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# Data Mining of the *Nephrops* Survey Database to Support the Scottish MPA Project

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## Summary

Marine Scotland Science conducts annual underwater television surveys to estimate the abundance of *Nephrops norvegicus* on muddy sediments in seas around Scotland. Underwater footage is recorded to DVD and reviewed by two independent observers. *Nephrops* burrows are counted and burrow densities over each survey tow are estimated from the average counts and viewed area. Additional data are also collected during the surveys, including sediment samples and observations on sea pen abundance, presence of fish and other benthic species and evidence of anthropogenic activities (trawl marks). All survey data are held in a purpose designed database, the '*Nephrops* survey database'.

In 2010, following discussions with Scottish Natural Heritage and the Joint Nature Conservation Committee, it was agreed that data within the *Nephrops* survey database would be used to assist with the Scottish Marine Protected Area project, specifically the mapping of burrowed mud and offshore deep mud habitats (biotopes). This report documents work carried out, including summaries for each area surveyed and maps based on Geographic Information System layers.

## Introduction

The Scottish Marine Protected Area (MPA) project is a joint initiative overseen by Marine Scotland Planning and Policy, involving Marine Scotland Science (MSS), Scottish Natural Heritage (SNH), the Joint Nature Conservancy Council (JNCC) and Historic Scotland, established to provide advice to Scottish Ministers on the selection of MPAs in the seas around Scotland. MPAs are part of the Scottish Government's three pillar approach to marine nature conservation, which is based on species conservation, site protection and wider seas policies and measures<sup>1</sup>. To support government objectives, SNH and JNCC have developed lists of Priority Marine Features (PMFs), habitats and species of conservation importance, and identified a subset of PMFs to be applied as search features in the MPA designation process (JNCC, 2012). Burrowed mud is a broad habitat search feature and further information on this habitat and component biotopes and species (which include sea pens and burrowing megafauna), in both Scottish territorial and offshore waters, is required to inform MPA site selection (MPA Network Report, 2011).

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<sup>1</sup> <http://www.scotland.gov.uk/Topics/marine/marine-environment/Conservationstrategy/>

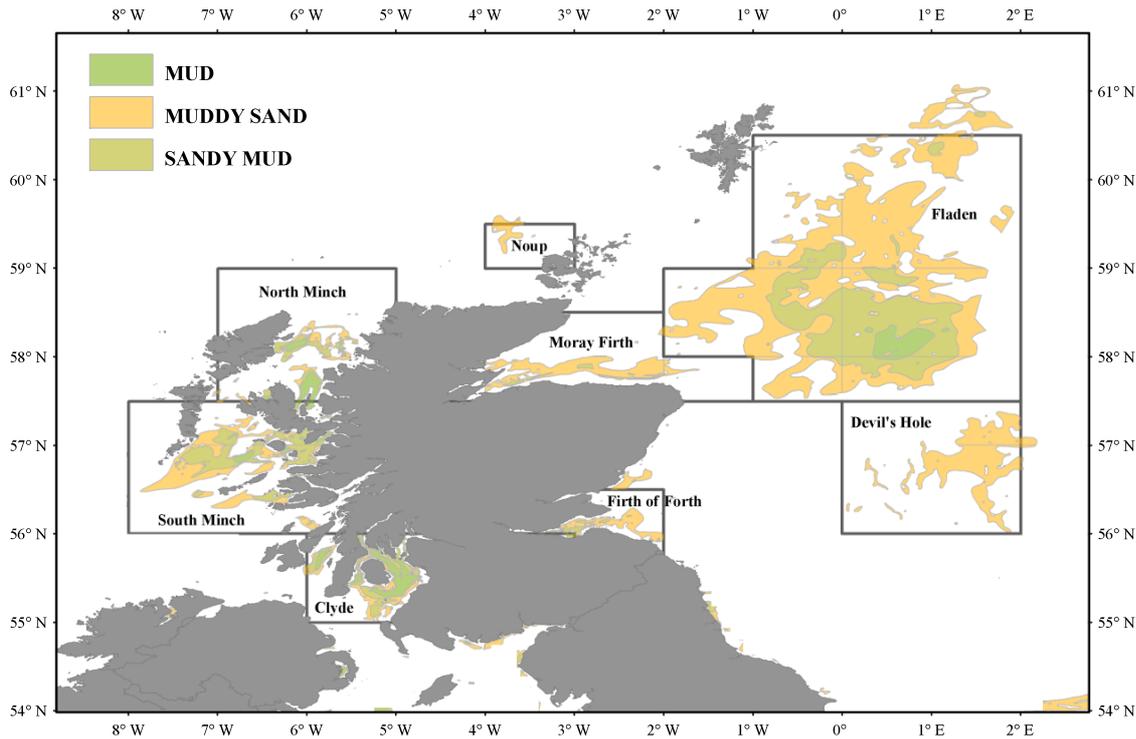
Marine Scotland Science conducts underwater television (UWTV) surveys of areas of burrowed mud around Scotland, on an annual basis, to assess stocks of the Norway lobster, *Nephrops norvegicus*. In August 2010, during discussions with SNH and JNCC, it became evident that the data collected during these surveys could usefully contribute to the MPA project. It was agreed that MSS would collate and explore data to:

- Generate Geographic Information System (GIS) layers based on available information, including mapping analysed sediment samples collected from surveys conducted between 2008 and 2010.
- Provide information on the distribution and abundance of *N. norvegicus* and sea pens, *Funiculina quadrangularis*, *Virgularia mirabilis* and *Pennatula phosphorea*.
- Provide information for shelf edge, deep water and sea loch areas where available.
- Compare the two scoring systems used by MSS and JNCC to assess sea pen abundance.
- Produce a written report on work carried out.

This report describes the 'data mining' work carried out. It includes background information on the *Nephrops* UWTV survey and summary information on the mud habitat in the main survey areas, including photographs and maps based on the GIS layers provided to JNCC and SNH. Various meetings were held to discuss and refine data outputs and interim data sets were provided during the course of the work, as detailed in Annex A.

### **MSS *Nephrops* UWTV Surveys**

*Nephrops* are burrowing megafauna, limited in their distribution by the extent of muddy sediment in which they construct their burrows. Within the main *Nephrops* assessment areas (referred to as functional units) (Figure 1), the sea bed areas surveyed are, in most cases, based on sediment distribution as mapped by British Geological Survey (BGS). The survey design is randomly stratified, with strata based on sediment type (BGS criteria; mud, muddy sand and sandy mud) and/or geographical divisions.



**Figure 1:** Nephrops functional units and distribution of mud sediments (from British Geological Survey, 2002) around Scotland.

*Nephrops* UWTV surveys were first carried out by MSS in inshore waters on an experimental basis in 1989 and surveys at Fladen started in 1992. In more recent years, survey effort has been focused in the main functional units, i.e. Fladen, Moray Firth, Firth of Forth, North and South Minch and the Clyde and latterly in the Sound of Jura and the Devil's Hole. The location and the precise number of stations surveyed in each functional unit vary from year to year. Other mud areas at Noup, Stanton Bank and in west coast sea lochs are surveyed periodically. Footage of offshore deep mud has also been collected opportunistically on MSS deepwater surveys which are primarily trawl surveys for deepwater finfish species.

The survey method, which was developed by MSS, typically involves the use of a purpose built sledge (Figure 2), which is deployed from a research vessel and towed along the sea bed at speeds of 0.6 to 1 knot for ca. 10 minutes. The sledge is equipped with lights, and both video and stills cameras, plus equipment to record the station depth, the height of the sledge (and camera) above the seabed and distance travelled during the tow. During each tow, approximate counts of *Nephrops* burrows are made and other species and features observed are noted. The footage, which is recorded onto DVD, is subsequently reviewed and *Nephrops* burrows are repeat counted according to agreed protocols by at least two individuals working independently (ICES, 2008). Average burrow densities are raised to the known area of stock distribution (typically based on sediment data) and these are then adjusted to account for known biases (ICES, 2007; ICES, 2009) to provide absolute estimates of *Nephrops* abundance.

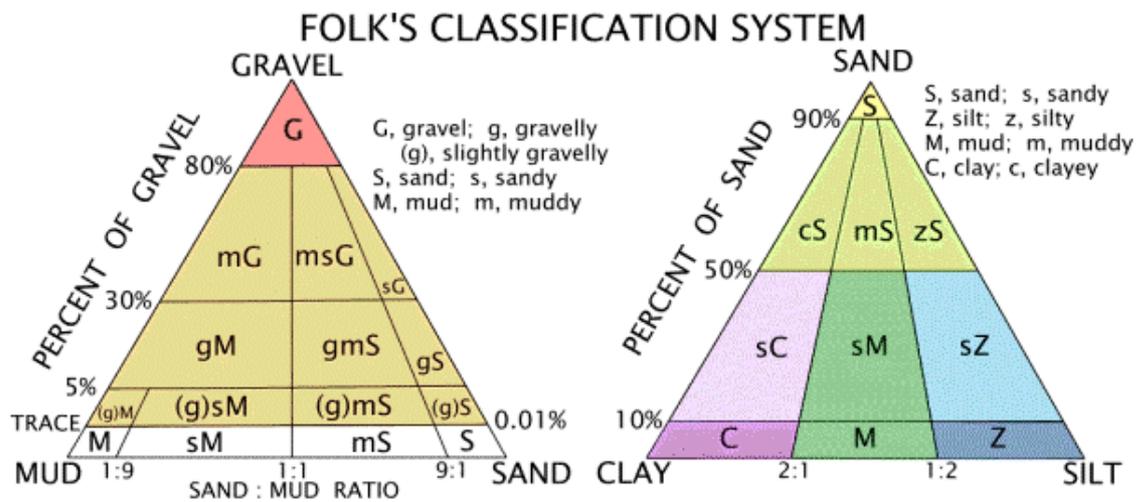


**Figure 2:** UWTV sledge used to survey *Nephrops* populations around Scotland.

At some of the deepwater survey stations it was not possible to deploy the UWTV sledge because of unsuitable sea conditions (large swells lifting the sledge off the seabed) and unknown ground type (possibility of rocks). Sea lochs are also potentially hazardous because they are confined areas, shallow and often densely creelred. In these situations areas were surveyed using a drop-frame arrangement, suspended approximately one metre above the sea bed and allowed to drift with the ship. Although sea bed UWTV footage was obtained, when using the drop frame it was not possible to derive reliable density estimates for any species or features observed because the viewed area can not be accurately calculated.

### **Sediment Sampling and Particle Size Analysis**

In addition to the information on *Nephrops*, various ancillary data and samples are collected during the surveys, notably sediment samples for particle size analysis (PSA). These are collected at the end of each UWTV run using a mini van Veen grab attached to the sledge, or occasionally using a Day grab if the mini-grab fails or the ground is unsuitable. A sub sample of sediment is frozen at sea in preparation for PSA. In the laboratory, samples are freeze dried and analysed using a laser diffraction granulometer to determine the particle size distribution of the sediment sample. All samples are analysed following United Kingdom Accreditation Service (UKAS) approved operating procedures. The Folk (1954) classification scale (Figure 3) is used to describe the sediment type. In terms of *Nephrops* habitat, the sediments of interest are 'muddy sand', 'sandy mud' and 'mud'. 'Muddy sand' is roughly equivalent to sediment comprised of 10-50% silt and clay, 'sandy mud' 50-90% silt and clay and 'mud' 90% or higher silt and clay.



**Figure 3:** The system devised by Folk (1954) is based on two triangular diagrams. It has 21 major categories and uses the term 'mud' (defined as silt plus clay). Diagram from United States Geological Survey website.

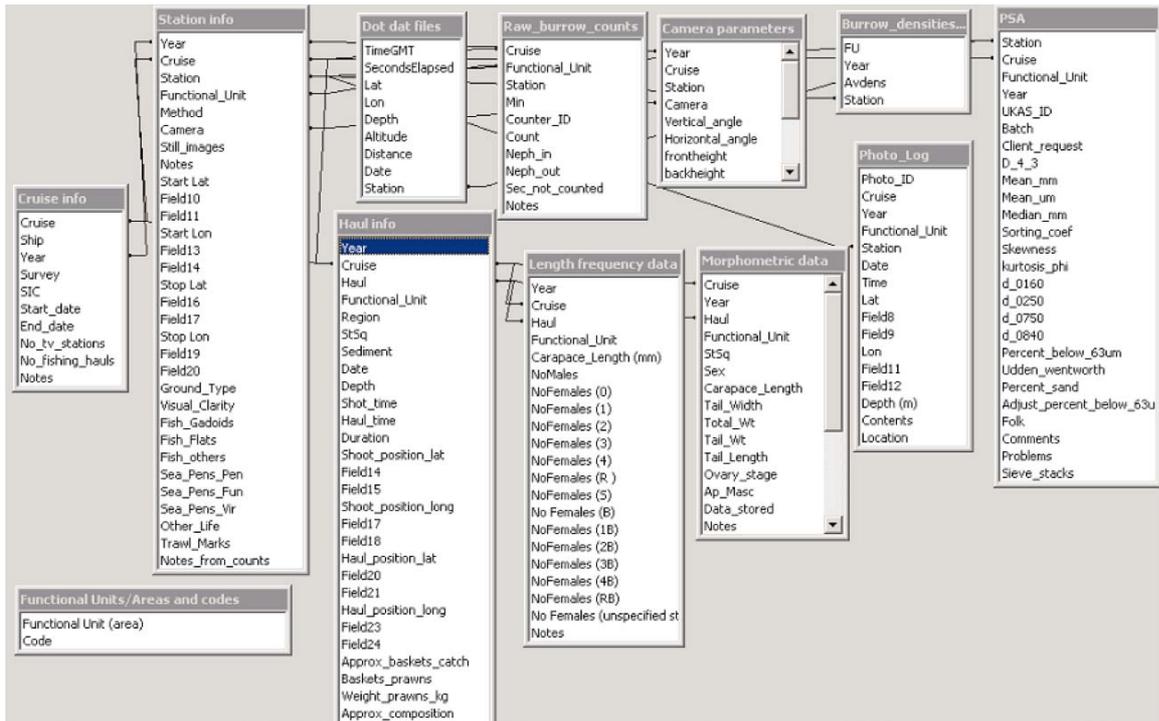
### Sea Pen Abundance and Other Observations

Since 2005, MSS has assessed the abundance of three species of sea pen, *F. quadrangularis*, *V. mirabilis* and *P. phosphorea*, according to a four point scale (Table 1). This assessment is made at the time the UWTV footage is reviewed and is based on the reviewers' overall impression of the occurrence of sea pens throughout the run. Prior to this (in 2003 and 2004), only information on the presence or absence of sea pens was noted during the review process. Other fish and benthic species observed during UWTV runs are also recorded, although these are not routinely quantified or consistently identified to genus or species. Evidence of anthropogenic activities e.g. trawl marks is also recorded.

### Data Mining

#### *Nephrops* Survey database

Initially, much of the work carried out for the MPA data mining project involved populating MSS' *Nephrops* survey database with all the data available from the recent UWTV surveys, i.e. those conducted from 2008 to 2010, inclusive. The database was developed with Microsoft Access and consists of twelve tables which can be broadly separated into those concerned with UWTV survey data and those containing trawl data (Figure 4). Relevant tables for this study included "Station info" which contains spatial information for each UWTV station and details on the occurrence of sea pens and other fauna and flora, and "PSA" which contains the results of the sediment analysis. Relationships are established between tables so that the database can be queried quickly and required data extracted. The *Nephrops* survey database was in its infancy at the time the data mining project was initiated and incorporation of (historical) data from earlier surveys continues as 'work in progress'.



**Figure 4:** Layout and relationships between tables in the *Nephrops* survey database.

### Comparison of MSS' ROCA and SACFOR abundance scales

A second aspect of the work was to compare MSS' ROCA abundance scale (Table 1) with the six point MNCR (Marine Nature Conservation Review) SACFOR (Super abundant, Abundant, Common, Frequent, Occasional, Rare) scale used by JNCC, to record the abundance or density of a variety of benthic flora and fauna. For the SCAFOR scale, different ranges of densities apply depending on the size of the organism (Table 2).

**Table 1**

ROCA abundance scale used by MSS. The scale is applied to *V. mirabilis*, *P. phosphorea* and *F. quadrangularis*.

Description	
Rare	Just a few (1-5) over the 10 minute run.
Occasional	A handful over the 10 minute run (a couple of dozen).
Common	Observed all the time, every few minutes.
Abundant	In almost all frames, multiples in frames.

**Table 2**

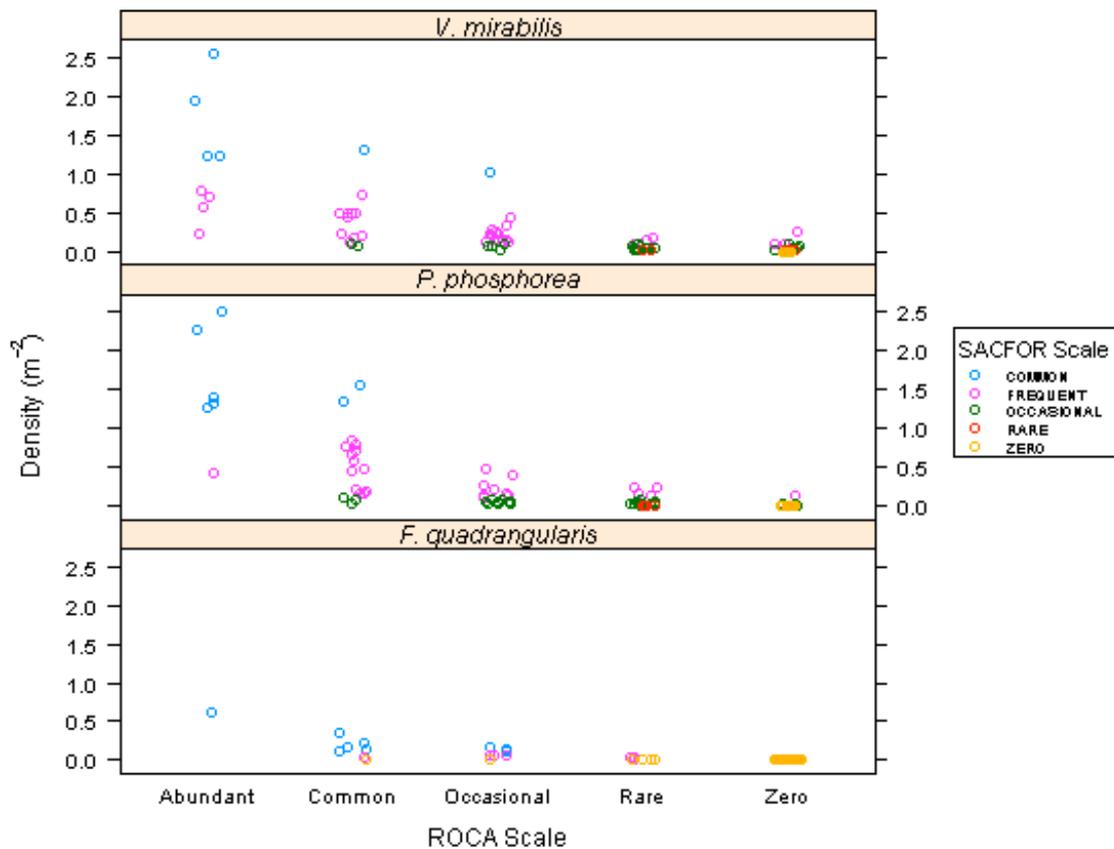
SACFOR abundance scale used by JNCC, with corresponding densities ( $\text{m}^{-2}$ ) for *V. mirabilis*, *P. phosphorea* and *F. quadrangularis*.

	<i>V. mirabilis</i> , <i>P. phosphorea</i> ( $\text{m}^{-2}$ )	<i>F. quadrangularis</i> ( $\text{m}^{-2}$ )
<b>Super Abundant</b>	100.0 – 1000.0	10.0 – 100.0
<b>Abundant</b>	10.0 – 100.0	1.0 – 9.0
<b>Common</b>	1.0 – 9.0	0.1 – 0.99
<b>Frequent</b>	0.1 – 1.0	0.01 – 0.09
<b>Occasional</b>	0.01 – 0.09	0.001 – 0.009
<b>Rare</b>	0.001 – 0.009	0.0001 – 0.0009

This comparison involved re-examination of footage from 82 survey stations at which sea pen abundance had been previously assessed according to the MSS' ROCA scale. The stations for review were recorded on five UWTV cruises over a two year period (2009 and 2010) and, therefore, a number of MSS staff had been involved in assessing the sea pen abundance. Footage was selected from the main Scottish *Nephrops* functional units (Firth of Forth, Moray Firth, Fladen, Devil's Hole, North Minch, South Minch, Sound of Jura and Clyde) and included the full range of abundance levels (from zero to abundant) for each sea pen species and a range of visibility levels (from poor to excellent). Each species (*V. mirabilis*, *P. phosphorea* and *F. quadrangularis*) was counted separately and counts were expressed as densities ( $\text{m}^{-2}$ ) for the ten minute run, where the viewed area was estimated as the product of the distance travelled by the sledge during the tow and the width of the viewed area (assumed to be 1 m, no adjustments were made for the sledge lifting or sinking).

Figure 5 shows the sea pen densities for each station, coloured to indicate the SACFOR scale classification. Sea pen densities, as determined from counts, were consistently within ranges for the 'Common', 'Frequent' or 'Occasional', classifications on the SACFOR scale. There were no stations where sea pens species would be classified as 'Abundant' or 'Super Abundant' on the SACFOR scale. At stations where sea pens were classified as 'Abundant' on the ROCA scale, densities were within the SACFOR 'Common' or 'Frequent' category. Densities of *V. mirabilis* and *P. phosphorea* with ROCA classifications of 'Common' and 'Occasional' were predominantly in the SACFOR 'Frequent' category. Densities of *F. quadrangularis* in the ROCA 'Common' displayed good agreement with 'Common' on the SACFOR scale.

Although the two scales were comparable, it was decided that the MSS' ROCA scale observations, as held in the *Nephrops* survey database, would be used to describe the sea pen abundance in each area.



**Figure 5:** Comparison of ROCA and SACFOR abundance scales at 82 stations for sea pens *P. phosphorea*, *V. mirabilis* and *F. quadrangularis*.

### Data Layers

Once all relevant data had been entered into the database, various data sets were extracted and ArcView was used to assemble and display spatial data and produce data layers. These were based on 1,205 stations, surveyed during nine dedicated *Nephrops* UWTV survey cruises carried out by MRVs, *Scotia*, *Clupea* and *Alba na Mara* between 2008 and 2010 (Table 3). The stations (plus seven sediment day grab sites) were in the Firth of Forth, Arbroath area, Moray Firth, Fladen, Devil's Hole, North Minch, South Minch, Clyde, Sound of Jura and west coast sea lochs.

Data from a further 214 stations in sea lochs, bays and tidal inlets on the west coast of Scotland, surveyed from MRVs *Clupea* and *Alba na Mara* in 2008 and 2010 (Table 4) and UWTV footage from 205 stations at Rockall, Anton Dohrn Seamount, Rosemary Bank, Shelf Edge and St. Kilda Basin, recorded on drop frame deployments during eight deepwater cruises from MRV *Scotia* between 2000 and 2009 (Table 5), were also included.

**Table 3**

Number of stations surveyed on *Nephrops* UWTV survey cruises, 2008-2010.

Year	Cruise	Vessel	No. Stations
2010	0110a	<i>Alba na Mara</i>	124 + 7 day grabs
2010	0710s	<i>Scotia</i>	237
2010	1110a	<i>Alba na Mara</i>	92
2009	0109a	<i>Alba na Mara</i>	82
2009	0809s	<i>Scotia</i>	199
2009	1309a	<i>Alba na Mara</i>	103
2008	0108c	<i>Clupea</i>	83
2008	0708s	<i>Scotia</i>	192
2008	0808a	<i>Alba na Mara</i>	93

Separate data layers were produced for *Nephrops* burrow densities, sea pen occurrence (based on MSS' ROCA scale), depth, sediment type (from PSA or observations) and presence of trawl marks. Other features likely to be of conservation interest, for example deep water areas where corals were observed, were also mapped. A project timeline including GIS layer packages provided to JNCC and SNH are detailed in Annex A. Summary descriptions of the burrowed mud in the main *Nephrops* functional units and other species observed are provided below.

**Table 4**

*Nephrops* UWTV sea loch cruises, areas surveyed and number of stations in 2008 and 2010.

Year	Cruise	Vessel	Area	No. Stations
2010	0110a	<i>Alba na Mara</i>	Chairn Bhain	6
			Eddrachillis Bay	13
			Glen Coull	8
			Glen Dhu	11
			Gruinard Bay	24
			Inchard	22
			Laxford	11
			Little Loch Broom	15
			Loch Broom	21
2008	0108c	<i>Clupea</i>	Inner Sound Applecross	3
			Inner Sound Broadford	2
			Inner Sound Crowlin	3
			Inner Sound Pabay	2
			Inner Sound Raasay	3
			Inner Sound Scalpay	3
			Loch Alsh	3
			Loch Carron	8
			Loch Duich	6
			Loch Hourn	6
			Loch Kishorn	3
			Loch Nevis	10
			Loch Torridon	22
Sound of Sleat	9			

**Table 5**

Number of *Nephrops* UWTV stations surveyed on deepwater cruises, 2000-2009.

Year	Cruise	Vessel	No. Stations
2000	1400s	<i>Scotia</i>	29
2002	1302s	<i>Scotia</i>	20
2004	1204s	<i>Scotia</i>	16
2005	1205s	<i>Scotia</i>	42
2006	1406s	<i>Scotia</i>	32
2007	1307s	<i>Scotia</i>	23
2008	1108s	<i>Scotia</i>	13
2009	1209s	<i>Scotia</i>	30

### Mud Biotopes - Area Summaries/Descriptions

#### Firth of Forth

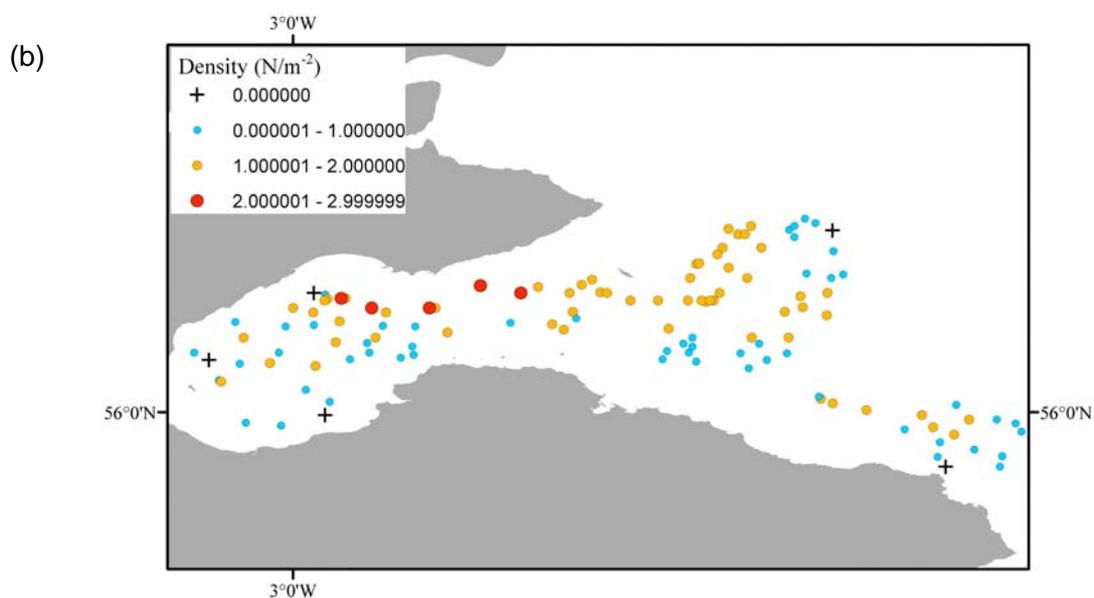
A total of 132 stations were surveyed in the Firth of Forth (43 in 2008; 48 in 2009 and 41 in 2010). Depth readings were available for 91 stations and ranged from 7 m to 79 m. Shallower stations were located in the southern region of the inner Firth of Forth whilst the deepest stations were in the outer Firth of Forth.

*Nephrops* burrow entrances tend to be smaller than those observed in the Fladen (Figure 6a). Mean *Nephrops* burrow densities were calculated for 122 stations and ranged from 0 to a maximum of 2.89 burrows m<sup>-2</sup> (Figure 6b). Most stations had a burrow density of less than 2 burrows m<sup>-2</sup>.

Particle size analysis was carried out on samples obtained at 130 stations. Of these, 104 stations are described by the Folk scale (1954) as 'muddy sand', 21 stations as 'sandy mud' and five stations as 'sand'. These results were mostly in agreement with the BGS maps, with the exception of the 'sand' results which the BGS described as 'muddy sand'. Sediment grabs were not possible at two sites where substrate was described by observation as 'mussel shells' and 'rocks'.

*F. quadrangularis* were observed at one station in the Firth of Forth in 2008, at a station where the sediment observation was 'mussel shells'. *P. phosphorea* were present at 55 stations and *V. mirabilis* at 56 stations, with both species recorded as 'Rare', 'Occasional', 'Common' or 'Abundant'. All records of 'Abundant' were stations in the outer Firth. *P. phosphorea* and *V. mirabilis* were found together at 31 stations.

Gadoids were present at 46 stations and flatfish at 45. Other marine fauna were recorded at most stations; they included *Goneplax rhomboids*, *Liocarcinus* sp., sea anemones and starfish. Trawl marks were observed at 22 stations, mostly in the deeper water in the outer Firth.



**Figure 6:** (a) Photograph of Firth of Forth seabed with typical *Nephrops* burrow complexes. (b) Map showing *Nephrops* burrow densities 2008-2010.

### Arbroath

Fifteen stations were surveyed off Arbroath between 2008 and 2010. Depth data were available for seven of these stations and ranged from 27 m to 87 m, with shallower stations closer to the shore. *Nephrops* burrows were present at eight of the stations; however, burrow densities have not been calculated for this area as it is not a functional unit and not considered in the stock assessment. Thirteen sediment samples underwent PSA; 12 stations were described as 'muddy sand' and one station as 'sand'. Sediment grabs were not possible at two stations where substrate was observed as 'rocks' and 'sandy with stones'. Gadoids were present at nine stations and flatfish in eight. Sea pens and trawl marks were not observed during any of the UWTV runs but the visual clarity was described as 'poor' in nine runs.

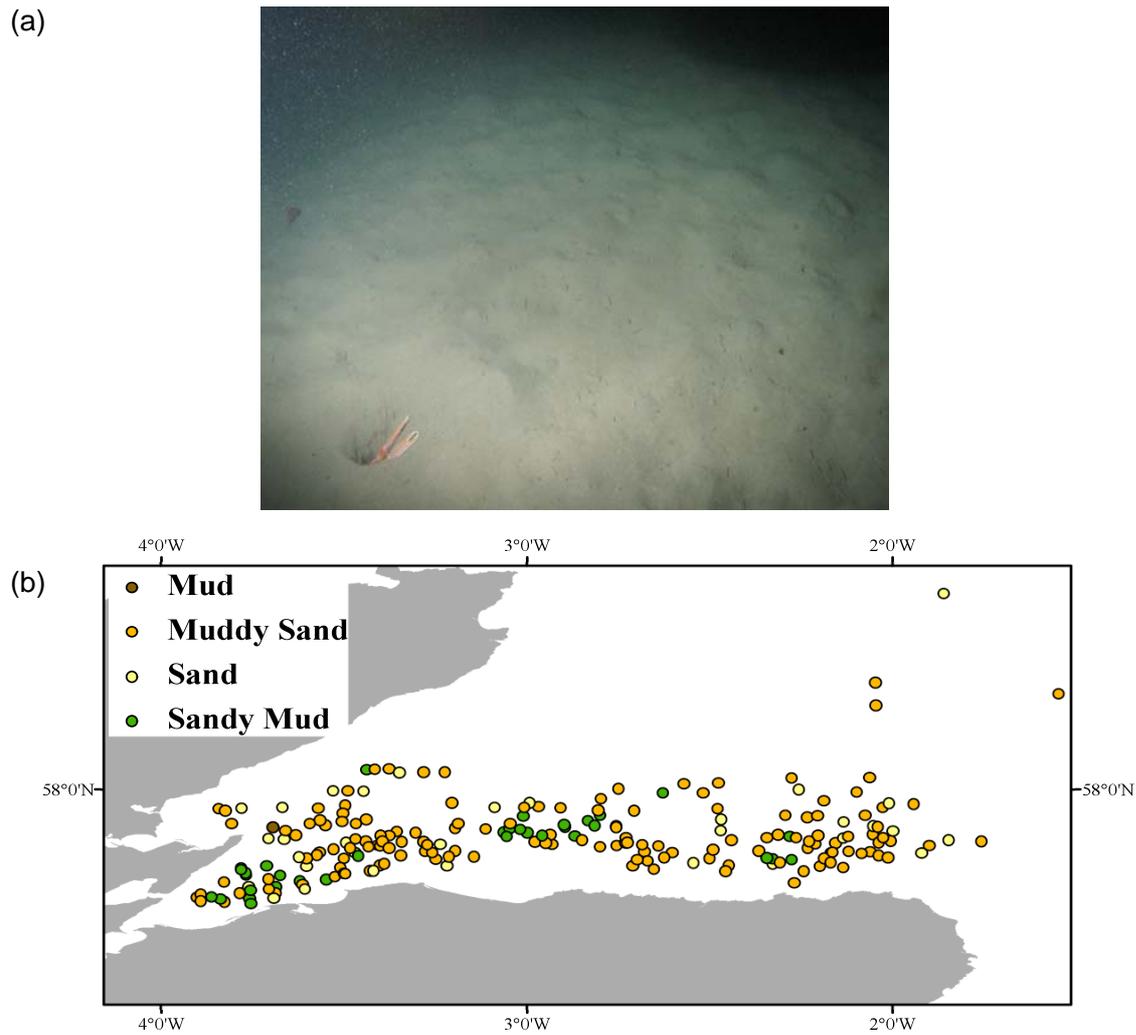
## Moray Firth

Data were available from 223 stations in the Moray Firth, of which 82 were surveyed for sediment mapping only (no *Nephrops* burrow or sea pen density estimates). Station depth (available for 211 stations) ranged from 18 to 229 m. The shallowest stations were in the inner Moray Firth and the deepest stations in the Southern Trench in the eastern Moray Firth.

*Nephrops* burrow densities, calculated for 135 stations in the Moray Firth, ranged from 0 to 1.2 burrows m<sup>-2</sup>. *Nephrops* burrow entrances are smaller than those observed in the Fladen (Figure 7a) and the majority of stations had a burrow density of less than 0.52 burrows m<sup>-2</sup>.

Particle size analysis on samples from 215 stations classified 148 stations as 'muddy sand', 34 as 'sandy mud', 32 as 'sand' and only one station was classed as 'mud' (Figure 7b). Sediment grabs were not possible at eight stations where observed ground types were 'rocks' (three stations), 'hard ground' (two stations), or 'sand with stones' (three stations). There were numerous discrepancies between BGS maps and PSA results concerning distribution of 'muddy sand' and 'sand'.

*F. quadrangularis* were not observed in the Moray Firth (Table 6). *V. mirabilis* were observed at 15 stations but were never recorded as 'Abundant'. *P. phosphorea* was present at 67 stations but only 'Abundant' in one station in the outer Moray Firth. Gadoids were observed at 79 stations and flatfish in 74. Other species observed included *G. rhomboides*, hermit crabs and starfish. Trawl marks were observed at three stations.



**Figure 7:** (a) Photograph of typical Moray Firth seabed with a *Nephrops* in burrow. (b) Map showing PSA results for 2008, 2009 and 2010.

**Table 6**

Number of stations where sea pens *P. phosphorea*, *V. mirabilis* and *F. quadrangularis* were observed for each functional unit (n = number of stations reviewed).

<b>FUNCTIONAL UNIT</b>	<b><i>P. phosphorea</i></b>	<b><i>V. mirabilis</i></b>	<b><i>F. quadrangularis</i></b>
Firth of Forth (n= 132)	55	56	1
Moray Firth (n=141)	67	15	0
Fladen (n=203)	150	147	1
Devil's Hole (n=39)	24	24	0
North Minch (n=176)	52	36	67
South Minch (n=104)	40	31	62
Sound of Jura (n=24)	5	6	0
Clyde (n=119)	10	38	16

## Fladen

The Fladen is the largest of the *Nephrops* functional units and is located in the central northern North Sea. Between 2008 and 2010 a total of 203 stations were surveyed. The majority were at depths of between 92 and 160 m, although depths of 266 m were recorded at one station surveyed in 2010. Deeper stations tended to be in the south east corner of Fladen.

*Nephrops* burrow densities (201 stations) ranged from 0 to 1.01 burrows m<sup>-2</sup>. Slightly higher densities were found in the south eastern corner of the Fladen ground. *Nephrops* burrow entrances tend to be larger than other functional units (Figure 8a).

Particle size analysis results for 201 samples described 110 stations as 'muddy sand', 87 stations as 'sandy mud' and four stations as 'sand' (Figure 8b). The 'sandy mud' was generally found in the south eastern corner. There were discrepancies between the PSA results and BGS maps because no 'mud' was revealed by PSA. Grabs were unsuccessful at two stations; one UWTV run was abandoned and the other station was described as 'sand with stones'.

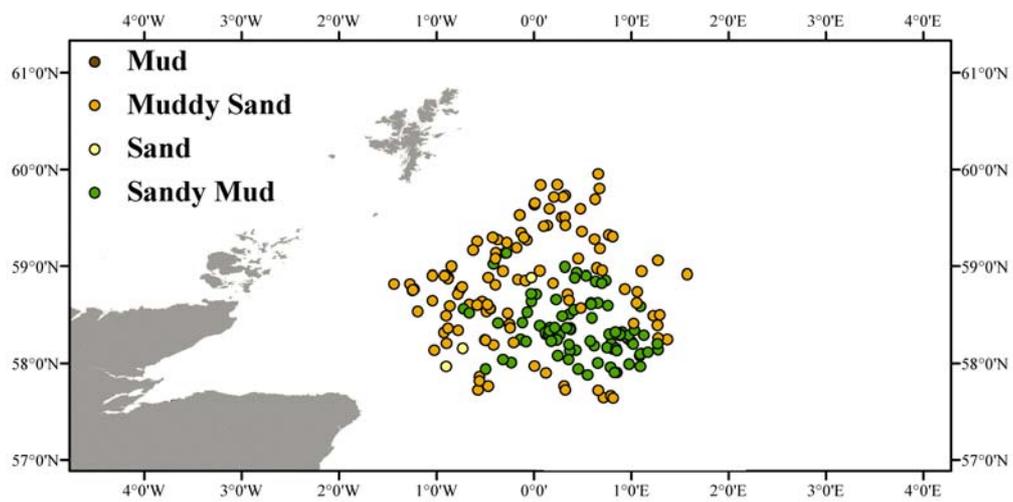
Sea pens were present at 169 stations in the Fladen. *F. quadrangularis* were observed at one station towards the centre of the Fladen ground in 2010 (Figure 8c), on a substrate characterized as 'sand'. *P. phosphorea* were observed at 150 stations and *V. mirabilis* at 147 stations. These two species were observed together at 118 stations.

Gadoids were observed at 83 stations and flatfish at 143 stations. Other species frequently noted include hagfish, rockling, dragonet, starfish, crabs and anemones. Trawl marks were observed at 65 stations.

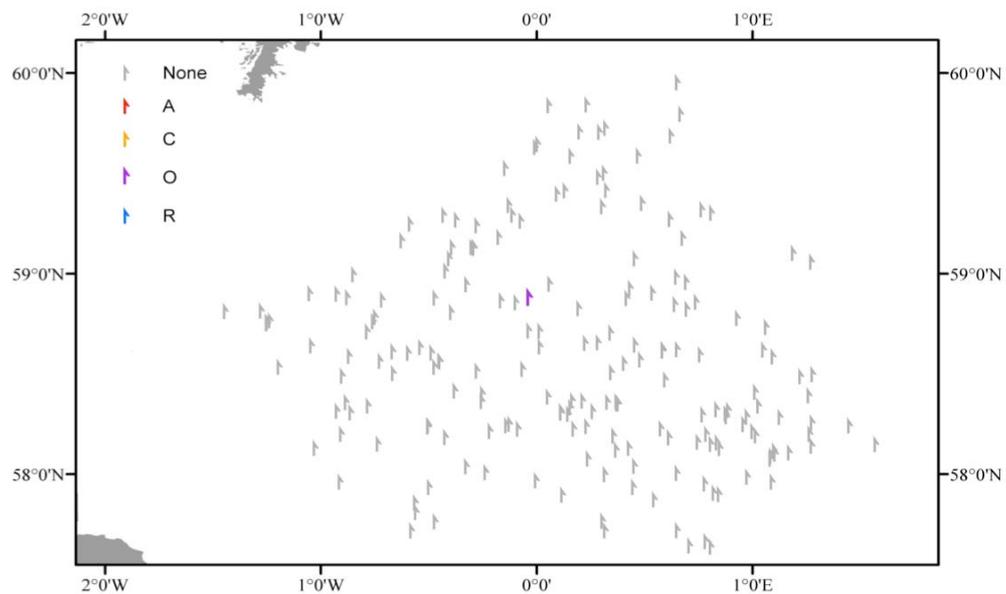
(a)



(b)



(c)

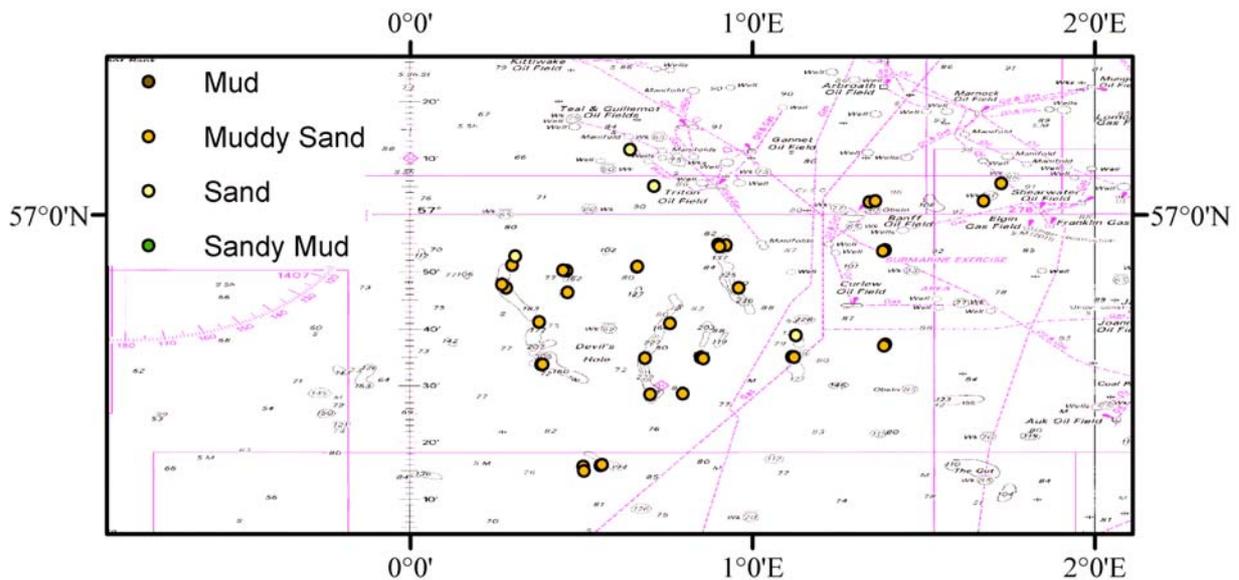


**Figure 8:** (a) Photograph of typical Fladen seabed with *Nephrops* burrow. (b) Map showing PSA results for 2008-2010. (c) Map showing abundance of *F. quadrangularis* observed 2008-2010.

## Devil's Hole

The Devil's Hole is an area to the south of Fladen which consists of several isolated deep trenches with 'muddy' sediments on the sea floor. The surrounding seabed is on average approximately 90 m deep but the 'holes' have very steep sides and can be 230 m deep. The area was surveyed in 2009 and 2010 with a total of 39 stations. *Nephrops* burrows were present at 35 stations, predominantly on 'muddy sand' substrate (one station on 'sand'). Particle size analysis described 'muddy sand' at 35 stations and 'sand' at four (Figure 9). This was mostly supported by the BGS maps with the exception of six stations which BGS described as 'sand' and PSA results showed as 'muddy sand'.

*F. quadrangularis* was not observed at the Devil's Hole but *P. phosphorea* and *V. mirabilis* were observed at 24 stations, occurring together at 17 stations. Gadoids were present at 11 stations and flatfish at 27. Other species observed include hagfish, rockling, hermit crabs and starfish. Trawl marks were noted at 12 stations.



**Figure 9:** A map showing PSA results for samples obtained during *Nephrops* UWTV surveys carried out in 2009 and 2010 in the Devil's Hole.

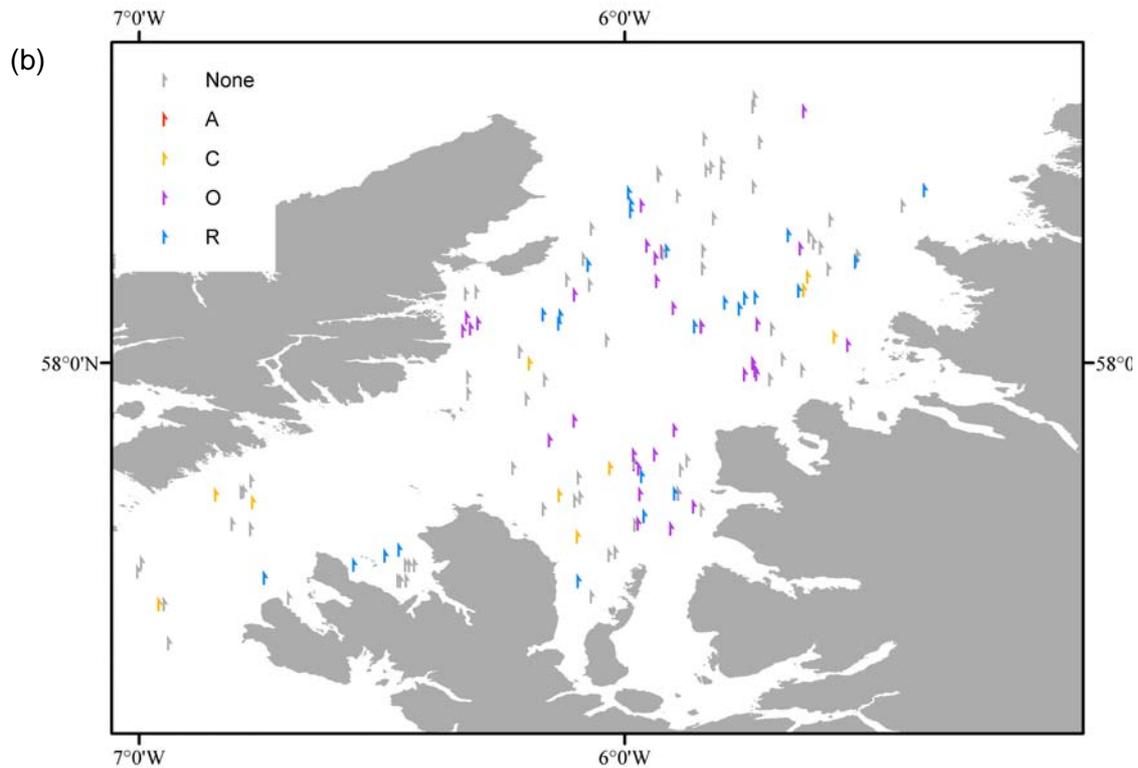
### North Minch

The North Minch is the sea area on the west coast of Scotland between the main-land and the Outer Hebrides, to the north of Skye. Between 2008 and 2010, 139 stations were surveyed, ranging in depth from 50 m to 295 m. *Nephrops* burrow entrances in this area usually appear smaller than those observed in the Fladen, with densities from 0 to 1.91 burrows m<sup>-2</sup>. In most areas, high densities of burrows made by other species, including *Calocaris*, resulted in sediment resembling 'Swiss cheese' (Figure 10a).

Particle size analysis results for 128 samples were 'muddy sand' (62 stations), 'sandy mud' (44 stations), 'mud' (18 stations) and 'sand' (four stations) with occasional patches of rock and hard ground (observations at 11 stations). The sediment type as assessed by PSA showed many discrepancies when compared to the BGS maps, especially in the area to the east of the Isle of Lewis where substrate was described as 'sand' by the BGS maps but revealed as 'muddy sand' by PSA.

*P. phosphorea* were recorded at 52 stations, *F. quadrangularis* at 67 stations and *V. mirabilis* at 36 stations. *F. quadrangularis* were observed as 'Rare', 'Occasional' or 'Common' but never as 'Abundant' (Figure 10b). Gadoid fish were observed at 64 stations and flatfish at 48 stations. Other species commonly observed included hermit crabs, crabs, sea cucumbers, urchins, fan worms, anemones and starfish. Trawl marks were recorded on 22 stations.

(a)



**Figure 10:** (a) Photograph of typical North Minch seabed with characteristic ‘Swiss cheese’ appearance of burrows and *V. mirabilis* sea pens. (b) Map showing abundance of *F. quadrangularis* observed on *Nephrops* UWTV surveys 2008-2010.

### South Minch

The South Minch is on the west coast of Scotland and located to the south of the North Minch. It comprises sheltered coastal regions and areas of more open water, and includes a

diverse range of sediment types and habitats. A total of 104 stations at depths ranging from 30 to 251 m were surveyed in the South Minch between 2008 and 2010.

*Nephrops* burrow entrances in the South Minch are smaller than those in the Fladen (Figure 11a) and high densities of burrows made by other species were typically observed. *Nephrops* burrow densities were between 0 and 1.3 burrows m<sup>-2</sup>.

Particle size analysis was carried out for samples collected at 97 stations. Sediments were classified as 'sandy mud' (51 stations) and 'muddy sand' (41 stations) with patches of 'sand' (three stations) and 'mud' (two stations). Sediment grabs were not possible at seven stations where ground type was described as 'rock' (five stations), 'hard ground' (one station) and 'seaweed/growth on harder substrate'. Sediment results were similar to the BGS maps except for a patch of 'mud' as described by BGS was analysed to be 'sandy mud' by PSA.

*P. phosphorea* were observed at 40 stations and classified mainly as 'Rare' or 'Occasional'. *V. mirabilis* were present at 31, and *F. quadrangularis* at 62 stations. *F. quadrangularis* was observed as 'Abundant' at only one station but noted as 'Common' at 16 stations, 'Occasional' at 26 stations and 'Rare' at 19 stations (Figure 11b). Gadoids were reported on 47 stations and flatfish on 38 stations. Other commonly observed species included: crabs, anemones, hermit crabs, squat lobsters, fan worms, shrimps and starfish. Trawl marks were observed at 28 stations.

## Sound of Jura

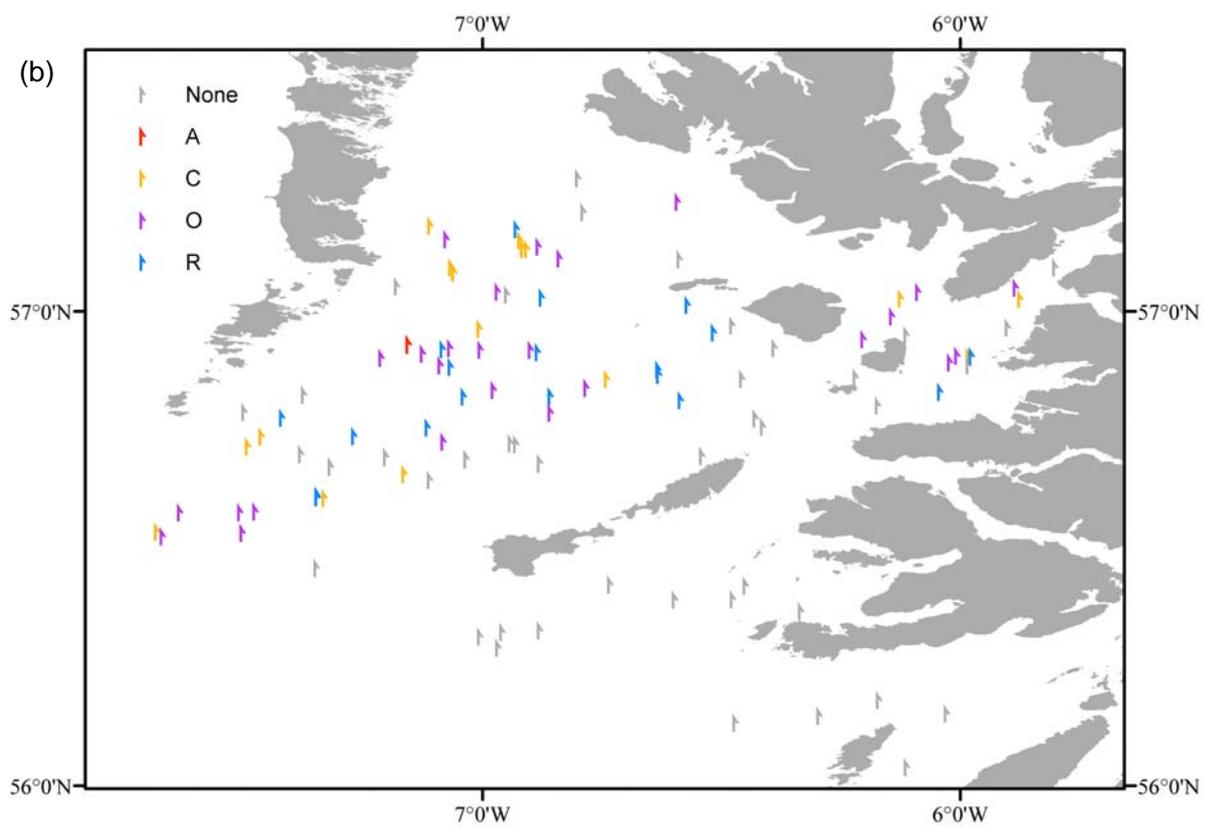
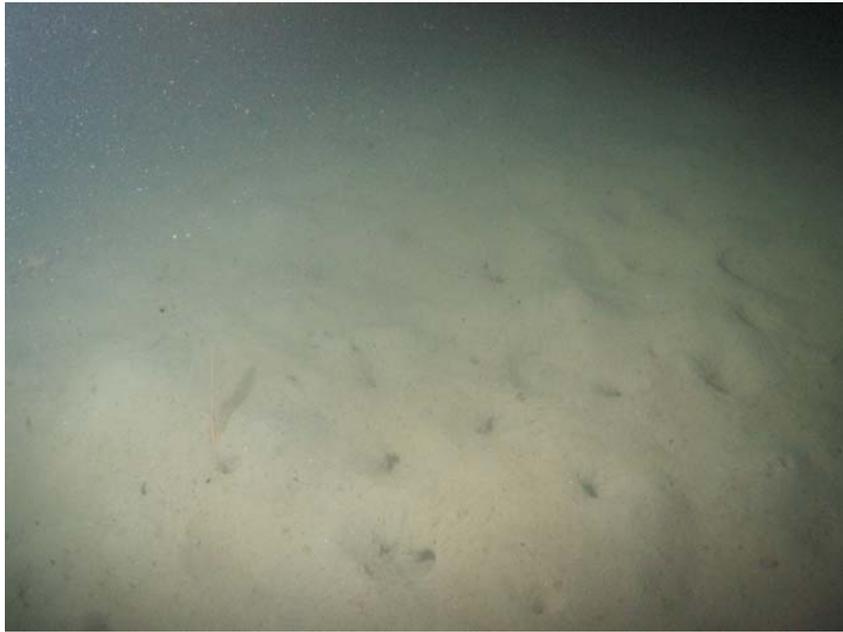
The Sound of Jura is a small strait on the west coast of Scotland between the Knapdale peninsula and the Isle of Jura. Data from 24 stations, 12 surveyed in 2009 and 12 in 2010, at depths ranging from 47 to 150 m were available in this area. *Nephrops* burrow entrances are generally larger than the South Minch (Figure 12a) and burrow density is also higher, ranging from 0.5-2.04 burrows m<sup>-2</sup>, with few other species burrow types observed.

Sediments were classified as 'muddy sand' on 10 stations and 'sandy mud' on 14 stations and differed slightly to the BGS maps as our PSA results did not reveal any true 'mud' (Figure 12b).

*P. phosphorea* were observed as 'Rare' at three stations and 'Occasional' at two, and *V. mirabilis* were observed as 'Rare' at two stations, 'Occasional' and 'Common' at one station each and 'Abundant' at two stations.

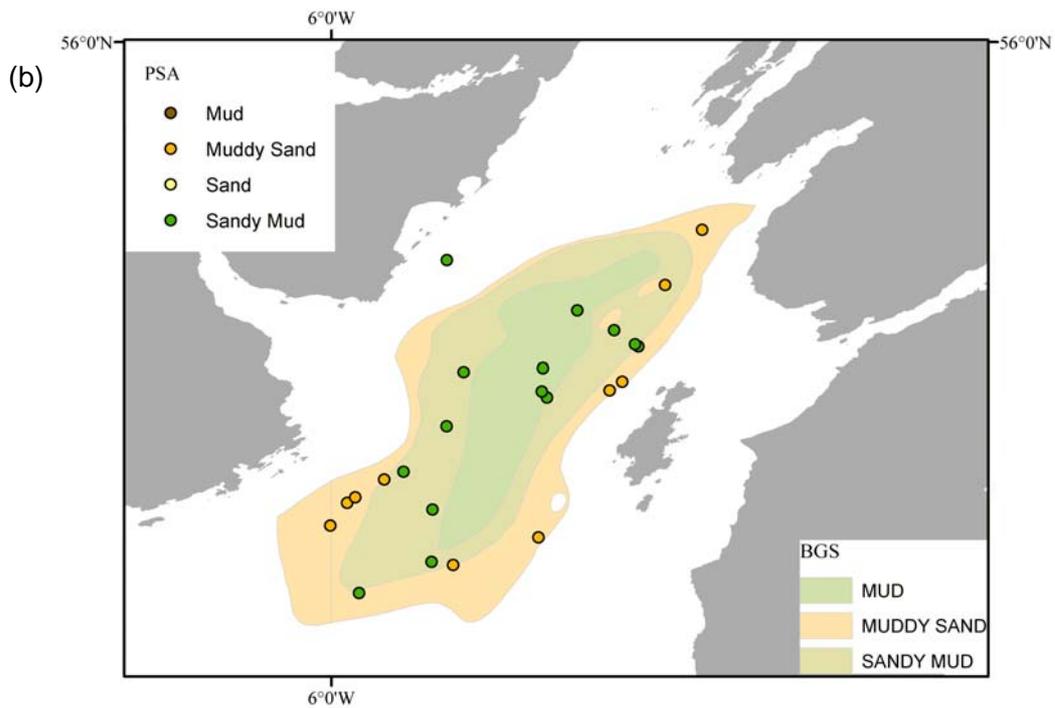
Gadoids were observed in seven UWTV runs and flatfish in six. Other species noted included shrimps, fan worms and anemones.

(a)



**Figure 11:** (a) Photograph of typical South Minch seabed with *Nephrops* burrows complexes. (b) Map showing abundance of *F. quadrangularis* (based on ROCA scale) observed in the South Minch on *Nephrops* UWTV surveys 2008-2010.

(a)



**Figure 12:** (a) Photograph of typical Sound of Jura seabed with *Nephrops* burrow and a *Nephrops* outside burrow. (b) Map showing PSA results for *Nephrops* UWTV stations surveyed in 2009-2010 overlaid on BGS map showing distribution of 'muddy' sediments (British Geological Survey, 2002).

## The Clyde

The Clyde was surveyed in 2008 (40 stations), 2009 (40 stations) and 2010 (39 stations). Stations depths ranged from 37 to 165 m and shallower stations were generally those to the south of Ailsa Craig.

High densities of *Nephrops* and other burrows, including those made by *Calocaris*, produce sediment resembling 'Swiss cheese' (Figure 13a). Visual clarity in the Clyde area is usually 'poor' because of the amount of suspended particles in the water column. *Nephrops* burrows appear smaller than burrows found in other functional units and burrow density is generally higher in the Clyde to the south of Ailsa Craig (up to 2.05 burrow m<sup>-2</sup>).

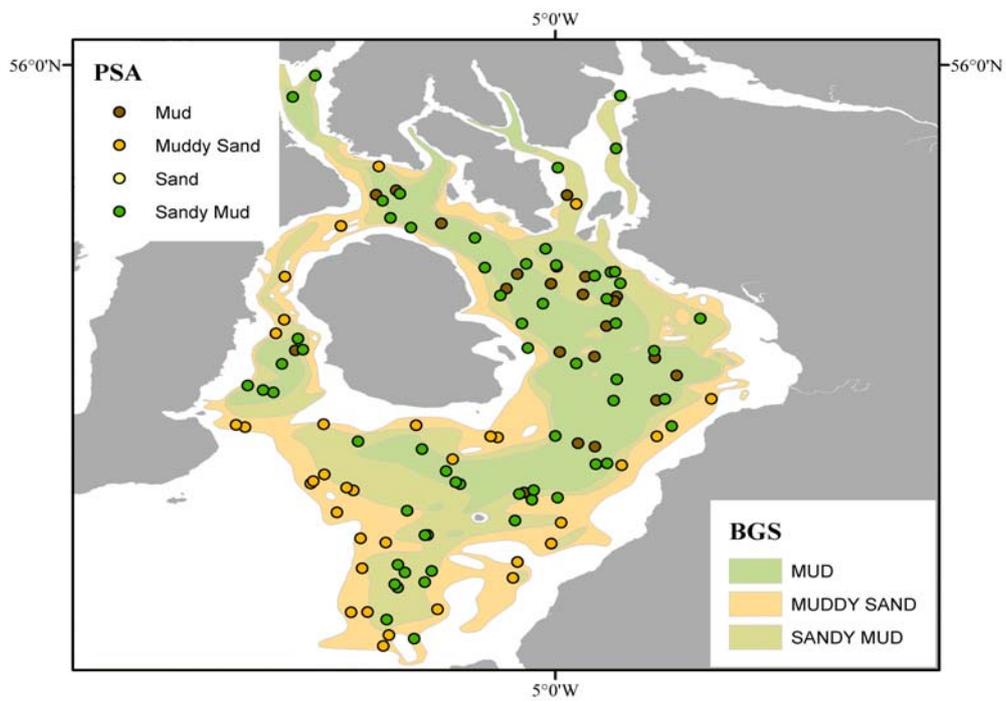
Particle size analysis classified 62 stations as 'sandy mud', 34 stations as 'muddy sand' and 21 as 'mud'. Muddy sand was predominantly found to the south of Ailsa Crag, with 'sandy mud' and 'mud' located to the north east of the Clyde (Figure 13b). Discrepancies between PSA and BGS maps occurred between PSA 'sandy mud' and BGS 'mud'. Grabs were not possible at two stations where 'rocks' were observed.

All three species of sea pens were observed in the area, *P. phosphorea* at 10 stations, *F. quadrangularis* at 16 stations and *V. mirabilis* at 38 stations. Gadoids were observed in 23 and flatfish in 44 UWTV recordings. Other species occasionally observed included brittle stars, hermit crabs, starfish, urchins, anemones, queen scallops, crabs and fan worms.

(a)



(b)



**Figure 13:** (a) Photograph of typical 'poor' visibility and 'Swiss cheese' appearance of sediment in Clyde. (b) Map showing PSA results from 2008-2010 surveys in the area, overlaid onto BGS map showing distribution of 'muddy' sediments (British Geological Survey, 2002).

## West Coast Sea Lochs

A total of 214 stations in various sea lochs, bays and tidal inlets on the west coast of Scotland were surveyed in two cruises in 2008 and 2010. Station depths ranged from 10 m to 204 m. All 83 UWTV stations were reviewed for 2008 but only nine UWTV stations have been reviewed from the cruise in 2010.

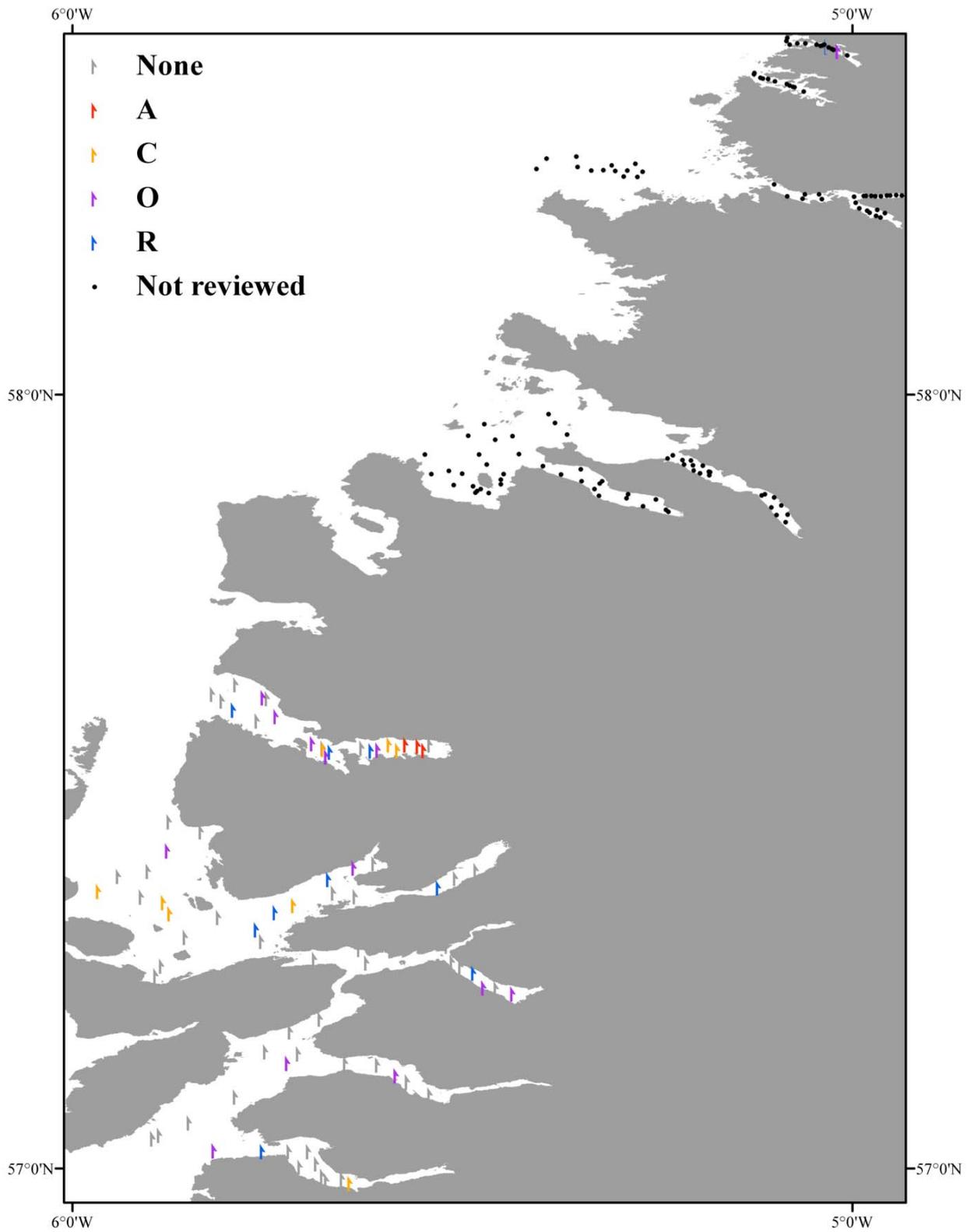
*Nephrops* burrows were observed at 156 stations (presence/absence data only as densities were not calculated because it was not possible to calculate the viewed area for the drop-frame).

Sediments types were determined by PSA for samples obtained at 204 stations, and classified mainly as 'sandy mud' (108 stations) and 'muddy sand' (84 stations), with patches of 'mud' (seven stations) and 'sand' (five stations). Sediment grabs were not possible at 10 sites where ground types were described as 'rocks' (six stations), 'sand with rocks' (three stations) and 'sand with stones' (one station). The BGS maps do not cover the sea loch areas surveyed therefore no comparisons could be made.

For the 92 reviewed UWTV stations, *F. quadrangularis* were observed at 39 stations and described as 'Abundant' at three stations in Loch Torridon and 'Common' at eight stations (three stations in the Inner Sound, three stations in Loch Torridon, one station in Loch Carron and one in Loch Nevis) (Figure 14). *P. phosphorea* were reported at 28 stations ('Abundant' at one station in Loch Torridon) and *V. mirabilis* was observed at 28 stations but never recorded as 'Abundant'. All three species were observed in the same UWTV run at five stations (two stations in Loch Kishorn, and one station in Loch Nevis, Loch Torridon and Loch Duich).

Gadoids were observed at 46 stations and flatfish at 13 stations. Other species such as pipefish, dogfish, rays, hagfish, urchins, scallops, squat lobsters, starfish, crinoids, sea cucumbers, anemones, fan worms and crabs were frequently reported.

A number of UWTV stations were relocated because of the presence of creels in the sea lochs. Creel marks or ropes were observed at five stations in Loch Torridon and the Inner Sound.



**Figure 14:** Observations of *F. quadrangularis* in west coast sea lochs, bays and tidal inlets (based on MSS' ROCA scale) at stations surveyed on *Nephrops* UWTV surveys in 2008 and 2010.

## **Deepwater West of Scotland**

A total of 205 stations were surveyed in areas of Rockall, Anton Dohrn Seamount, Rosemary Bank, Shelf Edge and St. Kilda Basin between 2000 and 2009, using the drop-frame array. Sediment classifications at stations were based on observations. Presence or absence of *Nephrops* burrows, sea pens, corals, fish and other flora and fauna were recorded 'live' whilst surveying. Footage has not been reviewed by independent observers.

### **Rockall**

A total of 85 stations were surveyed around Rockall: 28 in 2005, nine in 2006, 16 in 2007, 13 in 2008 and 19 in 2009. Depths ranged from 142 to 946 m.

Sediment types were described for 77 stations, as 'sand' (45 stations), 'sand with cobbles' (10 stations), 'mud' (nine stations), 'gravel' (six stations), 'rock' (six stations) and 'sandy mud' (one station) (Figure 15).

Sea pens were observed at four stations and corals on 23 stations. *Nephrops*-like burrows were observed during 11 UWTV recordings. Flatfish, gadoids and other fish were occasionally reported. Trawl marks were observed at one station east of Rockall.

### **Anton Dohrn Seamount**

In 2005, five stations were surveyed around the Anton Dohrn Seamount. Depth ranged from 555 to 650 m. 'Sand' was the only type of sediment observed, with one station also noting 'cobbles'. No sea pens, corals or *Nephrops*-like burrows were reported in this area.

### **Rosemary Bank**

Five stations were surveyed in the area of Rosemary Bank in 2007. Depths ranged from 352 to 777 m. Sediments types observed were 'sand' (three stations) and 'sand with cobbles' (two stations). Sea pens were observed at one station. No corals or *Nephrops*-like burrows were reported.

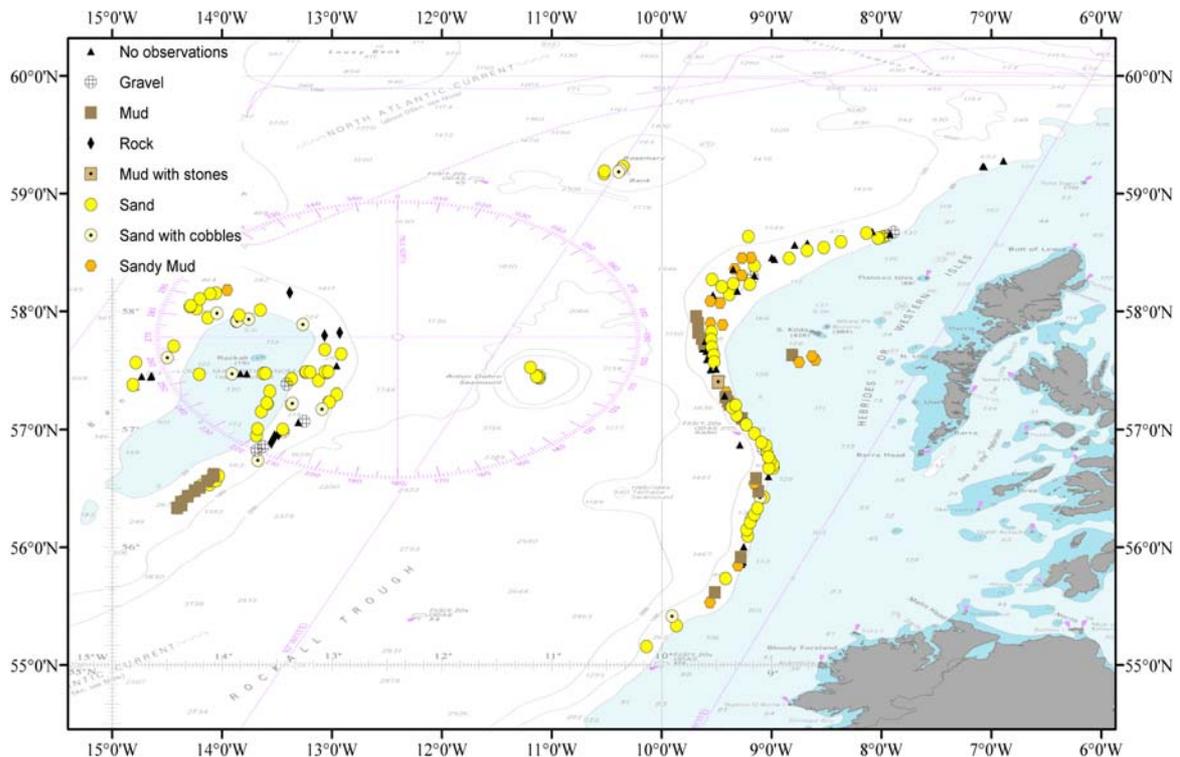
### **Shelf Edge**

A total of 106 stations were surveyed along Shelf Edge between 2000 and 2009 at depths ranging from approximately 249 to 690 m. Sediment types observed were described for 77 stations as 'sand' (41 stations), 'sandy mud' (14 stations), 'mud' (13 stations), 'sand with cobbles' (three stations), 'gravel' (four stations), 'mud with stones' (two stations).

*Nephrops*-like burrows were reported at 55 stations and corals at two stations. Flatfish, gadoids and other fish were frequently reported. Trawl marks were observed on 19 stations in various locations along the shelf edge.

## St. Kilda Basin

Four stations were surveyed in 2002 around the St. Kilda Basin. Depth ranged from 163 to 169 m and observed sediments were 'sandy mud' (three stations) and 'mud' (one station). *Nephrops*-like burrows were reported at two stations.



**Figure 15:** Sediment observations of deepwater UWTW stations off the west coast of Scotland on surveys from 2000-2009.

## Discussion

The data layers based on MSS' *Nephrops* UWTW survey have been used by JNCC and SNH to augment other sources of information on burrowed mud habitat and, at the time of writing, are contributing to the MPA site selection process. Sediment sampling and particle size analyses have in some cases confirmed putative mud distribution (ground truthing) and in other cases have provided new information on location of mud, particularly in inshore sea areas, sea lochs and on the shelf edge, areas which are not mapped by BGS or other surveys. *Nephrops* burrow density data from UWTW stations have been provided and ancillary data collected during the surveys were 'mined' to provide information on the occurrence and relative abundance of sea pens, including the tall sea pen *F. quadrangularis*, which are considered to be of particular relevance in a Scottish context.

It should be borne in mind that the MSS UWTV survey is designed to estimate densities of *Nephrops* burrows, which are widely distributed over relatively large sediment areas. There are, therefore, some limitations when using other data collected during the survey to map the distribution or estimate the abundance of other biota. The survey design would not be considered particularly suitable for mapping the distribution of more sparsely distributed species or locating fragmented populations.

In addition, the review and analysis of the UWTV footage collected during the survey is conducted primarily to derive accurate counts of *Nephrops* burrows. The presence or absence of other features is noted and since 2005 MSS has applied its ROCA scale to assess relative abundance of sea pens, but these procedures have not been subject to the rigorous QA and checking that is applied to burrow counts. It is possible that there will be instances when impressions may be misleading, particularly if tow speed is variable or visibility is reduced, or that the scale is not consistently applied by different observers. Clearly, counts could provide more accurate density data for sea pens (providing viewed area is accurately known), than those based on the reviewers' overall impression based on observation of the footage. However, the counting process is labour intensive and time available to review footage was limited. We were, however, reassured by those reviews carried out that the procedures in place in most cases are able to identify stations where sea pens were present, and that relative abundance as assessed on the ROCA scale was reasonably indicative of higher and lower densities and could be used to inform the MPA project.

In general, *P. phosphorea* and *V. mirabilis* were more frequently observed in UWTV footage from stations on the east coast of Scotland whilst *F. quadrangularis* was more frequently observed on the west coast of Scotland. *F. quadrangularis* was only observed once in the Firth of Forth and once in the Fladen. This is consistent with findings of Greathead *et al.* (2011) for reviewed footage from 50 survey stations in the Fladen in 2004, finding no *F. quadrangularis*. The brittle nature of the species and its inability to retract into the sediment are believed to make it extremely sensitive to physical disturbance and it has been suggested that increased fishing pressure may result in a decreased abundance. However, the west coast of Scotland is also heavily fished but *F. quadrangularis* has been frequently observed.

Evidence of fishing activity was recorded in all areas surveyed and included trawl marks, door marks, evidence of creel fishing, and boats in the vicinity.

The Folk classification system separates sediment type based on grain size distribution. However, our observations suggest that 'mud' biotopes vary regionally and on small spatial scales. Thus 'sandy mud' in the Fladen is not identical to 'sandy mud' in the Clyde. The presence of other burrows and variations in the depth and hydrography can significantly change the appearance of the sediment.

In the event of MPAs being established, displacement effects of fishing effort should be considered and its impact monitored. Data from *Nephrops* UWTV surveys date back to the early 1990's and continue to be collected on an annual basis. This information could potentially be used as baseline data for monitoring site condition.

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## Annex A

### Project Timeline

August - December 2010	Initial emails, meetings and proposal of work. <i>Nephrops</i> database is populated with sediment analysis results available from PSA and work begins on importing positional information for each UWTV station into the database.
January - June 2011	MSS staff attend GIS course. Work continues on populating <i>Nephrops</i> database with UWTV survey data and a temporary staff member is employed to assist with the process. PSA continues for sediment samples collected in 2010. <i>Nephrops</i> burrow counts are reformatted and imported into the database. Communication between MSS, SNH and JNCC continues through email and meetings. Preliminary GIS layers for the North and South Minch are created to help inform survey design for SNH.
July 2011	Meeting between MSS, SNH and JNCC to discuss progress to date. GIS layers for PSA, sea pen abundance and <i>Nephrops</i> burrow density are completed for 2010. Sea lochs and drop frame sampling issues are discussed. PSA completed and GIS layer package emailed for 2008, 2009 and 2010. Abundance scales (ROCA and SACFOR) are to be compared.
August - December 2011	Reformatted burrow counts and burrow density data are imported into database. Data are 'cleaned' and GIS layers are created. Data collected during deepwater surveys is entered and analysed. Photographs and descriptions of sampling and mud biotopes in of the main survey areas are produced. GIS layer package for all survey data from 2008, 2009 and 2010 is created and delivered to SNH and JNCC.
January – April 2012	<i>Nephrops</i> burrow presence/absence data (i.e. data from drop frame stations) are added to data file. Work begins on final report. Report completed end of August 2012.



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