Biogeosciences Discuss., 9, 18707–18753, 2012
www.biogeosciences-discuss.net/9/18707/2012/
doi:10.5194/bgd-9-18707-2012

Biogeosciences Discussions

Coral Patch seamount (NE Atlantic) – a sedimentological and macrofaunal reconnaissance based on video and hydroacoustic surveys

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Received: 7 December 2012 – Accepted: 10 December 2012 – Published: 19 December 2012

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The present study provides new knowledge about the so far largely unexplored Coral Patch seamount which is located in the NE Atlantic Ocean half-way between the Iberian Peninsula and Madeira. For the first time a detailed hydroacoustic mapping (MBES) in conjunction with video surveys (ROV, camera sled) were performed to describe the sedimentological and biological characteristics of this sub-elliptical ENE-WSW elongated seamount. Video observations were restricted to the south-western summit area of Coral Patch seamount (area: $\sim 8\,\mathrm{km}^2$, water depth: 560–760 m) and revealed that this part of the summit is dominated by exposed hard substrate, whereas soft sediment is just a minor substrate component. Although exposed hardgrounds are dominant for this summit area, and thus, offer suitable habitat for settlement by benthic organisms, the macrofauna shows rather low abundance and diversity. In particular, scleractinian framework-building cold-water corals are apparently rare with very few isolated and small-sized live occurrences of the species *Lophelia pertusa* and *Madrepora oculata*. In contrast, dead coral framework and coral rubble are more frequent pointing to a higher abundance of cold-water corals on Coral Patch during the recent past. This is even supported by the observation of fishing lines that got entangled with rather fresh-looking coral frameworks. Overall, long lines and various species of commercially important fish were frequently observed emphasising the potential of Coral Patch as an important target for fisheries that may have impacted the entire benthic community. Hydroacoustic seabed classification covered the entire summit of Coral Patch and its northern and southern flanks (area: $560\,\mathrm{km}^2$; water depth: 560–2660 m) and revealed extended areas dominated by mixed and soft sediments at the northern flank and to a minor degree at its easternmost summit and southern flank. Nevertheless, also these data predict most of the summit area to be dominated by exposed bedrock which would offer suitable habitat for benthic organisms. By comparing the locally restricted video observations and the broad-scale monitoring of a much larger and deeper seafloor area as derived by hydroacoustic seabed classification, it becomes

obvious that habitat information obtained by in situ sampling may provide a rather scattered pattern about the entire seamount ecosystem. Solely with a combination of both methods, a satisfactory approach to describe the diverse characteristics of a seamount ecosystem can be derived which is in turn indispensable for future scientific monitoring campaigns as well as management and conservation purposes.

1 Introduction

Seamounts are defined as isolated topographic features of the seabed that have a limited lateral extent and rise more than 1000 m from abyssal depths (Menard, 1964). Large seamounts usually originate as volcanoes and are primarily associated with intraplate hotspots and mid-ocean ridges (Staudigel et al., 2010). It is estimated that there exist tens of thousands of seamounts in the world's ocean (Wessel et al., 2010) thereby being in their sum one of the largest biomes on Earth (Etnoyer et al., 2010). Hence, although seamounts are globally significant habitats (Kitchingman and Lai, 2004; Yesson et al., 2011), to date fewer than 300 seamounts have been surveyed or even sampled and studied worldwide (Stocks, 2004; Etnoyer et al., 2010). In recent years seamounts have gained increasing interest (Mironov et al., 2006; Bergstad et al., 2008; Christiansen and Wolff, 2009) mainly because of their possible important role as local biodiversity hotspots (Richer de Forges et al., 2000; Samadi et al., 2006). The environmental conditions around a seamount, which acts as an abrupt and isolated topographic obstacle on the seafloor, are characterised by substantially enhanced currents (e.g. Rogers, 1994) and productivity (Genin et al., 1986; Genin, 2004). In addition, seamounts regularly contain hard substrate habitats in contrast to the background soft sediments that dominate the deep ocean (Rogers, 1994). All these aspects together may promote a rich benthic fauna that is typically dominated by suspension-feeding organisms, of which cold-water corals (Fig. 1) and sponges are dominant elements (Genin et al., 1986; Rogers, 1994; Clark et al., 2006). Nevertheless, biological studies on seamounts are still rare and address only single aspects of seamount systems, and

it is under debate whether the defined tenets of seamounts, as summarised above, are rather over-generalisations of a broad range of environmental types encountered on seamounts (McClain, 2007; Clark et al., 2010; Rowden et al., 2010). Finally, though many of the worldwide existing seamount ecosystems still need to be explored, they are already threatened by economic exploitation such as bottom trawling and mining for mineral resources (Grigg et al., 1987; Koslow et al., 2000; Clark et al., 2007, 2010).

In the warm temperate region of the NE Atlantic, seamounts are located along the Mid-Atlantic ridge, near the Azores and close to the Canary and Madeira Islands. For the latter region, a 700-km-long belt of irregularly spaced seamounts stretches from SW Iberia to the Madeira archipelago (Fig. 1). These seamounts belong to the southern margin of the Azores-Gibraltar Zone, a plate boundary between Eurasia and Africa (Buforn et al., 1988). The seamounts are late Mesozoic to Recent in age and reflect the north-eastward movement of the African plate over the Madeira volcanic hotspot with Madeira Island being the most recent volcanic construction (Geldmacher and Hoernle, 2000; Surugiu et al., 2008). The seamounts are surrounded by abyssal plains (Tagus, Horseshoe, Seine; Fig. 1) and ascend from water depths of 4000 to 4800 m up to a few hundred metres below the sea surface, except from Gorringe bank and Ampère seamount whose summits reach the photic zone in water depths of 25 to 60 m. The so-called Horseshoe seamounts (comprising, e.g. Gorringe bank, Ampère, Coral Patch, and Josephine seamounts) surrounding the Horseshoe abyssal plain consist of basalts and tuffs (Hatzky, 2005). Because of their volcanic origin and their remoteness from any detritic sediment input, they commonly provide only two types of benthic habitats (a) hard substrata, and (b) bioclastic sand formed by the remnants of benthic organisms colonising the seamounts and pelagic ones (von Rad, 1974).

The area of the Horseshoe seamounts is situated well inside the North Atlantic subtropical gyre and is directly influenced by the eastward flowing Azores Current (Stramma, 2001). At intermediate water depths (700–2000 m) the seamounts are influenced by the Mediterranean Outflow Water (MOW) and the Antarctic Intermediate Water (AAIW) (van Aken, 2000). The MOW is most prominent between 900 to 1500 m depth with higher temperatures and salinities but lower oxygen content than adjacent Atlantic seawater (Halbach et al., 1992). It flows westward through the Strait of Gibraltar and enters the seamount area unimpaired from the eastern side before it flows through the passages between the seamounts. Below the MOW and AAIW flows the North Atlantic Deep Water (NADW) in a southward direction between 2000 m to 3000 m depth. This water mass is again underlain by the Antarctic Bottom Water (AABW) flowing northward (van Aken, 2000). The seamounts themselves act as a kind of disturbed crossing of the major oceanic flow systems described above that may cause partial mixing of the water masses. Thereby, ocean currents encountering a seamount cause upwelling on its upstream side. If these currents are steady and strong enough they will lead to the formation of a Taylor column, an anticyclonic eddy above the summit (Chapman and Haidvogel, 1992).

The study presented here focuses on the Coral Patch seamount which comprises the eastern part of Ampère bank, with Ampère seamount being its western counterpart (Fig. 1). The Coral Patch seamount was discovered in 1883 during an expedition for laying telegraph cable between Cádiz and the Canary Islands (Buchanan, 1885). Buchanan (1885) remarks that a dredge from $\sim$ 970 m water depth revealed many fragments of the crinoid *Neocomatella pulchella* (Pourtalès, 1878) and a large quantity of live occurrences of the cold-water coral *Lophelia pertusa*, the latter findings presumably giving the inspiration for the geographic name. Coral Patch is a sub-elliptical ENE-WSW elongated seamount, about 120 km long and 70 km wide (D'Oriano et al., 2010). Bathymetric and seismic data show that Coral Patch is a composite structure as it originates from a pre-existing sedimentary structural high that extends to a water depth of up to 2500 m (Zitellini et al., 2009) while on the upper part of the seamount volcanic edifices are emplaced (D'Oriano et al., 2010). Eight distinct coalescent volcanic cones were identified to cluster on the south-western top of Coral Patch seamount, while in the northeast a single isolated cone of 8 km in diameter is developed (called Vince volcano; D'Oriano et al., 2010). According to D'Oriano et al. (2010) the south-western top reaches at its shallowest part a water depth of about $\sim$ 645 m, therefore it

belongs to the group of "deep" seamounts which are defined to arise with their summits to a water depth of up to 400 m (Martin and Christiansen, 2009). However, so far the knowledge about this seamount is still rather scattered, in particular regarding its biotic cover (Buchanan, 1885; D'Oriano et al., 2010).

The present study aims to accomplish for the first time a detailed sedimentological and biological reconnaissance of Coral Patch seamount. By combining video observations, faunal sampling and hydroacoustic data, the primary objective of this reconnaissance is to define the facies or habitat types occurring on top of Coral Patch seamount. This information is associated with the distribution, abundance and diversity of the benthic biota, whereby special emphasis is placed on the occurrence of scleractinian cold-water corals. Finally, evidence for anthropogenic activities will help to determine potential environmental impacts of fishing activities on the macrofaunal benthic community.

With the approach to analyse hydroacoustic data for its backscatter information, interpreted in conjunction with the video-derived in situ ground-truthing data, a mapping tool is applied that generates extrapolated seabed classification maps in short times, at low costs, and over large areas of the seafloor (e.g. Kostylev et al., 2001; Roberts et al., 2005; Blondel and Gómez Sichi, 2009; Brown and Blondel, 2009; Coiras et al., 2011). Thereby predictive maps of benthic habitats are derived which are essential for sustained monitoring, management and conservation purposes of marine ecosystems (Pickrill and Tood, 2003; Davies et al., 2008; Schlacher et al., 2010).

Although this case study concentrates on one individual seamount and applies a rather descriptive approach, it will help to identify factors controlling the abundance of benthic populations on Coral Patch in particular, and thus, will add valuable information on the large variability of Atlantic seamounts in general providing the opportunity to put this individual seamount into a comparative context to adjacent seamounts.

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2 Material and methods

All data used to describe the sedimentological, biological and hydrographical characteristics of Coral Patch seamount derived from video surveys, hydroacoustic mapping, and one CTD measurement that were conducted during R/V *PELAGIA* expedition 64PE284 in spring 2008 (Hebbeln and cruise participants, 2008). In addition, two grab samples collected in 1997 during R/V *VICTOR HENSEN* cruise VH97 were analysed for its macrofaunal content to complement information about faunal diversity on Coral Patch seamount.

2.1 Video surveys

Three video surveys were carried out by means of a camera sled and a remotely operated vehicle (ROV) to obtain in situ data about the facies distribution and the benthic macrofauna on Coral Patch seamount. Two surveys (GeoB 12763 and GeoB 12764; Table 1) were carried with a camera sled (designed by the Royal NIOZ, Texel, The Netherlands) providing real-time video observations. This so-called HOPPER camera sled is equipped with a downward-looking camera and a self-made digital video-recording system. Videos, time- and position-referenced data were simultaneously stored to produce GIS (Geographic Information System) based plots of the sled track and associated data.

In addition, one dive (GeoB 12767; Table 1) was carried out with the ROV CHEROKEE (Sub-Atlantic, Aberdeen, Scotland; operated by MARUM, Bremen, Germany). The ship-based IXSEA global positioning system (GAPS) coupled with the ship's differential global acoustic positioning system (DGPS) provided an absolute positioning accuracy within 0.2 % of the slant range. The ROV is equipped with a hydraulic manipulator system for sampling purposes and four video cameras including a colour video zoom camera for detailed seafloor observation and a digital still camera. All video and still image data were digitally stored. Navigational data (ship, ROV), video recordings, and still images are all time referenced.

The track lengths of the three video surveys carried out on Coral Patch seamount varied between 1.28 and 1.57 km (Table 1) and had an ENE-WSW to ESE-WNW orientation (Fig. 2). A total of approximately four hours of video footage was recorded (Table 1). In addition, more than 100 high-resolution photographs were taken with the ROV's still camera and three seafloor samples were collected. The video surveys focussed on the south-western top area of the seamount and covered a water depth range between 560 and 760 m, thereby crossing the shallowest peak of the seamount's summit (GeoB 12763; Figs. 2, 5).

2.2 Video analyses and classification scheme

The complete video footage plus high-resolution images photographed with the ROV's still camera, were visually analysed to describe the variety of geological and biological characteristics as well as human-mediated disturbances present on Coral Patch seamount. According to the Coastal and Marine Ecological Classification Standard of the Federal Geographic Data Committee (FGDC-CMECS, 2012), the classification scheme used in this study is built up of different groups of components comprising substrate components (SC), biotic components (BC), water column components (WC), and anthropogenic impact components (AIC). All components are described separately and are subsequently divided into sub-classes (Fig. 2). Thereby, the defined SCs describe the character and composition of the surface substrate (Table 2) and are treated as a primary (basic) layer (Fig. 2). Biological characteristics (BC, WC) and signs of anthropogenic impact (AIC) overlay the SCs as secondary layers (Fig. 2). Regarding the macrofauna observed during video analyses, special emphasis was placed on the occurrence of scleractinian cold-water corals, hence the defined BCs vary from isolated live coral colonies to coral rubble (Fig. 2). The remaining benthic fauna (comprising sessile and mobile organisms) was only described in a general manner (see Table 3) and not considered for classification due to its low abundance. Fishes, occurring isolated or as schools, were treated as WCs. And finally, AICs describe litter and remnants of fisheries (Fig. 2).

The applied configuration offers the opportunity to produce a comprehensive compilation of all characteristics of the seamount and to easily access all potential combinations of natural and anthropogenic features (FGDC-CMECS, 2012). Moreover, this kind of classification is more applicable for comparison with existing, as well as upcoming, classification studies of seamounts. A similar approach has already successfully been applied for various seabed structures in the NE Atlantic Ocean hosting deep-sea ecosystems (e.g. cold-water coral mounds, mud volcanoes, cliffs; Wienberg et al., 2008, 2009).

2.3 Hydroacoustic imaging and topographic zonal classification

Seabed mapping on Coral Patch seamount was performed using a KONGSBERG EM300 multibeam echosounder system (MBES) which operates at a frequency of 30 kHz and uses 135 equidistant beams per ping. An angular coverage of 120° was adjusted during the surveys. The footprint of a single beam is limited to 1° by 2°. The motion of the vessel was registered by a KONGSBERG MRU-5 motion reference unit, and the ship's position and heading were determined with two GPS antennas. Motion and position information was combined in a SEAPATH 200 Real Time Kinematic (RTK) sensor to provide fast and highly accurate real-time heading, attitude and position information with a dynamic accuracy of 0.02° for roll and pitch. The EM300 was calibrated with a proper sound velocity profile calculated from salinity, pressure and temperature data recorded by a SEABIRD CTD system. The CTD was applied in close vicinity to the Coral Patch seamount (station GeoB 12761; position is indicated in Fig. 1) and lowered to a maximum water depth of 2500 m.

Bathymetric data processing was carried out with the CARIS HIPS & SIPS (v.7.1) data processing software. An area of 560 km^2 was mapped, manually edited and resulted in a bathymetric grid of 20 m cell size, covering water depths between 560 and 2660 m (Fig. 5). Total propagated uncertainties (TPU) were used to validate the final grid-product. The grid resolution was chosen according to data density and MBES footprint.

This bathymetric grid was initial point for further topographic analysis conducted with the Benthic Terrain Modeler (BTM) tool (Wright et al., 2005). The BTM was utilised to calculate (a) standardised (to avoid spatial auto-correlation) Bathymetric Position Indexes (BPI), which indicate the position of a referenced location relative to its surrounding, (b) rugosity, which is a measure of terrain complexity (texture or "bumpiness" of the seabed), and (c) the slope (for detailed information see Lundblad et al., 2006). According to a classification scheme based on Greene et al. (1999) and modified by Erdey-Heydorn (2008), topographic zonal classes were defined comprising, e.g. flat plains, slopes, depressions, and ridges (for details see Table 4). With respect to the FGDC-CMES (as applied for the video-based classification), these topographical classes are equivalents to geoform components (GC) which describe major geomorphic and structural characteristics of the seafloor (FGDC-CMECS, 2012).

Zonal classification maps were produced based on two differently scaled BPI-pairs using the BTM's Zone Classification Builder (Fig. 6). The first map is based on broad-scale BPI of 80 units for the inner radius (IR) and 90 units for the outer radius (OR), and a fine-scale BPI of 10-IR to 15-OR units. The second map utilises a broad-scale BPI of 10-IR to 20-OR units, and a fine-scale BPI of 3-IR to 6-OR units (Fig. 6). One unit is equal to a cell size of 20 m. The IR/OR-values were adjusted by trial-and-error considering the MBES footprint, swath width, and data density.

2.4 MBES backscatter analyses and seabed classification

Besides the water depth computed by the travel time of a transmitted and reflected wave signal, the hydroacoustic data obtained by an MBES provide also information about a number of seabed characteristics (e.g. Blondel, 2002; White et al., 2007). The shape of a returning wave signal (backscatter) reflects the sediment composition of the seabed, the seabed ruggedness, and biological components covering the seabed (Blondel and Murton, 1997; Lurton, 2002; van Rein et al., 2011). Thus, the backscatter information of an MBES can be used to classify and map seabed characteristics (e.g. Hamilton, 2011). Compared to locally restricted in situ information of

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seabed characteristics as obtained by video observation (limited to survey transects) or seabed samples (limited to sampling points), the remote hydroacoustic seabed classification offers the outstanding opportunity to image large areas of the seafloor, and thus, to generate predictive habitat maps which can be applied to optimise future scientific campaigns (Guisan and Zimmermann, 2000; Brown and Blondel, 2009; Guinan et al., 2009).

The post-processing of the MBES backscatter (beam-time series, in the following called side-scan) obtained for the Coral Patch seamount was conducted with QPS Fledermaus Geocoder Tool (FMGT v.7.3.3pre). Since backscatter data are influenced by various parameters like slope and beam angle or artefacts from the water column, several corrections (e.g. initial radiometric correction), filters (adaptive angle varying gain, anti-aliasing), a beam pattern correction and a bathymetric reference grid were applied to maximize the information content within the backscatter signals. Where possible, no nadir information was used. The final product was a side-scan mosaic with a grid cell size of 15 m (Fig. 6). This mosaic was used to distinguish distinct substrate types (soft sediment, hard substrate) by supervised classification (Figs. 7, 8). The classification was verified by in situ ground-truthing data obtained during video observations as described above. Thereby, the video analyses in combination with the FMGT patch analyser were used to outline training samples. Once the training samples were identified, a signature file was produced and utilised to calculate a textural Maximum Likelihood Classification (see also Heindel et al., 2010; Howell, 2010; Howell et al., 2011).

2.5 CTD measurement

To determine the physical parameters of the water masses in the area of the Coral Patch seamount, one CTD measurement was accomplished in close vicinity to the seamount (station GeoB 12761: 34°31.21′ N, 11°08.51′ W, 4430 m water depth; position is indicated in Fig. 1). The CTD measurement of the water column down to a maximum water depth of 2500 m was conducted using a SEABIRD "SBE 9 plus" underwater unit and a SEABIRD "SBE 11 plus" deck unit. The vertical profile over

the water column provided standard data for conductivity, temperature and pressure. Additionally, the CTD was equipped with sensors for optical backscatter (turbidity), fluorescence (chlorophyll) and dissolved oxygen. Conductivity and temperature data were used to compute salinity (Fig. 9). A Temperature-Salinity (T-S) plot was used to determine the water mass structure and stratification in the study area (Fig. 9).

3 Results

3.1 Video footage-based mapping

3.1.1 Substrate components (SC)

Two major seafloor types dominate the landscape of the south-western top area of the Coral Patch seamount: hard substrate and soft sediment, which are a function of the volcanic origin of the seamount (see Zitellini et al., 2009; D'Oriano et al., 2010) and of the accumulation of hemipelagic sediment (see also Auster et al., 2005). Variations and combinations of both main sediment types were defined into four SC classes (Table 2) representative for the specific sedimentological and geological features present on Coral Patch seamount.

Substrate component classes SC-A ("low-relief bedrock") and SC-B ("high-relief bedrock") describe both extensive areas with bedrock outcrops. Two colour variations were observed with dark brownish and light greyish to brownish bedrock, which might be related to the grade of alteration (Fig. 3c). Overall, the bedrock is strongly influenced by weathering, bio-erosion and encrustation of various organisms (e.g. sponges, bivalves) (Figs. 3a, b, 4e, f). The main difference between both bedrock classes is related to seabed roughness. SC-A comprises large and plain slabs, crusts, and banks that exhibit a smooth surface with occasional small-sized crevices (Fig. 3a). In contrast, SC-B has a rugged appearance which is attributed to the high abundance of crevices, cracks, and caves (Fig. 3b). Metre-sized boulders and fields with centimetreto decimetre-sized pebbles and cobbles, likely constituting strongly altered basaltic lava fragments (volcanic breccia), were found to lie exposed on smooth bedrock (Fig. 3c). At some places, successive scarps are present with each step having an elevation of up to 1 m (Fig. 3b, c). Whereas SC-A and SC-B are almost free of soft sediment except from occasional and small-sized sediment-filled pockets, SC-C ("mixed sediment") comprises a mixture of hard substrate and soft sediment. Variations of this class comprise thin veneers of sediment (< 1 cm thickness) irregularly covering bedrock (Fig. 3d), altered crusts having a pancake-like appearance with depressions in between being filled with trapped sediment (Fig. 3e), and scattered gravel- to cobble-sized rocks lying exposed on soft sediment (Fig. 3f). SC-D ("soft sediment") describes extensive plains of soft sediment most likely comprising bioclastic sands formed by the shells of pelagic and benthic organisms (Fig. 3g). Current ripples occur locally restricted in small-sized fields and are just a few centimetres in height, whereas the wavelength is difficult to determine but might be in the centi- to decimetre range as well (Fig. 3h). Just very sporadically scattered gravel- to pebble-sized rocks were observed.

Overall, exposed bedrock dominates the landscape of the video-surveyed area on the south-western top of Coral Patch seamount and is mainly associated with morphological highs and steep slopes (Fig. 2). In contrast, areas with mixed and soft sediments just account for approximately one third of the surveyed area, thereby being related to morphological depressions. The largest soft sediment plain with a lateral extension of ~ 350 m corresponds to a morphological depression that was crossed during survey GeoB 12767 (Fig. 2).

3.1.2 Macrofaunal diversity and anthropogenic impact

The macrofauna on Coral Patch seamount comprises benthic to epibenthic living organisms, which were observed as live occurrences as well as their skeletal remnants (e.g. shell hash, coral rubble). Overall, the macrofauna shows low diversity and abundance (Figs. 3, 4; Table 3). Higher abundances were only found for cidarid echinoids (Fig. 3f) and crinoids with the latter mostly being attached to current-exposed boulders

and below sediment-sheltered overhangs of e.g. ledges (Fig. 4c, e). Minor components of the benthic community are stylasterids, anemones, octocorals, antipatharians, asteroids and crustaceans (mainly decapod crabs, i.a. *Geryon* cf. *longipes*; Fig. 4g). Moreover, exposed rocky boulders and bedrock outcrops (SC-A, SC-B) are often strongly colonised by various species of small-sized sponges, and to a lesser degree incrusted by brachiopods (cf. *Grypheus*), bivalves and barnacles (Fig. 4c, e, f). Special emphasis was placed on the occurrence of scleractinian cold-water corals (defined as biotic components in Fig. 2). Live colonies of the species *Lophelia pertusa* and *Madrepora oculata* are rare and just comprise isolated small-sized (< 20 cm in diameter) frameworks with apical live portions including up to 2 polyp generations (Fig. 4a, b). Live coral colonies are solely associated to hard substrate, thereby being mainly found to colonise on high-relief bedrock (SC-B). Isolated dead coral colonies and coral rubble are more frequent. Thereby, it is obvious that larger accumulations of coral rubble correspond to the highest elevations observed during the video surveys (Fig. 2). In particular, the prominent peak crossed during video survey GeoB 12763 that arises to a water depth of up to 560 m is characterised by the highest density of coral rubble (Fig. 2).

However, the identification of organisms solely based on video footage is sometimes problematic (in particular to a genus or species level), and needs to be verified by seabed samples. A total of three samples were collected during ROV dive GeoB 12767. All samples comprised fossil remnants (and very few small live *Lophelia* polyps) of scleractinian cold-water corals which were identified as *L. pertusa*, *M. oculata*, various dendrophylliid coral species, and several solitary corals (Fig. 4d; Table 3). The finer fraction (< 0.5 mm) was composed of benthic and planktonic foraminifers, pteropods, bryozoans, serpulids, small gastropods, and shell hash. Additional information on the macrofaunal diversity was obtained by analysing two grab samples (VH97-91 and 92), which were sampled during a previous cruise with the R/V *VICTOR HENSEN*. The grabs were collected north and north-west of the video surveys in water depths of 1050 and 890 m, respectively (for position see Fig. 5). Also within these samples several fossil scleractinian cold-water corals (mainly solitary species) and various stylasterids were identified (Table 3).

During video observation, dead but relatively fresh-looking coral thickets were often observed to be entangled in lost fishing lines (in particular during ROV dive GeoB 12767; Figs. 3c, 4f) indicating that the seamount is likely highly frequented by fishing activities. This assumption is even strengthened by the observation of a species-rich fish population comprising *Lophius budegassa*, *Hoplostethus mediterraneus*, *Polyprion americanus* as well as macrourid fish, like *Coelorinchus* and *Nezumia* (defined as water column components in Fig. 2; see also Fig. 4, Table 3). Overall, clear evidence for anthropogenic impact were found at several places at the top of Coral Patch seamount which mainly comprised the remnants of fishing lines (i.a., long lines) that got entangled with rocky boulders or coral colonies and an anchor weight (probably a stone). Only at two locations, litter comprising small-sized unidentified objects made up of hard plastic were discovered (Fig. 2).

3.2 Hydroacoustic mapping

In contrast to the video-based mapping, which is locally restricted to a rather small area of $\sim 8\,\text{km}^2$ at the south-western summit of Coral Patch seamount comprising a water depth range of 560 to 760 m (Fig. 2), the hydroacoustic mapping encompasses an area of around $560\,\text{km}^2$ and covers the entire summit and the northern and southern flanks of Coral Patch down to a water depth of 2660 m (Fig. 5). Thereby, information about topographical and sedimentological characteristics of the seamount could be expanded (extrapolated) to a much larger area of the seafloor resulting in a predictive map of potentially important benthic habitats on Coral Patch seamount, such as exposed hard substrate for cold-water corals (Figs. 7, 8).

3.2.1 Bathymetric analysis, topographic zonal seabed classification

Although the hydroacoustic mapping does not cover the entire expansion of Coral Patch seamount, its sub-elliptical shape with an ENE-WSW elongation and distinct coalescent volcanic cones at its summit, as already described by D'Oriano (2010), are clearly displayed. The south-western part of the summit (comprising the video-surveyed area) arises to water depths between 600 and 900 m on average, while one single peak (volcanic cone) even has an elevation of up to 560 m (Fig. 5; note: shallowest water depth given in D'Oriano et al., 2010, is 645 m). To the north-east the summit gradually deepens to water depths between 900 and 1100 m. Overall, the summit area of Coral Patch seamount covers an area of $\sim 200\,\text{km}^2$ between 560 and 1100 m water depth. The southern flank is rather steep and is incised by several pronounced canyon-like structures. In contrast, the northern flank is characterised by a more gently dipping slope (Fig. 5).

More detailed information about topographical features present on Coral Patch seamount are derived from the topographic zonal seabed classification (Fig. 7). Considering the BTM products from a statistical point of view and taking into account the grids resolution, a total of nine classes were defined. Thereby, zonal classes 1–5 describe rather elevated topographical structures such as outcrops, ridges, boulders and pinnacles, whereas zonal classes 6–9 are ascribed to flat and extensive areas, including flat plains, broad slopes, and depressions of different size and origin (such as scours and gullies; for further details see Table 4).

The broad-scale zonal classification map reveals several distinct large patches defined as rock outcrop highs, local ridges, boulders and pinnacles (zonal classes 1–4), which concentrate on the south-western and north-eastern part of the summit of Coral Patch and along the edge of its upper southern flank (Fig. 7). The position of these patches apparently resemble distinct volcanic edifices as described by D'Oriano et al. (2010). Moreover, the video surveys conducted at the south-western summit cover one of these patches (Fig. 7). Zonal classes comprising flat plains, broad slopes

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and depressions (zonal classes 6–9) are more common on the central summit and clearly dominate the northern flank (Fig. 7). The fine-scale zonal classification map shows a more complex and widespread distribution pattern of rock outcrop highs, local ridges and boulders (zonal classes 1–4) across the entire summit and southern flank, whereas flat plains and depressions show a similar distribution pattern. Overall, the fine-scale thematic map reveals the rather small-scale alternating pattern of elevated morphological structures (e.g. local ridges, outcrop highs) and depressions which is, for example, clearly displayed for the video-surveyed south-western summit area (Fig. 8). Finally, zonal class 5 defined as flat ridge tops is clearly alternating with classes 1 and 4 (rock outcrop highs, local ridges on slopes) by comparing the fine- and broad-scale zonal maps (Fig. 7).

3.2.2 MBES backscatter, textural seabed classification

The subsequent textural seabed classification is based on four classes describing the variation of substrate types of the seafloor on Coral Patch seamount (labelled as classes 1–4 in Figs. 7, 8; note: classes 5 and 6 were used to exclude data gaps or artificially influenced areas due to strong reflection in the slant range area, respectively). According to the video-based classification (Table 2), the four textural seabed classes (or substrate components, SC; see chapter 3.1.1) are interpreted as low-relief bedrock (SC-A) comprising smooth bedrock and large boulders (textural class 1), high-relief bedrock (SC-B) composed of fractured bedrock, boulders and pinnacles (textural class 2), mixed sediment (SC-C) composed of soft sediment and gravel- to cobble-sized rocks (textural class 3), and soft sediment (textural class 4; SC-D; Figs. 7, 8).

A direct comparison between the distribution of topographic features and substrate types as defined by the textural classification reveals that soft sediment (textural class 4; SC-D) is mainly associated with depressions (zonal class 9) and to a minor degree with broad slopes (zonal class 7), whereas exposed bedrock (textural classes 1 and 2; SC-A, -B) mirrors the occurrence of outcrops, local ridges, boulders and pinnacles (zonal classes 1–5; Fig. 7). Overall, extended areas made up of soft sediment (textural

class 1, SC-A) dominate the gently dipping northern flank of Coral Patch seamount as well as its lower southern flank. Thereby, soft sediment plains often seem to be interspersed or covered by larger rocks as expressed by the partly scattered distribution of mixed sediment (textural class 3; SC-C). At the easternmost summit some larger patches of soft sediment are displayed as well. However, overall the entire summit area seems to be dominated be exposed bedrock comprising smooth and fractured bedrock as well as large boulders. Finally, the distribution of exposed bedrock as defined by the textural classification, being a suitable habitat for scleractinian cold-water corals, match $\sim 85\,\%$ of the in situ video observations of live coral occurrences, which can be treated as a measure for the reliability of the remote seabed classification (Fig. 8).

3.3 Physical water mass properties

A temperature and salinity (T-S) plot of the CTD observation (station GeoB 12761; see Fig. 1 for position) obtained in close vicinity of Coral Patch seamount clearly shows the different water masses present in the area (down to 2500 m water depth; Fig. 9). From the surface down to greater depths these are: the upper surface layer, the North Atlantic Central Water (NACW), the Mediterranean Outflow Water (MOW), the Antarctic Intermediate water (AAIW), and the North Atlantic Deep Water (NADW).

The vertical CTD profile shows that surface waters with high turbidity values correspond to chlorophyll maxima in the upper 50 m of the water column, indicating large amounts of fresh particles. In addition, highest values for temperature (17.6 °C), salinity (36.55) and oxygen content ($4.7\,\mathrm{mL\,L^{-1}}$) characterise the surface waters with all three parameters gradually decreasing with increasing depth, thereby the steepest gradient is recognised between 150 and 500 m depth (Fig. 9). A clear rise in salinity and (to a lesser degree) in temperature accompanied by a decrease in oxygen content between 600 m and ~ 1420 m water depth is interpreted to reflect the presence of MOW, this interval coincides with a temperature range of 8.5 to 11.2 °C, a salinity range of 35.58 to 36.01, and a range in oxygen content of 3.3 to $3.9\,\mathrm{mL\,L^{-1}}$ (Fig. 9). The south-western summit of Coral Patch seamount which extends to a water depth of up to

560 m (corresponding to one single peak, the summit on average covers a depth range of 600–900 m; see Fig. 5) is directly influenced by the upper part of the MOW. Below 1420 m water depth (down to 2500 m), temperature and salinity gradually decrease again, whereas oxygen content increases towards values that were found for the surface waters. No signs for the existence of nepheloid layers were detected as the turbidity values remain very low throughout the water column (Fig. 9).

4 Discussion

4.1 Sedimentological and morphological features

During video observation, a clear dominance of exposed bedrocks having a smooth or rugged appearance was observed for the south-western top of Coral Patch seamount (Fig. 2). In addition, the hydroacoustic seabed classification reveals that even the entire ENE-WSW elongated summit of the seamount is dominated by hard substrate (Fig. 7). However, areas with mixed and soft sediments are more frequent on the easternmost part of the summit and on the lower southern flank, and clearly dominate the northern flank (Fig. 7). This finding is confirmed by a former study by Moskalenko and Kogan (1995) based on seismic data. The authors describe the northern flank of Coral Patch seamount to be entirely covered by sediment. They further assume that the summit is covered by a thick (approximately 1 km) stratified complex of sedimentary deposits. However, the latter assumption might partly account for the easternmost part of the summit but not for its shallower south-western top area as revealed by video observation and textural classification (Figs. 2, 7). The rather limited occurrence of mixed and soft sediments on the top of Coral Patch seamount might be explained by locally enhanced currents at the seamount's summit that inhibits the deposition of sediments and/or causes a pronounced re-mobilisation of deposited sediment layers. Current-induced ripples, found in low number during video observation (Fig. 2), and distinct

current-scoured depressions, classified in the fine-scale zonal thematic map (Fig. 7), are clear evidence for high current speeds.

Although surface sediment samples are lacking it is assumed that due to the remoteness of Coral Patch from any continental sediment input, the soft sediment is composed of bioclastic sands which are formed by the shells of pelagic and benthic organisms. Rock samples (lava blocks) collected from the western summit of Coral Patch showed fissures in-filled or even cemented by lithified sedimentary carbonates also documenting that Coral Patch is today acting as an terrigenous-starved seamount (D'Oriano et al., 2010).

4.2 Macrofaunal abundance and diversity

The top area of Coral Patch seamount is clearly dominated by exposed bedrocks (Figs. 2, 7), and hence, would offer suitable and large habitat area for the settlement of various important benthic organisms. However, at least the macrofauna of the south-western summit area, having been subject to video observation, shows a rather low diversity and abundance (Figs. 2, 4). In particular, cold-water corals (including framework-building scleractinians, large erect antipatharians, and gorgonians), which are known to act as biogenic habitats and host a broad variety of associated species (more than 1300 species; see Roberts et al., 2006), show a rather sporadic abundance on this part of the seamount's summit. One factor that might account for this pattern on Coral Patch seamount is its geographic isolation. With respect to its distance from mainland (i.e. shelf, continental margin) and from other seamounts (except from Ampère seamount, which is directly connected to its western edge; Fig. 1) dispersal is the sole process by which benthic life can colonise the seamount (Gofas, 2007), and thus, may restrict colonisation of the seamount to species that produce only long-lived larvae (Clark et al., 2010 and references therein).

But even more significant are unfavourable environmental conditions that reduce recruitment. On one hand these comprise physical environmental parameters, such as temperature, salinity and oxygen content of the water. However, for the majority of taxa knowledge of environmental limits is still incomplete (Freiwald et al., 2004; Clark et al., 2006). For the important group of cold-water corals, the most comprehensive dataset to date exists for the cosmopolitan reef-forming species *Lophelia pertusa*, which has also been identified, though in very low number, to be present on Coral Patch seamount (Figs. 2, 4). Based on its present-day distribution in the NE Atlantic it has been found that this species tolerates a temperature range of 4 to 13.8 °C, a salinity range of 31.7 to 38.8 ‰, and dissolved oxygen levels that range from 2.6 to 7.2 $mL L^{-1}$ (Freiwald et al., 2004; Roberts et al., 2006; Davies et al., 2008). Water mass properties measured in close vicinity to Coral Patch seamount (Fig. 9) fit well into these defined environmental thresholds, at least for *Lophelia*.

Another essential requirement for the development of healthy and sustained ecosystems in the deep-sea is the supply of nutrients and food particles by currents to the filter- and suspension-feeding benthic organisms. The amount of available food in turn is directly linked to primary production in the surface waters and/or to mechanisms enhancing delivery of particles to the sessile organisms in intermediate to deep water depths (Davies et al., 2009). Coral Patch seamount is situated well inside the North Atlantic subtropical gyre (Stramma, 2001), and thus, under the influence of oligotrophic conditions, meaning the content of dissolved nutrients and thus primary production in the surface waters is low as visible in satellite derived data (Behrenfeld et al., 2005). Nevertheless, it is generally believed that seamounts are places in the deep-sea with locally enhanced productivity that causes increased biomass and diversity (Genin, 2004); even though during recent years a controversial debate started about the validation of this paradigm (Rowden et al., 2010). However, as seamounts act as obstacles for ocean currents, upwelling may occur on their upstream side, thereby nutrient-rich waters are transported upwards. Moreover, under a steady and strong current regime even a Taylor column may develop above the seamount's summit having a trapping effect for nutrients and food particles (Chapman and Haidvogel, 1992). Unfortunately, no appropriate data are available to directly prove if Coral Patch seamount is impacted by such current-topography-induced flow phenomena. However, for the adjacent Ampère

seamount some evidence for slight upwelling at its southern flank has been indicated (Kaufmann, 2005). The Great Meteor bank situated south of the Azores is one of the largest seamounts in the NE Atlantic with a wide plateau of ∼ 1500 km^2 developed between 400 m and its summit at 275 m water depth. There is some evidence for the formation of a (weak) Taylor cap. Nevertheless, no significant upwelling into the nutrient-depleted surface layers and also no significant enhancement of phytoplankton biomass could be detected (Beckmann and Mohn, 2002; Kaufmann, 2005). Comparable to Coral Patch seamount also for this seamount it has been found that the benthic macrofauna is relatively poor in terms of abundance and species diversity (Bartsch, 2008). It might be speculated that a seamount characterised by a wide and elongated summit, as found for Great Meteor bank and Coral Patch, possibly inhibits the development of an efficient Taylor column, and thus, a sustained enrichment of nutrients and food particles.

4.3 Impact of fisheries on benthic faunal communities

Another cause for the rather low abundance of benthic organisms on the Coral Patch seamount might be attributed to the impact of fishing activities. Many commercially important fish species (i.a., pelagic tunas, mackerels, orange roughy) are associated to seamounts where they form large and stable aggregations for spawning and feeding (Clark et al., 2010). This makes seamounts very attractive to fisheries as they enable very large catches. Hence, since the 1970s, extensive trawling on seamounts led to the overexploitation or even depletion of numerous fish species (Clark et al., 2007; Sissenwine and Mace, 2007). Also on Coral Patch seamount various important commercial fish species (see Table 3; Fig. 4h–k), were observed in partly high numbers which make this seamount a potential fishing target. While no trawl marks were identified during video observation, most probably related to the dominance of hard substrate at the south-western top area of Coral Patch seamount which would inhibit any imprint, lost long lines were frequently observed during video observation (Figs. 2–4).

Fishing not just threats fish stocks, it also has a negative effect on the benthic community colonising seamounts (Koslow et al., 2001; Clark and Rowden, 2009). Only few studies examined the effect of fishing on benthic organisms in detail, in particular regarding intermediate to deep seamount ecosystems. However, it is known that cold-water corals which are important components of the benthic seamount fauna are particularly vulnerable due to their longevity of hundreds to thousands of years (i.a., gorgonians, antipatharians) in combination with very slow growth rates in the range of µm to mm per year as indicated for antipatharians, gorgonians and scleractinians (Adkins et al., 2004; Roark et al., 2006; Orejas et al., 2011). Hence, recovery from any disturbance or damage takes several years or is even irreversible (Williams et al., 2010). Moreover, framework-building scleractinians (e.g. *Lophelia pertusa*) and large erect antipatharians and gorgonians form complex biogenic habitats as they provide refugia for a diverse mobile fauna (i.a., crustaceans, echinoids, fish) and attachment sites for a great variety of sessile filter-feeders (i.a., sponges, crinoids, brachiopods) (Roberts et al., 2006; Rogers et al., 2007; O'Hara et al., 2008). On an Australian seamount that had been heavily trawled, it has been found that cold-water corals showed no signs of re-colonisation even 10 yr after trawling had ceased and that the loss of coral habitat resulted in declines in diversity and density of other macrobenthos (Althaus et al., 2009). Thus, this case study strikingly demonstrates how severely fishing impacts the entire ecosystem of a seamount.

On the south-western summit of Coral Patch seamount several coral thickets were identified to be entangled with fishing lines (Figs. 3, 4). Thereby, some of the thickets showed clear evidence that there were transported over a certain distance as obvious fractures mark their skeleton. Moreover, one thicket was even looking relatively fresh with few live polyps and also the line around the thicket showed no signs of colonisation or alteration (Fig. 3c) emphasising that Coral Patch is still influenced by fishing activities. Finally, the rare and isolated occurrences of small-sized live coral colonies are mainly associated to high-relief bedrock (SC-B; Fig. 2) thereby the rough area might

offer natural refugia (small caves, depressions etc.) which are inaccessible to trawls or other fishing gears.

5 Conclusions

Although research on seamounts has progressed substantially over the last decades, adequate information about the sedimentological and macrofaunal settings of the thousands of seamounts in the World's Oceans is still limited and only available from a very small percentage (see also Morato et al., 2012). In particular the environment of isolated and intermediate to deep seamounts is rather difficult to explore due to their remote position in combination with a lack of appropriate sampling and observation tools. Only since the late 1990s, along with advances in marine technology, the application of sophisticated video-supported scientific equipment such as ROVs allows to obtain direct in situ information about the characteristics of a seamount by visual observation and dedicated sampling.

However, also video observation has a certain limitation with respect to the often huge dimension of seamounts and the large surface area that needs to be explored to gain a complete picture of the biological and sedimentological characteristics. Therefore, hydroacoustic seabed classification, verified by in situ video observations, provides a useful tool to image characteristics of the seafloor over large areas, and thus, can be used to predict suitable habitat for benthic seamount fauna. In particular with respect to future scientific campaigns, this information will be indispensable to create a dedicated and successful monitoring and sampling programme to obtain the complete range of habitat types and benthic communities present on a seamount. And even more important, such data will be essential to assess the vulnerability of a deep-sea ecosystem to develop appropriate and sustained conservation and management strategies. Nevertheless, the results of our study show that solely with a combination of both methods, a satisfactory approach to describe the diverse characteristics of a seamount ecosystem can be derived.

To sum up, the present case study of Coral Patch seamount provides for the first time detailed information about its sedimentological and biological characteristics. The video surveys being restricted to a rather small area of 8 km^2 on the south-western summit as well as the hydroacoustic seabed classification covering an area of 560 km^2 showed that exposed hard substrates (often associated to locally elevated morphological structures) are common on the entire summit area of Coral Patch seamount, and thus, may offer suitable habitat for many sessile benthic organisms. Nevertheless, the video data reveal that at least its south-western top is characterised by a low diversity and abundance of benthic organisms. In particular, cold-water corals, which form important biogenic habitat for other macrobenthos, are apparently rare and just comprise very isolated and small-sized live colonies of the species *Lophelia pertusa* and *Madrepora oculata*. This might be attributed to the oligotrophic conditions in the area in combination with a lack of appropriate mechanisms (upwelling, Taylor column, internal tides and waves) supplying sufficient food from other sources to the sessile suspension-feeders. But it is also likely that this pattern results from intense fishing activities, evident on Coral Patch seamount by several findings of fishing lines and destroyed coral thickets entangled in these lines. Benthic seamount communities including cold-water corals are extremely vulnerable to the impact of fishing because they are extremely long-lived and grow very slowly. Therefore, biogenic habitats that may accumulate over thousands of years can be rapidly reduced by fishing, whereas recovery from this severe destruction may span decades or even centuries. In addition, it is uncertain whether systems will ever recover to their original ecological structure.

Acknowledgements. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the HERMIONE project, grant agreement no 226354, and under the CoralFISH project, grant agreement no. 213144. In addition, this study was partially funded by LOEWE BiK-F Project A3.10. We thank the officers and crew of the R/V *PELAGIA*, the Royal NIOZ staff and technicians, the MARUM ROV CHEROKEE team, and the scientific crew for on-board assistance during cruise 64PE284 (2008). In this context, we appreciate the most valuable support of the Royal NIOZ, in particular the Marine Research Facilities coordinator Marieke J. Rietveld, and the barter agreement that

rules the exchange of ship's time within the European fleet of research vessels. The cruise was supported by the Deutsche Forschungsgemeinschaft (DFG) through the grants HE 3412/10 and HE 3412/11, and through the DFG-Research Center/Cluster of Excellence "The Ocean in the Earth System". Helmut Zibrowius (scleractinians, stylasterids), Michael Tuerkay (crustaceans), and Imants Priede (fishes) are kindly acknowledged for their support in taxonomic determination. We further thank André Freiwald for providing faunal content information of two grab samples collected during R/V *VICTOR HENSEN* cruise VH97 (1997), and Jürgen Titschack for plotting the UNEP-WCME-based cold-water coral distribution map for the NE Atlantic seamounts.

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Table 1. Metadata of HOPPER camera sled and ROV CHEROKEE video surveys conducted at Coral Patch seamount during R/V *PELAGIA* cruise 64PE284. Abbreviations: WD water depth, TL track length, RD recording duration. See Figs. 2 and 5 for position and orientation of dive tracks. ROV sampling positions are indicated in Fig. 2.

Station [GeoB-No]	Gear		Date	UTC [hh:mm]	Latitude [N]	Longitude [W]	WD [m]	TL/RD
12763	camera sled	Start:	6 Mar 2008	11:13	34°56.40′	11°58.03′	685	1.28 km
		End:	6 Mar 2008	12:07	34°56.47′	11°58.66′	738	0:54 h
12764	camera sled	Start:	6 Mar 2008	13:52	34°56.40′	11°56.96′	745	1.35 km
		End:	6 Mar 2008	14:42	34°56.28′	11°57.65′	710	0:50 h
12767*	ROV	Start:	7 Mar 2008	10:24	34°56.45′	11°57.71′	718	1.57 km
		End:	7 Mar 2008	13:28	34°56.71′	11°58.45′	760	3:04 h

* sampling during the dive at 670 and 700 m water depth.

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Table 2. Substrate component classes (SC) defined to describe the landscape of the south-western top area of Coral Patch seamount. SCs were defined based on the visual analyses of video footage and high-resolution images (colour-code according to Fig. 2). See ROV images presented in Fig. 3 for examples of SCs.

SC ID	SC Name	Colour code	Characteristics
SC-A	low-relief bedrock (Fig. 3a)	green	extensive areas with bedrock outcrops (including slabs, crusts, banks); surface has a smooth appearance and exhibits signs of weathering, bio-erosion and strong encrustation by various organisms
SC-B	high-relief bedrock (Fig. 3b, c)	blue	rugged surface due to abundant crevices and cracks, scarp sequences; small-sized pockets filled with soft sediment; metre-sized boulders and fields with centimetre- to decimetre-sized pebbles and cobbles lying exposed on smooth bedrock
SC-C	mixed sediment (Fig. 3d–f)	red	mixed facies composed of hard substrate and soft sediment; thin sediment veneer (< 1 cm) irregularly covering bedrock; pancake-like crusts with depressions between segments filled with soft sediment; scattered gravel- to cobble-sized rocks lying exposed on soft sediments
SC-D	soft sediments (Fig. 3g, h)	yellow	extensive plains of bioclastic sands (shells of pelagic and benthic organisms); locally restricted small-scaled current ripples (few centimetres in height); very sporadically scattered gravel- to pebble-sized rocks

Table 3. List of faunal species identified on Coral Patch seamount based on video analyses presented in this study. The list is supplemented by the faunal content of two grab samples (VH97-91: 34°58′ N, 11°57.3′ W, 1050 m; VH97-92: 34°57′ N, 11°55.9′ W, 890 m; position indicated in Fig. 5) collected during R/V *VICTOR HENSEN* cruise VH97 (unpublished data provided by A. Freiwald), and notes found in literature.

Group	Species	Source
PORIFERA		
	unident. yellowish encrusting sponge	this study
	unident. whitish encrusting sponge	this study
	unident. bluish encrusting sponge	this study
CNIDARIA		
hydroids	*Errina* sp.	VH97-91, 92
	Lepidopora sp.	VH97-91, 92
	Sertularella sp.	D'Oriano et al., 2010
	Stenohelia sp.	VH97-91
	?*Stylaster* sp.	VH97-91, 92
	unident. pennate hydroid	this study
actinians	unident. reddish actinian	this study
octocorals	unident. gorgonian	this study
scleractinians	*Aulocyathus atlanticus*	VH97-91, 92
	Balanophyllia cellulose	this study
	?*Caryophyllia sarsiae*	VH97-91
	Deltocyathus eccentricus	VH97-91
	Deltocyathus moseleyi	VH97-91, 92
	Flabellum macandrewi?	VH97-91
	Fungiacyathus crispus	VH97-91
	Fungiacyathus fragilis	VH97-91
	Peponocyathus folliculus	VH97-91
	Stenocyathus vermiformis	VH97-91, 92
	?*Thrypticotrochus* sp.	VH97-91
	unident. solitary coral	this study
	Lophelia pertusa	this study; VH97-91; Buchanan, 1885
	Madrepora oculata	this study; VH97-91,92; D'Oriano et al., 2010
	?*Dendrophyllia cornigera*	this study
	unident. Dendrophylliidae	this study
antipatharians	unident. curly whip-like antipatharian	this study

Table 3. Continued.

Group	Species	Source
ANNELIDA		
serpulids	*Filogranula stellata*	VH97-91
	unident. serpulid	D'Oriano et al., 2010
ARTHROPODA		
crustaceans	*Geryon* cf. *longipes*	this study
	Pandalidae (cf. *Aristeus*)	this study
	unident. lobster	this study
brachiopods	(cf. *Grypheus*)	this study
	Terebratula sp.	D'Oriano et al., 2010
	unident. encrusting brachiopod	this study
barnacles	unident. barnacle	this study
MOLLUSCA		
bivalves	*Asperarca* sp.	D'Oriano et al., 2010
	unident. encrusting bivalve	this study
gastropods	*Amphissa acutecostata*	D'Oriano et al., 2010
	Pedicularia sp.	VH97-91
ECHINODERMATA		
asteroids	unident. yellowish asteroid	this study
crinoids	unident. crinoid	this study
	unident. stalked crinoid	VH97-91
	Neocomatella pulchella	Buchanan, 1885
echinoids	*Cidaris* sp.	this study
FISH		
	Lophius budegassa	this study
	Hoplostethus mediterraneus	this study
	Polyprion americanus	this study
	Coelorinchus sp.	this study
	Nezumia sp.	this study

Table 4. Decision table summarising the topographical features used for the zonal classification (modified after Erdey-Heydorn, 2008).

Class	Classification Seabed Structure	Broad Scale BPI lower	Broad Scale BPI upper	Fine scale BPI lower	Fine scale BPI upper	Slope lower	Slope upper
1	rock outcrop highs, narrow ridges	100		100			
2	local ridges, boulders, or pinnacles in depressions		−100	100			
3	local ridges, boulders, or pinnacles on broad flats	−100	100	100			5
4	local ridges, boulders, or pinnacles on slopes	−100	100	100		5	
5	flat ridge tops	100		−100	100		
6	flat plains	−100	100	−100	100		5
7	broad slopes	−100	100	−100	100	5	45
8	scarps, cliffs	−100	100	−100	−100	5	
9	depressions (incl. scours, gullies)		−100		−100		

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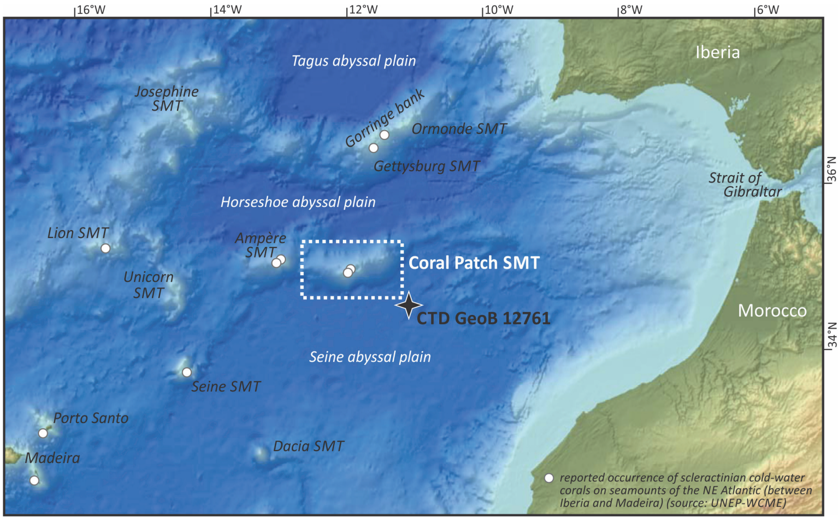

Fig. 1. Overview map (source: GEBCO) showing seamounts (SMT) of the NE Atlantic Ocean (between Iberia and Madeira) including the Coral Patch seamount (dashed box). Reported occurrences of scleractinian cold-water corals found on these seamounts are indicated (white dots; data are extracted from UNEP World Conservation Monitor Centre (UNEP-WCMC) global cold-water coral dataset v.2.0, 2006). Position of CTD station GeoB 12761 conducted during R/V *PELAGIA* cruise 64PE284 is marked by the black star.

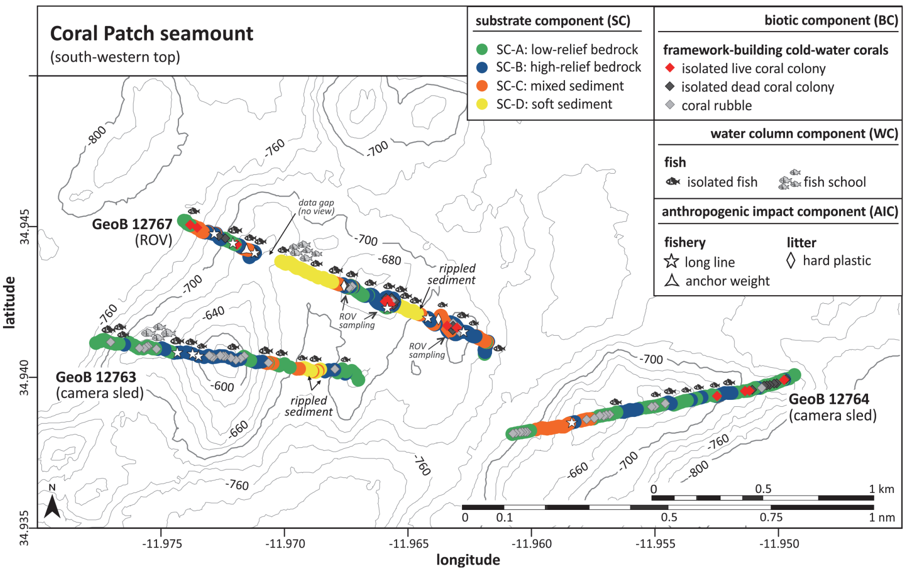

Fig. 2. Isobath-map of the south-western top area of Coral Patch seamount. Contour interval is 20 m. The map is overlain by video survey tracks (camera sled: GeoB 12763, 12764; ROV: GeoB 12767) that were analysed for substrate components (SC; for more details see Table 2), biotic components (BC; framework-building cold-water corals), water column components (WC; fish), and anthropogenic impact components (AIC; litter, fishery).

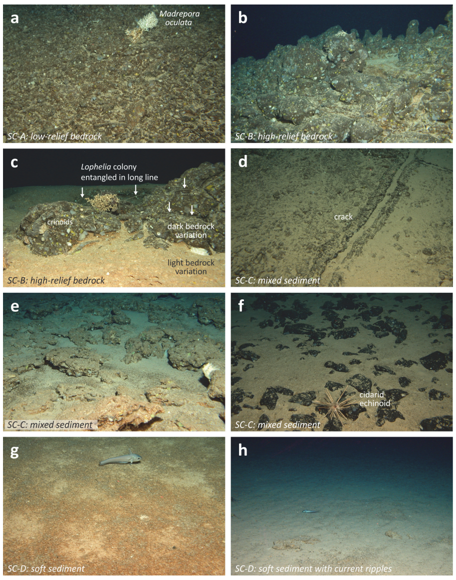

Fig. 3. ROV still images showing the variety of substrate components (SC) present on Coral Patch seamount (see also Table 2). **(a)** low-relief (smooth) basaltic bedrock (SC-A); **(b)** high-relief bedrock with small pockets filled with soft sediment (SC-B); **(c)** high-relief bedrock (SC-B) showing the two colour variations of bedrock; note *Lophelia* colony entangled in long line; **(d)** mixed sediment (SC-C): bedrock covered by a thin veneer of soft sediment; note the larger crack in the middle and the smaller one in the right upper corner; **(e)** mixed sediment (SC-C): pancake-like crusts with depressions in between filled with soft sediment (SC-C) **(f)** mixed sediment (SC-C): scattered basaltic pebble- to cobble-sized rock on soft sediment (SC-D); **(g)** soft sediment (SC-D); **(h)** soft sediment with current ripples (SC-D).

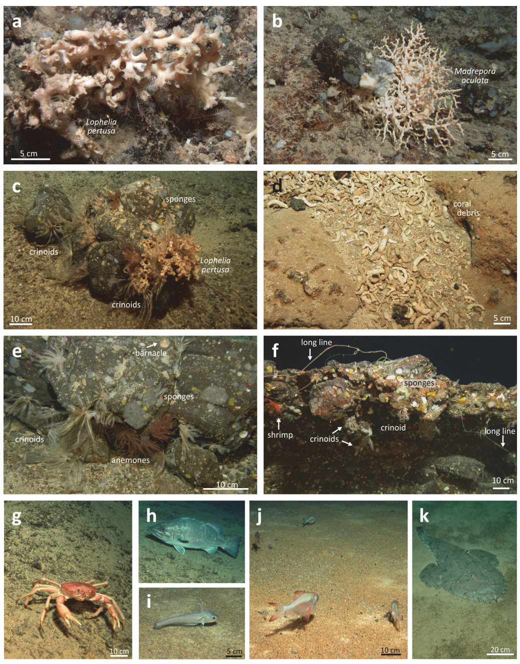

Fig. 4. ROV still images showing the variety of macrofauna (BC: biotic components) present on Coral Patch seamount and one example for anthropogenic impact (AIC). **(a)** *Lophelia pertusa* colonised by hydrozoans and crinoids; **(b)** *Madrepora oculata*; **(c)** *L. pertusa*, crinoids and sponges colonising a cobble-sized rock; **(d)** coral rubble accumulation made up of dendrophylliid and solitary coral species; **(e)** crinoids, anemones and sponges on bedrock; **(f)** fishing line entangled with a rocky slab; **(g)** *Geryon* cf. *longipes* on bedrock, **(h)** *Polyprion americanus*; **(i)** *Coelorinchus* sp.; **(j)** *Hoplostethus mediterraneus*; **(k)** *Lophius budegassa*.

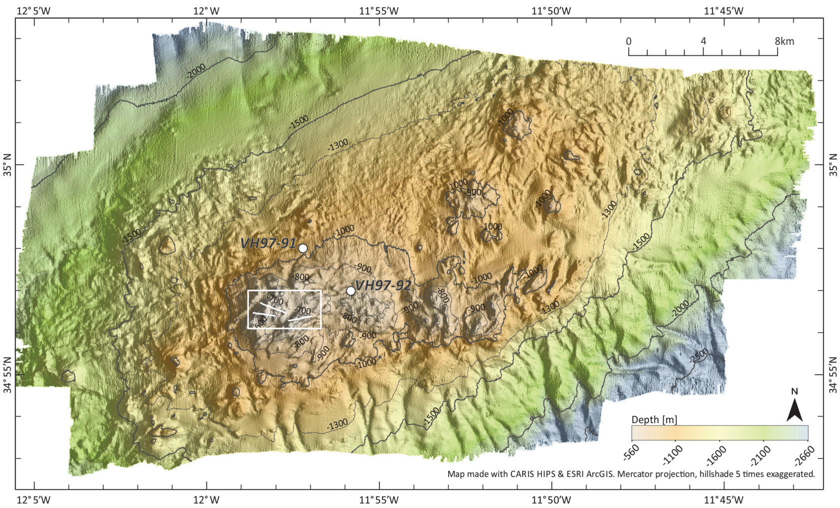

Fig. 5. Bathymetric map of Coral Patch seamount covering an area of 560 km^2 and a water depth range between 560 and 2660 m (Mercator projection, 5 times exaggerated, shaded relief). Displayed are the ENE-WSW elongated summit and the northern and southern flanks of the seamount, the latter being incised by several canyon-like structures. Inserted box shows video-surveyed area at the south-western top (see also Fig. 2). Two white dots indicate position of grab samples collected during R/V *VICTOR HENSEN* cruise VH97 (see also Table 3).

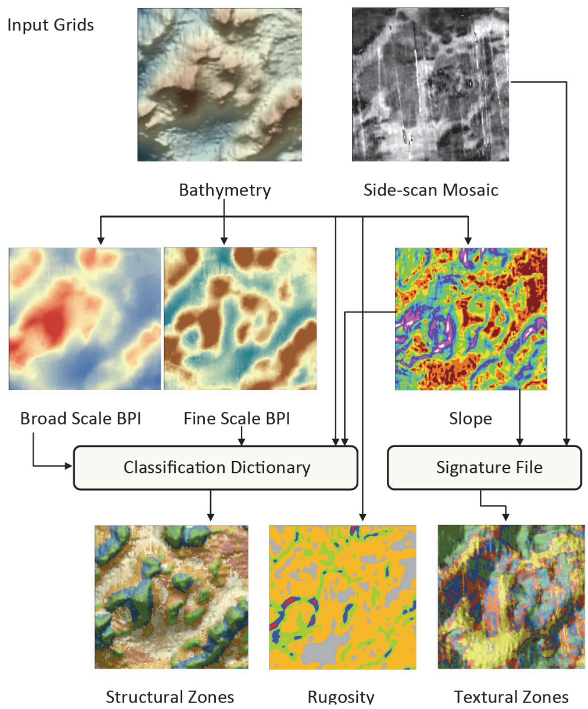

Fig. 6. Flowchart of hydroacoustic seabed classification methods applied for Coral Patch seamount. The dataset used for the flowchart displays a small area at the south-western summit. The final products (last image row) represent (a) topographical characteristics based on the bathymetry and derived products (BPI: Bathymetric Position Index), and (b) textural classes based on the side-scan mosaic and hillshade/slope.

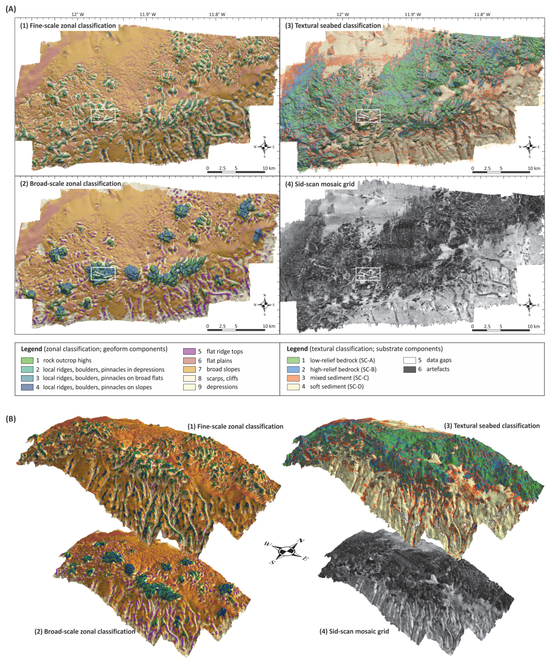

Fig. 7. Hydroacoustic seabed classification maps (**A**: 2-D-plots, **B**: 3-D-plots) of Coral Patch seamount. (1) Fine-scale and (2) broad-scale zonal classification maps both showing the distribution of geoform components (GC) comprising, e.g. flat plains, slopes, boulders, and local ridges (see Table 4 for detailed description). (3) Textural classification map showing the distribution of substrate components (SC; see Table 2 for detailed description). (4) Side-scan sonar mosaic grid. Inserted box on 2-D-plots indicates video-surveyed area at the south-western top of Coral Patch seamount.

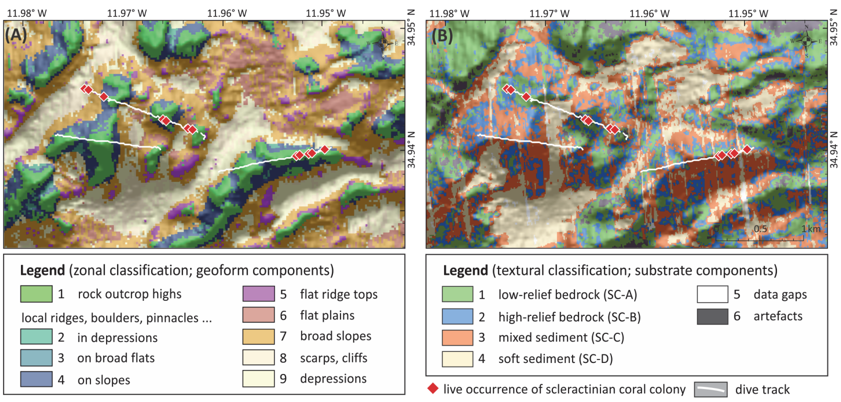

Fig. 8. Hydroacoustic seabed classification maps displaying the video-surveyed area on the south-western summit of Coral Patch seamount. **(A)** Fine-scale zonal classification (geoform components; see Table 4 for detailed description), and **(B)** textural seabed classification (substrate components; see Table 2 for detailed description). White lines: video transects; red diamonds: occurrence of live framework-building scleractinian cold-water corals observed during video observation (see also Fig. 2).

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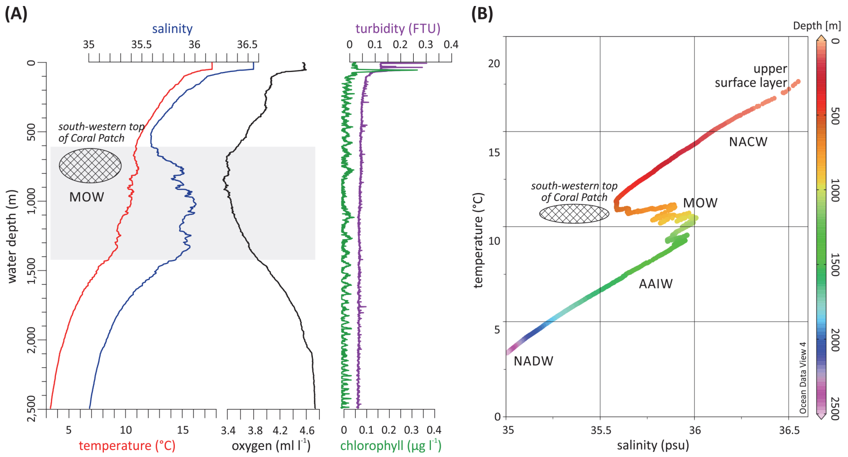

Fig. 9. (A) CTD profile (temperature, salinity, oxygen, fluorescence, turbidity), and **(B)** temperature and salinity (T-S) plot obtained for CTD station GeoB 12761. The CTD was lowered to a maximum depth of 2500 m south-east of Coral Patch seamount (see Fig. 1 for position). Major water masses are indicated: NACW North Atlantic Central Water, MOW Mediterranean Outflow Water, AAIW Antarctic Intermediate Water, NADW North Atlantic Deep Water (plotted using Ocean Data View v.4.5.1; http://odv.awi.de; Schlitzer, R., 2012). According to our bathymetric data the south-western top covers on average a water depth range between 600 and 900 m (indicated by the ruled ellipse), hence, is directly influenced by the upper part of the MOW. (Note: only one single peak even has an elevation of up to 560 m; see Figs. 2 and 5).