



Comment

Recommendations for best practice in deep-sea habitat classification: Bullimore *et al.* as a case study

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We assert that the reef framework-forming coral, *Solenosmilia variabilis* Duncan, 1873, is sometimes incorrectly recorded as another coral, *Lophelia pertusa* (Linnaeus, 1758) in surveys of deep-sea habitat (e.g. Bullimore, R., Foster, N., and Howell, K. 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). Accurate species lists are critical for developing robust deep-sea habitat classification schemes that allow us to map the distribution of different vulnerable marine ecosystems (VMEs) and predict their occurrences under future climate change scenarios, both of which help prioritize areas for marine protected areas. We recommend that the survey reported by Bullimore *et al.* (2013), as well as analogous surveys, consider the likelihood of *Solenosmilia* having been misidentified, and revise their data if necessary. We also make two further recommendations for best practice in deep-sea habitat classification using Bullimore *et al.* (2013) as a case study. Preferably, physical specimens should be obtained during deep-sea surveys. However, in the absence of identifications confirmed with specimens, image-based analyses of deep-sea communities can be achieved with high confidence when (i) independent validation is provided by senior taxonomic specialists in taxa that are indicators of VMEs, such as cold-water coral reefs, coral gardens, sponge grounds, cold seeps and xenophyophore fields; and (ii) stronger consideration is given to methods in classical taxonomy, the chemical oceanographic setting and community ecology.

Keywords: cold-water corals, coral gardens, *Lophelia pertusa*, *Solenosmilia variabilis*, taxonomy.

Introduction

Bullimore *et al.* (2013) provide a framework for readily identifying the OSPAR-listed deep-sea habitat “coral gardens”. Using species records obtained during photographic seabed surveys in the Northeast Atlantic (Hatton Bank, Rockall Bank, George Bligh Bank, Rosemary Bank and Anton Dohrn Seamount), they applied a multivariate community analysis to characterize deep-sea assemblages for identifying potential coral gardens. Eight types of potential coral garden assemblage were identified and distinguished from one another by their unique composition of species and the depths at which they occurred (shallow or deep).

However, we provide evidence that Bullimore *et al.* (2013) may have incorrectly characterized at least one species of coral in these

deep-sea assemblages. Specifically, we focus on what appears to be a misidentified scleractinian coral species. While reviewing high-resolution still images obtained by remotely operated vehicle from the Hebrides Terrace Seamount (Roberts *et al.*, 2013) during the 2012 Changing Oceans Expedition (RRS *James Cook* cruise 073), we observed dense aggregations of the reef framework-forming coral *Solenosmilia variabilis* Duncan, 1873, along the deep (1200–1800 m) flanks. A routine quality assurance and quality-control check of coral taxonomy was provided by a senior scleractinian taxonomist, who confirmed our visual identification with a high degree of confidence (S. Cairns, pers. comm.). Comparison of images from the deep (> 1200 m) flanks of Anton Dohrn (e.g. Coral Gardens assemblage d10 according to Figure 3 in Bullimore *et al.*, 2013) with

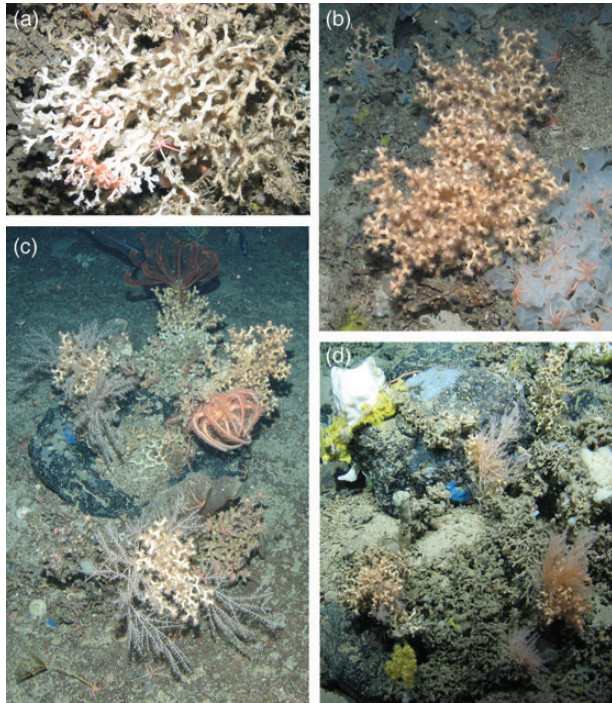


Figure 1: Comparison between representative images of *Lophelia pertusa* and *Solenosmilia variabilis* from the Anton Dohrn and Hebrides Terrace seamounts. (a) White colony of *L. pertusa* from 790 m on Anton Dohrn (station AD_DC_09). (b) Colony of *S. variabilis* from 1647 m water depth on Anton Dohrn (station AD_DC_13). (c) Mixed live and dead coral framework of *S. variabilis* at 1566 m water depth showing rich associated biological communities (station AD_DC_02). (d) Same as (a), but from the Hebrides Terrace at 1370 m water depth (Dive 035). Note what are likely the same blue encrusting sponges nearby and the same bamboo colonies associated with *Solenosmilia* framework in both (c) and (d). Images (a–c) © JNCC, image; (d) joint © JNCC, NERC and Heriot-Watt University.

new images from the Hebrides Terrace (Figure 1) revealed that these corals were morphologically identical across seamounts, yet *S. variabilis* was not recorded from Anton Dohrn either by Bullimore *et al.* or during earlier habitat mapping initiatives on this seamount. We then reviewed 1533 images from the deep flanks of Anton Dohrn (transects AD_DC_02, AD_DC_12, AD_DC_13 in Stewart *et al.*, 2009) and as a result, we consider Bullimore *et al.*'s records of the coral *Lophelia pertusa* (Linnaeus, 1758) deeper than 1200 m on this seamount to be equivocal. It would therefore appear that Bullimore *et al.* (2013) may have incorrectly characterized some of their deep coral gardens and other deep-sea assemblages, and below we substantiate our claim with supporting taxonomic, oceanographic and ecological information.

Classical taxonomy

Both *L. pertusa* and *S. variabilis* are colonial caryophylliid scleractinians with wide degrees of phenotypic variability, making them difficult to identify from video or stills imagery even by experienced researchers (e.g. Mortensen *et al.*, 2008). However several senior taxonomists (Tyler and Zibrowius, 1992; Cairns and Kitahara, 2012) noted some key morphological differences between *S. variabilis* and *L. pertusa* that can be detected in suitably high-resolution deep-sea

images. We confirm these differences and suggest others that may help distinguish the two species in image-based analyses.

A principal taxonomic character distinguishing the two corals is the branching pattern. Both species exhibit intratentacular budding, but in *Solenosmilia* budding is distomodeal, whereby two new polyps develop and emerge from the same tentacular ring (see Plate I in Cairns and Kitahara, 2012). This budding mode typically results in an apparently dichotomous branching appearance, which is most pronounced near the distal colony edges. Corals from >1200 m water depth on both seamounts exhibited this branching pattern, with each pair of distal polyps gently bifurcating outwards; colonies also had an overall peach-orange coloured skeletal pigmentation (Figure 1). In contrast, images of corals from shallower sites on Anton Dohrn appeared white. Branches were slender and less compact, with polyps emerging at sharper angles. In contrast to *Solenosmilia*, *Lophelia* exhibits monostomaecous budding, in which a single new polyp emerges from the tentacular ring (Cairns and Kitahara, 2012). In the images we reviewed from Anton Dohrn, the branching pattern of corals from shallower sites did not appear dichotomous (Figure 1). This morphological evidence suggests that corals >1200 m water depth on Anton Dohrn reported by Bullimore *et al.* (2013) are very likely *S. variabilis*, while those at shallower depths are probably *L. pertusa*.

To our knowledge, no physical specimens of corals at depths >1200 m have been recovered from Anton Dohrn, except for corals dredged from ~1500 m on the seamount's eastern flank and also identified as *L. prolifera* (= *L. pertusa*) (Jones *et al.*, 1994). However these specimens were not properly labelled and are now difficult to locate (J. Dunn and R. Siddall, pers. comm.), precluding a formal taxonomic diagnosis on a physical specimen. It is however noteworthy that physical samples of *S. variabilis* and not *L. pertusa* were found to constitute the main reef framework-building coral in fisheries bycatch at deeper (>1200 m) sites in the Northeast Atlantic on Hatton Bank, and in the Celtic Sea and Porcupine Seabight (Hall-Spencer *et al.*, 2002; Durán Muñoz *et al.*, 2010).

Chemical oceanography

Lophelia pertusa and *S. variabilis* inhabit chemically quite different environments. At water depths >1500 m, seamounts in the Rockall Trough are bathed by Wyville Thomson Ridge Overflow Water (WTOW) and Labrador Sea Water (LSW), more enriched in oxygen, less saline, cooler, and much less saturated in aragonite than upper mid-depth water mass layers in the Rockall Trough (McGrath *et al.*, 2012). This deeper environmental setting more closely corresponds to the global suitable habitat observed for *S. variabilis* and less so to that for *L. pertusa* (Davies and Guinotte, 2011). This chemical oceanographic niche could also explain the general observation that *S. variabilis* is typically found at greater water depths than *L. pertusa* in the North Atlantic (Tyler and Zibrowius, 1992). Conductivity–temperature–depth casts on the Hebrides Terrace Seamount confirmed the transition from ENAW, where no *Solenosmilia* was found, to WTOW and LSW with low aragonite saturation levels but dense coral occurrences (Roberts *et al.*, 2013). Shoaling aragonite saturation horizons will therefore impact *Solenosmilia* habitats first, but the oceanographic setting of this species means that it may be better adapted than *Lophelia* to compensating for low aragonite saturation and climate change.

Ecology

Both *Lophelia* and *Solenosmilia* construct biologically rich biogenic Annex I reef habitats, and both are broadcast spawners with typically

bathyal distributions. However, our inspection of seabed images from Anton Dohrn and the Hebrides Terrace suggests that coral habitats with *Lophelia* and *Solenosmilia* have ecological differences that result in different species being associated with the habitats they help create. *Lophelia* appears to occur at shallower depths than *Solenosmilia* on Anton Dohrn, generally at depths <1000 m (see Figure 1). *Lophelia* was not observed on the Hebrides Terrace Seamount: the flat summit of this seamount occurs at around 1000 m water depth in contrast to the shallower summit of Anton Dohrn at around 600 m. The only colonial scleractinian observed so far from the Hebrides Terrace Seamount is *S. variabilis*, where it is found at depths of ~1200–1800 m. Bullimore *et al.*'s analyses revealed significant taxonomic differences in shallow versus deep coral assemblages; we suspect these differences are explained by species-specific environmental tolerances that partly constrain the distribution and connectivity of cold-water corals and other deep-sea fauna in the Northeast Atlantic to specific water mass characteristics (Flögel *et al.*, 2013) that change with depth in the Rockall Trough (McGrath *et al.*, 2012). Conversely, coral habitats >1200 m water depth on both seamounts are bathed by similar oceanographic settings and appear to harbour taxonomically similar and possibly identical communities (Figure 1). In addition to differences in environmental niches and community ecology, *Lophelia* and *Solenosmilia* exhibit species-specific and regional-specific differences in reproductive phenology (Pires *et al.*, 2013); the habitats they form could thus have different capacities for recovery from disturbances if the spawning season is short or infrequent.

Recommendations for best practice

There is a need for physical specimens to ground-truth habitat classification schemes and species distribution models. Given that resources and time are finite, developing robust habitat classification schemes is often limited to deep-sea photo and video analyses conducted by small research groups that cannot be expected to possess the breadth of taxonomic expertise covering every group of organisms. Obtaining genus- and species-level data from even the highest quality digital images can be challenging, although the use of machine-learning algorithms as emerging tools for scoring species and habitats from images has much promise, provided they are developed using taxonomic expertise from senior specialists.

Notwithstanding these limitations, an error in the taxonomy of Annex I reef framework-forming cold-water corals can hinder aspects of deep-sea conservation. Accurate species lists are the foundations of robust deep-sea habitat classification schemes because they demonstrate the full range of habitats, species–environment relationships and species-specific associations. Classifying these biotic assemblages using sound identifications allows us to accurately map these habitats, including those defined as vulnerable marine ecosystems (VMEs), in order that they can be readily identified and prioritized as ecologically coherent marine protected areas to safeguard ecological and population connectivity of species across their geographical ranges. Because marine taxa, including cold-water corals, have species-specific environmental niches, accurate species records are therefore also needed to ensure robust predictive models are developed to address knowledge gaps in underexplored areas on the High Seas and under climate change scenarios relevant to deep-sea taxa (e.g. the shoaling aragonite saturation horizon).

We have compiled a list of published and on-line literature that we suggest should be interpreted cautiously due to the potential for confusion between *Solenosmilia* and *Lophelia* (Table 1). Although such errors may be symptomatic of the global decline in taxonomic expertise, they ultimately impair our endeavour to protect and conserve deep-sea ecosystems.

We therefore make two key recommendations for best practice in deep-sea habitat classification schemes. In the absence of sample-based identifications, we recommend that image analyses can be achieved with high confidence when (i) independent validation is provided by what is now an increasingly limited pool of senior taxonomists that specialize in taxa that are indicators of VMEs, such as cold-water coral reefs, coral gardens, sponge grounds, cold seeps and xenophyophore fields. We also recommend that those conducting image analyses give more consideration to methods in classical taxonomy that emphasize morphological differences, as well as to the environmental and oceanographic setting of an organism, and differences in community ecology.

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Table 1. Reverse chronological list of published and on-line studies possibly impacted by taxonomic confusion between *Lophelia* and *Solenosmilia* on Anton Dohrn.

Study	Reference
Coral-characterized benthic assemblages of the deep Northeast Atlantic: defining “coral gardens” to support future habitat mapping efforts	Bullimore <i>et al.</i> (2013)
Using species–area relationships to inform baseline conservation targets for the deep north East Atlantic	Foster <i>et al.</i> (2013)
Mapping deep-sea features in UK waters for use in marine protected area network design	Davies (2012)
Use of predictive habitat modelling to assess the distribution and extent of the current protection of “listed” deep-sea habitats	Ross and Howell (2012)
SAC Selection Assessment Document, and Offshore Special Area of Conservation Version 5	Joint Nature Conservation Committee of the UK (2012)
Using predictive modelling to map the distribution of selected habitats listed as MPA search features in Scottish waters	Howell <i>et al.</i> (2011)
Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC)	ICES (2012)
Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC)	ICES (2011)
JNCC Offshore Natura Survey of Anton Dohrn and East Rockall Bank Areas of Search	Long <i>et al.</i> (2010)
JNCC Offshore Natura Survey, and JNCC Offshore Natura Survey: Anton Dohrn Seamount and East Rockall Bank	Stewart <i>et al.</i> (2009)

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