ICES Journal of Marine Science

ICES Journal of Marine Science (2013), 70(3), 511–522. doi:10.1093/icesjms/fss195

# Coral-characterized benthic assemblages of the deep Northeast Atlantic: defining "Coral Gardens" to support future habitat mapping efforts

Ross D. Bullimore, Nicola L. Foster, and Kerry L. Howell*

*School of Marine Science and Engineering, Plymouth University, Drake Circus, Plymouth PL4 8AA, UK*

**Corresponding Author: tel: (44) 1752 584544; fax: (44) 1752 586101; e-mail: kerry.howell@plymouth.ac.uk*

Bullimore, R. D., Foster, N. L., and Howell, K. L. 2013. Coral-characterized benthic assemblages of the deep Northeast Atlantic: defining "Coral Gardens" to support future habitat mapping efforts – ICES Journal of Marine Science, 70: 511–522.

Received 13 June 2012; accepted 5 December 2012; advance access publication 23 January 2013.

Providing statistically robust maps of habitat distributions on which to base spatial planning and management of the marine area is reliant upon established and agreed descriptions and definitions of habitats. "Coral Gardens" is an Oslo–Paris Convention (OSPAR) listed habitat, which currently cannot be reliably mapped as a result of poorly developed deep-sea habitat classification systems and habitat definitions. The aim of this study is to assess and inform development of the current definition of this habitat to support future mapping efforts. This study uses multivariate community analysis of video data to identify deep-sea benthic assemblages characterized by coral taxa and thus constituting a potential "coral gardens" habitat. Assemblages are assessed against a set of qualifying criteria, derived from current definitions of "coral gardens", first at the assemblage level then sample by sample. The current definition of "coral gardens" captures a range of benthic assemblages, thus "Coral Gardens" cannot be considered a single "habitat". While 19 assemblages are identified as being characterized by one or more coral garden taxa, only 8 meet the qualifying criteria. It is suggested that the current definition incorporates descriptions of the different "Coral Gardens" assemblages together with guidance on threshold densities for coral species specific to each assemblage type.

**Keywords:** Biotopes, Cold-water coral, Deep sea, Habitat classification, Marine protected areas, OSPAR, VME.

## Introduction

International, European, and national (UK) initiatives are responding to global calls for improved spatial management of the marine environment, and the establishment of networks of marine protected areas (MPAs) for the purpose of protecting marine habitats from ongoing anthropogenic damage, and conservation of marine biodiversity.

A key target of the Convention on Biological Diversity (CBD) is the establishment of a global network of comprehensive, representative, and effectively managed protected areas in marine systems by 2020. In the Northeast Atlantic region, this global call is aligned with a regional call for a similar network of protected areas under the Oslo–Paris (OSPAR) Convention. Within the deep sea, these initiatives are also loosely aligned with United Nations General Assembly resolution 61/105 (United Nations General Assembly, 2003), which requires the protection of Vulnerable Marine Ecosystems (VMEs) from damaging fishing practices. UNGA 61/105 has been cited in the closure of a number of areas to bottom-trawl fishing, effectively creating MPAs (albeit with limited protection afforded to them).

Protecting "vulnerable" or "threatened" habitats and species is one of the central themes of most MPA policy. Annex V of the OSPAR Convention (On the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area) provides a list of Threatened and/or Declining Species and Habitats (OSPAR, 2008b), which may be considered for protection within an MPA network. This list has been developed based upon nominations by contracting parties and observers to the convention.

In the case of shallow-water environments, there are many well-known and agreed descriptions of species assemblages, communities, and (in the case of habitat-forming species) habitats, which are themselves defined within established biological classification systems such as the European Habitat Classification Scheme EUNIS (Davies *et al.*, 2004) or the Marine Habitat Classification for Britain & Ireland (Connor *et al.*, 2004). Within these systems, these assemblages, communities, and habitats, together with their underlying environmental conditions, are collectively termed "biotopes". Biological habitat classification systems facilitate conservation efforts by providing a common language that can be used to describe and map biological variation (Howell, 2010; Howell *et al.*, 2010). Alignment of listed habitat descriptions with agreed units of mapping such as EUNIS biotopes allows a more coordinated approach to management of the marine area.

However, in deep-sea areas, this alignment is lacking. There have been few coordinated large-scale descriptions of deep-sea benthic assemblages (a prerequisite for the definition of biotopes) attempted (Le Danois, 1948; Laubier and Monniot, 1985; Howell *et al.*, 2010), and, as a result, the development of deep-sea biological habitat classification systems is still in its infancy. While some deep-sea benthic assemblages, communities, and habitats are widely recognized and have been described as mapping units or biotopes within EUNIS (e.g. *Lophelia pertusa* reefs), many are described only through the political process. Deep-sea habitats defined within EUNIS and listed as "Threatened and Declining" by OSPAR (2008b) include Carbonate mounds (EUNIS code: A6.75), Deep-sea sponge aggregations (EUNIS code: A6.62), Oceanic ridges with hydrothermal vents/fields (EUNIS code A6.94), Seamounts (EUNIS code: A6.72), and *Lophelia pertusa* reefs (EUNIS code: A5.631 and A6.611, National Marine Habitat Classification code: SS.SBR.Crl.Lop). The OSPAR listed habitat "Coral Gardens" is currently undefined in any marine habitat classification system, and, thus, attempts to map its distribution to facilitate the implementation of appropriate management methods are problematic.

The OSPAR definition of the habitat "Coral Gardens" describes it as a relatively dense aggregation of colonies or individuals of one or more coral species occurring on a wide range of soft and hard seabed substrata. Soft-bottom "coral gardens" may be dominated by solitary scleractinians, sea pens, or certain types of bamboo corals, whereas hard-bottom "coral gardens" are often found to be dominated by gorgonians, stylasterids, and/or black corals (ICES, 2007; OSPAR, 2008a). The "coral gardens" habitat is listed as occurring within eight EUNIS seabed types: A6.1 Deep-sea rock and artificial hard substrata, A6.2 Deep-sea mixed substrata, A6.3 Deep-sea sand, A6.4 Deep-sea muddy sand, A6.5 Deep-sea mud, A6.7 Raised features of the deep sea bed (and shallower features such as fjords, island flanks, and seamounts), A6.8 Deep-sea trenches and canyons, channels, slope failures, and slumps on the continental slope, and A6.9 Vents, seeps, hypoxic and anoxic habitats of the deep sea. However, these EUNIS types are so broad that maps produced at this EUNIS level would be of little use in spatial planning and informing the establishment of appropriate management measures for the protection of "coral gardens" habitat.

Despite attempts to improve the definition of the habitat through inclusion of density values associated with coral stands and associated fauna, ICES (2007) found *in situ* quantification of density, or abundance of coral bycatch in fishing gear, was often not possible. As a result, the definition of the habitat "coral gardens" continues to lack mention of the densities of colonies of coral species which constitute the designation of a "coral garden" (Christiansen, 2007), it also does not provide guidance on agreed criteria and methods for identifying and discriminating "coral gardens" from other OSPAR listed habitats.

Recognition of habitats at scales relevant to mapping efforts, and utilizing data collected with cost-effective methods commonly used in habitat mapping (e.g. acoustic survey and video ground truthing), requires working definitions that clearly establish the divisions between named habitats. Agreed conventions on characteristic species and their densities must be available to ensure that named habitats can be identified reliably, and efficiently incorporated into existing hierarchical classification (e.g. Connor *et al.*, 2004; Davies *et al.*, 2004).

This study aims to use epibenthic megafaunal video survey data coupled with multivariate statistical analysis to (i) identify and describe deep-sea benthic assemblages that, in accordance with current definitions, can be classed as "coral gardens" habitat; (ii) determine whether current definitions are adequate for discriminating "coral gardens" habitat from other listed habitats; and (iii) provide suggestions for the further refinement of current definitions in order to facilitate efforts to map the distribution of "coral gardens" in support of policy objectives.

## Methods

Data were collected from the Northeast Atlantic over a 1-month period (August–September) in 2005 aboard the commercial research vessel Kommandor Jack; over a 2-month period (August–October) in 2006 aboard the commercial research vessel MV Franklin; and over a 1 month period (July) in 2009 aboard the commercial research vessel MV Franklin. During the three research cruises, video-transects (16 in 2005, 77 in 2006, and 17 in 2009) were taken across five sites in the Northeast Atlantic: Hatton Bank, George Bligh Bank, Rosemary Bank, Rockall Bank, and Anton Dohrn Seamount (Table 1). Video tows were between 175 and 1400 m in length, with the majority being ~500 m. They ranged in depth from 200 to 1800 m.

The Seatronics drop frame camera system, comprising a 5 megapixel Kongsberg digital stills camera and an integrated DTS 6000 digital video telemetry system, was deployed from the starboard side of the vessel. In 2005, the video stream from the viewing screen of the digital stills camera provided video data; in 2006 and 2009, separate video (Kongsberg 14-366) and stills cameras were used. Cameras were mounted at an oblique angle (video, 24°; stills, 22° from the horizontal) to the seabed to aid in species identification. Sensors monitored depth, altitude, and temperature, and an Ultra Short Base Line (USBL) beacon provided accurate position data for the camera frame.

For the majority of tows, vessel speed was ~0.5 knots (min 0.3 and max 0.7 knots). The drop frame was towed in the water column between 1 and 3 m (dependent on substratum type and currents) above the seabed (average of 1.8 m across all tows). At the beginning of each tow, starting from when the seabed became visible, a 2–3 min period was allowed before sampling, to enable the camera to stabilize before commencing the transect. The fields of view of both the stills and video cameras were calibrated using a gridded quadrat of known dimensions. Calibrations were made for "on bottom" (drop frame fully landed on the seabed) and at 1, 2, and 3 m above the seabed to aid in quantitative analysis and particle size discrimination of the substratum.

### Video analysis

Analysis of video transect data was undertaken in two phases as a result of the data having been used for two separate studies prior to this study. Those transects <1100 m were analysed as part of one

**Table 1.** Sampling effort, depth range, and substrates sampled at each site location in the Northeast Atlantic.

| Dataset | Site | No. of transects | No. of 10 m subsamples | Depth range (m) | Average depth (m) | Substrates |
|---|---|---|---|---|---|---|
| Shallow | Anton Dohrn | 12 | 225 | 520–726 | 596 | Sand, gravelly sand (pebbles), bedrock, sandy gravel (pebbles and cobbles), gravel (biogenic— not coral), and gravel (boulders and cobbles) |
| Shallow | East Rockall | 10 | 594 | 389–1032 | 640 | Sandy gravel (pebbles and cobbles), gravelly sand (pebbles), mud, bedrock, gravel (boulders and cobbles), gravel (coral rubble), and sand |
| Shallow | George Bligh | 7 | 333 | 425–1364 | 847 | Gravel (boulders and cobbles), gravelly sand (pebbles), sand, gravel (biogenic—not coral), gravel (coral rubble), and bedrock |
| Shallow | Hatton Bank | 49 | 2290 | 464–966 | 682.6 | Gravelly sand (pebbles), sand, gravel (boulders and cobbles), bedrock, gravel (coral rubble), sandy gravel (biogenic—not coral), sandy gravel (pebbles and cobbles), and bedrock with carbonate veneer |
| Shallow | Rosemary Bank | 14 | 620 | 348–941 | 555 | Gravelly sand (pebbles), sandy gravel (pebbles and cobbles), bedrock, gravel (boulders and cobbles), and sand |
| Deep | Anton Dohrn | 8 | 856 | 849–1887 | 1403 | Gravelly sand (pebbles), bedrock, sandy gravel (pebbles and cobbles), sand, gravel (boulders and cobbles), gravel (coral rubble), and bedrock with carbonate veneer |
| Deep | East Rockall | 6 | 360 | 1018–1600 | 1246 | Sand, gravelly sand (pebbles), gravel (boulders and cobbles), bedrock, sandy gravel (pebbles and cobbles), and mud |
| Deep | George Bligh | 3 | 157 | 1071–1364 | 1170 | Bedrock, gravel (biogenic—not coral), gravel (boulders and cobbles), sand, sandy gravel (pebbles and cobbles), and gravelly sand (pebbles) |

study and hereinafter are referred to as the "shallow dataset", while those >1100 m were used in a different study and are referred to as the "deep dataset". The methods used to analyse the shallow and deep datasets differed slightly, and so the two datasets were treated separately throughout this study.

All videos were reviewed, and megafaunal morphospecies (Howell *et al.*, 2010) were identified using Howell and Davies (2010), and quantified. In general. morphospecies corresponds to species; however, for some groups where the taxonomy is uncertain (e.g. some corals) or where identification without physical specimens is particularly problematic (e.g. sponges), it may correspond to genus, family, or higher taxonomic level. For both datasets, counts were used for individuals or colonial organisms with a distinct structure, e.g. some corals such as Gorgonacea and Antipatharia, and some sponges such as Geodids, some Axinellids, etc. For encrusting forms, the estimated percentage cover was used in the shallow dataset whereas the number of occurrences (pseudo-count data) was used for the deep dataset. Substratum type was visually classified along the video transect using the Wentworth Scale (Wentworth, 1922) and a modified version of the Folk (Folk, 1954) classification (Connor *et al.*, 2004). Transects were then split into 10 m long subsamples such that each 10 m subsample corresponded to a single substratum type within a transect. Subsamples of <10 m were removed from the analysis.

Each 10 m subsample covered an area of ~15.21 m$^2$. At 1.8 m above the seabed (average height of the camera system), the length and area of the camera fields of view were 1.37 m and 2.09 m$^2$, respectively. Thus, a 10 m subsample was composed of 7.28 "fields of view", which equates to ~15.21 m$^2$ (7.28 × 2.09).

## Data analysis

Deep and shallow datasets were analysed separately. In order to combine and allow a single analysis of shallow count and percentage cover estimate data, whilst retaining relative abundance, data were standardized on abundance and cover estimate totals, respectively, and distributions checked for comparability before being combined and analysed. Count and pseudo-count data of the deep dataset did not require this step of standardization. All highly mobile species (e.g. fish) and groups of undetermined species were removed from both datasets at this stage.

All data were analysed using PRIMER v.6 (Clarke and Warwick, 2001). Data were square root transformed to avoid overweighting the presence of rarer species, and cluster analysis with group-averaged linking was performed on a Bray–Curtis similarity matrix with the addition of a dummy variable in order to remove the effect of shared zeros in the similarity matrix (Clarke *et al.*, 2006). To identify distinct benthic assemblages, clustering was performed with the inclusion of the SIMPROF (similarity profile) routine to test the defined clusters for evidence of significant differences at the 95% confidence level based on 1000 permutations and 99 simulations (Clarke and Gorley, 2006).

As a result of the number of permutations performed by the SIMPROF analyses, it could not be directly applied to either shallow or deep datasets as a result of their size. Therefore, a second-stage SIMPROF method was used (B. Clarke, pers, comm.). An initial cluster analysis was performed and used to guide the division of the dataset into smaller subsets. Each subset was then analysed using SIMPROF and samples averaged at the level of significant differences in clusters identified by SIMPROF. This had the result of reducing the size of the dataset such that a single analysis could then be undertaken. Averaged samples were then used in a single second stage SIMPROF analysis of the dataset.

The SIMPER routine in PRIMER v.6 (Clarke and Warwick, 2001) was used to identify characteristic species of each assemblage, and abundances in the form of count and percentage cover and count and pseudo-count data for shallow and deep data, respectively, were divided by the sample area to calculate morphospecies densities (per $m^2$) together with the proportion of samples in which each species was recorded.

### Assessment of potential "coral gardens"

The current definition describes a coral garden as a relatively dense aggregation of colonies or individuals of one or more coral species. Assemblages were first identified as potential, or potentially containing, "coral garden" habitats through examination of the outputs from the SIMPER routine in PRIMER v.6 (Clarke and Warwick, 2001). Assemblages identified in the analysis of SIMPER outputs were then investigated further against the following criteria derived from OSPAR definitions given in ICES (2007), OSPAR (2008a, 2010), and the definition proposed by Rogers *et al.* (2013).

(i) The assemblage is identified by SIMPER analysis as being characterized by at least one species from the taxonomic groups listed as characteristic of a coral garden: Alcyonacea, Gorgonacea, Pennatulacea, Antipatharia, Scleractinia, and Stylasteridae.

(ii) The density of coral garden-characterizing species must be $> 0.1$ colonies $m^{-2}$.

(iii) Reef-forming corals (e.g. *Lophelia* and *Madrepora*), if present, occur only as scattered colonies, not as the dominant habitat-forming species. Therefore, the total density of non-reef-forming coral garden species must exceed the density of reef-forming species.

(iv) Consistent with the extent used by other OSPAR listed biogenic habitats, each potential "coral garden" must extend across an area of at least 25 $m^2$. Taking a conservative approach, given the narrow field of view of the video analysed in this study, potential "coral gardens" identified consisted of a minimum of two consecutive samples.

Assemblages identified by SIMPER that passed criterion (i) but failed criterion (ii) were investigated at the sample level against criteria (ii)–(iv), and speculatively against the threshold proposed by Rogers *et al.* (2013); to qualify as "coral gardens" habitat, coral species densities must be $>10$ times the background density of coral species. Within this study, background density was calculated as the average density of coral garden-characterizing species across the whole assemblage (cluster) identified by SIMPROF.

## Results

In total, in the shallow dataset, 4029 samples (of 10 m) were analysed from 91 transects covering a total area of 61 281 $m^2$. In the deep dataset 1373 samples were analysed from 17 transects covering an area of 20 883 $m^2$. Depths and substrates were not sampled evenly, reflecting differences in substratum availability and depth variability at each site (Table 1).

Hierarchical cluster analysis with the inclusion of the SIMPROF in PRIMER v.6 identified 44 statistically distinct clusters from the shallow data and 22 statistically distinct clusters from the deep data (Figure 1).

In light of the size of these datasets, and the demands for robust and reliably recognizable habitat definitions, final clusters made up of $<10$ samples were not considered further; therefore, 28 clusters from the shallow data and 12 clusters from the deep data made up of $<10$ samples each were not considered further. In total, 26 assemblages from across all depths and substrate types were identified by cluster analysis with SIMPROF, with sufficient samples to provide a reasonable description of a biotope mapping unit.

### Assessment of potential "coral gardens"

Of the 26 assemblages identified using SIMPROF, 19 were identified by SIMPER as being characterized by at least one coral garden species (Table 2). Descriptions, full morphospecies lists, and comparisons with deep-sea benthic assemblages described by Howell *et al.* (2010) for the assemblages identified by SIMPROF are provided in the Supplementary material, S1. However, none of these 19 assemblages, when viewed in their entirety, met the minimum requirement of criterion (ii; 0.1 colonies $m^{-2}$) for densities of coral garden-characterizing species, as given by current definitions (Table 2). It was therefore not possible to identify positively any of the assemblages in their entirety, as identified by SIMPROF, as potential "coral gardens".

There was considerable variation in densities of coral garden species among samples within clusters. Densities ranging from 0 to $>1.5$ colonies $m^{-2}$ were typical, while in the most extreme case densities ranged from 0.0 to 20.9 colonies $m^{-2}$.

Investigation of the assemblages identified by SIMPROF on a sample-by-sample basis (Figure 2) identified 49 potential "coral garden" areas from within eight assemblages (clusters), meeting the minimum stated criteria; full metadata for the 49 identified areas are provided in the Supplementary material, Table S2. Of the potential "coral garden" areas, 15 were identified from the shallow dataset and the remaining 34 from the deep dataset. Notably, of the areas identified, 14 were isolated from the SIMPROF assemblage d15, characterized by the Xenophyophore *Syringammina fragillissima* and Caryophyllids, and a further 13 areas were identified from the SIMPROF assemblage d9, also characterized by Caryophyllids. Of the remaining areas, seven were isolated from the SIMPROF assemblage s6, five from d8, three from each s5 and s10, and two areas each from of d10 and s42.

The definitions of "coral gardens" and assessment criteria applied here have identified eight potential coral garden biotopes (Figure 3, Table 2).

Of the areas identified as potential "coral gardens", 14 were isolated from the SIMPROF assemblage d15. This assemblage was found predominantly on sand and gravel substrates and was characterized by the Xenophyophore *S. fragillissima* and Caryophyllid species. The areas identified were dominated by sandy gravel substrate, with occasional dense aggregations of Caryophyllids and Xenophyophores. Caryophyllids occurred in aggregations $>5$ colonies $m^{-2}$ across a number of samples, exceeding the ten times background density criterion, and peaking at an abundance of 318 colonies in a single 10 m sample, an area of 15.21 $m^2$ (Supplementary material, S1).

The SIMPROF assemblage d9 was found to contain 13 potential "coral garden" areas. This assemblage was identified by the SIMPER routine as being characterized by Caryophillids in addition to the sponge *Phakellia ventilabrum* and a further four sponge morphospecies (Table 2). *Lophelia pertusa* and a range of

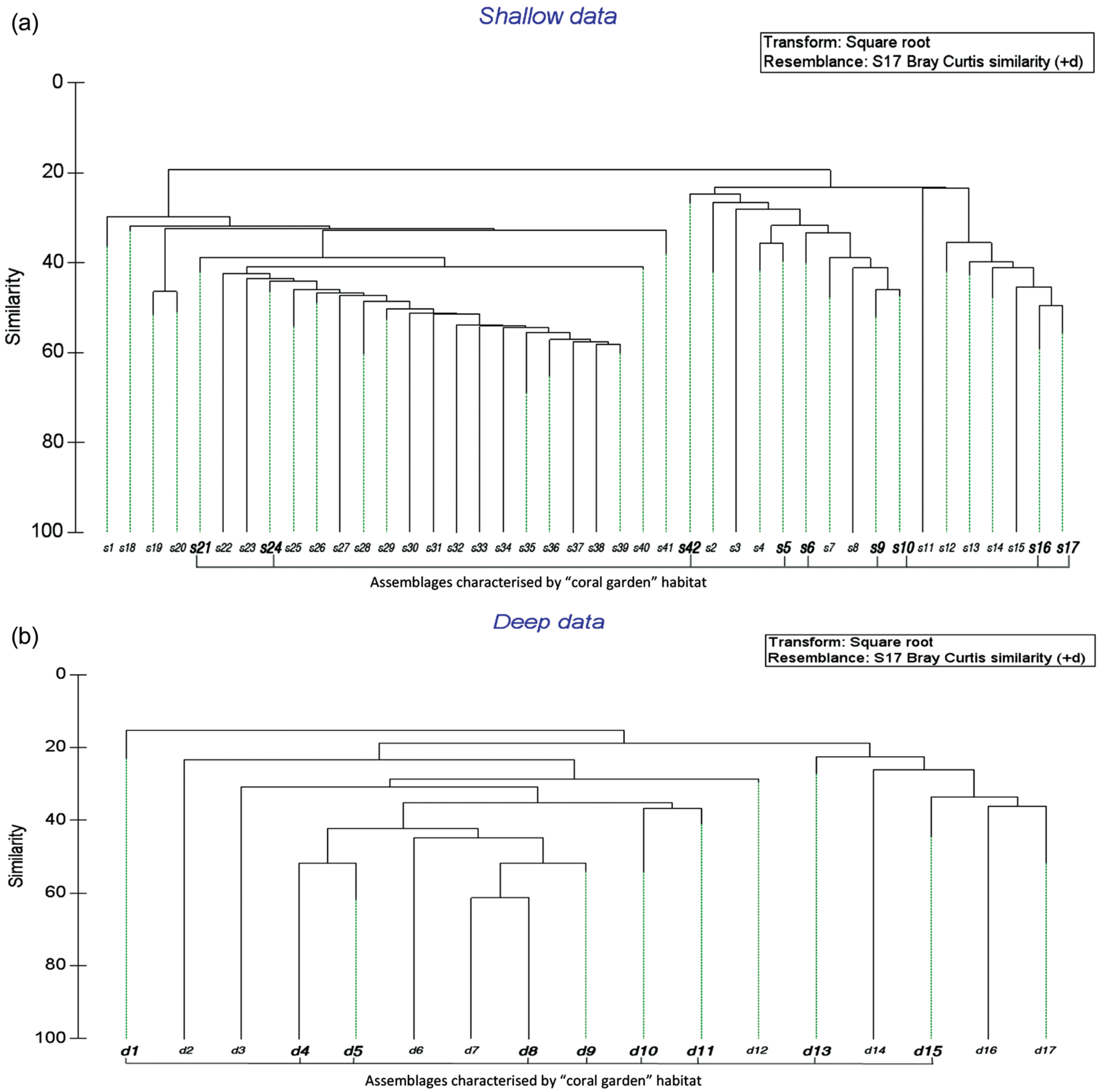


**Figure 1.** Cluster analysis of species data with the inclusion of the SIMPROF routine for (a) shallow datasets and (b) deep datasets. Potential coral garden assemblages are indicated and clusters are collapsed where dictated by SIMPROF.

soft corals were also present; however, Caryophillids remained the most abundant of the coral species present.

The SIMPROF assemblage s5 was also characterized by a combination of coral and deep-sea sponge species. Coral species were observed to be present predominantly on dead frameworks of reef-forming corals and coral rubble, interspersed by areas of sand and gravel dominated, once again, by Caryophyllid species.

Areas identified as potential "coral gardens" from the SIMPROF assemblage s6 were isolated from sparse boulder and cobble substrates colonized by coral species, including occasional *Callogorgia verticillata* colonies. Within the indicated areas, dominated by the stylasteridae species *Pliobothrus* sp., there remained a high level of variation in the abundance of coral species while still meeting both the minimum criteria and ten times background density thresholds for inclusion as a potential "coral garden".

The areas isolated from the assemblages s10 and s42, exceeding both minimum and ten times background density thresholds, were recorded on coral rubble substrate featuring sparsely distributed coral garden species, including occasional gorgonians and soft coral species, such as *Anthomastus grandiflorus*.

The areas identified from assemblage d8 were recorded exclusively from bedrock substrate and featured a range of coral garden species; however, while meeting the minimum thresholds, these assemblages did not exceed the ten times background density criterion.

The final areas were recorded from assemblage d10 on dense frameworks of dead reef-forming coral, coral rubble, and bedrock. Identified by SIMPROF, assemblage d10 was characterized and dominated by gorgonians on the dead frameworks of *L. pertusa*.

**Table 2.** Assemblages identified as potential "coral gardens" from the clusters identified by the SIMPROF routine.

| IMPROF assemblage | Proposed coral garden biotope | Transects | No. of samples | Area ($m^2$) | Depth range (m) | Average depth (m) | Substrate | SIMPER similarity level % | SIMPER characterizing species (characteristic of "coral gardens") | Average density (colonies $m^{-2}$) of coral species |
|---|---|---|---|---|---|---|---|---|---|---|
| s5 | * | 6 | 44 | 669 | 546–978 | 845 | Sand, gravelly sand (pebbles),sandy gravel (pebbles and cobbles) | 31.23 | **Caryophyllia sp. 2**, *Phakellia ventilabrum*, Lobose sponge, ***Stichopathes cf. gravieri***, Cerianthidae sp. 1, ***Madrepora oculata***, ***Lophelia pertusa***, Green encrusting sponge, Ascidiacea sp.1, *Aphrocallistes* sp. | 0.0044 |
| s6 | * | 19 | 64 | 973 | 471–895 | 644 | Sandy gravel (pebbles and cobbles), sandbedrock, gravel (boulders and cobbles), gravelly sand (pebbles) | 27.01 | ***Pliobothrus* sp.**, Cerianthidae sp. 1, *Parastichopus tremulus*, Lobose sponge, Yellow encrusting sponge, ***Madrepora oculata***, *Phelliactis* sp. 1, Paguridae spp | 0.0066 |
| s9 | | 2 | 21 | 319 | 755–821 | 319 | Gravelly sand (pebbles), sandy gravel (pebbles and cobbles) | 57.10 | ***Lophelia pertusa***, *Corallimorphidae* sp.1, **Stichopathes cf. gravieri**, Lobose sponge, Actiniaria sp. 9, ***Acanella* sp.1**, **cf. Antipathella spp.**, *Phelliactis* sp. 1, **Parantipathes sp.**, *Koehlermetra porrecta* | 0.0186 |
| s10 | * | 38 | 296 | 4502 | 466–895 | 679 | Sandy gravel (pebbles and cobbles), gravelly sand (pebbles), mud, bedrock, gravel (boulders and cobbles) | 27.85 | ***Lophelia pertusa***, ***Madrepora oculata***, *Phelliactis* sp. 1, ***Stichopathes cf. gravieri***, Corallimorphidae sp. 1, ***Cidaris cidaris***, Lobose sponge | 0.001 |
| s16 | | 4 | 56 | 852 | 813–826 | 821 | Gravel (boulders and cobbles), bedrock, gravelly sand (pebbles), sandy gravel (pebbles and cobbles) | 45.29 | ***Lophelia pertusa***, ***Madrepora oculata***, *Koehlermetra porrecta*, **cf. *Antipathella* spp.**, Ascidiacea sp. 2, **Stichopathes cf. *gravieri***, *Aphrocallistes* sp., ***Caryophyllia* sp. 2**, Lobose sponge, **Octocorallia sp. 1** | 0.0027 |
| s17 | | 5 | 19 | 289 | 512–839 | 763 | Gravel (boulders and cobbles), gravelly sand (pebbles), sandy gravel (pebbles and cobbles) | 48.33 | ***Lophelia pertusa***, ***Stichopathes cf. gravieri***, ***Madrepora oculata***, Ascidiacea sp. 2, Lobose sponge, *Koehlermetra porrecta*, *Aphrocallistes* sp, ***Parantipathes* sp.**,Yellow encrusting sponge, **cf. *Antipathella* spp.**, ***Caryophyllia* sp. 2** | 0.0184 |
| s21 | | 6 | 12 | 183 | 339–950 | 740 | Sand | 36.64 | ***Caryophyllia* sp. 3**, Actiniaria sp. 1, Ascidiacea sp. 2 | 0.0091 |
| s24 | | 8 | 23 | 350 | 238–860 | 680 | Bedrock, Gravel (Coral Rubble), Sand, Gravel (Boulders and Cobbles) | 33.42 | Majidae sp. 2, **Gorgonian** | 0.0038 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| s28 | | 7 | 15 | 228 | 471 – 978.1 | 740 | Gravelly sand (pebbles), bedrock, sandy gravel (pebbles and cobbles), gravel (boulders and cobbles) | 53.91 | ***Pliobothrus* sp.** | 0.0074 |
| s42 | * | 21 | 100 | 1521 | 210 – 1247 | 713 | Gravelly sand (pebbles), bedrock, sandy gravel (pebbles and cobbles), gravel (boulders and cobbles) | 15.42 | ***Stichopathes cf. gravieri***, *Phelliactis* sp. 1, **Gorgonian**, Actiniaria sp. 1, *Cidaris cidaris*, Cerianthidae sp. 1, *Brisingella coronata / Brisinga endecacnemos*, Ophiuroidea sp. 1, ***Madrepora oculata***, ***Lophelia pertusa***, ***Anthomastus grandiflorus***, ***Alcyonacea sp. 3***, Porifera massive globose sp. 4, Globose sponge | 0.016 |
| d1 | | 16 | 351 | 5339 | 1006 – 1806 | 1341 | Gravelly sand (pebbles), bedrock, sandy gravel (pebbles and cobbles), sa gravel (boulders and cs), gravel (coral rubble), mud, gravel (biogenic—not coral) | 1.61 | *Ophiomusium lymani*, Blue encrusting sponge, *Yellow encrusting sponge*, ***Lepidisis sp.*** | 0.0003 |
| d4 | | 2 | 11 | 167 | 1156 – 1313 | 1235 | Bedrock, bedrock with carbonate veneer, gravel (coral rubble) | 42.00 | ***Lophelia pertusa*** *Phakellia ventilabrum*,**Gorgonacea sp. 16**, **Gorgonacea sp. 12**, ***Madrepora oculata***, *Brisingella coronata / Brisinga endecacnemos*, *Koehlermetra porrecta* | 0.0334 |
| d5 | | 2 | 94 | 1430 | 115 – 1516 | 1337 | Bedrock, bedrock with carbonate veneer, gravel (coral rubble), sandy gravel (pebbles and cobbles) | 31.48 | ***Madrepora oculata***, ***Lophelia pertusa***, Green encrusting sponge, *Phakellia ventilabrum*, ***Callogorgia verticillata***, Porifera lamellate sp. 10, ***Anthomastus grandiflorus***, Blue encrusting sponge, *Koehlermetra porrecta*, **Gorgonacea sp. 12**, Porifera massive lobose sp. 18, *Coryphaenoides rupestris*, Yellow encrusting sponge, ***Caryophyllia* sp. 2**, ***Keratoisis* sp. 3** | 0.0021 |
| d8 | * | 4 | 82 | 1247 | 1156 – 1806 | 1505 | Sandy gravel (pebbles and cobbles), gravel (coral rubble), bedrock, gravelly sand (pebbles), gravel (boulders and cobbles) | 51.00 | Green encrusting sponge, Blue encrusting sponge, ***Lophelia pertusa***, Yellow encrusting sponge, ***Caryophyllia* sp. 2**, ***Madrepora oculata*** | 0.62 |
| d9 | * | 10 | 114 | 1734 | 1068 – 1806 | 1342 | Sandy gravel (pebbles and cobbles), bedrock, gravelly sand (pebbles),gravel (coral rubble), gravel (boulders and cobbles), sand | 31.89 | ***Caryophyllia* sp. 2**, Blue encrusting sponge, *Phakellia ventilabrum*, Green encrusting sponge, Porifera lamellate sp. 10 | 0.21 |

*Continued*

**Table 2.** *Continued*

| IMPROF assemblage | Proposed coral garden biotope | Transects | No. of samples | Area ($m^2$) | Depth range (m) | Average depth (m) | Substrate | SIMPER similarity level % | SIMPER characterizing species (characteristic of "coral gardens") | Average density (colonies $m^{-2}$) of coral species |
|---|---|---|---|---|---|---|---|---|---|---|
| d10 | * | 1 | 48 | 730 | 1769–1448 | 1517 | Gravel (coral rubble), bedrock | 46.60 | ***Lophelia pertusa***, **Gorgonacea sp. 6**, Blue encrusting sponge, **Gorgonacea sp. 16**, ***Madrepora oculata***, *Koehlermetra porrecta*, *Calveriosoma fenestratum*, ***Keratoisis* sp. 2** | 0.0064 |
| d11 | | 5 | 63 | 958 | 1006–1516 | 1229 | Sand, bedrock, sandy gravel (pebbles and cobbles), gravel (coral rubble) | 34.96 | ***Lophelia pertusa***, Blue encrusting sponge, *Pentametrocrinus atlanticus*, Brisingida sp., *Koehlermetra porrecta* | 0.5 |
| d13 | | 11 | 120 | 1825 | 1068–1651 | 1225 | Sand, gravel (coral rubble), sandy, gravel (pebbles and cobbles), gravelly sand (pebbles), bedrock, mud, gravel (biogenic—not coral), gravel (boulders and cobbles) | 18.71 | Cerianthidae sp. 1, Phakellia ventilabrum, Echinus spp., *Syringammina fragillissima*, Blue encrusting sponge, *Phelliactis* sp. 1, **Gorgonian**, *Aphrocallistes* sp. | 0.0009 |
| d15 | * | | 401 | 6099 | 1068–1651 | 1346 | Sandy gravel, (pebbles and cobbles), gravelly sand (pebbles), sand, bedrock, gravel (boulders and cobbles) | 44.81 | *Syringammina fragillissima*,***Caryophyllia* sp. 2** | 0.0022 |

Details of area, depth, substrate, similarity, characteristic species, and their average density are included for each assemblage. Assemblages considered as coral garden biotopes are indicated.

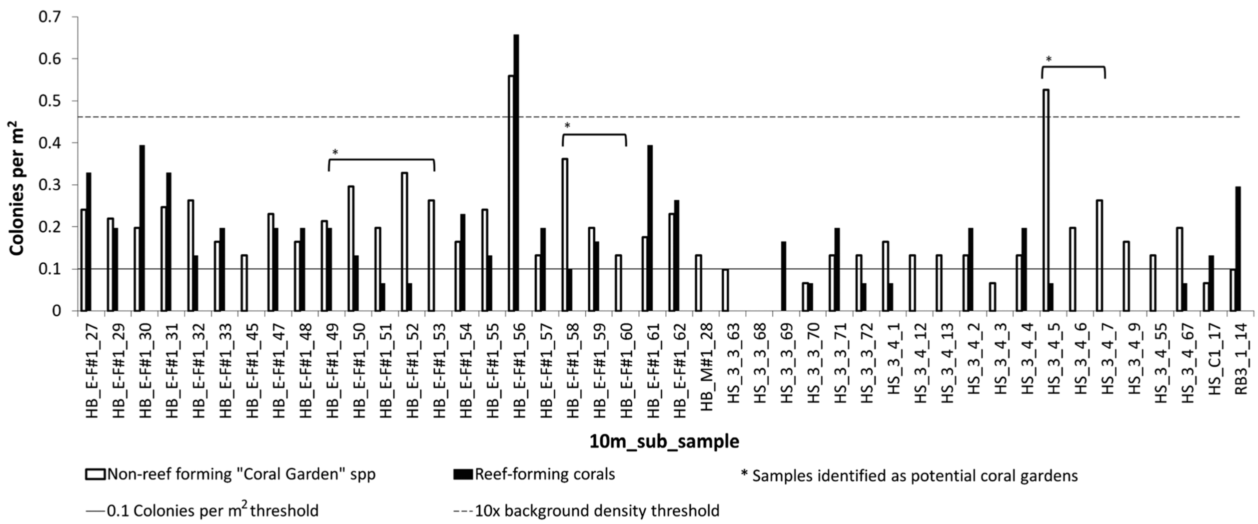

**Figure 2.** Example graph illustrating sample-by-sample investigation of the SIMPROF assemblage s5. Critical thresholds of 0.1 colonies $m^{-2}$ and ten times the background density of coral species are displayed, and areas within the assemblage identified as potential coral garden areas are indicated.

## Discussion

These data suggest that the current definition of "coral gardens" captures a range of benthic assemblages and their associated environmental conditions (or biotopes in the language of the EUNIS classification system), reflected by the number of substrate types within which the habitat "coral garden" is listed as occurring (ICES, 2007; OSPAR, 2008a), and therefore cannot be considered a single unit in either ecological or biological habitat mapping terms.

In order to assess whether the current definition actually results in the identification of "coral gardens" habitat, it is necessary to make an a priori decision on what a "coral garden" habitat is. This leads to a circular scenario in the development of a definition for the habitat.

The current definitions of "coral gardens" as applied in this study are not sufficient to discriminate between "coral gardens" habitat and other "listed" deep-sea habitats. The overarching characterization of the assemblages d9 and s5 by deep-sea sponge species suggests the need for further investigation of these assemblages for potential overlap with the OSPAR listed habitat "deep-sea sponge aggregations". Current coral garden definitions note, "the definition does not encompass deeper-water habitats where sponges (deep-sea sponge aggregations) dominate", but continue to list deep-sea sponge species being associated with coral garden habitats. There are no attempts made in the current definitions to give a threshold at which sponge species observed are no longer considered to be "associated" species, and, therefore, "dominant", and thus classed as a separate, distinct assemblage.

These data also presented difficulties in discriminating between cold-water coral reefs and coral garden habitats. Areas identified as potential "coral gardens" within the assemblage s5, although meeting the criteria to be considered "coral garden" habitats, were situated on dead *L. pertusa* framework structure associated with a live reef area later in the transect. The gorgonian-dominated areas identified within the assemblage d10 were observed to extend across a wider area of the SIMPROF assemblage, d10, than identified by the sample-by-sample analysis. Closer examination revealed that the sample-by-sample analysis had rejected a large proportion of the visually identified "gorgonian-dominated coral garden" because the coral garden species themselves were growing on extensive frameworks of, mainly dead, reef-forming corals and coral rubble, thus resulting in a high background density of coral species, particularly reef-forming species. As reef-forming species are still considered a habitat component when dead (OSPAR, 2008a), across much of this assemblage the density of reef-forming corals exceeded that of the nevertheless abundant non-reef-forming coral garden species, thus rejecting these areas from being identified under criterion (iii), set out above. Neither current definitions of "coral gardens" or cold-water coral reefs, nor the selection criteria suggested here successfully account for this eventuality. Given only the current definitions, it is not possible adequately to allow discrimination of these two listed habitats.

Efforts to resolve this point are hampered by the lack of a clear definition of threshold densities of coral species in order to class an assemblage as a reef. OSPAR (2008a) priority habitat definitions do not include a specified density or description of a threshold level at which aggregations of reef-forming corals are agreed to constitute a cold-water coral reef. This problem is not restricted to deep-water habitat classification; the process of classifying coral reef systems in shallow water remains equally arbitrary. The European Habitats Directive (92/43/EEC; EC, 1996) defines a reef as a biogenic concretion arising from the seabed which supports a community of animals. Hatcher (1997) observes that although no-one defines a solitary coral polyp, a lone coral "bommie" in a lagoon system, or the algal flat of an atoll rim as a "coral reef", they all exhibit many of the attributes associated with coral reef systems and are simply parts of the coral reef. The point at which these individual elements together are considered a "reef" remains unclear.

Difficulties in discriminating coral garden habitat from coral reef habitat on the basis of sample data could be eased through the application of the following criteria to sample assessment: the total density of non-reef-forming coral garden species must

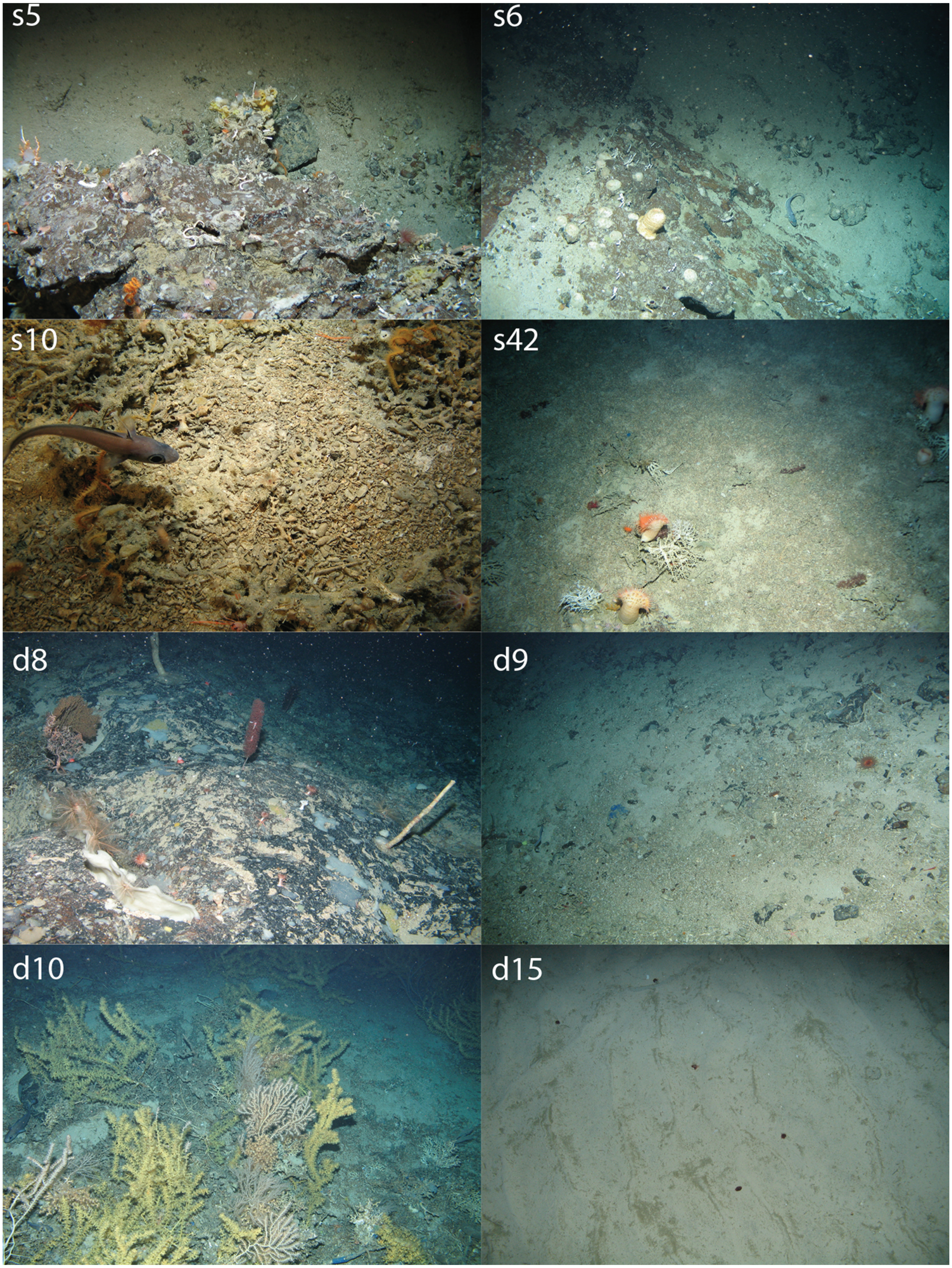


**Figure 3.** Representative images for the eight assemblages identified as containing potential "coral gardens" and considered as coral garden biotopes.

exceed the density of reef-forming species for a sample to qualify as a "coral garden". In addition, in order to discriminate between sponge species occurring in association with coral species and the listed habitat "deep-sea sponge aggregations", it is necessary to include in future definitions agreed threshold densities at which sponge species are considered "dominant" and, thus, classed as a separate, distinct assemblage. A similar model of minimum density criteria to that set out here could be applied to identifying these deep-sea sponge aggregations. However, the same threshold values cannot be assumed to apply across different taxonomic groups; these must be discussed and agreed to be representative of deep-sea sponge species distribution before inclusion in future definitions.

It is clear that for the purpose of habitat mapping, current definitions do not reliably isolate and identify a unified "coral garden" habitat and, thus, it is not possible for such a habitat to be identified by standard multivariate methods, thereby removing the need for arbitrary decision-making in the process of defining these deep-sea benthic habitats. In order to provide a more succinct and reliable definition, we must return to the underlying reasoning for the nomination of "coral garden" habitats for designation under OSPAR in order to offer special protection to dense aggregations of coral species.

The term "coral garden" was first used to describe gorgonian-dominated, dense stands of non-reef-forming corals of densities comparable with those described by Buhl-Mortensen and Mortensen (2004). Comparable with "trees" in the cold-water environment (Andrews *et al*., 2002), such gorgonian-dominated "coral garden" assemblages form highly complex three-dimensional habitats, are long lived, slow growing, highly susceptible to damage (Andrews *et al*., 2002), and support both mobile and sessile associated species, including fish (Freiwald *et al*. 2004).

The current definition (OSPAR 2008a) has, however, taken on a wider range of both hard and soft substrata assemblages. The inclusion of soft substrata assemblages, such as those isolated by this analysis, dominated by solitary Caryophyllid species, sea pens, or bamboo corals, is not, however, supported by any attempt to quantify the extent or densities at which these assemblages must occur in order for them to provide functional habitats or to be considered of sufficient value toward conservation of biodiversity to illicit protection.

If the desire to conserve "coral gardens" was with the aim of providing protection for aggregations of coral species which provide a functional habitat, at a specified scale, then the critical densities at which the species present can be considered to do so must be ascertained through further research, and future definitions must reflect this. However, if the extension of the definition to feature a wider range of coral species and assemblages is with the aim of protecting large numbers of long-lived and slow-growing species within a small area (which is a credible aim), then the decision as to the threshold that constitutes a sufficiently high species diversity and density to be worth conserving is a purely arbitrary and political one.

The density criteria used in this study to identify potential "coral gardens" resulted in the classification of a number of areas as potential "coral gardens", which on the basis of visual inspection would most probably be discarded. In addition, the criteria proposed by Rogers *et al*. (2013), of ten times the background density of coral garden species, as applied in this study, excludes many areas that would visually be considered as exemplar coral garden habitat. This difficulty in assigning a unified threshold to coral species densities reflects the variety and range of benthic assemblages (biotopes) currently encompassed by the "coral garden" definition. The implementation of the ten times background density threshold in particular is extremely dependent on an overarching coral species density level being pre-determined and agreed, which is confounded, in this analysis, by the number and variety of assemblages identified by SIMPROF as being characterized by "coral garden" habitat. If the definition of "coral gardens" habitat is to continue to cover the existing range of "coral garden" assemblages, it will be necessary for density thresholds and background densities to be agreed separately for different "coral garden" assemblages (biotopes).

In the context of mapping efforts, it is important to establish how any density thresholds could be applied. While mapping of coral garden assemblages (those assemblages that are characterized by coral garden-forming species and containing samples that reach critical densities) could be achieved using standard methods on an assemblage-by-assemblage basis (Howell *et al*., 2011); a second mapping layer could then highlight those areas where coral densities within that assemblage are above the critical threshold. Approaches such as predictive habitat modelling could then be used to produce full coverage maps of the distribution of these highly dense "coral gardens" areas by assemblage type (Ross and Howell, 2012), rather than the single OSPAR unit "coral gardens" which is not a coherent ecological entity. Management measures could then be applied to each "coral gardens" type in the strictest sense to conserve only areas of the highest density and diversity of species in the smallest area possible, equivalent to the sample-by-sample assessment approach used here. Alternatively, in line with the precautionary principle, it may be wise to consider protecting areas of highest density and diversity encompassed by a "buffer zone" area of equivalent species assemblage but where coral counts fall below critical threshold levels. Ultimately, the latter approach is more in line with the call for MPA networks to be "representative", where examples of all different biological assemblages are considered for inclusion with a network, but, at the level of an individual assemblage, consideration of which exact areas is made on the basis of selecting those examples of that assemblage that are the most diverse or deemed exemplar by some other criteria. In the case of "coral gardens", the selection would simply be made on the basis of those areas that had the highest densities of coral garden-forming species for each assemblage type.

## Supplementary material

Supplementary material is available at the *ICESJMS* online version of the manuscript. Supplementary S1 provides descriptions of potential "coral garden" assemblages including full morphospecies lists with recorded density values and comparisons with biotopes previously defined by Howell *et al.* (2010). Supplementary Table S2 provides metadata for identified potential coral garden areas.

## Acknowledgements

The authors would like to acknowledge with thanks the scientists, officers, and crew of RV Kommandor Jack and MV Franklin, the staff at Geotek and Marin Matteknik AB, the wider project partners, J. Davies, H. Stewart, C. Jacobs, and N. Golding, and those involved in previous analyses of these data, S. Mowles, L. Robinson, and R. Ross. The collection of data used was funded by the Department for Business, Enterprise and Regulatory Reform through Strategic Environmental Assessment

7 (formerly the Department for Trade and Industry) and the Department for Environment, Food and Rural Affairs through their advisors the Joint Nature Conservation Committee and the offshore Special Areas for Conservation programme.

## References

Andrews, A., Cordes, E., and Mahoney, M. 2002. Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (Primnoa resedaeformis) from the Gulf of Alaska. Hydrobiologia, 471: 101–110.

Buhl-Mortensen, L., and Mortensen, P. B. 2004. Symbiosis in deep-water corals. Symbiosis, 37: 33–61.

Christiansen, S. 2007. Coral Gardens: Case Report for the Initial OSPAR List of Threatened and/or Declining Species and Habitats. OSPAR case report: Coral Gardens.

Clarke, K., Somerfield, P., and Chapman, M., 2006. On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray–Curtis coefficient for denuded assemblages. Journal of Experimental Marine Biology and Ecology, 330:55–80.

Clarke, K. R., and Gorley, R. N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K. R., and Warwick, M. R. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 2nd edn. PRIMER-E, Plymouth.

Connor, D. W., Allen, J. H., Golding, N., Howell, K. L., Lieberknecht, L. M., Northen, K. O., and Reker, J. B. 2004. The Marine Habitat Classification for Britain and Ireland Version 04.05 JNCC, Peterborough. http://www.jncc.gov.uk/MarineHabitatClassification.

Davies, C. E., Moss, D., and Hill, M. O. 2004. EUNIS Habitat Classification Revised. Report to the European Topic Centre on Nature Protection and Biodiveristy. European Environment Agency, Paris.

EC. 1996. Interpretation manual of European Union habitats. In: Council Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora. Version EUR 15, European Commission Directorate General XI Environment, Nuclear Safety and Civil Protection, Nature Protection, Coastal Zones and Tourism, Brussels.

Folk, R. L. 1954. The distinction between grain size and mineral composition in sedimentary-rock nomenclature. Journal of Geology, 62: 344–359.

Fossa, J. H., Mortensen, P. B., and Furevik, D. M. 2000. Lophelia Coral Reefs in Norway: Distribution and Effects of Fishing. Institute of Marine Research, Bergen, p. 94.

Freiwald, A., Fosså, J. H., Grehan, A., Koslow, T., and Roberts, J. M. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

Gonzalez-Mirelis, G., Bergström, P., and Lindegarth, M. 2011. Interaction between classification detail and prediction of community types: implications for predictive modelling of benthic biotopes. Marine Ecology Progress Series, 432: 31–44.

Hatcher, B. G.. 1997. Coral reef ecosystem: how much greater is the whole than the sum of the parts? Coral Reefs, 16:S77–S91.

Howell, K. 2010. A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. Biological Conservation, 143:1041–1056.

Howell, K. L., and Davies, J. S. 2010. Deep-sea Species Image Catalogue. Marine Biology and Ecology Research Centre, Marine Institute at the University of Plymouth. On-line version http://www.marlin.ac.uk/deep-sea-species-image-catalogue/

Howell, K. L., Davies, J. S., and Narayanaswamy, B. E. 2010. Identifying deep-sea megafaunal epibenthic assemblages for use in habitat mapping and marine protected area network design. Journal of the Marine Biological Association of the United Kingdom, 90: 33.

Howell, K. L., Holt, R., Pulido Endrino, I., and Stewart, H. 2011. When the species is also a habitat: comparing the predictively modelled distributions of Lophelia pertusa and the reef habitat it forms. Biological Conservation, 144:2656–2665.

ICES. 2007. Report of the Working Group on Deep-Water Ecology (WGDEC). 26–28 February 2007. ICES Adviory Committee on Ecosystems. ICES Document CM 2007/ACE: 01.

Mortensen, P., Buhl-Mortensen, L., Gordon, D. C. Jr., Fader, G. B., MacKeown, D. M., and Fenton, D. G. 2004. Effects of fisheries on deep-water gorgonian corals in the Northeast Channel, Nova Scotia (Canada). Proceedings of the Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics and Management. American Fisheries Society Symposium, 41: 369–382.

OSPAR. 2008a. Descriptions of Habitats on the OSPAR List of Threatened and/or Declining Species and Habitats. OSPAR Agreement 2008-07.

OSPAR. 2008b. OSPAR List of Threatened and/or Declining Species and Habitats. OSPAR Agreement 2008-06, pp. 1–4.

OSPAR Commission. 2010. Background Document for Coral Gardens. OSPAR Biodiversity Series.

Rogers, A. D., Taylor, M. L., Kemp, K., Yesson, C., and Davies, A. J. 2013. The diseases of deep-water corals. In: Diseases of Corals, Ed. by C Downs. CRC Press, London, New York.

Ross, R., and Howell, K. L. 2012. Use of predictive habitat modelling to assess the distribution and extent of the current protection of 'listed' deep-sea habitats. Diversity and Distributions, in press.

United Nations General Assembly. 2003. Oceans and the Law of the Sea. Report of the Secretary General; A/58/65, 26668(March).

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology, 30: 377–392.

*Handling editor: Rochelle Seitz*