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Implications of defining fisheries closed areas based on predicted habitats in Shetland: a proactive and precautionary approach

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Highlights:
- Mechanism to allow proactive development of fisheries spatial management plans
- Multibeam backscatter provided good quality, accurate species maps
- Species bed definitions were defined for maerl and horse mussels
- Procedural recommendations were made for surveying existing closed areas
- Proactive closures were beneficial when backed up with acoustic surveys

Abstract

During 2010 a set of 22 voluntary closed areas, distributed around Shetland, were proposed by local industry in order to help protect and conserve threatened habitats from potential physical disturbance from scallop dredging. Initially, closed areas were implemented on a precautionary basis over predicted beds of maerl and horse mussel (Modiolus modiolus) derived from historical data. Horse mussel and maerl beds are classed as priority habitats which have been identified as being threatened and requiring conservation under the UK Biodiversity Action Plan (UK BAP). Legalisation of the voluntarily adopted closed areas occurred in 2011. Detailed surveys were conducted to map each closed area with specific reference to the defining features located within. Closed areas were surveyed using a hull mounted multibeam system and ground-truthed with an underwater camera system. Information was imported to a Geographic Information System (GIS) in order to create georeferenced habitat maps of the two species of interest. The appropriateness of each closed area was assessed and a proposed methodology and procedure outlined for any future closed areas. The primary aim was to provide information on which to test the validity of initial closed area boundaries and subsequently allow managers to refine and add to them in the future. The survey illustrated the need to have good quality acoustic and visual survey work undertaken whenever areas have been closed based on historical data and/or predicted habitats. Predicted beds were not found to be representative of the survey findings. The survey highlighted the lack of good quality, robust, accurate, and up to date species information for the waters around Shetland, especially with regard to priority marine features. Although some were neither fully protecting the UK BAP habitats they were designed to protect nor were protecting any UK BAP habitats, a degree of protection had been conferred to some priority features in the first iteration of implementation of closed areas. Survey data were subsequently used to legally alter the closed area boundaries to more appropriately reflect the distribution of priority features. Recommendations were made on appropriate procedures for defining a species bed and on the wider implications of the study’s findings for other fisheries areas developing spatial management plans.
Keywords:
Multibeam acoustic habitat mapping
Inshore fisheries management
Species bed/biogenic reef definition
Modiolus modiolus
maerl
Marine Spatial Planning

1 Introduction
National policy within Scotland is moving progressively toward de-centralised, stakeholder-driven management of inshore fisheries [1], and this will require Inshore Fisheries Groups to develop robust spatial management plans. During 2010 the Shetland Shellfish Management Organisation (SSMO), assisted by NAFC Marine Centre and in consultation with local fishermen and Marine Scotland, proposed a set of voluntary closed areas to scallop dredge fishing in order to help protect and conserve threatened habitats found within the Shetland six nautical mile zone from potential physical disturbance. Although it is generally accepted that physical disturbance from benthic trawling, such as scallop dredging, impacts both horse mussel, Modiolus modiolus, and maerl beds [for examples see; 2, 3-7], additional natural and anthropogenic factors also have the potential to cause physical changes to such biogenic beds. Modiolus modiolus beds and maerl beds are classed as priority habitats which have been identified as being threatened and requiring conservation under the UK Biodiversity Action Plan (UK BAP), listed as OSPAR habitats, and as Annex 1 habitats under the EU Habitats Directive. In Scotland, this is taken forward by the Scottish Government as part of the Scottish Biodiversity Strategy.

The location of each proposed closed area was initially based on historical point records and ‘predicted species bed’ data of M. modiolus and maerl from various sources and agencies which had been combined and collated in the Shetland Marine Spatial Plan [8]. Closed areas were initially adopted by local fishermen on a voluntary basis, the first example of such a development within the UK. Subsequent legalisation of the closed areas came into force in 2011 through legislation provided for within the Shetland Regulating Order, which empowers the SSMO to make local management decisions within six nautical miles of Shetland for all shellfisheries. Although some local fishermen disputed the presence of priority features within some of the areas proposed for closure, agreement was reached to act on a precautionary basis pending subsequent detailed survey work.

Although M. modiolus is found off all British coasts, M. modiolus beds are more commonly found on northern or western coasts [9]. Modiolus modiolus have been recorded down to 280 m depth [9] but M. modiolus beds are more commonly recorded from five to 70 m depth [10]. Modiolus modiolus are active suspension feeders, slow growing (although they have a fast growth rate in the first four to six years probably due to predation), and long lived (20 to 100 years) with a high predation pressure in the first three to six years of life [9]. Recruitment is sporadic with a variable, and sometimes unclear, spawning period [9]. Modiolus modiolus beds are sensitive to physical disturbance (natural and anthropogenic), contaminants, and natural fluctuations [9, 10] with no known studies done on the recovery of damaged beds [10].
Maerl is a collective term for several species of calcified red seaweed [11]. There are three main bed-forming species of maerl found in Scotland namely, *Lithothamnion corallioides* [12], *Lithothamnion glaciale* [13], and *Phymatolithon calcareum* [14]. Due to the difficulty in distinguishing between species, especially from video footage, the term maerl will be used throughout the manuscript. Maerl is found round most of Scotland, including Shetland [12-14], typically in water less than 20 m deep [12, 14] or in the mid-lower regions of the photic zone [13] with some live maerl found as deep as 40 m [11]. It is believed that maerl grows throughout its life at a rate of 1–2 mm/year [15] with a size limitation due to fragmentation [12, 14] and is thought to live for 20 to 100 years [12-14]. Maerl beds have a very high sensitivity to physical disturbance with recoverability listed as "Very low/none" [12-14].

The objective of the surveys conducted was to define the presence/absence of priority features and their extent within closed areas to scallop fishing and compare the results to the original predictive maps on which the areas had been based. The ultimate aim of the study was to provide information for fisheries managers to assess the validity of the existing closures and refine the local spatial management plan for the inshore fishing sector.

2 Materials and Methods
Closed areas were widely distributed around Shetland amounting to just over 24 km$^2$ of sea surface area closed to scallop dredging (Fig. 1, see also Table 4). The amount of area closed varied greatly from area to area with Area 05 being the smallest closure at 0.003 km$^2$ and Area 02a, the largest at 14.6 km$^2$. Area 02a contributed to 60% of the total area closed. Variation in size was primarily due to the type of defining feature (point or predicted bed) and the quantity of defining features reported in the area (Table 4).

On arrival at each site, the location was assessed for any potential hazards or obstructions. In some instances the closed area was close to shore but the historical data point for the defining feature was located on the land. In these instances, the closed area was surveyed as well as a large surrounding area. Care was also taken when surveying close to shore, with the majority of surveying taking place in water deeper than six metres.

Fig. 1 about here
Coverage of 200% (100% coverage in one direction with overlapping swaths combined with an additional 100% coverage perpendicular to that) was carried out at each survey area using a hull-mounted multibeam (WASSP WMB-160F) mounted aboard the NAFC Marine Centre’s vessel, *MV Moder Dy*. The multibeam was connected to its own GPS unit, a Furuno satellite compass (model: IF-NMEASC), and to a plotting system (Olex) which automatically corrected the bathymetry to the lowest astronomical tide. Once 200% coverage was achieved, the backscatter output was assessed, *in situ*, and potential ground-truthing sites were identified. Ground-truthing was carried out using a drifting, drop-down underwater video camera system (a Micro Seacam Hi-Res digital colour camera with two mini seabeam lights fitted to a custom made A-frame). The camera and lights were connected to a control box via a 200 m umbilical. Images were recorded straight to DVD from a Sony Super HAD CCD recorder with 480 TV lines resolution. Recording commenced prior to deploying the camera system over the stern of the vessel. Once at the seabed, the vessel’s track was recorded on the Olex. Duration of drifts varied depending on the site and ranged from two to 25 minutes. Video recording and
vessel track were both stopped prior to retrieval of the camera system. All DVDs were labelled and returned to the laboratory for further analysis.

Processing and analysis of the data was carried out using ArcGIS v10 and any anomalies were removed prior to processing. Bathymetry was interpolated using either the natural neighbour or spline functions in ArcGIS. In addition, hillshade and slope of the interpolated bathymetry were also calculated. Backscatter and camera drift information were imported into ArcGIS and georeferenced. Camera drifts were digitized and transformed into route data with 1 m intervals marked along each route.

Video analysis was carried out as a ‘blind analysis’ (i.e. the person analysing the video footage had no knowledge of where the sites were or what features were expected to be present). During video analysis, time stamps were noted when the camera system reached the seabed, when any distinct change in habitat type was noted, and when a species of interest was seen. In particular, time stamps were recorded for the two main habitats of interest, *Modiolus modiolus* and maerl beds. In addition to recording time stamps, an estimated percentage cover or abundance was also noted (Table 1). Each time stamp was then converted to a distance along the camera drift which could then be digitised into GIS using the route information. Conversion to a distance along the drift path assumed a constant drifting speed. In order to minimise error in the distance calculation, backscatter and bathymetry information were additionally used as a guide in locating habitats with greater accuracy. Polygons were created for each surveyed species distribution and their abundance, based on backscatter information. These were termed “Surveyed”. In addition, areas of similar backscatter output for that surveyed area were identified and termed “Potential”.

In order to estimate species abundance, a modified SACFOR abundance scale was used (Table 1). SACFOR abundance scales are semi-quantitative estimates of numbers or cover of plants and animals and were first used by Crisp and Southward [see 16]. Species abundance was assigned based on the abundance of that species within the overall area, or zone, which it occupied. Abundances were not assigned to individual time stamps or to the entire length of the drift but rather the overall period of sighting. Where a change in abundance occurred, the time stamp was recorded and a new abundance was estimated.

**Table 1 about here**

2.1 Definition of a species bed

No clear, suitable definition could be found as to what constitutes a species bed. Nor was there a clear distinction made between a species bed and a biogenic reef. In many cases these two terms were intermixed. No information could be found on either the Scottish Natural Heritage (SNH) or the Joint Nature Conservation Committee (JNCC) websites which clearly defined a species bed. After direct consultation with staff at SNH and JNCC, it was clear that although definitions of beds and biogenic reefs did exist there was not a definitive definition. Since such a definition is fundamental to develop spatial management plans, we have proposed our own definition for a species bed.

Both the Habitats Directive (SNH, personal communication) and the OSPAR Commission [17] did not distinguish between a bed and a biogenic reef and these terms remained interchangeable under the same definition with regards to *M. modiolus*. A biogenic reef would
be continuous, dense, and distinctly raised above the level of the seabed as discussed in a 1998 report [18] which defined a biogenic reef as: “Solid, massive structures which are created by accumulations of organisms, usually rising from the seabed, or at least clearly forming a substantial, discrete community or habitat which is very different from the surrounding seabed. The structure of the reef may be composed almost entirely of the reef building organism and its tubes or shells, or it may to some degree be composed of sediments, stones and shells bound together by the organisms.” This definition was also cited by OSPAR [17]. OSPAR expanded on this further by stating “Patches [of M. modiolus] extending over >10 m² with >30% cover by mussels should definitely be classed as “bed”. However, mosaics also occur where frequent smaller clumps of mussels so influence ecosystem functioning that for conservation and management purposes lower thresholds can be accepted.” [17]. Modiolus modiolus beds are a biogenic reef if they meet the above requirements; however, a maerl bed is not a biogenic reef (JNCC, personal communication). In the context of this study, both species habitats will be referred to as a bed.

For the purposes of this study a species bed was defined by amalgamating the two definitions outlined above [17, 18]. The definition for this study states:

A species (Modiolus modiolus and maerl) bed was defined as one which contained species with an abundance category of Abundant or greater (see Table 1) and distributed over a relatively large area, in the order of at least one metre across as a minimum and covering an area of more than 10 m². With regards to M. modiolus, a Common abundance (10 to 19% cover, large patches, as defined in this study) was classed as borderline and would not necessarily be classed as a bed. However, an area may be classed as a bed where a Common abundance was noted with a distribution over more than 10 m², as suggested by OSPAR [17].

The OSPAR Commission stated that “Maerl beds may be composed of living or dead maerl or varying proportions of both.” but did not definitively define the extent of the bed or the abundance of maerl required to constitute a bed [19]. In the context of this study, no distinction was made between living maerl, dead maerl, or the combination of the two, as outlined by the OSPAR Commission.

3 Results

Surveying commenced on the 14th April 2011 and concluded on 13th July 2011. A total of 20 areas were surveyed covering 20.74 km² of surface area (see Table 4). Out of the 20 sites surveyed, 12 were found to have either Modiolus modiolus, maerl, or both (Table 2 and 4). Of these 12, nine were found to have a feature within the existing closed area and only two areas, Area 01 (see Section 3.1) and Area 11b (see Section 3.8), had a closed area which completely encapsulated all the surveyed features. A total of six areas were deemed to contain at least one Modiolus modiolus bed and four areas were identified for maerl beds (Table 2). Video footage was obtained throughout the whole survey amounting to 21 hours 20 minutes of underwater footage, equivalent to 25.3 km. Surveyed species depth distribution varied in M. modiolus from 5.6 m to 39.6 m and in maerl from 8.2 m to 27.0 m (Table 2). No defining features were found in eight of the surveyed areas, namely: Areas 04, 06a, 07di, 07dii, 07diii, 09, 10, and 14.
3.1 Area 01: Cunnister
The defining features of the area included a predicted *M. modiolus* bed located in the centre of the area and a point feature to the north. The point feature to the north was not surveyed due to the shallow nature of the site and the proximity of an aquaculture site. The surveyed area covered the majority of the predicted bed with both the northern and southern limits of the survey defined by aquaculture sites. The area surveyed totalled 0.24 km$^2$. The maximum depth in the survey area was 20 m in the centre of the channel to the south of the area. The central channel was found to be relatively flat with gently sloping edges towards the shore. Four camera drifts were carried out totalling 33 minutes of underwater footage covering 669 m of seabed. *Modiolus modiolus* was recorded at varying abundances from Rare to Super Abundant (Fig. 2, Table 2) with a depth distribution of 12.6 m to 19.1 m (Table 3). The backscatter showed two distinct areas along the east and west boundaries of the surveyed area which corresponded well with the underwater video footage. There would be a high probability of finding *M. modiolus* in these areas. The area classed as Super Abundant was located within the designated feature (a predicted *M. modiolus* bed) although the predicted bed covered an area much larger than the survey results showed (Fig. 2). However, some records were located outside the area along with potential habitats identified from the backscatter. The remaining recordings were listed as Occasional or Rare (i.e. scattered individuals with no patches and few sightings).

3.2 Area 02: Yell-Fetlar
The defining features included both point and predicted bed data for *M. modiolus* and maerl. The area surveyed totalled 14.36 km$^2$. The maximum depth in the survey area was 41 m in the east of the area. The majority of the area was found to be relatively flat. Steep areas corresponded with headlands and islands with some ridge formations in the southern section of the survey site. Thirty three camera drifts were carried out totalling five hours 11 minutes of underwater footage covering 8.5 km of seabed. Both *M. modiolus* and maerl were recorded in the area at varying abundance levels (Fig. 3, Table 2). *Modiolus modiolus* showed a depth distribution of 13 to 32 m and maerl from 8.2 to 25.8 m (Table 3). Potential maerl areas were found to extend down to 34 m depth. The dominant feature found was maerl with several locations found to be Extremely Abundant. Although *M. modiolus* was recorded in the area, abundances were relatively low. However, brittlestars were Super Abundant in the upper section of Linga Sound to such a high density that it was not possible to determine what was beneath them. An association between brittlestars and *M. modiolus* was noted from other areas and it may be possible that this association was taking place in Linga Sound with a potential *M. modiolus* bed in the area. The location of such a bed would only weakly correspond with the large predicted *M. modiolus* bed indicated in the north of the area (Fig. 3). Although the majority of features were located inside the existing closed area, maerl was recorded to the south, outside the closed area, along with a potential maerl habitat defined from the backscatter. In addition to the large predicted *M. modiolus* bed in the north, a predicted maerl bed in the southwest was also indicated but no maerl was found (Fig. 3). Extensive areas of the large predicted maerl bed, used as a defining feature for the area, were found not to contain maerl. The backscatter output for this area had a distinct striped appearance. This was due to the strong tides in the area pushing the vessel off track.
3.3 Area 03: Ramnageo
The defining feature of the area was a potential maerl bed. The area surveyed totalled 0.54 km$^2$. The maximum depth in the survey area was 25 m in the south of the area. The area was found to be flat in the central section with steeper sections located closer to shore in the east and west of the surveyed area. Four camera drifts were carried out totalling 29 minutes of underwater footage covering 497 m of seabed. Maerl was located in the southern section of the survey area with an Abundant abundance (Fig. 4, Table 2) and a depth distribution of 18.8 to 23.9 m (Table 3). Two additional areas were defined for the potential of maerl to occur based on the survey outputs and had a depth distribution of 16 to 24 m. The southern sections of these areas were located outside the closed area. The predicted maerl bed used as the defining feature for the area was further north than the surveyed and potential maerl locations (Fig. 4).

3.4 Area 05: Hoo Field
The defining feature of the area was a *M. modiolus* point feature. The area surveyed covered a much greater area of 0.64 km$^2$ compared with the closed area which had a surface area of 0.003 km$^2$. The maximum depth in the survey area was 61 m in the southeast of the area. The area was found to have a gradual slope from shore to deeper water with an area of flat seabed in the north. Seven camera drifts were carried out totalling one hour 36 minutes of underwater footage covering 1.24 km of seabed. *Modiolus modiolus* was recorded in the shallower areas of the surveyed site with a varying degree of abundance from Rare to Abundant and a depth distribution of 14 to 33 m (Table 3). The closed area was found to have *M. modiolus* recorded as Abundant with additional species potential (Fig. 5, Table 2). *Modiolus modiolus* were also recorded at several areas outside the closed area with abundance ranging from Rare through to Abundant. In addition, potential habitat, as defined by the backscatter, was also identified outside the closed area (Fig. 5). The point feature used as the defining feature for the area was located in a potential habitat area adjacent to a surveyed area of Abundant *M. modiolus* (Fig. 5).

3.5 Area 06b: Sullom Voe
The defining feature of the area was a *M. modiolus* point feature. The area surveyed covered a surface area of 0.14 km$^2$. The maximum depth in the survey area was 26 m in the southwest of the area. The survey area sloped from shore to deeper water in the northwest of the site with some steep areas found in the north and south. Four camera drifts were carried out totalling 36 minutes of underwater footage covering 595 m of seabed. *Modiolus modiolus* was recorded as both Common and Abundant but not inside the closed area (Fig. 6, Table 2) with a depth distribution of 5.6 to 22.7 m for surveyed distributions and four to 26 m for potential distributions (Table 3). Three large areas were identified for the potential occurrence of *M. modiolus*, as defined by the backscatter. These areas covered the majority of the surveyed...
area. The point feature used to define the area was not located close to any of the surveyed or potential habitat areas (Fig. 6).

3.6 Area 07a: Busta Voe
The defining feature of the area was a *M. modiolus* point feature. The area surveyed covered a surface area of 0.24 km$^2$. The maximum depth in the survey area was 26 m in the south of the area. The survey area was found to slope down from the shore to deeper water where the surface was found to be relatively flat. Seven camera drifts were carried out totalling 46 minutes of underwater footage covering 615 m of seabed. *Modiolus modiolus* was recorded with an abundance of Common in two distinct areas of the backscatter (Fig. 7, Table 2) with a depth distribution of 9.2 to 20.8 m (Table 3). The larger area was located to the west of the survey site with the northern section within the closed area. Although this large area in the west was termed as Common, a recording of Abundant was noted in the south of the area. The smaller *M. modiolus* area was located to the north of the survey area. The point feature used to define the site was located in an area of Common abundance for *M. modiolus* (Fig. 7).

Fig. 6 about here

Fig. 7 about here

3.7 Area 08: West Linga
The defining feature of the area was a predicted maerl bed and a maerl point feature. The survey area covered a surface area of 0.26 km$^2$. The maximum depth in the survey area was 31 m in the central northeast of the area. The majority of the surveyed area was found to be flat with the exception of steep surfaces to the north, south, and northwest. Six camera drifts were carried out totalling 37 minutes of underwater footage covering 702 m of seabed. A Super Abundance of maerl was recorded within the survey area and within the closed area (Fig. 8, Table 2). Maerl showed a depth distribution of 18.3 to 27.0 m with areas of potential distribution found from 17 to 29 m depth (Table 3). Several areas were identified as potentials for maerl, based on the survey outputs. Three potential maerl habitats and a surveyed maerl area of Common abundance were located outside the closed area. Although the predicted bed did overlap with potential maerl habitat from the survey, and a small area of maerl with Occasional abundance, it did not accurately represent the surveyed output (Fig. 8).

3.8 Area 11: Wadbister
Area 11 was sub-divided into 11a and 11b. Defining features for both areas were predicted *M. modiolus* beds.

The survey area for Area 11a covered a surface area of 0.38 km$^2$. The maximum depth in the survey area was 29 m in the northern, central region of the area. The surveyed area was relatively flat with the exception of the southeast corner which had steep surfaces. Six camera drifts were carried out totalling 63 minutes of underwater footage covering 629 m of seabed. Both maerl and *M. modiolus* were recorded at the site (Fig. 9, Table 2). Maerl showed a depth distribution of 11.0 to 15.5 m depth (Table 3). All recordings were located in the southeast corner. Maerl was the most abundant feature with only a Rare occurrence of *M. modiolus*. Most of the features were found within the closed area with the exception of two occurrences
of Abundant maerl. No features were found within the defining feature area of the predicted *M. modiolus* bed (Fig. 3).

The survey area for Area 11b covered a surface area of 0.21 km$^2$. The maximum depth in the survey area was 39 m in the south of the area. A central ridge, protruding from land to deeper water, was clearly seen in the bathymetry which was reflected in the slope data showing steep surfaces along the ridge. The remaining surveyed area showed a slight slope. Four camera drifts were carried out totalling 37 minutes of underwater footage covering 578 m of seabed. Only one instance of *M. modiolus* was recorded (Table 2) with a depth distribution of 22.1 to 24.0 m (Table 3). The abundance was noted as Rare, with the sightings over a small area, and was found within the closed area. This did not constitute a bed, as defined in Section 2.1. This did not match with the expectation of a predicted *M. modiolus* bed which was used as the defining feature for the area.

**Fig. 8 about here**

**Fig. 9 about here**

3.9 Area 12: Weisdale and Whiteness Voes
The defining feature for the area was a point feature of *M. modiolus*. The survey area covered a surface area of 0.49 km$^2$. The maximum depth in the survey area was 31 m in the west of the area near the central channel of the Voe. The northern portion of the surveyed area was found to be deeper with a shallow bank visible in the south. The deeper area was found to be flatter with the seabed gently sloping in the south. Steep surfaces were recorded close to shore in the northeast. Nine camera drifts were carried out totalling one hour 24 minutes of underwater footage covering 1.8 km of seabed. *Modiolus modiolus* were recorded as Occasional in abundance in the shallower ground to the south of the surveyed area (Fig. 10, Table 2) with a depth distribution of 7.8 to 21.6 m (Table 3). No features were found within the closed area.

The defining feature for the area was a point feature of *M. modiolus*. The survey area covered a surface area of 0.87 km$^2$. The maximum depth in the survey area was 34.2 m in the south of the area. The area close to shore was steep with a relatively flat seabed running north-south through the centre of the surveyed area. Three camera drifts were carried out totalling 36 minutes of underwater footage covering 595 m of seabed. *Modiolus modiolus* were recorded in two areas within the closed area (Table 2) with a depth distribution of 7.2 to 19.3 m (Table 3). Both were classed as Rare in abundance and so did not constitute a bed. The point feature defining the area was located on land.

The defining feature for the area was a point feature of *M. modiolus*. The survey area covered a surface area of 0.24 km$^2$. The maximum depth in the survey area was 51 m in the south of the area. Shallower depths were recorded to the west and in the centre of the surveyed area. This was clearly seen in the bathymetry and also the slope data with deeper areas shown to be flatter. Four camera drifts were carried out totalling 32 minutes of underwater footage covering 385 m of seabed. *Modiolus modiolus* were recorded in the shallower, more rocky areas of the site (Fig. 11, Table 2) with a depth distribution of 13.6 to 39.6 m with areas of potential distribution recorded as 11 to 44 m in depth (Table 3). Abundances varied from Rare
to Super Abundant. Although a small portion of potential habitat was found within the closed area, the majority of potential and surveyed *M. modiolus* were found outside the closed area.

**Fig. 10 about here**

**Fig. 11 about here**

**Table 4 about here**

4 Discussion

The surveys revealed that in most cases there was poor correspondence between the historical data used to define closed areas and the actual distribution of the relevant priority features. In some cases fishing has been restricted in areas or parts of areas where there was no justification to do so, while in others the area was not entirely appropriate to provide protection to the full extent of priority features present. However, it should be noted that this does not imply that scallop fishing activity occurred in the areas outside of the boundaries containing features, as not all areas are fished. This study provided an opportunity to refine the existing spatial plan to better reflect the distribution of priority features within the areas surveyed, and local legislation was changed to reflect this within two weeks of data being released. Although the findings of the study showed that the initial areas defined, which were established on a precautionary basis, were not ideal, they did provide an initial starting point from which further refinements could be made.

The implementation of fisheries policies such as spatial management plans can be problematic, but the current process provides an example of an iterative, stakeholder-driven approach that may be relevant for other areas. The approach is particularly valid in the absence of full area survey coverage or the means to conduct the same, which will be the situation in most inshore fisheries areas. In the present example waiting for surveys to be completed would have delayed the establishment of the closed areas for nearly two years. The more proactive approach taken protected at least some features in the interim period, albeit at the cost of restrictions to some fishing grounds that were not necessary. The stakeholders that engaged in this process felt this precautionary approach involving the potential for unnecessary closures was an appropriate starting point, particularly when subsequent changes could be made by the local management organisation quite easily via the Shetland Regulating Order. This Order empowers the local management organisation to enforce regulations within the region without them being approved by central government. This empowerment will also facilitate the addition of any further priority features that are confirmed in the future, and the SSMO spatial management plan makes provision for this. The results also inform where additional work may need to be directed to determine the extent of beds that may have extended beyond the areas scrutinised.

The majority of the underlying data used as defining features for the closed areas came from the mid-1980s and early-1990s. The use of such point data as a guide to the location of *M. modiolus* and maerl beds is invaluable for initial site identification but care should be taken in their interpretation. This is especially the case where the data are old and, more importantly, if there is no information on the aims of the original study and methodology used in the data collection. In cases where a discrepancy between the position and/or presence of a bed has
occurred, it is not possible to determine if the long period between the data record collection and the current surveys have led to actual changes or whether the original data was inaccurate, insufficient, or flawed.

Habitat areas (predicted beds) estimated from point data, in some instances a single point (see Area 08, Fig. 8 for an example) should be treated with a degree of caution. These types of predicted beds rely on knowledge of the life history of the species (e.g. the species depth distribution) and the assumption of habitat homogeneity between points. As was discussed in the Introduction, the depth distribution of a maerl bed is considered to be, at the maximum depth, 20 m. However, living maerl has been recorded as deep as 40 m and maerl beds have also been shown to have a depth distribution related to photic depth. Photic depth varies geographically and is dependent on factors such as light intensity and water clarity, among others, which suggests maerl beds may be found deeper than 20 m. Such predictions of bed size, based on a small number of data points, always overestimate the actual size of the bed which, in this study, was not found to be a good match to the surveyed habitats (see Figs. 2-4, 8-9).

Local fishermen questioned the presence of priority features in some of the original proposed closed areas, primarily from knowledge of by-catch from the general location but also from commercial and recreational diver observations. Areas 04, 09, and 10 were all questioned and each of these subsequently failed to reveal the presence of any priority feature. The incorporation of local knowledge is a valuable guide to refining areas through subsequent survey, and in this case direct contact with fishermen has led some to suggest other discrete areas beyond those known previously that have the potential to contain priority features.

This study has shown that the proactive and precautionary approach of closing areas based on existing data of unknown quality can result in the partial protection of priority habitats while the often time consuming process of survey work is carried out. It has also shown that existing habitat data are often not accurate and that the protection of priority marine features can be greatly enhanced through the incorporation of local knowledge and stakeholder participation.

4.1 Implications of the study findings
Although this study focused on areas specifically closed to scallop dredgers in order to protect priority habitats, the findings are not only transferable but also have wider implications. There is a requirement, under the Marine (Scotland) Act and the UK Marine and Coastal Access Act, to produce a network of Marine Protected Areas (MPAs) in UK seas with an aim of protecting biodiversity. Fundamental to this would be a definitive, unambiguous, definition of what constitutes a species bed/biogenic reef. Such definitions are imperative in order to protect and conserve species and/or their habitats. This study tried to address this issue but the authors acknowledge that their definition of a bed has the potential to be refined further.

This study also highlighted the lack of good quality, recent data on the abundance and position of priority features around Shetland and demonstrated that a predicted approach to habitat mapping proved inaccurate and in many cases wrong. However, this study has shown that using such data can be of benefit in initially defining areas to protect and conserve priority features but should be followed up with a good quality acoustic, ground-truthed survey. Without such a survey, there is a high probability that closed areas may not yield optimal benefits. The utilization of multibeam echosounders to accurately map areas can be cost
effective by reducing the amount of ground-truthing required (in terms of both sampling and processing time), while increasing the quality of the habitat maps produced while covering a large area.

5 Acknowledgements

Thanks go to the crew of the NAFC Marine Centre’s vessel for their help during the survey, and to the NAFC staff who provided comments on the manuscript, particularly the definition of a bed. Thanks also go to the Shetland Shellfish Management Organisation (SSMO) for providing funds to help carry out the video analysis.

6 References

**Fig. 1.** Scallop closed areas around Shetland (dark shading). See Table 4 for further details. Area numbers are indicated.

**Fig. 2.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 01. The initial closed area (dashed border) is shown.

**Fig. 3.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 02. The initial closed area (dashed border) is shown.

**Fig. 4.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 03. The initial closed area (dashed border) is shown.

**Fig. 5.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 05. The initial closed area (dashed border) is shown.

**Fig. 6.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 06b. The initial closed area (dashed border) is shown.

**Fig. 7.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 07a. The initial closed area (dashed border) is shown.

**Fig. 8.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 08. The initial closed area (dashed border) is shown.

**Fig. 9.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 11a. The initial closed area (dashed border) is shown.

**Fig. 10.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 12c. The initial closed area (dashed border) is shown.

**Fig. 11.** Surveyed species distribution and species information, including point data and predicted beds, obtained from Map 16a of the Marine Spatial Plan for Shetland covering Area 12e. The initial closed area (dashed border) is shown.
Figure 2
Figure 4
Figure 5
Figure 6
Figure 7

Legend
- Land boundary
- Initial closed area

Surveyed species distribution
- Modiolus modiolus, Surveyed
- Modiolus modiolus, Potential
- maerl, Surveyed
- maerl, Potential

Predicted beds
- Horse mussel
- maerl

Historical species point data
- Horse mussel
- maerl
Figure 9
Figure 11
<table>
<thead>
<tr>
<th>Abundance</th>
<th><em>Modiolus modiolus</em></th>
<th>maerl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely abundant</td>
<td>&gt;80% cover</td>
<td>&gt;90% cover</td>
</tr>
<tr>
<td>Super abundant</td>
<td>50-79%</td>
<td>60-90%</td>
</tr>
<tr>
<td>Abundant</td>
<td>20-49%</td>
<td>&gt;30%</td>
</tr>
<tr>
<td>Common</td>
<td>10-19%, Large patches</td>
<td>5-30%</td>
</tr>
<tr>
<td>Frequent</td>
<td>5-9%, Scattered individuals, small patches</td>
<td>&lt;5% cover, distinct zone</td>
</tr>
<tr>
<td>Occasional</td>
<td>1-5%, Scattered individuals, no patches</td>
<td>Scattered, indistinct zone</td>
</tr>
<tr>
<td>Rare</td>
<td>&lt;1%, Few sightings along track</td>
<td>Few sightings along track</td>
</tr>
</tbody>
</table>

*Table 1.* Abundance scales, based on a modified SACFOR scale, used for *Modiolus modiolus* and maerl.
Estimated area abundance (range)

<table>
<thead>
<tr>
<th>Area</th>
<th>Modiolus modiolus</th>
<th>maerl</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Occasional (R to S)</td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Occasional (R to A)(^a)</td>
<td>Abundant (O to E)</td>
</tr>
<tr>
<td>03</td>
<td></td>
<td>Abundant</td>
</tr>
<tr>
<td>05</td>
<td>Common (R to A)</td>
<td></td>
</tr>
<tr>
<td>06b</td>
<td>Common (C to A)</td>
<td></td>
</tr>
<tr>
<td>07a</td>
<td>Common (C to A)</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td></td>
<td>Abundant (O to S)</td>
</tr>
<tr>
<td>11a</td>
<td>Rare</td>
<td>Abundant</td>
</tr>
<tr>
<td>11b</td>
<td>Rare</td>
<td></td>
</tr>
<tr>
<td>12c</td>
<td>Occasional</td>
<td></td>
</tr>
<tr>
<td>12d</td>
<td>Rare</td>
<td></td>
</tr>
<tr>
<td>12e</td>
<td>Abundant (R to S)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) A possible large *M. modiolus* bed may be located in Linga Sound (see Section 3.2).

### Table 2.
Estimated abundances, and abundance range where appropriate, of each closed area found to contain either *M. modiolus* or maerl. Abundances in bold did not constitute a bed for that species (as discussed in Section 2.1). See Table 1 for descriptions of abundances.
**Modiolus modiolus**

<table>
<thead>
<tr>
<th>Area</th>
<th>Surveyed</th>
<th>Potential</th>
<th>Surveyed</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>12.6 to 19.1 m</td>
<td>8 to 17 m</td>
<td>8.2 to 25.8 m</td>
<td>9 to 34 m</td>
</tr>
<tr>
<td>02</td>
<td>13.4 to 29.0 m</td>
<td>13 to 32 m</td>
<td>18.8 to 23.9 m</td>
<td>16 to 24 m</td>
</tr>
<tr>
<td>05</td>
<td>14.0 to 26.0 m</td>
<td>17 to 33 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06b</td>
<td>5.6 to 22.7 m</td>
<td>4 to 26 m</td>
<td>8.2 to 25.8 m</td>
<td>9 to 34 m</td>
</tr>
<tr>
<td>07a</td>
<td>9.2 to 20.8 m</td>
<td></td>
<td>18.3 to 27.0 m</td>
<td>17 to 29 m</td>
</tr>
<tr>
<td>08</td>
<td></td>
<td></td>
<td>11.0 to 15.5 m</td>
<td>11 to 13 m</td>
</tr>
<tr>
<td>11a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11b</td>
<td><strong>22.1 to 24.0 m</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12c</td>
<td>7.8 to 21.6 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12d</td>
<td><strong>7.2 to 19.3 m</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12e</td>
<td>13.6 to 39.6 m</td>
<td>11 to 44 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*b* Both *M. modiolus* (Rare) and a small area of maerl (Abundant) were recorded outside the surveyed area.

**Table 3.** Depth distribution of surveyed and potential species recordings. Abundances in bold did not constitute a bed for that species (as discussed in Section 2.1).
### Table 4

Surveyed areas comparing the total sea surface area of the closures with the total area surveyed. Species of interest found within each area are listed. Areas in bold were not surveyed.

<table>
<thead>
<tr>
<th>Area</th>
<th>Defining feature</th>
<th>Feature type</th>
<th>Closed area (km²)</th>
<th>Area surveyed (km²)</th>
<th>Species of interest found</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td><em>M. modiolus</em></td>
<td>Point and bed</td>
<td>2.03</td>
<td>0.24</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>02</td>
<td><em>M. modiolus</em></td>
<td>Point and bed</td>
<td>14.63</td>
<td>14.36</td>
<td>Both</td>
</tr>
<tr>
<td>03</td>
<td>maerl</td>
<td>Bed</td>
<td>0.41</td>
<td>0.54</td>
<td>maerl</td>
</tr>
<tr>
<td>04</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>1.66</td>
<td>0.12</td>
<td>None</td>
</tr>
<tr>
<td>05</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.003</td>
<td>0.64</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>06a</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.009</td>
<td>0.29</td>
<td>None</td>
</tr>
<tr>
<td>06b</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.08</td>
<td>0.14</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>07a</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.02</td>
<td>0.24</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>07b</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07c</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07d</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.01</td>
<td>0.17</td>
<td>None</td>
</tr>
<tr>
<td>07di</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.01</td>
<td>0.11</td>
<td>None</td>
</tr>
<tr>
<td>07dii</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.01</td>
<td>0.13</td>
<td>None</td>
</tr>
<tr>
<td>08</td>
<td>maerl</td>
<td>Point and bed</td>
<td>0.09</td>
<td>0.26</td>
<td>maerl</td>
</tr>
<tr>
<td>09</td>
<td><em>M. modiolus</em></td>
<td>Bed</td>
<td>0.29</td>
<td>0.45</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td><em>M. modiolus</em></td>
<td>Point and bed</td>
<td>0.25</td>
<td>0.40</td>
<td>None</td>
</tr>
<tr>
<td>11a</td>
<td><em>M. modiolus</em></td>
<td>Bed</td>
<td>0.28</td>
<td>0.38</td>
<td>Both</td>
</tr>
<tr>
<td>11b</td>
<td><em>M. modiolus</em></td>
<td>Bed</td>
<td>0.11</td>
<td>0.21</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>12c</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.01</td>
<td>0.49</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>12d</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.010</td>
<td>0.87</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>12e</td>
<td><em>M. modiolus</em></td>
<td>Point</td>
<td>0.01</td>
<td>0.24</td>
<td><em>M. modiolus</em></td>
</tr>
<tr>
<td>13</td>
<td>maerl</td>
<td>Point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td><em>M. modiolus</em></td>
<td>Bed</td>
<td>0.10</td>
<td>0.46</td>
<td>None</td>
</tr>
</tbody>
</table>

TOTAL  20.02  20.74

c Area 07d had a sea surface area of 4.16 km² however, this was defined by three point features of *M. modiolus*. The point features were surveyed individually as Areas 07d, 07di, and 07dii. The overall surface area for the closed areas would be 24.15 km².