	Cobbles and boulders with rocky outcrops
DAPSIR	Drivers Activities Pressures and Impact on Ecosystem Services
DOI	Digital Object Identifier
DSI	Digital still image
EU	European Union
FQ	*Funiculina quadrangularis* individuals
FeAST	Feature Activity Sensitivity Tool
GeMS	Geodatabase of marine features adjacent to Scotland
GIS	Geographic Information System
GLMM	Generalised linear mixed model
HD	High definition
HDV	High definition video
ICES	International Council for the Exploration of the Sea
ICG-EcoC	OSPAR Intersessional Correspondence Group on Cumulative Effects
IEEE	Institute of Electrical and Electronic Engineers
ISSN	International Standard Serial Number
JNCC	Joint Nature Conservation Committee
LC	*Leptometra celtica* individuals
MM	*Modiolus modiolus* beds
MPA	Marine Protected Area
MRV	Marine Research Vessel
MS	Mixed sediment
MSC	Mixed sediment with cobbles
MSCB	Mixed sediment with cobbles and boulders
NAFO	North Atlantic Fisheries Organisation
NC	Nature Conservation

OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PA	*Parazoanthus anguicomus* individuals
PMF	Priority Marine Feature
PNAS	Proceedings of the National Academy of Sciences
POLCOMS	Proudman Oceanographic Laboratory of Coastal Ocean Modelling System
SAC	Special Areas of Conservation
SAR	Swept area divided by the area of the grid cell
SC	*Swiftia pallida* communities
SCS	Scientific Council Summary
SDM	Species distribution model
SMI	Small Isles
SMR	Scottish Marine Region
SP	*Swiftia pallida* individuals
SS	Soft sediment
UK	United Kingdom
UKBAP	United Kingdom Biodiversity Action Plan
VME	Vulnerable Marine Ecosystem
VMS	Vessel monitoring system
WKEUVME	Workshop on European Union regulatory area options for Vulnerable Marine Ecosystems protection

1. Introduction

1.1 Biodiversity of the Small Isles Marine Protected Area

The Small Isles Marine Protected Area (SMI MPA; Fig. 1) is one of Scotland's biggest inshore MPAs, covering more than 800 km^2 and containing a complex mosaic of habitats. The SMI MPA includes the Sound of Canna, a submerged valley with depths exceeding 250 m. The seabed habitats within the SMI MPA are some of the most diverse in Scotland and support a wide range of seafloor (benthic) species that have been identified nationally and internationally as needing protection from damaging activities.

Some of the habitats and species found in the SMI MPA are categorised as Priority Marine Features (PMFs). The list of PMFs developed by NatureScot, formerly Scottish Natural Heritage, and the Joint Nature Conservation Committee (JNCC) is intended to inform marine conservation in Scotland (Tyler-Walters et al., 2016; NatureScot, 2020b). During the SMI MPA surveys summarised in this report, four shellfish and other invertebrate species on the PMF list were encountered alongside multiple biotopes or species components from three intertidal and continental shelf habitats: burrowed mud, horse mussel beds and northern sea fan and sponge communities (NatureScot, 2020b; Table 1). Additional PMF species and habitat components were encountered during subsequent coastal surveys in shallower water as described by O'Dell et al. (2021).

Many, but not all, of the PMF species or habitat components occurring in the SMI MPA are listed as protected features for the MPA (see section 1.2) and the majority also occur on related conservation lists or have legal protection. *Atrina fragilis, Arachnanthus sarsi, Funiculina quadrangularis, Pachycerianthus multiplicatus* and *Swiftia pallida* are all included in the Scottish Biodiversity List, with 'conservation action needed' for all but *A. fragilis*; this species is listed as 'avoid negative impacts' (NatureScot 2020c). *Atrina fragilis* is afforded legal protection under the Wildlife and Countryside Act 1981 and is included on the UKBAP list. *F. quadrangularis, P. multiplicatus* and *S. pallida* are also included on the UKBAP list and have each seen declines in Scotland greater than 25%[1]. *Arachnanthus sarsi* is considered a

[1] Declines under the M4 criterion of the Scottish Biodiversity List are defined as "An observed, estimated, inferred or suspected significant decline (exceeding expected or known natural fluctuations) in numbers, extent or quality of a marine habitat or species in Scotland (for species, quality relates to life history parameters). Significant decline should be assessed as 25% reduction of area or numbers, or other appropriate threshold (which must be stated and justified)."

rare species in Scottish Waters[2]. *Modiolus modiolus* beds as a habitat is included on the Scottish Biodiversity List, where conservation action is needed, and negative impacts should be avoided; *M. modiolus* beds are also included on the UKBAP list. Both *M. modiolus* beds and Seapen and burrowing megafauna communities are considered threatened and declining habitats by OSPAR (OSPAR Commission, 2008).

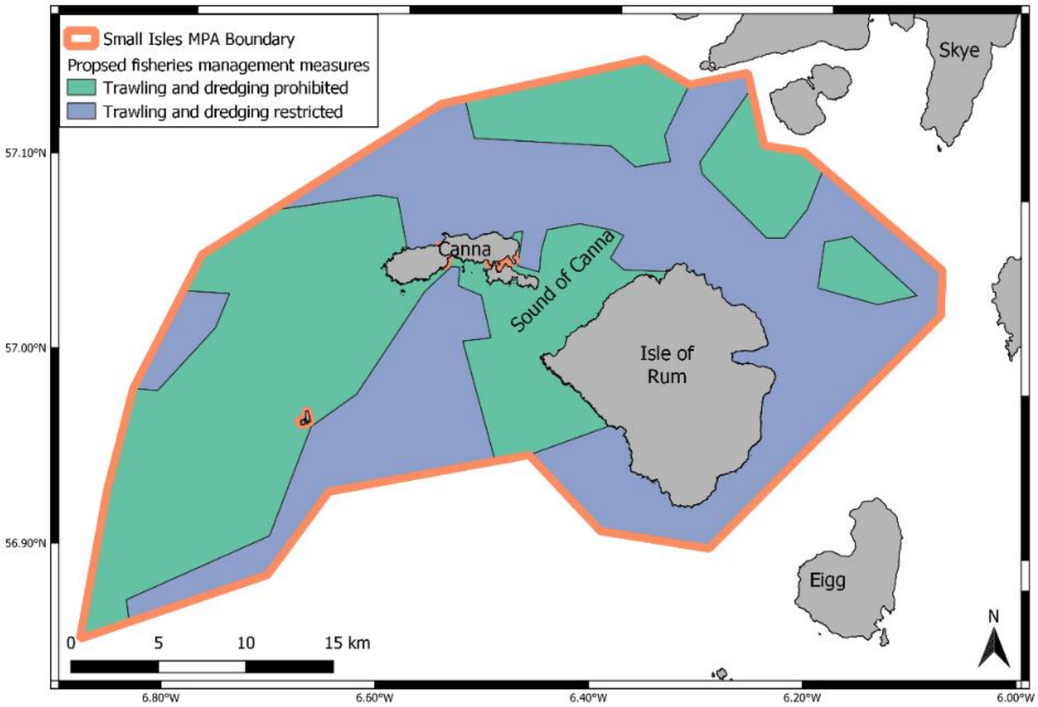

Figure 1. Location of the Small Isles MPA, as designated in July 2014 with proposed fisheries management measures of August 2016 (green and blue). The category of 'Trawling and dredging restrictions' in the map refers to some fishing activities being permitted subject to conditions under the proposed fisheries management measures. [Contains information from Scottish Government (Marine Scotland) and NatureScot licenced under Open Government Licence v3.0, and Land Cover for Scotland Data (Macaulay Land Use Research Institute 1993).]

[2] Rare species under the M2a criterion of the Scottish Biodiversity List are defined as "Species that are rare in Scottish waters, where rarity is assessed as species that occur in less than 6 (c. 1%) of the total number of 10 x 10 km squares or less than 3 (c. 5%) of the ICES rectangles. A mobile species qualifies as nationally rare if the total population size is known, inferred or suspected to be fewer than 250 mature individuals. Vagrant species should not be included under this criterion."

Table 1

Priority Marine Feature (PMF - NatureScot, 2020b) species and habitat components found within the Small Isles MPA.

PMF type	PMF species or habitat
Shellfish and other invertebrate species	*Arachnanthus sarsi* (burrowing cerianthid anemone)
	Atrina fragilis (Fan mussel)
	Leptometra celtica (Northern feather star)
	Parazoanthus anguicomus (White cluster anemone)
Intertidal and continental shelf habitats	Burrowed mud
	Horse mussel (*Modiolus modiolus*) beds
	Northern sea fan (*Swiftia pallida*) and sponge communities

The Sound of Canna within the SMI MPA contains one of the largest aggregations of *A. fragilis* in the UK (Howson et al., 2012; Stirling et al., 2016, 2018) and the deepest *M. modiolus* bed in Scotland, at 120 – 180 m water depth (Moore and Roberts, 2011). The rocky sides and reefs of the Sound of Canna also support PMF species or habitat components, such as *S. pallida*, *L. celtica* and *P. anguicomus*. In other areas of the SMI MPA, expanses of flat seabed are covered by mixed muddy sediments, providing habitat for seapens (*Pennatula phosphorea, Virgularia mirabilis* and *F. quadrangularis*: O'Dell et al., 2021) and burrowing megafauna, such as *Nephrops norvegicus*. These muds are heavily bioturbated by burrowing megafauna, with burrows and mounds typically forming a prominent feature of the sediment surface. The bioturbation of the muddy sediment by burrowing megafauna increases structural complexity and oxygen penetration, enhancing the survival of other species and increasing biodiversity in what would otherwise be a low diversity habitat (Widdicombe et al., 2004). The burrows also provide a source of refuge for smaller invertebrates and fish (Hughes, 1998).

1.2 Marine protection in the SMI MPA

The SMI MPA was designated by Scottish Ministers on 7th August 2014 (Scottish Government, 2014). The Conservation Objectives for the MPA are:

"5. – (1) The conservation objectives of the Small Isles MPA are that the protected features –

a) so far as already in favourable condition, remain in such condition; and
b) so far as not already in favourable condition, be brought into such condition, and remain in such condition.

(2) In paragraph (1) “favourable condition” with respect to a marine habitat, means that –

a) its extent is stable or increasing; and
b) its structures and functions, its quality, and the composition of its characteristic biological communities are such as to ensure that it is in a condition which is healthy and not deteriorating.

(3) In paragraph (2)(b) the reference to the composition of the characteristic biological communities of a marine habitat includes a reference to the diversity and abundance of species forming part of, or inhabiting, that habitat.”

The protected features of the SMI MPA include many of the PMFs mentioned in section 1.1, alongside additional features (Table 2). It is important to note that some PMF shellfish and other invertebrate species, such as the Fan mussel and Northern feather star, are only considered to be protected features within the SMI MPA where they form aggregations, and for the latter, only on mixed substrata. Horse mussels are only considered to be protected features where they form beds. White cluster anemones are protected features regardless of density or substrata. Specific guidance is available for determining what constitutes an ‘aggregation’ for Fan mussels and the Northern feather star, and for what constitutes a ‘bed’ for Horse mussels (NatureScot, 2018a,b,c).

Despite the SMI MPA being designated in 2014, the fisheries management measures have not yet been finalised (as of January 2023) (Fig. 1).

Table 2

Protected features for the Small Isles MPA, taken from the Small Isles Marine Protected Area Order 2014 (Scottish Government, 2014), Schedule 2, Article 4. The terminology for feature type in this table reflects the PMF listing provided by Tyler-Walters et al. (2016).

Protected feature	Type of feature
Black guillemot	Mobile species
Burrowed mud	Habitat
Circalittoral sand and mud communities	Habitat
Fan mussel aggregations	Habitat
Horse mussel beds	Habitat
Northern feather star aggregations on mixed substrata	Low or limited mobility species
Northern sea fan and sponge communities	Habitat
Shelf deeps	Large-scale feature
White cluster anemones	Low or limited mobility species
Quaternary of Scotland – glaciated channels/troughs, glacial lineations, meltwater channels, moraines and streamlined bedforms	Geomorphological

1.3 Pressures arising from human activity in the SMI MPA

Two of the most extensive activities occurring in the SMI MPA are trawling by the *Nephrops* fishery and, with a smaller footprint, scallop dredging. Within the SMI MPA burrowed mud habitats coincide with high levels of demersal trawling, with scallop dredging targeting harder substrates nearer to the shoreline. Some of the PMFs that occur within the SMI MPA are known to be sensitive to pressures related to fishing activities. For example, in terms of classification, *A. fragilis* aggregations have high sensitivity to the removal of non-target species and subsurface abrasion or penetration, and medium sensitivity to surface abrasion, whilst Northern featherstar aggregations on mixed substrata have medium sensitivity to both removal of non-target species and surface abrasion (FeAST, 2013). Some PMF species or habitat components within the SMI MPA that are known to be sensitive to abrasion pressure (Tillin et al., 2010) lie outside the footprint of bottom-contacting towed gear (Marine Scotland vessel monitoring data). However, where overlaps occur, the presence of such fishing activity has the potential to affect the distribution of PMF species and habitats (Stirling et al., 2016).

In addition to fishing activity, there is an active seawater finfish aquaculture site northeast of Rum. There are also dredge spoil disposal sites in the SMI MPA, located within complex topography within the Sound of Canna (Fig. 2). This area has not been exposed to high levels of activity from bottom-contacting towed gear historically (Howson et al., 2012) with the dredge spoil disposal site acting as a localised *de facto* refugium from the action of bottom-contacting towed gear (Shepard et al., 2012; Stirling et al., 2016).

The OSPAR Commission (OSPAR Commission, 2022) has also formally agreed a list of pressures occurring within the North East Atlantic marine environment and their associated definitions. The list, developed by the Intersessional Correspondence Group on Cumulative Effects (ICG-EcoC), includes descriptions of pressures that are linked to certain fishing activities, such as penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion, and the removal of target or non-target species. In the regional context of the SMI MPA, the Scottish Marine Assessment 2020 (Moffat et al., 2020) identifies the removal of target and non-target species and surface and sub-surface abrasion amongst its list of top pressures occurring within the West Highlands Scottish Marine Region (SMR) where the SMI MPA is located. Whilst occurrence of such pressures may not always result in an impact of concern, the Scottish Marine Assessment 2020 concluded that fishing, (including bottom-contacting and pelagic fishing), is the dominant pressure-causing activity across the Scottish Marine Regions due to the size of the geographical footprint of fishing and the nature of the activity.

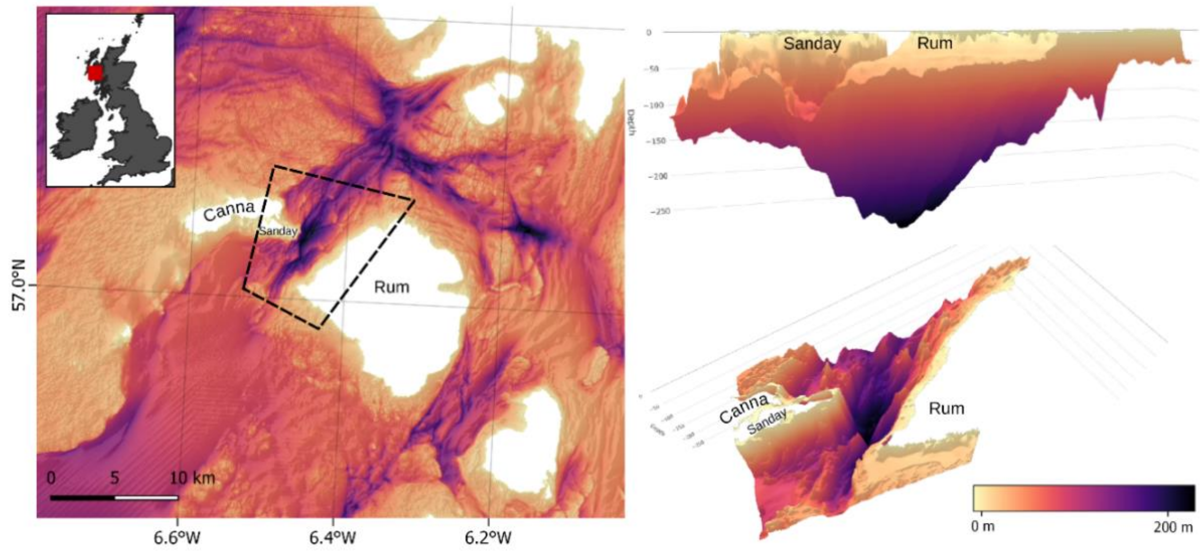

Figure 2. Left: bathymetric map of the Small Isles region illustrating the position of the Small Isles MPA in relation to Scotland (inset) and the dredge spoil disposal sites in the Sound of Canna (black hatch box). Right: 3D bathymetric plots of the dredge spoil disposal sites in the Sound of Canna, illustrating the complex topography and depth of the seafloor between Sanday and Rum (top) and Canna, Sanday and Rum (bottom). For all plots cool colours are deeper (more than 200 m water depth) and warmer colours are shallower. [Bathymetry from Oceanwise].

1.4 Biodiversity status and pressures reporting for the SMI MPA

The aims of this report on the biodiversity status and pressures related to fishing activity in the SMI MPA are twofold:

1. To provide extensive baseline data from the seabed within and around the SMI MPA, with specific focus on benthic PMF species or components of PMF habitats occurring in the study area (see section 2.1).
2. To assess the impact that bottom-contacting towed gear may have on the distribution of PMF species, habitats, or habitat components using information on fishing vessel activity, environmental variables, and the abundance of the Tall seapen (*Funiculina quadrangularis*) in the wider area of the Minch, Inner Sound and Sea of Hebrides (see section 2.2).

To support monitoring efforts, baseline benthic data were obtained through surveys conducted from the MRV *Alba na Mara* in and around the SMI MPA over a six-year period (2012 – 2017). The primary objective of these surveys was to establish the "before" time point of a BACI study (Before, After, Control, Impact: Green, 1979) that would have the ability to assess the effectiveness of fisheries management measures within the MPA. BACI studies associated with assessing the impact of fishing within MPAs are intended to detect changes over time by comparing the "before" and "after" status for a "control" area that would remain fished and an "impact" area where fisheries management measures effect a reduction in anthropogenic pressure. Monitoring long-term change and attributing that change to natural or anthropogenic sources is a key aim of such BACI surveys. Baseline and monitoring surveys need to be carefully designed to effectively determine if changes in density or distributions of species or habitats within MPAs result from the removal of fishing or are attributable to other coincidental factors.

As part of the baseline surveys conducted, high-definition video (HDV) and high-definition digital still images (DSI) were recorded outside the SMI MPA boundary, and inside and outside the areas where fisheries management measures have been proposed within the SMI MPA (Fig. 1). The surveys described in this report were conducted over six years, affording the opportunity to obtain extended "before" data.

Since measures are yet to be implemented for the SMI MPA, the surveys from all six years covered the "before" aspect of the BACI design. Thus, this report does not test for the impact of measures on SMI MPA target species or features, as was originally intended. Instead, the report provides an extensive description of the distribution and density of target species and features within and close to the SMI MPA, both over space and time.

Assessing the impact of fishing on *F. quadrangularis* was considered a priority for this report, in part because the species is of conservation importance within the Greater North Sea and Celtic Sea (OSPAR areas II and III, respectively). The associated “seapen and burrowing megafauna communities” habitat is of key conservation importance as a defined habitat under Annex V of the 1992 Oslo Paris (OSPAR) Convention (OSPAR Commission, 1992, 2010). In addition, existing seapen Vulnerable Marine Ecosystem (VME) closed areas within the Northwest Atlantic Fisheries Organisation (NAFO) regulatory area were assessed as having a high overall risk of significant adverse impacts from bottom fishing activities (NAFO, 2016).

Funiculina quadrangularis is not listed as a “PMF shellfish and other invertebrate species”, however it is a component of the ‘Tall seapen’ biotope within ‘burrowed mud PMF habitat’, listed under intertidal and continental shelf habitats (NatureScot, 2020b). The burrowed mud PMF habitat (NatureScot, 2020b) broadly aligns with the SMI MPA protected feature of ‘Burrowed mud’ habitat (Scottish Government, 2014). Thus, according to the Small Isles Marine Protected Area Order 2014, *F. quadrangularis* could be considered a species component of the SMI MPA burrowed mud habitat protected feature (see section 1.2).

Funiculina quadrangularis is a colonial cnidarian adapted for life on soft muddy or sandy sediments (Manuel, 1988; Hayward and Ryland, 1990). Individual colonies can exceed 200 cm in length, with approximately one-quarter of their structure buried and the rest protruding above the sediment (Ager, 2003). They are found across a wide range of depths, from 20 to more than 200 m, with their European distribution being restricted to the deep muddy areas around the northwest coasts of Ireland and Scotland (Greathead et al., 2007), Norwegian fjords (Rosenberg et al., 1996), and the continental slopes off northern Spain (Serrano et al., 2006). Given their sedentary lifestyle and upright position in the sediment, physical abrasion pressure from demersal fishing activities may have a modifying effect on seapen distribution (Malecha and Stone, 2009; Tyler-Walters et al., 2009), with the action of bottom-contacting towed gear causing in-situ mortality or bringing about their removal, forming unwanted bycatch.

Understanding the environmental preferences of *F. quadrangularis* and how fishing activities may impact it is an important step towards designing fisheries management measures that can provide effective protection for this species and its associated habitat. Previous work indicates that *F. quadrangularis* exhibits strong environmental preferences, allowing their distribution to be modelled successfully within a species distribution model (SDM) framework (Greathead et al., 2015; Downie et al., 2021). Correlational methods can also offer powerful prognostic tools to assess the effects of various drivers of ecosystem change, such as the abrasion pressure caused by bottom-contacting towed fishing gears. Thus, in this report we utilised DSI data collected during 2017 surveys, Vessel Monitoring System (VMS) fisheries data, and environmental information in a modelling approach to determine the impact of fishing on *F. quadrangularis* distribution.

2. Methods Summary

This section provides an overall summary of the methods used to generate the Marine Scotland Small Isles MPA dataset (2012 – 2017) and to create this report. A comprehensive description of the methods is available in the full methods version provided in Annex C of the Annex Materials document (Greathead at al. 2023).

2.1 Baseline benthic monitoring

Imagery data in the form of DSI and HDV were recorded from 1) inside the areas covered by the proposed fisheries management measures; 2) inside the wider SMI MPA but outside proposed fisheries management measures; and 3) in areas outside the MPA boundary.

Imagery surveys used lander frames, which were set down on the substrate to collect DSI, and more traditional drop camera frames that drifted over the substrate at a fixed height. Lander frames had the advantage of offering a fixed focal length, producing stable images of a known area, but were not suitable for very rough ground. Time, depth and vessel position were recorded for both types of deployment, lander and drop frame. Annex B, Table B.1 (Greathead at al. 2023) summarises the year and month of each cruise and information on the equipment used. DSI and HDV footage were collected from both the lander and drop frame configurations. Due to differences in the survey design, only HDV were analysed in the drop frame configuration and only DSI were analysed in the lander configuration. The HDV collected by lander and DSI collected by drop frame were stored as back-up imagery data for habitat or species identification, if needed.

Depths surveyed ranged from 50 to 250 m (see Annex A, Tables A.1 and A.2 in Greathead at al. (2023)). Transects for HDV lasted a minimum of 10 minutes at a target speed of less than 1 knot, with mean tow speeds in the different survey boxes ranging from 0.32 to 0.96 knots (see Annex A, Table A.2). A minimum of three DSI stations were recorded in each transect (start, middle and end), with five DSI captured at each station.

There was limited prior information on the distribution of species and habitats over the entirety of the SMI MPA, thus surveys conducted during 2012 and 2013 served as scoping surveys that informed later refinements to the size and location of survey boxes. The 2012 and 2013 surveys used information provided by NatureScot and seabed morphological data from the ship's sounders to help draw the boundaries of potential survey boxes. Species distribution models (SDMs) produced by Marine Scotland for several PMF species or habitat components enabled the identification of viable survey areas not yet known to contain such records (e.g., Greathead et al., 2015; Stirling et al., 2016), further widening the area of survey. Over time, this process allowed the delineation of survey boxes that targeted the full range of PMF species or PMF habitat components thought to be present in the area.

During the study period, some survey boxes were rejected if they did not contain target species or habitat or if they were too difficult or dangerous to survey. This approach resulted in the selection of 25 survey boxes from the original 31 for further survey (Fig. 3a, 3b). These 25 boxes were designed to survey ten features relevant to PMFs and were grouped according to different levels of future protection (inside/outside proposed measures and outside the SMI MPA) (Table 3; Annex A, Tables A.1 and A.2). More detailed notes on each research survey are contained in Annex B, Table B.2 (Greathead et al., 2023).

Survey boxes were subdivided by seven primary target features (BS: seapens, including *Virgularia mirabilis* and *Pennatula phosphorea*; BF: burrowed mud with *Funiculina quadrangularis*; MM: *Modiolus modiolus* beds; SC: *Swiftia pallida* communities; LC: *Leptometra celtica*; PA: *Parazoanthus anguicomus*; and AF: *Atrina fragilis*) and three secondary target features (BM: burrowed mud; BP: burrowed mud with *Pachycerianthus multiplicatus*; and AS: *Arachnanthus sarsi*) (Table 3). In addition to division by target features, survey boxes were also assigned to one of five major habitat types adopted for the purposes of survey design (soft sediment; mixed sediment; mixed sediment with cobbles; mixed sediments with cobbles and boulders; and cobbles, boulders and bedrock) and one of three site categories (inside/outside measures within the MPA and outside the MPA: see Table 3). Although it was not possible to find suitable survey boxes for each category, the survey design allows comparison between several possible categories inside/outside proposed measures or the SMI MPA for each target feature.

Table 3

Small Isles MPA survey boxes for ten target feature groupings, including: three priority marine feature (PMF) habitats, three biotopes of the burrowed mud PMF habitat, and four shellfish and other invertebrate PMF species (NatureScot, 2020b). Target features were distributed amongst five broad substrate types adopted for the purposes of survey design: soft sediment (SS), mixed sediment (MS), mixed sediment with cobbles (MSC), mixed sediment with cobbles and boulders (MSCB), and bedrock with mixed cobbles and boulders (CBR). Three site categories are identified for the target features: inside/outside management measures within the MPA and outside the MPA.

Feature code	**Target feature**	**Feature type**	**Substrate type**	**Survey boxes**		
				Inside measures	**Outside measures**	**Outside MPA**
BM	Burrowed mud	PMF habitat	SS	S06, S40	S09, S17	S10
BS	Seapens and burrowing megafauna in circalittoral fine mud	PMF biotope of BM habitat	SS	S06, S40	S05, S07, S08, S09, S11, S51	S10, S64, S23, V11
BF	Burrowed mud with Tall seapen (*Funiculina quadrangularis*)	PMF biotope of BM habitat	SS	S19, S40	S05, S07, S08, S11, S51	S10, S12, S23
BP	Burrowed mud with Fireworks anemone (*Pachycerianthus multiplicatus*)	PMF biotope of BM habitat	SS/MS	S06, S15, S40, S67	S05, S17	S10, S12, S64
MM	Horse mussel (*Modiolus modiolus*) beds	PMF habitat	MSC	S03, S04		
SC	Northern seafan (*Swiftia pallida*) and sponge communities, (occasionally with *Caryophyllia smithii*)	PMF habitat	MSCB/ CBR	S16, S41, S46, S68 V05	S17, S66	V11
AS	*Arachnanthus sarsi*	PMF species	MS	S03, S15, S67	S17	S12, S64, V11
PA	*Parazoanthus anguicomus*	PMF species	MSCB/ CBR	S06, S41, S46, S68	S17, S66	
LC	*Leptometra celtica* aggregations (on mixed sediment or Rock)	PMF species	MS/ MSC or MSCB/ CBR	S06, S40, S46, S67	S17, S66	S64
AF	*Atrina fragilis*	PMF species	MSC	S03, S04, S15		V11

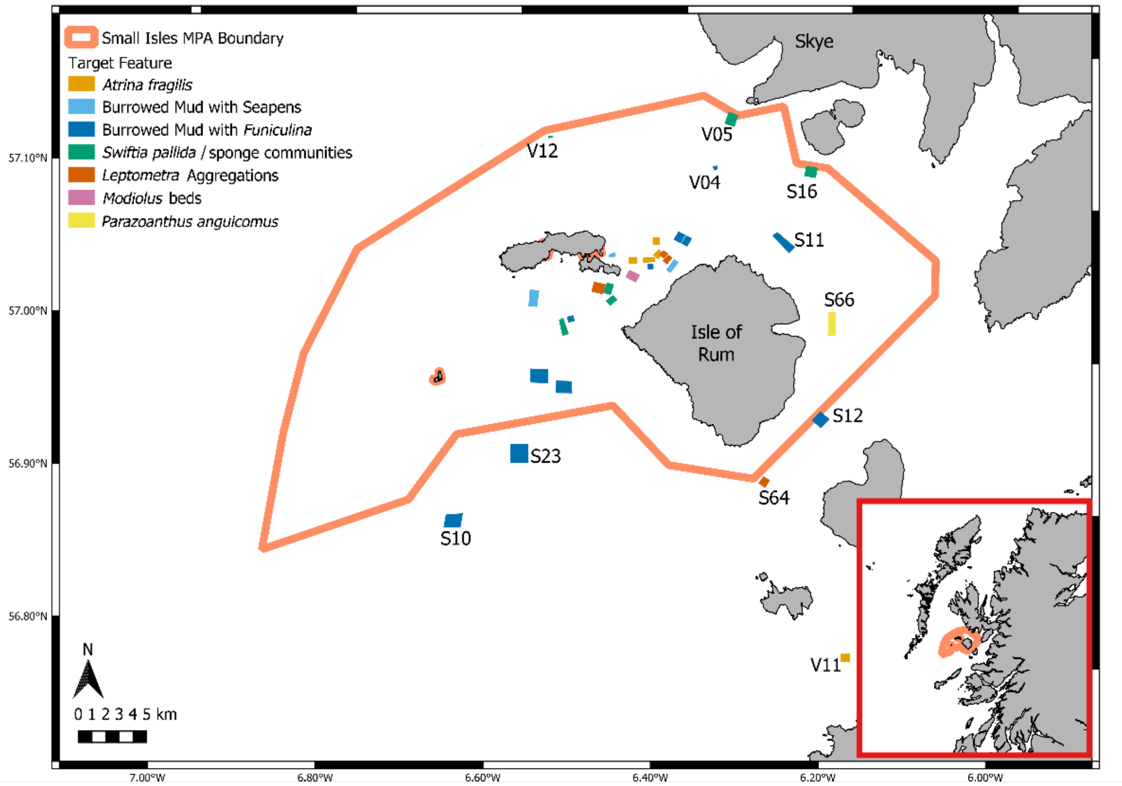

Figure 3a. Small Isles (SMI) MPA survey boxes with their target features. A detailed view of the survey boxes in the Sound of Canna is provided in Fig. 3b.

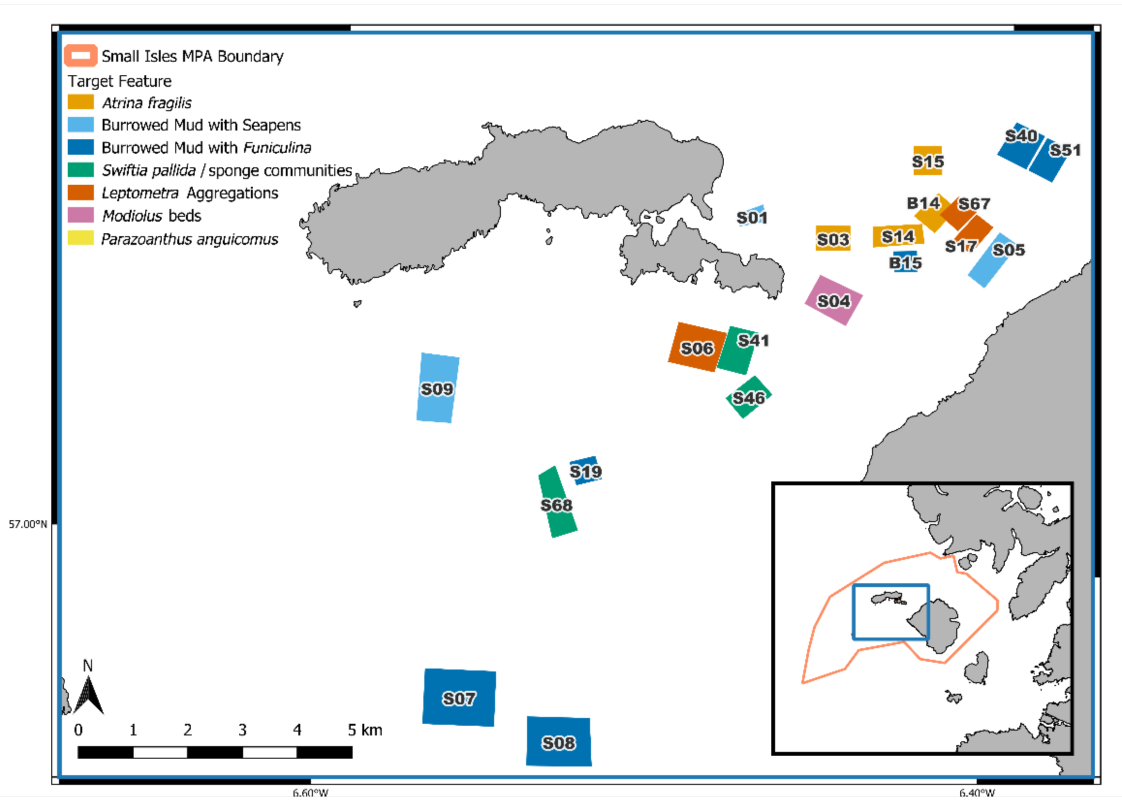

Figure 3b. Small Isles (SMI) MPA survey boxes within the Sound of Canna.

2.1.1 Species identification

Species identification was standardised using identification keys based on existing taxonomic works (Hayward and Ryland, 1990; Manuel, 1988) and modified to emphasise identification features that could be distinguished from digital formats. Electronic annotation (within Photoshop Elements 12) was used to ensure that each DSI could be re-analysed to confirm identification. All target species identified in the video transects were assigned a time code so that they could be easily found again for identification verification. Only features identifiable at a size of 10 mm or more were included in the analysis. Where smaller species were identifiable to genus level (e.g., *Caryophyllia* sp.), such species were classified if there was a high confidence in being able to consistently identify the feature.

The details of how taxa were identified and quantified from DSI and HDV imagery are available in the full methods, provided in Annex C.

2.1.2 Estimating species density

Species density estimates were derived from the two different survey methods employed over the course of the study; lander and drop frame. DSI quadrats were only used from the lander deployments. Due to its fixed focal length and angle, DSI quadrats from the lander frame produced a known “area under view” and were used preferentially in the survey of soft sediment habitats. The drop frame, which drifted approximately 80 cm over the seabed instead of “landing” on it, was used from 2015 onwards to record HD video across harder substrates where high levels of ruggedness precluded landing a frame. Obtaining HDV and DSI using the towed drop frame, although not as stable as the lander, also increased the area under survey over hard substrates.

The DSI area-under-view from the drop frame was not quantifiable and, therefore, these images were not used for analysis, but were used to verify species identification from the drop frame video transects. It should be noted that lander surveys in 2012, 2014 and 2015 also included areas of harder substrate, which from 2015 onwards were surveyed using HD video obtained from the drop frame. More information on the equipment used to collect imagery data across years is provided in Annex B, Table B.1; details on the imagery data types used to determine survey box-level density values for the different target species are provided in Annex A, Tables A.3 – A.10 of the Annex Materials document (Greathead et al., 2023).

The density of the eight target species was calculated at the survey box-level using a custom R-script (version 4.1.3; R Development Core Team, 2022), based on abundance within individual DSI quadrats or HDV tows and the total viewed area of seabed within each survey box for any given year and survey box combination. For seven species where detailed box level results are provided, density is reported as individuals or colonies within a metre squared ($n.m^{-2}$); for *P. anguicomus*, density was reported as the number of occurrences (spatially distinct groupings) within a metre squared ($o.m^{-2}$). More comprehensive details of how species density was determined from DSI and HDV imagery are available in the full methods, provided in Annex C.

To investigate whether survey box-level changes in density over time were statistically significant, a case study was produced using *F. quadrangularis* and *S. pallida* abundance data from a subset of survey boxes and years. The main results of this case study are presented under '3.1 Baseline Benthic Monitoring'; the full case study, including methods, is available in Annex D of the Annex Materials document (Greathead et al., 2023).

2.2 Assessing the impact of fishing activity on *Funiculina quadrangularis* abundance

To assess the possible impact of fishing on the distribution of *F. quadrangularis*, a wider survey across three adjoining areas, the Sea of the Hebrides, the Inner Sound and the Minch was conducted in 2017. The survey areas were known to contain suitable substrates for *F. quadrangularis,* as indicated by species distribution models (Greathead et al., 2015) and confirmed during a subsequent Marine Scotland survey conducted in 2014. The survey areas were also known to vary in the intensity to which they were exposed to bottom-contacting towed gear.

To assess the effect of fishing intensity on the abundance of *F. quadrangularis*, study boxes across the wider West coast of Scotland were surveyed during September 2017 on the MRV *Alba na Mara* (Fig. 4). The 29 survey boxes with available vessel monitoring system (VMS) data were used for further analysis, with each study box being approximately 1.5 x 1 km in size. The survey adopted the lander methodology described earlier, using DSI quadrats to determine counts of *F. quadrangularis*. Within each survey box, a minimum of four transect tows of the lander were made. Conditions permitting, each tow would comprise of eight to ten stations of five DSI quadrat images. Quadrats within each station were placed according to the prevailing drift of the vessel and were all within 15 m of each other. This protocol aimed to collect a total of 30 – 50 stations (150 – 250 DSI quadrats) of known area in each box.

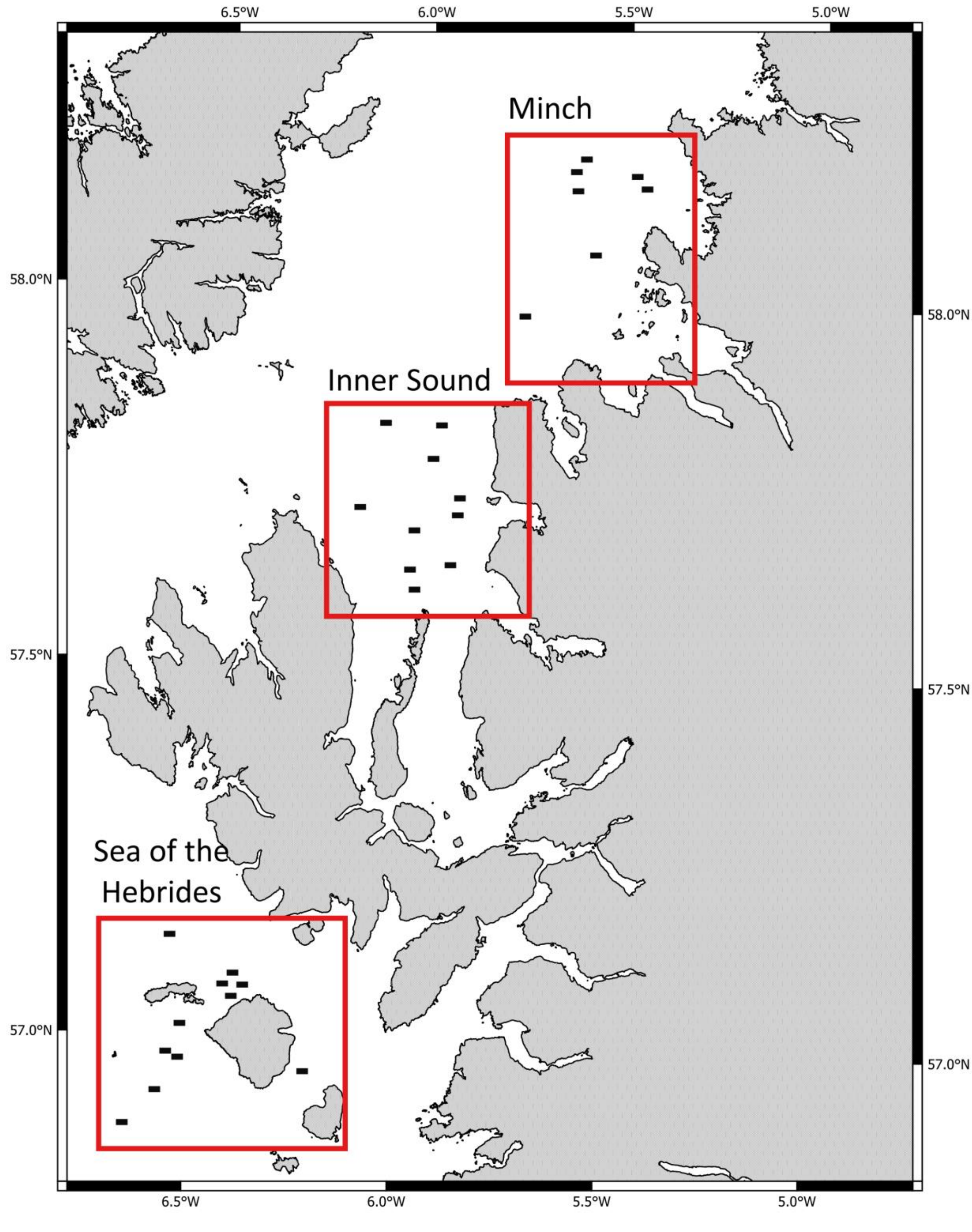

Figure 4. Sea of the Hebrides, Inner Sound and Minch locations (red rectangles) and their survey boxes (solid, black rectangles) surveyed in 2017 to assess the impact of bottom-contacting towed gear on the distribution of *Funiculina quadrangularis*.

2.2.1 Deriving fishing intensity from Vessel Monitoring System data

A spatially resolved index of fishing intensity for bottom-contacting towed gear was derived from VMS data. Although VMS data presented the best available fishing data for the study period, it should be noted that there is no data requirement to collect VMS data for vessels shorter than 12 m in length and it is therefore an incomplete record. Fishing data for the years 2014 – 2016, the three years preceding the *F. quadrangularis* seafloor survey, were downloaded from the International Council for the Exploration of the Sea (ICES) website (ICES, 2018) on 9 March 2020. Swept-area ratios (SARs) were provided for both the seabed surface and subsurface; surface abrasion is defined as disturbance of surface features only (top 2 cm of sediment), and subsurface abrasion is penetration and/or disturbance of the sediment deeper than the surface of the seabed (≥ 2 cm). Due to *F. quadrangularis* being situated with three quarters of its body protruding above the sediment surface (Ager, 2003), and the nature of its interaction with towed fishing gear, only surface abrasion was included in subsequent analyses.

Further details on how fishing intensity was derived from VMS data are available in the full methods, provided in Annex C.

2.2.2 Environmental data

Environmental variables known to affect the distribution and extent of *F. quadrangularis* (Greathead et al., 2015) were included in subsequent analyses: bathymetry, percentage mud, sand and gravel, and salinity (Table 4). The bathymetry layer was then used to produce two additional environmental layers relating to the seabed - slope and curvature - using the spatial analyst and the benthic terrain model tools in ArcGIS.

Further details on how environmental data were derived are available in the full methods, provided in Annex C.

Table 4

Environmental variables considered in the *Funiculina quadrangularis* analysis

Variable	Description	Source / Derivation
Depth	High resolution (25 m^2) digital terrain model of the subsea surface iteratively synthesized using high resolution multibeam bathymetry surveys.	SeaZone, 2013. Bathymetric Data historically supplied under licence 122006.004; data management tools in ArcMap 10.0.
Slope and curvature	Derived from depth at the final resolution.	Depth and spatial analyst tools in ArcMap 10.0.
Sediment: mud (%), sand (%), and gravel (%)	Sediment layers obtained after interpolation with inverse distance weighting, using the coastline as a barrier, grabs data from Marine Scotland and BGS.	Marine Scotland and BGS grabs; spatial analyst tools in ArcMap 10.0.
Salinity near bottom	Minimum values calculated for the period 1988–2004 using R and resampled to the final resolution using the bilinear resampling algorithm tool.	POLCOMS model (Holt et al., 2005); R package “ncdf” (Pierce, 2011); and data management tools in ArcMap 10.0.

2.2.3 Statistical analyses

The effects of fishing intensity, depth, sediment, salinity, slope and curvature, and study area (Sea of the Hebrides, the Inner Sound and the Minch) on *F. quadrangularis* counts (FQ count) within each station were examined within a Generalised linear mixed model (GLMM) framework within the R package, lme4 (Bates et al., 2015). The data were centred relative to the median before analysis. Preliminary modelling indicated that little between-quadrat heterogeneity existed in the covariates within stations, favouring the use of station level data due to the low number of counts per quadrat. The full fixed effect model structure was:

FQ count $_{[Station]}$ ~ area + depth + fishing intensity + % mud + % gravel + salinity + slope + curvature

Survey box and station were included as random effects (McCulloch et al., 2008). Random-effects structures were compared with more parsimonious models within a GLMM framework that excluded the random effect component. Counts were modelled using a Poisson probability distribution with a log link function. Correlation between the explanatory variables was checked for collinearity using Spearman rank correlations and Variance Inflation Factors (Zuur et al., 2009). The full model was then simplified in a backwards stepwise procedure with model selection based on Akaike's Information Criteria (Akaike, 1974). The relative importance of each variable was assessed by a likelihood ratio test. Residual plots were examined for evidence of lack of fit or departures from the modelling assumptions. All statistical analyses were done in R (version 3.6.3; R Development Core Team, 2020).

3. Results

3.1 Baseline benthic monitoring

In total, 9,374 DSI quadrats were obtained during the study period. Of these DSI quadrats, 8,137 were suitable for the analysis of species abundance (Annex A, Table A.1). In addition, 3,690 minutes of quantifiable video footage were obtained (Annex A, Table A.2).

Box-level density values for the eight target species across each available box and year combination are provided in Annex A, tables A.3 – A.10 (Greathead et al., 2023). In general, target species were surveyed sporadically across the survey period using a mix of DSI and HDV footage, with gaps in spatial or temporal coverage making it difficult to detect trends in density across sites and survey years. Given the baseline nature of the survey where different sites were visited in different years, it was considered most appropriate for the spatial or temporal trends in species density at the survey box level to be reported descriptively. The exception to this is the case study for *F. quadrangularis* and *S. pallida* (Annex D), where apparent changes in species density over time were examined in a few example locations to illustrate the potential for statistical analysis based on a modelling approach.

Funiculina quadrangularis was found in the majority (22) of survey boxes (Table 5; Annex A, Table A.3) but was not encountered in nine of the original 31 survey boxes. *Funiculina quadrangularis* was most consistently recorded from S07 just south of the Sound of Canna, where it was present in all the survey years that box was visited (2012, 2014 – 2017). The highest box-level densities for *F. quadrangularis* were recorded from S10 (southwest of Rum outside the MPA), S11 (north of Rum within the MPA) and S12 (southeast of Rum and outside the MPA). The highest box-level *F. quadrangularis* density was in S12 in 2017 (0.510 $n.m^{-2}$); S10, S11 and S12 were the only locations to record box-level densities of *F. quadrangularis* greater than 0.100 $n.m^{-2}$. There were 21 box and year combinations where *F. quadrangularis* was observed but at low densities of 0.010 $n.m^{-2}$ or less. All the low density combinations occurred after 2014, except for B15 and V11 in 2014. Indeed, after 2014 all box-level densities for *F. quadrangularis* were lower than 0.100 $n.m^{-2}$, apart from box S12 in 2017, which had a density of 0.510 $n.m^{-2}$.

Table 5

Densities (n.m^{-2}) of *Funiculina quadrangularis* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *F. quadrangularis* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *F. quadrangularis* was present; full density results are available in Annex A, Table A.3.

Survey Box	2012	2013	2014	2015	2016	2017
B14	-	-	0.021	-	-	-
B15	-	-	0.010	-	-	-
S05	0.018	-	-	-	-	0.009
S06	0.048	-	-	0.006*	0.006*	0.016*
S07	0.058	-	0.074	0.003	0.003	0.006
S08	0.060	-	0.087	0.006	0	0
S09	0	-	0	-	-	0.002*
S10	0.285	-	0.303	-	-	0.082
S11	0.149	-	0.182	-	-	-
S12	0.430	-	0.295	-	0.056	0.510
S15	-	-	-	0.008*	0.019	0.012*
S17	0.011	-	-	0.026*	0.005*	0.002*
S19	-	-	-	0.029	0.031	0.011
S23	-	-	-	0.006	0	0.005
S40	-	-	-	0.047**	0.034	0
S51	-	-	-	0.075*	-	0.045
S64	-	-	-	0.073*	0.083*	-
S66	-	-	-	0.030*	-	-
S67	-	-	0	0.024*	0.017*	0.005*
S68	-	-	-	0.006**	0.008**	-
V04	-	-	0.048	-	-	-
V05	-	-	0	-	0.230*	-
V11	-	-	0.005	0.006*	0.002*	0.010*

The *F. quadrangularis* case study sought to determine whether apparent decreases in box-level density from 2014 through 2015, 2016 and 2017 were statistically significant. Density was modelled for survey boxes S07 and S08 (southern Sound of Canna) across the survey period. Significant decreases in *F. quadrangularis* were detected for both survey boxes between 2014 and all subsequent survey years (2015, 2016 and 2017). Case study details, including the outcome of statistical tests, are provided in Annex D.

Swiftia pallida was observed in approximately half (15) of the original 31 survey boxes (Table 6; Annex A, Table A.4). The highest recorded densities of *S. pallida* occurred at V05 and S16 (both south of Skye in the northeast of the MPA) and at S68 (southern part of the Sound of Canna); these were the only locations where box-level densities greater than 1.000 n.m^{-2} were recorded. The single highest box-level density for *S. pallida* was in S16 in 2013 (5.317 n.m^{-2}); this location was not surveyed in subsequent years. There were eight box and year combinations where *S. pallida* was observed but at low densities of 0.100 n.m^{-2} or less. All the low density combinations occurred after 2014, except for S03 in 2012 which was not surveyed in subsequent years. Apparent density changes over time did not demonstrate consistent patterns across boxes.

Table 6

Densities (n.m^{-2}) of *Swiftia pallida* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *S. pallida* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *S. pallida* was present; full density results are available in Annex A, Table A.4.

Survey Box	2012	2013	2014	2015	2016	2017
S03	0.007	-	-	-	-	-
S06	0.193	-	-	0.345*	0.124*	0.106*
S15	-	-	-	0*	0.011	0*
S16	-	5.317	-	0.215*	-	-
S17	0.110	-	-	0*	0.004*	0.192*
S19	-	-	-	0.636	0.319	0
S41	0.146	-	-	0.225*	-	0.193*
S46	-	-	-	0.011*	0.005*	0.023*
S64	-	-	-	0.021*	0*	-
S66	-	-	-	0.102*	-	-
S67	-	-	0	0.479*	0.098*	0.470*
S68	-	-	-	3.316**	0.615**	-
V05	-	-	1.777	-	0.302*	-
V11	-	-	0.352	0.682*	0.265*	0.613*
V12	-	-	0.798	-	-	0.403

The *S. pallida* case study sought to determine whether there were any statistically significant changes in box-level density across 2015, 2016 and 2017. Density was modelled for survey boxes S06 and S67 using available HDV data, which was only available for these three years. No significant changes in *S. pallida* were detected for survey boxes S06 and S67 (both within the Sound of Canna) between 2015, 2016 and 2017. Case study details, including the outcome of statistical tests, are provided in Annex D.

Parazoanthus anguicomus was observed in nine of the survey boxes (Table 7; Annex A, Table A.5), all of which occurred within the Sound of Canna apart from S66 (east of Rum) and V05 (south of Skye). The highest box-level densities of *P. anguicomus* were recorded in S41 in 2012 (0.216 o.m^{-2}); and S66 in 2015 (0.109 o.m^{-2}); these were the only year and box combinations where densities of *P. anguicomus* greater than 0.100 o.m^{-2} were recorded. There were eight survey box and year combinations where *P. anguicomus* was observed but at low densities of 0.010 n.m^{-2} or less; all these combinations occurred in 2016 or 2017 apart from S06 in 2012. Apparent density changes over time did not appear to demonstrate consistent patterns across boxes.

Table 7

Densities (o.m^{-2}) of *Parazoanthus anguicomus* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *P. anguicomus* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *P. anguicomus* was present; full density results are available in Annex A, Table A.5.

Survey Box	2012	2013	2014	2015	2016	2017
S06	0.004	-	-	0.015*	0.005*	0.003*
S17	0.038	-	-	0*	0*	0.002*
S19	-	-	-	0.029	0	0
S41	0.219	-	-	0.011*	-	0.007*
S46	-	-	-	0.025*	0.001*	0.013*
S66	-	-	-	0.109*	-	-
S67	-	-	0	0.017*	0.002*	0.020*
S68	-	-	-	0.039**	0.030**	-
V05	-	-	0	-	0.002*	-

Atrina fragilis was only recorded in three survey boxes in the northern Sound of Canna (S03, S04, S15) and in one survey box outside of the MPA at V11, southeast of the island of Muck (Table 8; Annex A, Table A.6). The previously unknown occurrence of *A. fragilis* at V11 was revealed during a wider survey in 2014, guided by the output of SDMs produced by Marine Scotland. *Atrina fragilis* within S03 and S04 occurs within the wider dredge spoil disposal area, whereas S15 is located outside of the localised *de facto* refugium the dredge spoil disposal site provides. The highest density of *A. fragilis* was recorded for S03 (0.691 $n.m^{-2}$) but this box was not surveyed after 2012. Box-level density for S04 appeared to decrease across 2012, 2015 and 2017 (0.075, 0.040 and 0.025 $n.m^{-2}$ respectively). Similar patterns appeared to occur for S15 across 2015, 2016 and 2017 (0.012, 0.011 and 0.007 $n.m^{-2}$) and for V11 across 2014, 2015 and 2016 (0.005, 0.001, 0.001 $n.m^{-2}$). Box-level density was lower for V11 compared to the three Sound of Canna boxes, with no live *A. fragilis* observed at V11 after 2016.

Table 8

Densities ($n.m^{-2}$) of *Atrina fragilis* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *A. fragilis* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *A. fragilis* was present; full density results are available in Annex A, Table A.6.

Survey Box	2012	2013	2014	2015	2016	2017
S03	0.691	-	-	-	-	-
S04	0.075	-	-	0.040*	-	0.025*
S15	-	-	-	0.012*	0.011	0.007*
V11	-	-	0.005	0.001*	0.001*	0*

Leptometra celtica was recorded in approximately half (15) of the original 31 survey boxes (Table 9; Annex A, Table A.7). The *L. celtica* records all occurred within the Sound of Canna apart from S66 east of Rum, S64 south of the MPA boundary, and S16 and V05 south of Skye. The highest box-level densities of *L. celtica* were all recorded from the Sound of Canna: S06 (2012, 2015 and 2017); S17 (2012, 2015 and 2016); and S67 (2014). These were the only year and box combinations where densities of *L. celtica* greater than 1.000 n.m^{-2} were recorded. The highest box-level density of *L. celtica* was for S17 in 2015 (4.236 n.m^{-2}). There were nine survey box and year combinations where *L. celtica* was observed but at low densities of 0.100 n.m^{-2} or less. Apparent density changes over time did not appear to demonstrate consistent patterns across boxes.

Table 9

Densities (n.m^{-2}) of *Leptometra celtica* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell (‘-’) denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of ‘0’ indicates that *L. celtica* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *L. celtica* was present; full density results are available in Annex A, Table A.7.

Survey Box	2012	2013	2014	2015	2016	2017
S06	3.336	-	-	1.217*	0.805*	1.221*
S08	0	-	0	0.006	0	0
S14	-	-	0.014	-	-	-
S15	-	-	-	0.020*	0	0.001*
S16	-	0	-	0.062*	-	-
S17	1.660	-	-	4.236*	1.640*	0.504*
S19	-	-	-	0	0.044	0
S40	-	-	-	0**	0.156	0.015
S41	0.219	-	-	0.479*	-	0.117*
S46	-	-	-	0.198*	0*	0.129*
S64	-	-	-	0.090*	0.039*	-
S66	-	-	-	0.514*	-	-
S67	-	-	1.139	0.479*	0.760*	0.10*
S68	-	-	-	0.311**	0**	-
V05	-	-	0	-	0.242*	-

Modiolus modiolus observations only occurred within S03 and S04, two near-adjacent survey boxes in the Sound of Canna (Table 10; Annex A, Table A.8). S03 was only surveyed in 2012, where box-level *M. modiolus* density was 0.677 n.m^{-2}. The *M. modiolus* density at S04 appeared to decrease between 2012 and 2015 (12.868 and 0.525 n.m^{-2}, respectively) with no *M. modiolus* observed in 2017.

Table 10

Densities (n.m^{-2}) of *Modiolus modiolus* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *M. modiolus* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *M. modiolus* was present; full density results are available in Annex A, Table A.8.

Survey Box	2012	2013	2014	2015	2016	2017
S03	0.677	-	-	-	-	-
S04	12.868	-	-	0.525*	-	0*

Arachnanthus sarsi was recorded in nine of the survey boxes, five within the Sound of Canna, one from S66 east of Rum, two outside of the MPA at S12 and S64 south of the MPA boundary, and one at V11 southeast of Muck (Table 11; Annex A, Table A.9). Box-level densities of *A. sarsi* were consistently low, with the highest density occurring at S15 in 2017 (0.015 n.m^{-2}). All other box and year combinations where *A. sarsi* was recorded had densities less than 0.010 n.m^{-2}. There were no consistent patterns in density apparent across boxes or years.

Table 11

Densities (n.m^{-2}) of *Arachnanthus sarsi* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *A. sarsi* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *A. sarsi* was present; full density results are available in Annex A, Table A.9.

Survey Box	2012	2013	2014	2015	2016	2017
S03	0.007	-	-	-	-	-
S12	0	-	0	-	0.005	0
S15	-	-	-	0.002*	0*	0.015*
S17	0.005	-	-	0*	0*	0.001*
S46	-	-	-	0*	0*	0.002*
S64	-	-	-	0.004*	0.001*	-
S66	-	-	-	0.001*	-	-
S67	-	-	0	0*	0.001*	0.002*
V11	-	-	0	0.001*	0*	0.006*

Pachycerianthus multiplicatus was recorded in nine survey boxes (Table 12; Annex A, Table A.10). Six of these boxes occurred within the Sound of Canna and three boxes (S10, S12 and S64) were located south of the MPA boundary. Box-level densities were low for *P. multiplicatus* at all locations. The highest *P. multiplicatus* density was 0.009 n.m^{-2}, which was recorded from S12 in 2012 and S05 in 2017. There were no apparent patterns in density across boxes or years.

Table 12

Densities (n.m^{-2}) of *Pachycerianthus multiplicatus* within the Small Isles region sampled between 2012 and 2017. *Densities calculated from High Definition Video (HDV); **Densities calculated from Digital Still Image in a year when HDV data are also available. Any empty cell ('-') denotes years in which no data are available for that survey box. Densities are reported to three decimal places; a value of '0' indicates that *P. multiplicatus* was not observed from the seabed surveyed in that box and year. Density results are only reported for boxes where *P. multiplicatus* was present; full density results are available in Annex A, Table A.10.

Survey Box	2012	2013	2014	2015	2016	2017
S05	0	-	-	-	-	0.009
S06	0.004	-	-	0.001*	0*	0*
S10	0	-	0	-	-	0.007
S12	0.009	-	0	-	0	0
S17	0	-	-	0*	0.003*	0.002*
S40	-	-	-	0**	0.003	0
S46	-	-	-	0*	0*	0.001*
S64	-	-	-	0.001*	0.003*	-
S67	-	-	0	0.002*	0.001*	0*

3.2 Assessing the impact of fishing activity on *Funiculina quadrangularis* abundance

In total, 29 boxes targeting *F. quadrangularis* were surveyed during 2017 within the Sea of the Hebrides, Inner Sound and Minch, some located within the larger PMF survey boxes described in section 3.1 (Fig. 5; Annex A, Table A.11 of the Annex Materials document, Greathead et al. (2023)). Mean densities of *F. quadrangularis* within the surveyed boxes ranged from 0.00 to 3.80 $n.m^{-2}$ over the three areas. Percentage mud ($X^2 = 2.888$, $p = 0.08$), depth ($X^2 = 3.610$, $p = 0.06$), slope ($X^2 = 13.064$, $p < 0.001$), curvature ($X^2 = 14.357$, $p < 0.001$) and area ($X^2 = 13.430$, $p < 0.01$) were found to have a significant effect on the abundance of *F. quadrangularis*. Percentage mud had a positive relationship with *F. quadrangularis* mean densities, with depth, slope, and curvature negatively related to *F. quadrangularis* density. The Sea of the Hebrides had lower densities of *F. quadrangularis* than the Inner Sound and the Minch, with the Minch recording the highest densities. Box F16 within the Minch, sited west of Lochinver, recorded *F. quadrangularis* at nearly four times (3.80 $n.m^{-2}$) the level of any other box surveyed. Fishing intensity ($X^2= 1.238$, $p = 0.26$), gravel content ($X^2= 0.355$, $p = 0.55$) and minimum salinity ($X^2 = 3.068$, $p = 0.08$) were not found to have a significant effect on *F. quadrangularis* density. To assess whether the higher densities observed at F16 were driving the relationships with environmental variables, an additional model run was conducted excluding F16 from the dataset. The removal of F16 from the dataset was not found to affect the overall structure of the final model.

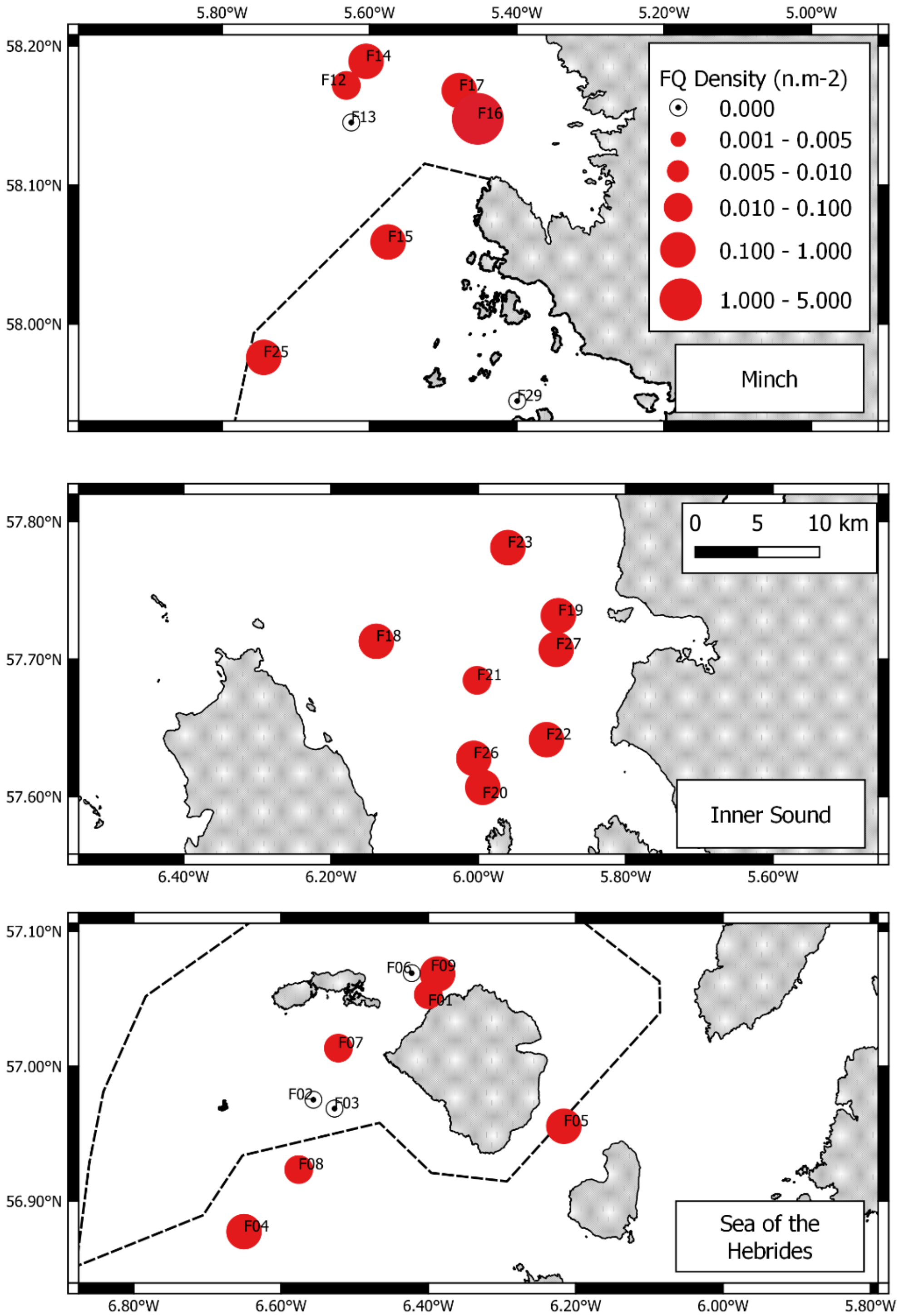

Figure 5. Mean densities (n.m^{-2}) of *Funiculina quadrangularis* recorded during the 2017 survey of the three study areas (Minch, Inner Sound, Sea of Hebrides). The red circles indicate mean densities, with larger circles representing greater densities. A mean density of '0.00' is indicated by the white circles with an inner black point. Mean *F. quadrangularis* densities and associations with multiyear priority marine feature survey boxes are shown in Annex A, Table A.11. [Contains information from Scottish Government (Marine Scotland) and NatureScot licenced under Open Government Licence v3.0, and Land Cover for Scotland Data (Macaulay Land Use Research Institute 1993)].

4. Discussion

4.1 Priority marine feature species and habitat components

The six-year Marine Scotland survey programme outlined in this report provides a baseline record of the SMI MPA at a spatial coverage and temporal resolution previously unavailable. The data analysed for this report strengthen the evidence base underpinning the Scottish MPA network and enable the further development and refinement of models, such as connectivity models, that can inform the establishment of future management measures to support an ecologically coherent network. Making these data available for such future applications is essential, thus the full dataset is archived and stored in line with the Scottish Government's Open Data Strategy and data relating to PMFs were provided to the Geodatabase of Marine features adjacent to Scotland (GeMS) curated by NatureScot. Access to the full dataset and associated information can be gained via the Marine Scotland Data Portal; DOI: 10.7489/1614-1.

The areas under survey in this study extend to waters in the SMI MPA that are deeper than previously recorded within the GeMS database, or visited in subsequent surveys (O'Dell et al., 2021), providing additional evidence on the distribution of PMF species or habitat components within the MPA. What is significant about the SMI MPA is that parts of the Sound of Canna have been not been exposed to high levels of activity from bottom-contacting towed gear historically, possibly due to challenging seabed topography and the navigational impediments created by a long-established dredge spoil disposal site (Howson et al., 2012). In this localised area the dredge spoil disposal site acts as a *de facto* refugium from the action of bottom-contacting towed gear (Shephard et al., 2012; Stirling et al., 2016). However, such refugia do not exist across the entirety of the MPA.

The findings detailed in this report confirm that the Sound of Canna has higher densities of some PMF species and habitat components, such as *S. pallida*, *P. anguicomus* and *L. celtica*, compared to other locations within the SMI MPA. For some species, the only occurrences within the SMI MPA were within the Sound of Canna. *Modiolus modiolus* was only recorded from two survey boxes within the Sound of Canna and *Atrina fragilis* was only recorded from three Sound of Canna boxes within the MPA and one box south of the MPA boundary.

Based on the survey results, *F. quadrangularis* appeared to show changes in box-level density over time. The lowest box-level densities for *F. quadrangularis* were consistently recorded after 2014, with densities of *F. quadrangularis* for all survey boxes within the SMI MPA having post-2014 values lower than 0.100 $n.m^{-2}$. The quantitative assessment of changes in *F. quadrangularis* over time for two survey boxes in the south of the Sound of Canna (S07 and S08) identified significant decreases in the density of *F. quadrangularis* between 2014 and all subsequent survey years (2015, 2016, 2017) (see Annex D of the Annex Materials document, Greathead et al. (2023)). These two boxes occurred within the boundaries of the MPA where fishing activity was apparent.

The two other species that appeared to show a decrease in density over time, *A. fragilis* and *M. modiolus*, were only encountered at a few sites and in generally low numbers. These apparent decreases in density could reflect inherent variation in the underlying data, a natural change in the suitability of environmental conditions for these species, or a response to a potential increase in human activities. Testing for these potential effects is not possible with the current dataset, particularly considering that the surveys were originally designed as the “before” stage of a BACI to assess the impact of management measures and not to provide a detailed view of all habitats and species within the SMI MPA.

The low power for detecting changes in *A. fragilis* and *M. modiolus* density reflects the challenges associated with repeatedly surveying these species over time. Both species can occur singly and in large aggregations, with *A. fragilis* reliant on soft sediment, whilst *M. modiolus* can colonise a range of substrates (Tyler-Walters and Wilding, 2017; Tyler-Walters, 2007). Patchily distributed individuals or aggregations are more likely to be missed by standard benthic survey methods relying on the drift of the vessel during the deployment of equipment, such as the surveys conducted on the MRV *Alba na Mara*. Consequently, it is possible that the apparent decreases in density for *A. fragilis* and *M. modiolus* reflect spatial gaps in survey coverage where patchily distributed individuals or aggregations were missed. From an MPA management perspective, it is worth noting that *A. fragilis* within S03 and S04 occurs within the localised *de facto* refugium provided by the dredge spoil disposal site, whereas S15 is located outside of this and has the potential to be subjected to higher fishing pressure.

For other species, such as *A. sarsi, P. multiplicatus*, *S. pallida*, *P. anguicomus* and *L. celtica*, there were no consistent patterns in density apparent across boxes or years. The quantitative assessment of changes in *S. pallida* over time for two survey boxes in the south of the Sound of Canna (S06 and S67) did not detect any significant change in *S. pallida* density between 2015, 2016 and 2017 (see Annex D). Some of the variation in density for *A. sarsi*, *P. multiplicatus*, *S. pallida*, *P. anguicomus* and *L. celtica* may, again, be an artefact of spatial gaps in survey coverage. Challenges in consistently surveying these species are linked to their biological traits, for example, a solitary lifestyle on the seafloor for the tube-dwelling anemones *A. sarsi* and *P. multiplicatus*; and a reliance on patchily distributed hard substrates such as rocks and boulders for *S. pallida* and *P. anguicomus* (Wilson, 2007; 2008). Previous work suggests that *L. celtica* has a reliance on shelly gravel (Rowley, 2007), although the SMI MPA surveys also encountered this species on other substrates. Hard substrates were often highly localised in the SMI MPA, interspersed by larger areas of habitat that would be regarded as unsuitable for many species requiring hard substrate. Ultimately, the lack of consistent density patterns for *A. sarsi, P. multiplicatus*, *S. pallida*, *P. anguicomus* and *L. celtica* points to high variability in the spatial distribution of these species on the seafloor, which complicates assessments of change in density over space and time and the use of sentinel hypothesis-based monitoring in their conservation.

The high variation in density and abundance of some target features over space and time in the Small Isles region suggests that the baseline data presented here may have limited power to inform monitoring efforts, on their own. This finding highlights the difficulties in using standard photographic and video survey methods to robustly assess the wide range of PMF species and habitat components within the SMI MPA. Subsequently, power analyses of wider monitoring efforts across the Scottish MPA network, including the study at the Small Isles, are needed to ensure that benthic monitoring can detect ecological change. The detailed *F. quadrangularis* and *S. pallida* case study (Annex D) goes some way towards demonstrating what is possible in terms of detecting significant change in survey boxes, where sufficient data are available.

Recent power analyses conducted for other marine environments indicate that very large areas with multiple replicates may need to be surveyed to detect changes in benthic species in response to anthropogenic impacts (Ardron et al., 2019). Consequently, where species are reliant on habitats with patchy distributions that are difficult to survey repeatedly over time, consideration is needed as to how the baseline data collected could be used to inform monitoring and assessment of future MPA management measures. For some species or habitats, the resolution of the data collected may not be sufficient to detect a change or deterioration in status over time or space, thus sentinel hypothesis-based monitoring may be less effective for some species.

4.2 The impact of fishing on *Funiculina quadrangularis* densities

The action of bottom-contacting towed gears is widely acknowledged as the main pressure causing activity on marine benthic ecosystems (Halpern et al., 2008; Hiddink et al., 2017; Rijnsdorp et al., 2018; Moffat et al., 2020), with the ability to cause large-scale changes in species distribution (e.g., Tillin et al., 2006; Hinz et al., 2009). However, careful design of baseline and monitoring surveys within MPAs is needed to determine if changes in density or distributions of seabed organisms and habitats result from the removal of anthropogenic pressures, such as fishing, instead of other coincidental factors.

The survey locations used in the study of the distribution of *F. quadrangularis* were selected based on suitable habitat (derived from SDMs initially but confirmed by observation) and the intensity of activity from bottom-contacting towed gear. However, despite the employment of a stratified design to limit the influence that environmental niche might play in their distribution, no effect of fishing on the density of *F. quadrangularis* was found. Anecdotally, this finding is supported by the existence of high densities of *F. quadrangularis* recorded in the Minch; nearly four times that recorded elsewhere despite this area being exposed to high levels of activity from bottom-contacting towed gear year-on-year (Annex A, Table A.11). The significant effect of environmental variables such as mud, depth, slope, and curvature on the density of *F. quadrangularis* found in our study accords with SDMs produced for this species around the West of Scotland (Greathead et al., 2015), although it should be noted that the stratified design employed in our study is likely to reduce their influence in the model.

Nevertheless, due to its erect profile and inability to retract into the substrate when disturbed, *F. quadrangularis* is thought to be particularly vulnerable to the action of the otter trawl used by the commercially important *Nephrops norvegicus* fishery (Greathead et al., 2005), which causes abrasion at the surface and deeper into the first few centimetres the seabed (Eigaard et al., 2016). In another Marine Scotland study looking at different seapen species, there was evidence of an association between trawling and a reduction in the abundance of seapens, although the authors acknowledged that the number of stations used was only just sufficient to detect this association (Harrald et al., 2018). *Funiculina quadrangularis* is a known bycatch species and has been recorded in the cod-ends of trawl nets used in the assessment of the *Nephrops* fishery (Milligan and Neil, 2010) and in other parts of trawl gear, such as the wings and top and bottom panels of the extension (Glendinning, 2012). Assessment of *F. quadrangularis* bycatch based on cod-end collection alone estimated a mean of 21 seapens being collected every hour of trawling (Milligan and Neil, 2010). A later survey including *F. quadrangularis* caught in other sections of the gear noted that bycatch of *F. quadrangularis* could be highly variable, with one trawl collecting 410 seapens from the cod end and 30 from other sections of gear, resulting in a combined mean gear value of 92 *F. quadrangularis* collected each hour of trawling time (Glendinning, 2012).

Variability in the number of seapens collected as bycatch by Glendinning (2012), despite using the same gear and methodology for survey, may suggest that *F. quadrangularis* can have a patchy distribution with localised areas of high density, which would complicate efforts to assess natural or fishing-induced changes in abundance of this species over space and time. This variability could account for the lack of a detectable change where we looked at *F. quadrangularis* density in the Sea of Hebrides (including the SMI MPA), Minch and Inner Sound. In that instance, bycatch could be expected to be dependent on the overlapping distribution and intensity of fishing with the abundance and distribution of *F. quadrangularis*. Considering that seapens were observed in our study to sometimes be lying at an oblique angle to the seabed when currents were high, it is possible that bycatch events may also be dependent on the direction of the prevailing current in relation to towing. Previous evidence does suggest that the sensitivity of other erect seapens to trawling impacts may vary depending on physical aspects such as their profile (Hill et al., 2000). It is also important to note that there is no information available on the age structure of the seapens observed on the seafloor in our study, thus it is not possible to determine if seapen mortality resulting from periodic fishing activity leads to seapens with a younger age structure occurring in areas that are more heavily fished.

In contrast to our findings relating to seapen densities, it should be noted that a recent study of *F. quadrangularis* distribution across the UK continental shelf found that the species is more likely to be recorded in areas where there had been no surface abrasion from fishing activity (Downie et al., 2021). The authors fitted SDMs for two separate eco-regions, and then used the model from one eco-region to predict to the distribution of *F. quadrangularis* in the other eco-region. Differences in fishing activity between the regions was proposed by the authors as a possible explanation for the poor model transferability that was found. Qualitative comparison of predictions and actual presences suggested *F. quadrangularis* may be restricted to sandier habitats in the Greater North Sea, compared to the muddier habitats the species prefers in the Celtic Seas Region (Downie et al., 2021). However, the hypothesis that fishing pressure caused the differences in habitat preference between the two regions was not formally tested by the authors. What is pertinent to our study is that Downie et al. (2021) only considered the effect of towed fishing activity on the distribution of *F. quadrangularis* at larger regional scales, compared to our smaller scale analysis conducted across multiple locations.

Vessel monitoring systems position data, such as those used by Downie et al. (2021) and in our study, typically have a polling rate of once every one or two hours

(Shepperson et al., 2018). For our study, this limited spatial resolution of fishing activity equates to a 0.05 x 0.05 degree grid, approximately 15 km² at 60 °N latitude. The coarse resolution of these aggregated VMS data in relation to the spatial scale of seapen records makes it difficult to quantitatively analyse the impact of fishing activity on distributions, even at regional scales (Downie et al., 2021). For example, one of the dredge spoil disposal sites in the Sound of Canna, had an annual SAR of > 3 between 2014 – 2016 according to the aggregated VMS data, even though these areas cannot be fished because of depth and topography. A threshold of 0.43 SAR (equivalent to 0.5 hours of trawling within a km over a year) is typically used as a cut-off for significant adverse impacts (ICES, 2020); where fishing effort exceeds this, the biomass of seapens, sponges and certain corals on the seafloor is low. Conversely, areas containing suitable habitat that are subject to fishing effort below the 0.43 SAR threshold would be expected to have greater seapen biomass present that could subsequently be at risk from further fishing activities (NAFO, 2016). Considering that VMS data is likely to underrepresent true levels of fishing activity for vessels under 12 m, vessels that are known to be active in all three study sites (Kafas et al., 2014), this will further confound potential associations between towed fishing and seapen density.

4.3 The future surveys of priority marine features

The development of survey equipment in-house by Marine Scotland delivered marked improvements to the survey design. The ability to switch between lander and drop frame using an integrated frame meant that surveys could be altered quickly to match survey to sea state. Considering the vast amount of footage (65 hours) taken during the SMI MPA study, the future introduction of dedicated benthic image analysis and annotation software is expected to deliver further quality assurance and archival advantages for assessing changes in species density and distribution over space and time. Engaging with the wider scientific community in the development of standardised approaches for collecting, annotating, analysing and archiving imagery data through ongoing national (e.g. The Big Picture Project: JNCC, 2021) and international (e.g. The Challenger 150 Megafaunal Image-Based Technical Working Group: Challenger 150, 2021) initiatives will also ensure the datasets generated can be combined and shared to improve the evidence base for an ecologically coherent Scottish MPA network.

The development of Autonomous Underwater Vehicles (AUVs) that can record seabed imagery across a more tightly defined transect, and target survey locations more precisely than cameras towed from a vessel, may help to counteract the high levels of variation in box-level species density associated with habitat heterogeneity. Issues relating to water clarity and excessive towing speeds when using a drop frame may be improved with the development of AUV technology. Such technology could provide uninhibited access to the survey site, which is currently a very real impediment to traditional survey techniques in locations where static fishing gear is deployed. AUV platforms can also collect accurate geospatial information on the seafloor environment using attached sensor arrays, supporting more accurate predictions of where suitable habitats may occur for species of interest. However, AUVs can have limited ability to conduct imagery surveys on topographically complex habitats, such as rock walls, and the quality of imagery data collected will still be constrained by the resolution and lighting of the camera system mounted on the AUV platform (JNCC, 2018).

The baseline data collection design presented in this report is novel in that it uses several published (Greathead et al., 2015; Stirling et al., 2016) and unpublished SDMs to direct survey effort, in addition to traditional records of observation. Using these SDMs meant that survey effort was better directed across previously un-surveyed locations, focussing on those that presented habitat conditions suited to the features of interest. This technique enabled the identification of the first *A. fragilis* aggregation located outside the Sound of Canna in Scottish waters in recent times (Stirling et al., 2016), southeast of the island of Muck. The newly discovered *A. fragilis* aggregation, which lies to the south of the SMI MPA, falls within the Sea of Hebrides Nature Conservation MPA. This MPA was designated in December 2020, although it is not likely to provide additional protection to the *A. fragilis* aggregation, given that the protected features for this MPA are basking sharks, minke whales, fronts, and the marine geomorphology of the Scottish Shelf seabed (NatureScot, 2020a). However, there is a commitment to implement protection for PMFs (such as *A. fragilis*) outside of MPAs and proposals consulted on in 2018 included the location of the *A. fragilis* aggregation to the southeast of Muck within a draft PMF management zone (NatureScot, 2018a).

5. Summary

The Marine Scotland survey programme builds on previous datasets, especially further offshore, and strengthens the growing body of evidence available to determine the biological status of the Small Isles Marine Protected Area (SMI MPA) and to inform future management of the MPA. In combination, these new and pre-existing datasets enable 1) the preliminary identification of potential changes to priority marine feature (PMF) species or habitat components over time and space, and 2) initial investigations into the effect of fishing pressure.

This study indicates that specific areas within the SMI MPA appear to be important to certain PMF species or habitat components, with some species only recorded from a small number of locations. The Sound of Canna has some of the highest recorded densities of the Northern seafan *Swiftia pallida*, White cluster anemone *Parazoanthus anguicomus*, and the Northern featherstar *Leptometra celtica* across the MPA. The Sound of Canna also provides the only known records of the Horse mussel *Modiolus modiolus* and Fan mussel *Atrina fragilis* within the SMI MPA. These results suggest that the Sound of Canna and neighbouring areas of seabed may benefit from tailored management measures for the conservation and recovery of PMF species and habitat components located there, with the aim of contributing to the regional health of these features.

A few PMF species or PMF habitat components appear to be showing decreases in density within the SMI MPA and the wider area over time. The Tall seapen *Funiculina quadrangularis* was consistently recorded at lower densities within the SMI MPA after 2014. Statistically significant decreases in *F. quadrangularis* density between 2014 and all subsequent survey years (2015, 2016, 2017) were detected for two survey boxes in the south of the Sound of Canna. Although these two boxes occurred where fishing activity was apparent, causal links between the significant decrease in *F. quadrangularis* density and fishing activity could not be tested. The assessment of *F. quadrangularis* density and distribution across the Minch, Inner Sound, and Sea of Hebrides was unable to establish linkages between density of *F. quadrangularis* and the occurrence of fishing activity despite the stratified design. Considering the wider literature, it is likely that greater spatial and temporal resolution of fishing pressure data is needed to determine conclusively if bottom-contacting towed gear causes distributional changes in *F. quadrangularis*.

The two other species that appeared to show a decrease in density over time, *A. fragilis* and *M. modiolus*, were only encountered at a few sites and in generally low numbers, making it difficult to assess if these decreases were real, a result of natural variation, or if they reflected challenges in surveying these species consistently using standard benthic ecology survey methods. The quantitative assessment of changes in *S. pallida* over time for two survey boxes in the south of the Sound of Canna did not detect any significant change in *S. pallida* density between 2015, 2016 and 2017. Other species, such as *A. sarsi, P. multiplicatus*, *P. anguicomus* and *L. celtica*, did not appear to demonstrate consistent patterns in density across boxes or years. Elucidating spatial and temporal trends for species occurring in low densities, in aggregations, or in habitats with complex patchy distributions presents different challenges compared to species with relatively homogeneous distributions.

Higher spatial and temporal resolution of biological survey data, potentially using new technology, would help to determine trends in species associated with the wide range of habitats occurring within the SMI MPA. However, where species have biological traits that make them difficult to survey repeatedly over time, sentinel hypothesis-based monitoring may be less effective. One potential alternative could be to focus monitoring efforts on the pressure-causing activities at high spatiotemporal resolution rather than attempting to consistently monitor small-scale patchily distributed biological features. Different management measures and monitoring strategies may be required to effectively conserve PMF species and habitat components with different distribution patterns.

Continued survey of the SMI MPA and surrounding region will be needed to monitor changes to PMF species or habitat components over space and time, and to assess the effectiveness of any future management measures. To ensure efficient processing and analysis of the extensive imagery data generated from continued survey efforts, new methods or approaches may need to be implemented in line with current best practice, for example the use of image annotation software, or even automated processing using artificial intelligence. Existing data archiving infrastructure will need to be maintained to ensure the underlying data continue to be stored and shared in line with the Scottish Government's Open Data Strategy, thus making these data available for further analyses of trends in PMF species and habitat components.

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Data Availability

The full Marine Scotland Small Isles MPA dataset (2012 – 2017) including the data used to create this report is archived and stored in accordance with the Scottish Government's Open Data Strategy. Data relating to Priority Marine Features (PMFs) were provided to the Geodatabase of Marine features adjacent to Scotland (GeMS) curated by NatureScot. Access to the full dataset and associated information can be gained via the Marine Scotland Data Portal; DOI: 10.7489/1614-1. The Main Report and Annex Materials document can be accessed via the Scottish Government website.

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