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Quantifying relationships between abundances of cold-water coral *Lophelia pertusa* and terrain features: A case study on the Norwegian margin

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ABSTRACT

An understanding of how terrain features influence abundance of a particular species greatly aids in the development of accurate predictive habitat suitability models. In this study, we investigated the observed seafloor coverage of cold-water coral *Lophelia pertusa* in relation to seabed topography at the Sotbakken and Røst Reefs on the Norwegian margin. The primary terrain features at the study sites are a SW-NE stretching mound at Sotbakken Reef and SW-NE running ridges at Røst Reef, located at depths of ~300–400 m and ~250–320 m respectively. Ship-borne multibeam bathymetry data, JAGO dive video data and JAGO positioning data were used in this study. Terrain variables were calculated at scales of 30 m, 90 m and 170 m based on the bathymetry data. Additionally, we investigated the relationships between the terrain variables at multiple scales using the Unweighted Pair Group Method.

The observed *L. pertusa* coverage at both reefs was found to be significantly correlated with most investigated terrain variables, with correlations increasing in strength with increase in analysis scale, suggesting that large scale terrain features likely play an important role in influencing *L. pertusa* distribution. Small scale terrain variations appear less important in determining the suitability of a region of seafloor for *L. pertusa* colonization. We conclude that bathymetric position index and curvature, as well as seabed aspect, most strongly correlate with coral coverage, indicating that local topographic highs, with an orientation into inflowing bottom currents, are most suitable for *L. pertusa* habitation.

These results indicate that developing habitat suitability models for *L. pertusa* will benefit from inclusion of particular key terrain variables (e.g. aspect, plan curvature, mean curvature and slope) and that these should ideally be computed at multiple spatial scales with a greater gap in scales than we used in this study, to maximize the inclusion of the key variables in the model whilst minimizing redundancy.

1. Introduction

The cold-water coral (CWC) *Lophelia pertusa* (azooxanthellate scleractinian) has a cosmopolitan distribution at depths ~39–3380 m, and is particularly abundant in North Atlantic waters (Davies and Guinotte, 2011; Fosså et al., 2002; Freiwald et al., 2004; Roberts et al., 2009a). *L. pertusa* is the primary reef framework builder in the North Atlantic (Roberts et al., 2009a, 2009b), forming large carbonate mounds, e.g. those on the Irish margin (Dorschel et al., 2007; Mienis et al., 2009; Wheeler et al., 2007), or extended reef complexes, at depths often associated with the continental shelf edge, particularly on the Norwegian margin (Freiwald et al., 2004; Mortensen, 2000; Purser et al., 2013). *L. pertusa* reef habitats support a high diversity of benthic species, with more than 1300 species identified at such reefs in the NE Atlantic (Buhl-Mortensen et al., 2010; Henry and Roberts, 2007; Kutti et al., 2014; Roberts et al., 2006). However, 30–50% of *L. pertusa* reef areas on the Norwegian margin are either damaged

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or impacted by bottom trawling reported by Fosså et al. (2002).

Lophelia pertusa distribution was previously thought to be dependent on local hydrocarbon seepage and chemoautotrophic production (hydraulic theory) (Hovland and Risk, 2003). Recent studies indicate that CWC ecosystems are often largely sustained by the passive settling delivery of phytodetritus, zooplankton, or particulate organic matter derived from near-surface primary productivity (Carlier et al., 2009; Davies et al., 2009; Dodds et al., 2009; Duineveld et al., 2007; Kiriakoulakis et al., 2007; van Oevelen et al., 2009; Wagner et al., 2011). Lateral advection of food particles may also play an important role in maintaining CWC communities (Thiem et al., 2006; Thomsen, 2002). Periodic downwelling of fresh, labile material from near-surface waters is an alternative primary food supply mechanism at some reefs (Davies et al., 2009; Duineveld et al., 2012; Wagner et al., 2011). In addition to the availability of a suitable food source, near-seabed water chemistry and hydrodynamics, seabed substrate and seabed topography are also controlling factors in determining CWC habitat suitability (Duineveld et al., 2012; Mienis et al., 2012; Purser, 2010; Purser et al., 2013; Rüggeberg et al., 2011; Somoza et al., 2014; Tittensor et al., 2009).

Seabed topography influences CWC distribution by governing current regimes, therefore influencing the delivery of food particles (Mienis et al., 2007; Mortensen and Buhl-Mortensen, 2004; Thiem et al., 2006; Wagner et al., 2011), and also sediment distribution, which is important for initial coral settlement (Bryan and Metaxas, 2006). CWCs are often observed on topographic highs with accelerated currents, such as sills (Lavaleye et al., 2009; Wagner et al., 2011), ridges (Freiwald et al., 2004; Freiwald et al., 2002; Purser et al., 2013; Tong et al., 2013b), mound structures or seamounts (Lo Iacono et al., 2014; Mohn et al., 2014; Rowden et al., 2010; Vertino et al., 2010; White, 2007). The localized increased current velocity passing such topographic features promotes advection of food particles within the benthic boundary layer for utilization by CWCs (Kiriakoulakis et al., 2007; Thiem et al., 2006). High bottom current velocity also clears coral surfaces of deposited material, preventing living coral colonies from being buried by sediment (Mienis et al., 2007; White et al., 2005). On some areas of sloping topography, breaking internal waves resuspend organic matter or promote mixing to depth of surface waters, thereby further increasing food supply (Frederiksen et al., 1992). Hard substrate is commonly associated with steeper slopes or topographic highs. Therefore, the terrain variables slope, curvature (plan curvature, profile curvature and mean curvature) and bathymetric positioning index (BPI), which effectively capture the variation of sloping topography and topographic highs, may act as proxies for bottom current velocity and seabed substrate hardness, and may therefore be linked with the distribution of CWCs. Aspect provides information on the orientation of seabed terrain, and in regions with prevalent current direction conditions this parameter may be of particular relevance for suspension-feeding fauna (Guinan et al., 2009b; Wilson et al., 2007).

Cold-water corals are often observed on areas with strong structural components, e.g. rocky outcrops, rather than flat areas (Fabri et al., 2014; Purser et al., 2013; Qurban et al., 2014; Roberts et al., 2005), which may be closely linked to the seabed variation captured by the terrain variability or complexity indices, rugosity and terrain ruggedness index (TRI) (Jenness, 2006; Riley et al., 1999). The terrain variability indices at a local scale distinguish complex habitats with strong structural features from flat terrain, whilst at broader scales capture variations related to seabed morphology characteristics (Wilson et al., 2007).

In recent years, bathymetry-derived terrain variables such as slope, aspect, curvature (plan curvature, profile curvature, mean curvature), BPI, rugosity and TRI, are increasingly applied in studies of habitat classification and habitat suitability modeling (Dolan et al., 2008; Giusti et al., 2014; Guinan et al., 2009a; Guinan et al., 2009b; Howell et al., 2011; Tong et al., 2013a, 2013b, 2012; Wilson et al., 2007). Terrain variables at multiple scales have been shown to have an ecological relevance in determining distribution of benthic fauna, with the terrain parameters often acting as proxies for bottom current velocity regimes (Guinan et al., 2009b; Rengstorf et al., 2012, 2013; Savini et al., 2014; Tong et al., 2013a, 2013b; Wilson et al., 2007). Wilson et al. (2007) comprehensively summarizes these variables to each belonging to one of four groups- slope, orientation (aspect), curvature and relative position (plan curvature, profile curvature, mean curvature and BPI), and terrain variability (rugosity and TRI).

Investigating CWC distribution in relation to seabed topography is important for understanding the terrain habitat selection of these species, and for the development of predictive habitat models. Guinan et al. (2009b) report a strong correlation between *L. pertusa* cover and certain terrain variables (slope, aspect, BPI and rugosity) at scales of 90 m and 270 m within carbonate mound provinces on the Irish margin. Particularly strong correlations were observed between the *L. pertusa* cover and BPI, rugosity and slope at an analysis scale of 270 m (Guinan et al., 2009b). Accordingly, Guinan et al. (2009b) suggested that the relationship between the coral abundance and terrain variable is scale dependent. However, the degree to which this relationship applies to other CWC habitats, such as the Sotbakken Reef and Røst Reef provinces on the Norwegian margin, where reefs cover a more substantial area of seafloor with considerably more robust and vertically extensive structures, is not known. Additionally, the strength of the relationship between *L. pertusa* cover and other terrain variables often used in habitat modeling is also unclear. Similarly how closely terrain variables (extracted from multibeam bathymetry data) correlate with each other in these regions is also unknown.

In this study, we investigate the video observations of *L. pertusa* cover in relation to multiscale terrain variables introduced above at the Røst and Sotbakken Reefs on the Norwegian margin. The aim of the investigation was to determine if any particular terrain variables (and at which analysis scales) significantly correlate with *L. pertusa* cover. Further, we investigate the interrelationship of these terrain variables and determine which should be adopted for use in developing habitat suitability models, to both include the key terrain information relating to coral distribution whilst simultaneously minimizing redundancy.

2. Methods

2.1. Study area

Sotbakken Reef and Røst Reef are two CWC reef complexes located on the Norwegian margin (Purser, 2010). Both were investigated in 2007 during the International Polar Year (IPY) Polarstern ARK XXII/1a expedition (Klages and Thiede, 2011), with the acquired multibeam bathymetry data, video data, and submarine positioning data collected by the expedition used in this study.

The Sotbakken Reef is located on a large mound at the NW extremity of a plateau in the northernmost cross-shelf trough Håkjerringdjupet (off Tromsø) on the Norwegian continental shelf (Ottesen et al., 2008) (Fig. 1). This mound is of ~20 m height above the surrounding plateau, and stretches for >1000 m distance in a SW-NE direction at depths ~250–320 m (Fig. 2).

The Røst Reef complex was discovered in May 2002, and protected from bottom trawling from 2003 (Fosså et al., 2004). The reef complex is situated on the Norwegian shelf break, and composed of many large *L. pertusa* reefs at depths ~300–400 m (Fosså et al., 2005) (Fig. 1). Numerous dissected ridges (tens of meters