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In-situ observation of deep water corals in the northern Red Sea waters of Saudi Arabia

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ABSTRACT

Three sites offshore of the Saudi Arabia coast in the northern Red Sea were surveyed in November 2012 to search for deep-water coral (DWC) grounds using a Remotely Operated Vehicle. A total of 156 colonies were positively identified between 400 and 760 m, and were represented by seven species belonging to *Scleractinia* (3), *Alcyonacea* (3) and *Antipatharia* (1). The scleractinians *Dasmosmilia valida* Marenzeller, 1907, *Eguchipsammia fistula* (Alcock, 1902) and *Rhizotrochus typus* Milne-Edwards and Haime, 1848 were identified to species level, while the octocorals *Acanthogorgia* sp., *Chironephthya* sp., *Pseudopterogorgia* sp., and the antipatharian *Stichopathes* sp., were identified to genus level. Overall, the highest abundance of DWC was observed at Site A1, the closest to the coast. The most abundant species in the study area was *D. valida*, which lives attached to rocky substrates and represented 42% of the total coral population at site A1. Water column attributes at this depth were quite homogenous with temperature ca. 21.6 °C, salinity ca. 40.56, dissolved oxygen ca. 1.75 ml L^{-1} and current velocity from 0.6 to 34.5 cm s^{-1} with a mean value of 9.5 cm s^{-1}. Interestingly, these DWC can cope with high temperature and salinity, compared to those in other regions.

1. Introduction

The ahermatypic and azooxanthellate coral species are less constrained in their distribution by light penetration, temperature and salinity compared to hermatypic and zooxanthellate corals. Usually they occur on continental margins and topographical highs from polar to tropical latitudes, and reaching depths greater than 1000 m (Roberts et al., 2009; Levin and Dayton, 2009). Collectively called "Deep Water" Corals (DWC) or Cold Water Corals (CWC), these include stony corals (*Scleractinia*), gorgonians, sea fans, bamboo corals and black corals (*Antipatharia*), and hydrocorals (Stylasteridae). Among the 723 azooxanthellate scleractinian coral species currently known, the majority (532 species, 73.6%) are solitary in habit while the remainder (191, 26.4%) are colonial. The distribution of DWC is governed by various factors including temperature and calcium carbonate saturation (Cairns, 2007), topographic relief (Mortensen and Buhl-Mortensen, 2004; Buhl-Mortensen et al., 2010; Guinan et al., 2009; Yesson et al., 2012), sedimentary regime and currents (Thiem et al., 2006; Bryan and Metaxas, 2006; Wilson et al., 2007; Dolan et al., 2008).

The Red Sea has an average depth of 500 m, with a maximum of over 2500 m in its axial trough, and is noted for some of the hottest (around 40 °C) and most saline (up to 46) surface seawater in the world (Behairy et al., 1992; Taviani, 1998). The Red Sea bathyal depths house a relatively diverse benthic fauna, adapted to its highly saline and warm deep waters (PERSGA, 2006). Contrary to the well-known shallow-water coral reefs, not much information is available on DWC in the Red Sea basin. Nevertheless, the biodiversity of the present day Red Sea "deep water" benthos seems to be substantially less than in the adjacent Indian Ocean, as a response to restricted water exchange and extreme environmental conditions (Taviani et al., 2007). Previous geomarine investigation of the deep environments of the Red Sea has produced some evidence of subfossil DWC species such as *Javania insignis* Duncan (1876), *Trochocyathus virgatus sensu* Marenzeller (1907), and possibly *Guynia annulata* Duncan (1872), which inhabited the Red Sea during the late Pleistocene, becoming extinct at around the Last Glacial Maximum due to adverse environmental conditions (Bäcker et al., 1975; Taviani et al., 2007).

DWC were first sampled in the Red Sea by the Austrian/Hungarian vessel S.M.S. Pola (1895–1898). Six taxa were recorded from 212 to 987 m by Marenzeller (1907): *Balanophyllia rediviva* Moseley (1881), *Dasmosmilia valida* Marenzeller (1907), *Javania*

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insignis Duncan (1876), *Madracis interjecta* Marenzeller (1907), *Rhizotrochus typus* Milne-Edwards and Haime (1848), and *Trochocyathus virgatus* Alcock (1902). Further records include *Guynia* sp. (Taviani, 1998) and *Acabaria biserialishas* from the northern Red Sea (Schuhmacher, 1973; Grasshoff, 1976; Ben-Yosef and Benayahu, 1999). In addition, submersible surveys in the twilight/aphotic zone (105–205 m) of the Gulf of Aqaba revealed the presence of important coral growth in the form of reefs of azooxanthellate corals, such as *Madracis interjecta* Marenzeller (1907) and *Dendrophyllia* spp. (*e.g.*, *D. minuscula* Bourne, 1905) as main frame builders (Fricke and Hottinger, 1983; Fricke and Schumacher, 1983; Fricke and Knauer, 1986). Roder et al. (2013) reported corals *e.g.*, *Eguchipsammia fistula*, *Dendrophyllia* sp., an undetermined species of *Caryophyllidae*, *R. typus*, solitary red polyp and solitary white polyp, at depths of 230–740 m in the central Red Sea, where they occur at temperatures exceeding 20 °C in highly oligotrophic and oxygen-limited waters.

The exploration of the deep ocean is accelerating steadily, taking advantage of the sophisticated and only slightly invasive technologies such as Remotely Operated Vehicles (ROVs), which are credited with the discovery of a number of DWC sites around the World. However, there are very few published studies on azooxanthellate DWC from the low latitude seas when compared to the studies reported from high latitude seas. Although the presence of DWC in deep waters (400–1000 m) of the Red Sea was first recorded in the late nineteenth century (Marenzeller, 1907), it took more than a century to collect fresh DWC specimens from >250 m depths and provide some details on their distribution and habitat from these waters (Roder et al., 2013). Globally, DWC corals are facing threats from the disturbances caused by deep-sea trawling, impacts associated with oil and gas exploration and development, and ocean acidification. Hence for protecting and conserving the DWC habitats in every region, it is required to locate, map, characterize, and conduct a baseline assessment of DWC habitats. Here, we report an *in situ* study of these DWCs. We provide an inventory of the DWC observed (and collected in some instances) and in conjunction with hydrographical and current data, discuss the conditions that enable their presence and survival at these depths.

2. Materials and methods

2.1. Study area

Three areas located off Duba (Fig. 1) were randomly chosen for the survey. Area 1 (A1) (27°28′12″ to 27°29′49″N; 35°21′46″ to 35°23′42″E) was located at a depth of 312–622 m and approximately 17 km from the coast. Area 2 (A2) (27°24′31″ to 27°26′31″ N; 35°15′7″ to 35°17′2″E) and Area 3 (A3) (27°21′3″ to 27°22′40″N; 35°15′39″ to 35°17′42″E) were located at depth ranges of 636–770 m and 654–766 m, respectively, and approximately 29 and 32 km, respectively, from the coast. In each area, two square-shaped tracks consisting of an inner perimeter of around 6 km and outer perimeter of around of 12 km were surveyed.

2.2. Video survey and analysis

The survey was conducted during November 1–6, 2012 using the Research Vessel *R. V. Aegaeo*, belonging to the Hellenic Centre for Marine Research (HCMR). Sea bottom inspection and sampling was carried out using ROV *Max Rover* (DSSI, USA) operated from the vessel through a 1300 m umbilical cable. The ROV was equipped with a built-in CCD color video system consisting of two wide-angle cameras and a macro-zoom camera making a continuous recording that was stored on a hard disk. In addition, a wide-angle HDTV camera with a shorter recording time was rigged to the ROV in an unconnected housing. The ROV was equipped with a 5-function manipulator arm to facilitate sample collection.

The ROV was navigated using a compass, echo sounder, and sonar with Tracklink ultra-short baseline transponder system (Linkquest, USA) to track its position on the ship navigation computer. A total of 70 h of video was recorded over the course of six days. Video transects were typically flown at an altitude of 2–3 m over the bottom at a vehicle speed of 0.5 m s^{-1}. Distribution of megafauna was mapped from the images obtained with both forward- and downward-looking cameras. Some close-ups of the coral communities were also obtained and these were useful for taxonomic identification of the megafauna. A few specimens of megafauna were collected using the ROV for later identification. A multi beam survey was conducted to map the topography of the study area.

The video footage was visually analyzed to classify the various substrates. The occurrence of DWCs and their positions were used to develop an ArcGIS distribution map. The scleractinians were identified based upon images and actual samples, whenever available. The octocorals and black corals were identified in ROV images with the help of taxonomists and based on published information (Brugler et al., 2013).

2.3. Environmental data collection

Two types of measurements were conducted to characterize the current patterns of the region. A hull-mounted ADCP with deep-water profiling capabilities was used to measure the water current and direction at different depths throughout the track of the vessel within the study area. Two long-range ADCPs were attached to a mooring line and deployed at a station near the surveyed locations to gather the data on water circulation over a period of one month. Profiles of temperature, salinity (conductivity), dissolved oxygen, and depth, with measurements at 1 m intervals, were obtained using a Sea-Bird-9plus CTD system. Water samples obtained during the CTD cast were used for the measurement of nutrients. Concentrations of nitrate, nitrite, phosphate, and silicon were measured photometrically using a SKALAR San Plus model Auto-Analyzer using the analytical methods given by the manufacturer.

Sediment samples were collected from 45 stations in the three areas (15 gridded stations from each area) using a box corer with a 0.1 m^2 sampling area, and were analyzed for the estimation of sediment grain sizes (Carvar, 1971).

3. Results

The visual analyses of video footage and the analyses of sediment samples collected from selected stations revealed two main habitats: mound and intermound. The former corresponds to positive topographic features of various sizes, extending from about 5 to 50 m in height and at least 250 m in lateral extension. The latter consists of level to gently sloping areas situated between the mounds (Fig. 1). Most of the mound and slope areas are formed of hard rocky substrata whereas the intermound areas are mainly covered with mud or fine sediment and locally dotted with smaller reliefs. While Area A1 had extensive rocky mounds and relatively smaller intermound areas covered with muddy habitats, Areas A2 and A3 comprised mainly intermound areas with rare occurrences of small rocks. Plateaus, steep slopes, cliffs, and deep trenches were observed in Area A1. A thin layer of fine sediment over rock was observed at some stations in Area A1. This was

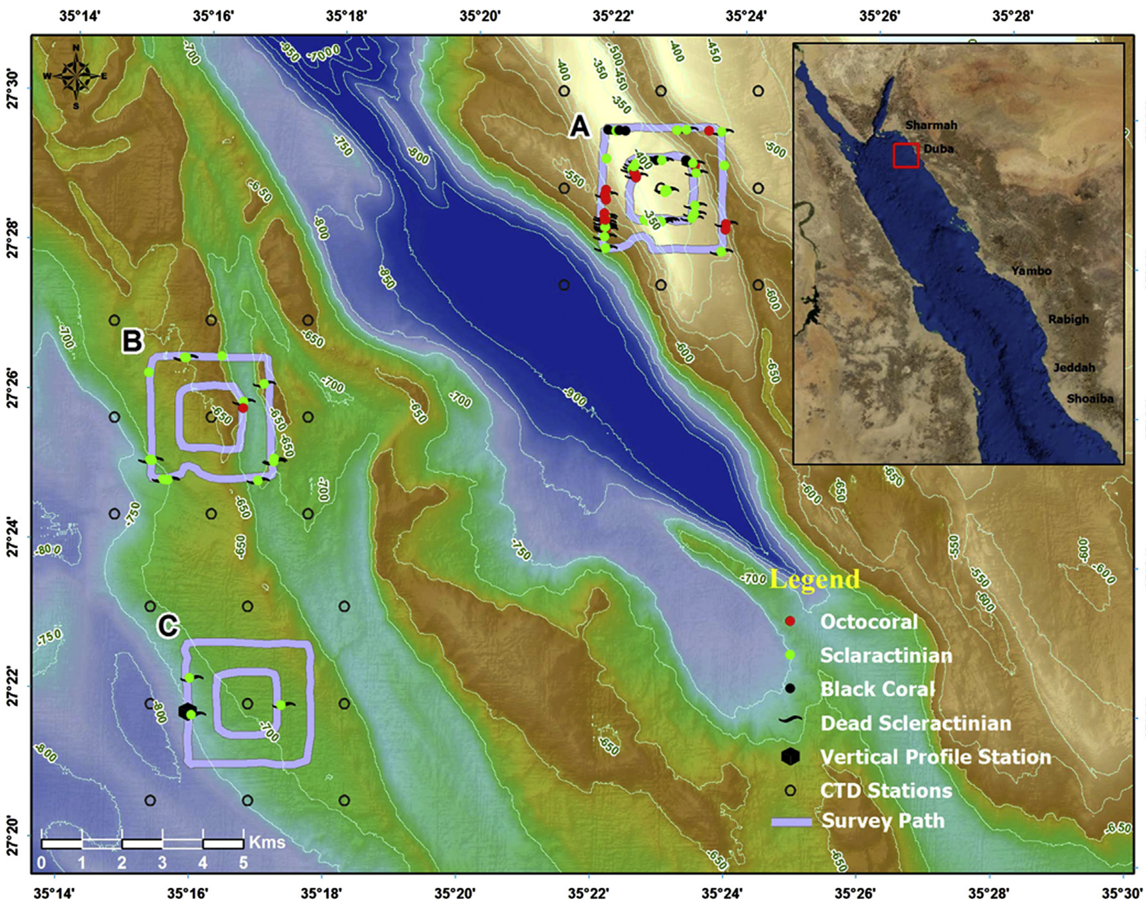

Fig. 1. Map showing the Red Sea study area and the locations of observed deep-water corals.

Table 1
Details of live deep-water corals and coral rubble observed from the study area.

Taxa	Live corals/colonies (number of occurrences)				Coral rubble[a] (number of occurrences)				Habitat types
	A1	A2	A3	Depth of occurrence (m)	A1	A2	A3	Depth (m)	
Scleractinia									
Dasmosmilia valida	50	29	1	357–720	29	14	3	312–731	Rocky and soft sediment
Eguchipsammia fistula	–	1	–	683	1	–	–	592	Rocky and soft sediment
Rhizotrochus typus	10	–	–	344–593	19	–	–	362–614	Rocky
Alcyonacea									
Acanthogorgia sp.	3	–	–	362–594	–	–	–	–	Rocky
Chironephthya sp.	11	1	–	362–673	–	–	–	–	Rocky
Pseudopterogorgia sp.	20	–	–	494–614	–	–	–	–	Rocky
Seafans (unidentified)	12	–	5	360–720	–	–	–	–	Rocky
Antipatharia									
Stichopathes sp.	13	–	–	357–437	–	–	–	–	Rocky

[a] Dead corals are given as number of patches for *D. valida* and *E. fistula* and as solitary coral number for *R. typus*.

inferred from the lesser amount of sediment obtained in the box-corer samples from selected stations.

Habitats such as rocky crests and boulders, bioturbated silt sediment, scleractinian colonies on soft and hard bottom, scleractinian coral rubble, octocorals and black corals on hard bottom were observed along with sea anemones, sponges, fishes, and crustaceans.

3.1. Distribution of corals and associated benthic communities

A total of 156 DWC colonies were recorded from the study area. Video observations and the coral specimens collected revealed the occurrence of eight species of corals belonging to orders *Scleractinia* (stony corals), *Alcyonacea* (octocorals) and *Antipatharia* (black corals) (Table 1). Scleractinians were represented by *D. valida* Marenzeller (1907), *E. fistula* (Alcock, 1902) and *R. typus* Milne-Edwards and Haime (1848) (Fig. 2). The octocorals recorded were *Acanthogorgia* sp., *Chironephthya* sp., *Pseudopterogorgia* sp. and an unidentified seafan (Fig. 3). Black corals were represented by a species of *Stichopathes*, a genus characterised by an unbranched whip with polyps arranged in a uniserial row along the axis (Fig. 3G and H).

3.1.1. Area A1

Of the three areas surveyed, A1 was the most biologically diverse, with the occurrence of seven DWC species. Nearly 76% of the total live coral colonies recorded from the whole study area

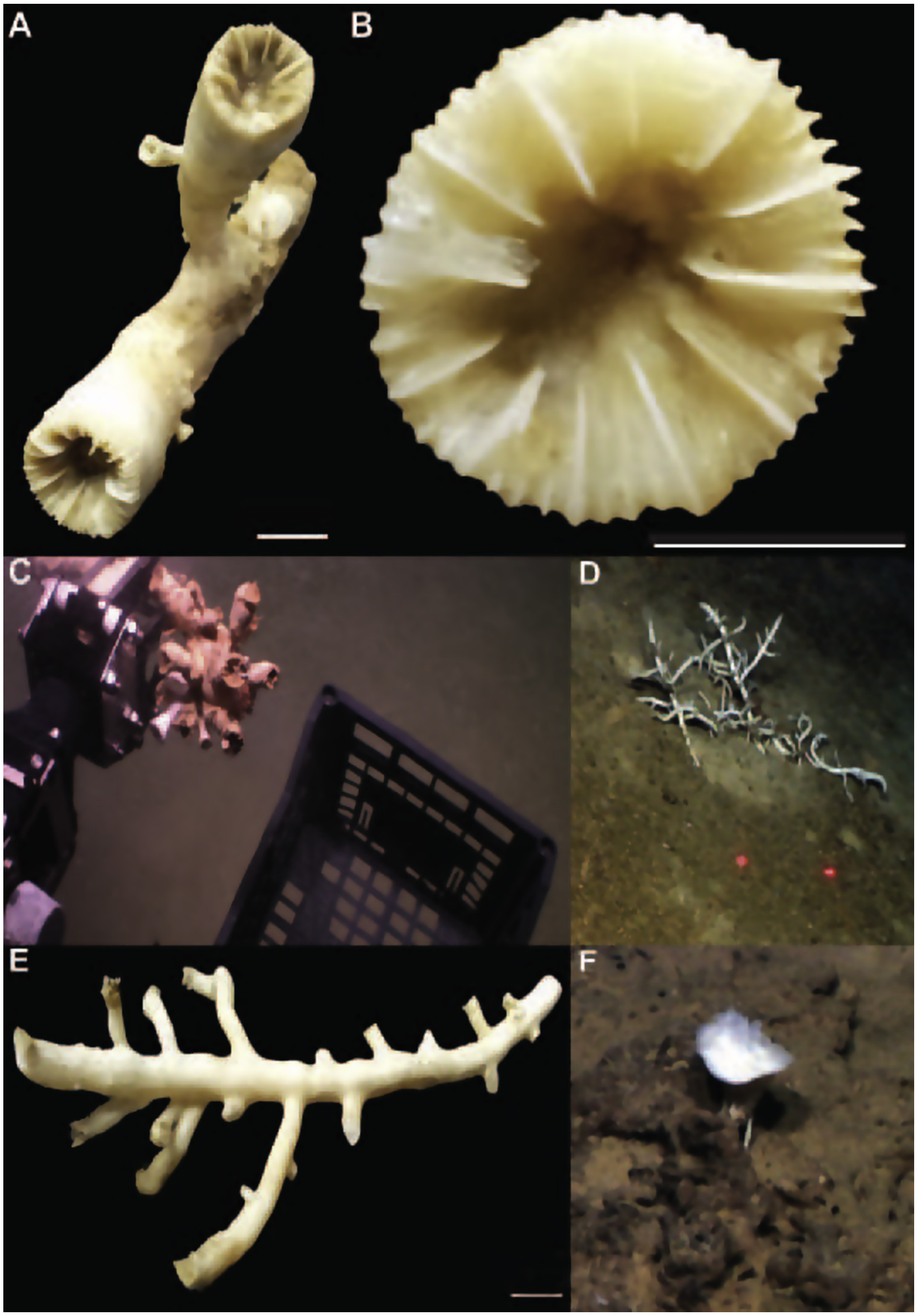

Fig. 2. Scleractinian corals identified from the study area. ((A)–(C)) *Dasmosmilia valida*. (A) Side view of branches (scale bar 1 cm); (B) calicular view (scale bar 1 cm); (C) *in-situ* photograph. ((D) and (E)), *Eguchipsammia fistula*. (D) *in-situ* photograph (distance between two red laser points is 10 cm); (E) side view. (F) *Rhizotrochus typus*, *in-situ* photograph.

were from Area A1 (Table 1). *D. valida* was by far the most common (42% of the total corals in the A1 site) species and was observed mainly on rock. Some colonies were also found scattered in the soft sediment, which consisted of a thin layer of mud over the rock that provided a hard substratum for the corals (Fig. 2). Another scleractinian, *R. typus*, was recorded only from A1 as a single record. Four octocorals were recorded from A1, of which *Pseudopterogorgia* sp. and *Acanthogorgia* sp. were recorded only from this area (Table 1). The octocorals were restricted as isolated colonies to rocky cliffs. The black coral, *Stichopathes* sp. was also recorded only in Area A1 (Table 1) where it occurred at relatively shallow depths (<440 m).

Patches of coral rubble, composed mainly of *D. valida*, were common in Area A1 (Table 1). These dead corals occurred as a few scattered pieces to larger patches each covering an area of approximately 5 m^2 (Fig. 4). Patches of coral rubble >1 m^2 were also observed at eight locations in Area A1. In most cases, large patches of coral rubble observed at the bases of large rocks appeared distinctly patinated. Coral rubble of *R. typus* was observed occasionally, while *E. fistula* occurred once, as some fragments intermingled with *D. valida.*

The diversity of associated macro- and megafauna was generally low (Fig. 5). The two taxa that were commonly observed on the rocks near the corals were sea anemones and sponges. Gamba

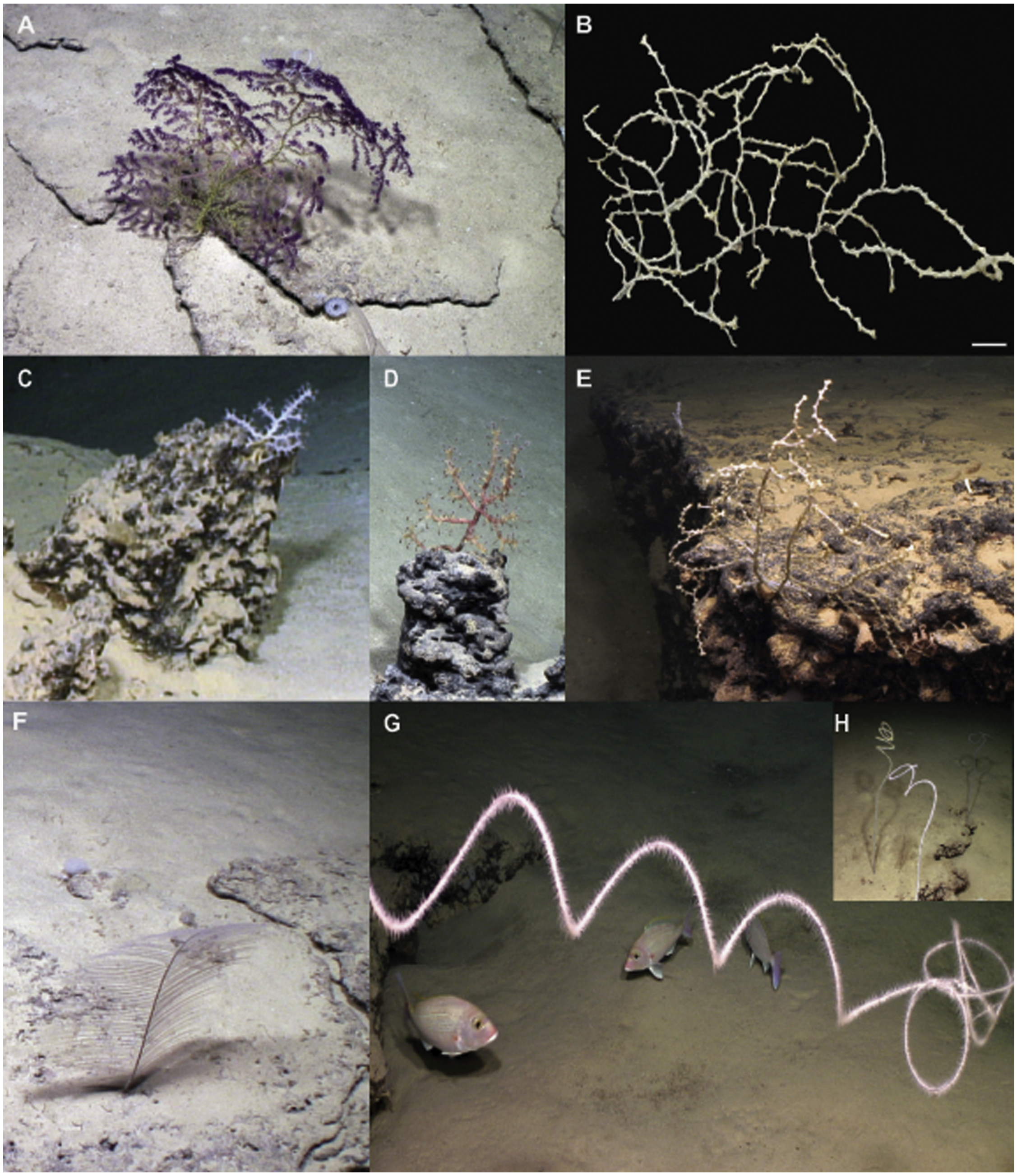

Fig. 3. Octocorals and black corals identified from the study area. ((A) and (B)) *Acanthogorgia* sp. (A) Specimen photographed *in situ*; (B) in the laboratory (scale bar 1 cm). ((C) and (D)) *Chironephthya* sp. (E) *Pseudopterogorgia* sp. (F) Sea fan. ((G) and (H)) *Stichopathes* sp. (Fishes seen in (G) are *Pagellus* sp.).

shrimp (*Aristeus* sp.), and fish species *Pristigenys niphonia* and *Pagellus* sp., were found associated with dead coral debris. Starfish, sea urchins, sea lilies, crabs, and serpulid polychaetes were also observed, but only rarely in the vicinity of corals (Fig. 6).

3.1.2. Area A2

Three coral species were recorded in Area A2, of which *D. valida* was the most common (Table 1). *E. fistula* was only found at Area A2. In some instances, *D. valida* occurred on a thin layer of mud over the rock (probably attached to a hard ground below), as observed in Area A1. Coral rubble of *D. valida* was observed occasionally in Area A2. Three coral rubble patches were found, each around 1 m^2 in surface. Sea anemones and sponges were the only macrobenthic animals found associated with corals at Area A2.

3.1.3. Area A3

The habitat in Area A3 consisted mainly of intermound areas draped by mud, with very rare occurrences of rock boulders; as a result, the deep-water corals were very sparse. *D. valida,* which was observed frequently at Areas A1 and A2, was recorded only once in the rocky habitats in Area A3. Seafans were found occasionally and small patches of coral rubble were observed, but only rarely. Sea anemones and sponges were seen among the rocks.

3.2. Hydrographical parameters, nutrients, and productivity

The hydrographical parameters recorded from the three areas are presented in Table 2. A three-layer system, consisting of a surface mixed layer 50 m thick followed by a strongly stratified thermocline between the mixed layer and 200 m, was observed (Fig. 1). A deep layer was recorded below this thermocline, with a homogeneous temperature (21.6 °C) and salinity (40.6). The Red Sea surface waters are essentially oxygen saturated, and the present survey recorded a dissolved oxygen (DO) value of 3.91 to 4.39 ml L^{-1}. A relatively lower oxygen zone with a DO of 1.53 to 1.58 ml L^{-1} was present at intermediate depths (~500 m) below the thermocline and halocline. The oxygen concentrations increased slightly toward the bottom to 2.04 ml L^{-1}, probably due to deep-water circulation. The average current velocity was relatively high (17 cm s^{-1}) near the sea surface (at 30 m), and it reduced to 5 cm s^{-1} at a depth of around 300 m. However, the average current speeds increased to 9.5 cm s^{-1} near the bottom. The surface currents flowed predominantly to the west-southwest, while the bottom currents flowed mainly toward the southeast–southwest (Table 2). The sinking surface water in the northern Red Sea flows southward as deep-water currents, which may act as a food supply mechanism for these deep-water corals.

Concentrations of nitrate, phosphate, and silicon were in traces in the euphotic zone and increased below with depth to attain, respectively, >8, >0.3 and >5 μmol L^{-1} near the bottom. The scarcity of nutrients at the surface also had an influence on primary production, limiting the latter to rates not more than 3 μg C L^{-1} h^{-1} and 36 nmol N L^{-1} h^{-1} (Qurban et al., 2014). The export production (equivalent to new production or nitrate uptake) was no more than 100 μmol N m^{-2} h^{-1}. Allowing for remineralization below 200 m depth, the amount of organic matter reaching a 1 m^2 area of seafloor from the surface would not be more than a few tens of μmol C h^{-1}.

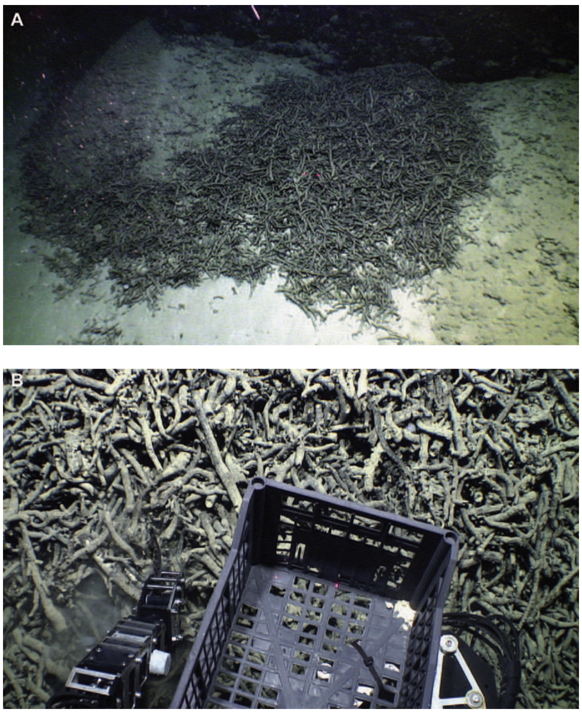

Fig. 4. *in situ* photographs of dead corals observed during ROV dives in the study area. (A) A large patch of dead corals. (B) A close-up view.

4. Discussion

We report the occurrence of DWC at a depth of 344–720 m from the northern Saudi Arabian Red Sea waters. DWCs are usually occur in areas of pronounced topographic relief and their distribution and abundance are influenced by environmental factors such as temperature, water current and substrate type (Mortensen and Buhl-Mortensen, 2004; Buhl-Mortensen et al., 2010; Guinan et al., 2009; Yesson et al., 2012; Bryan and Metaxas, 2006; Tong et al., 2012; Rengstorf et al., 2013). In our study, the maximum abundance and diversity of DWC was recorded from an area (A1) that is located relatively near the shore (Fig. 1). This may reflect the

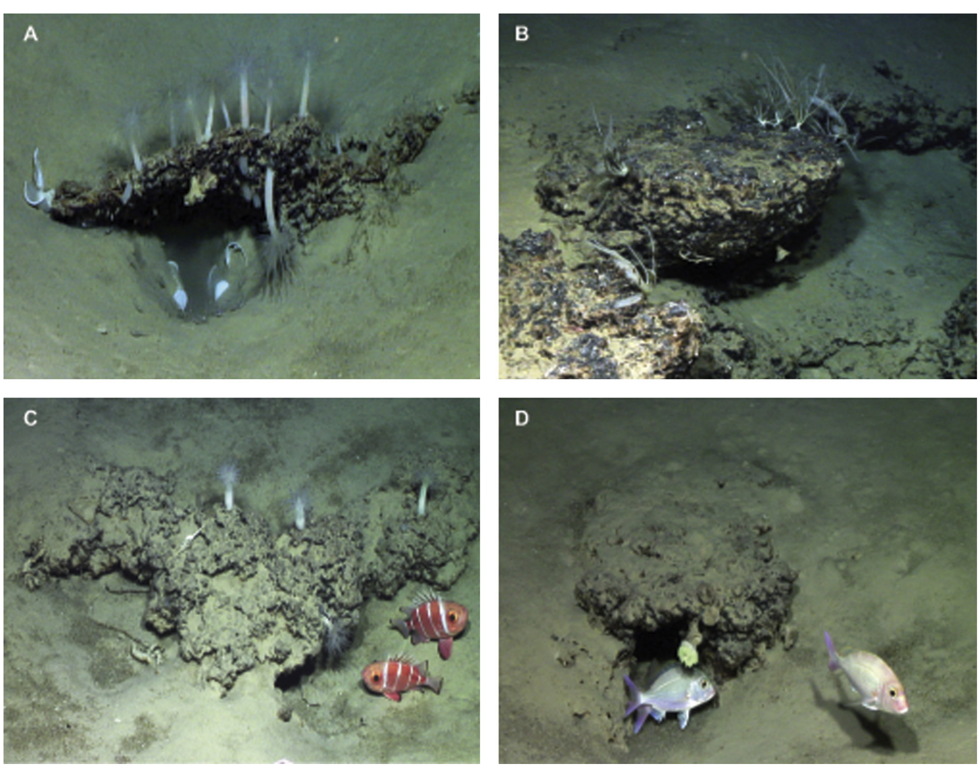

Fig. 5. *in situ* photographs of benthic communities observed during ROV dives in the study area. (A) Sea anemones. (B) Sea lilies. (C) *Pristigenys niphonia*. (D) *Pagellus* sp.

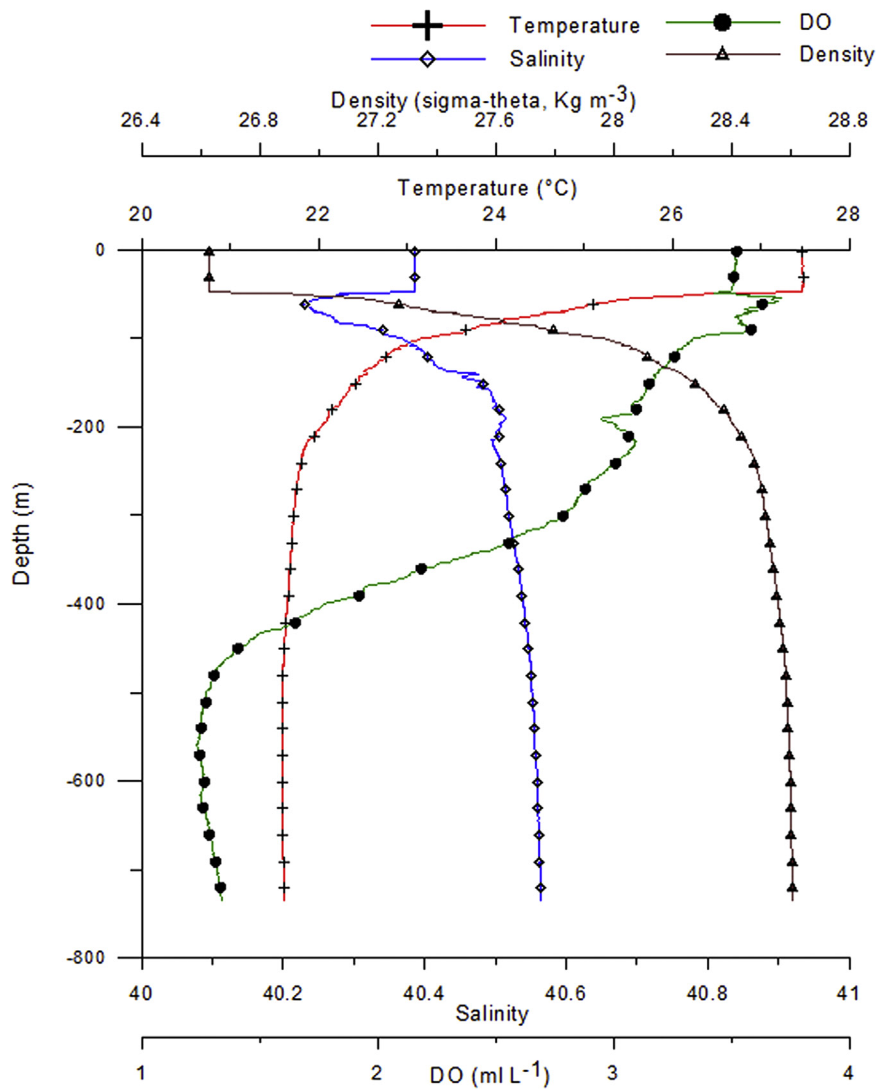

Fig. 6. Vertical profile of temperature (°C), salinity, DO (ml L^{-1}) and density at a representative station in Area A3, located near a deep-water coral colony.

Table 2
Hydrographical parameters (range, wherever applicable) recorded from the study area.

Parameters	A1		A2		A3	
	Surface	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
Depth (m)	404–600		645–759		735	
Temperature (°C)	28.04–28.22	21.59–21.60	27.91–28.25	21.59–21.61	27.46	21.61
Salinity	40.38–40.39	40.55–40.56	40.28–40.37	40.56	40.39	40.56
DO (ml L^{-1})	3.91–4.32	1.53–1.58	4.29–4.39	1.49–2.04	4.29	1.63
NO_3 (μmol L^{-1})	0.02–0.23	7.67–10.17	0.07–0.3	7.8–8.63	0.2	8.8
NO_2 (μmol L^{-1})	0.09–0.17	0.08–0.15	0–0.04	0–0.17	0.08	0.08
PO_4 (μmol L^{-1})	0.06–0.09	0.55–0.75	0–0.09	0.32–0.41	0.04	0.74
Si (μmol L^{-1})	0.83–0.93	7.86–9.40	0–0.18	0.91–5.36	0.78	7.71
Chlorophyll-*a* (μg L^{-1})	0.09–0.13		0.06–0.2		0.06	
Bottom current speed (cm s^{-1})		0.6–34.5		0.6–29.2		2.2–6.9
Bottom current direction		Southeast and Southwest		South-southeast		East-southeast

combination of availability of multiple suitable habitats coupled with favorable environmental conditions such as stronger water currents.

The bottom current regime (velocities ranging from 0.6 to 34.5 cm s^{-1}; mean 9.5 cm s^{-1}) within the study area (Table 2) is favorable for supplying food particles to DWC. The deeper part of the Red Sea basin is ventilated by slope convection fed by the outflow from the Gulf of Suez and the Gulf of Aqaba (Quadfasel and Baunder, 1993; Quadfasel, 2001). Due to the large water reservoir of the Gulf of Aqaba, the latter outflow is steadier and provides a more permanent source for the Red Sea Deep water (Quadfasel, 2001; Sofianos and Johns, 2007). This leads to a southward flow that merges with the southward flow of the lower thermocline in the interior of the basin to make up the outflow of Red Sea Water through Bab El Mandeb. Laboratory and field observations have shown that DWC can selectively feed on live zooplankton or suspended particulate organic matter (Mortensen et al., 2001; Freiwald et al., 2002; Kiriakoulakis et al., 2007; Tsounis et al., 2010). Relatively high nutrient levels were observed in the bottom layers (Table 2) compared to the surface layers, which indicates the availability of organic matter. Unfortunately, particular organic matter (POM) in bottom seawater samples were not collected and analyzed as part of this study.

The deep water column at the DWC sites is very homogeneous in terms of temperature (21.6 °C), salinity (40.56) and dissolved oxygen (1.75 ml L^{-1}), with very little seasonal variation (Quadfasel, 2001). Most of the DWC species have been found to inhabit environments with temperatures ranging between 3.5 and 13.5 °C and salinities ranging between 34 and 37 (Mortensen et al., 2001; Freiwald et al., 2002; Taviani et al., 2005). DWC species in the Red Sea live at considerably higher temperatures (>20 °C) and salinities (>40). Recently six DWC species have been recorded from the central Red Sea, where they occur at temperatures exceeding 20 °C in highly oligotrophic and oxygen-limited waters (Roder et al., 2013). The DWC species have been found in considerable abundance in the Mediterranean Sea where many of them survive well at the uppermost end of their temperature range of 4–13.8 °C (Freiwald et al., 2004; Taviani et al., 2005; Roberts et al., 2006; Orejas et al., 2009). A recent laboratory study has documented the survival in aquaria of two common DWC species (*i.e.*, *Dendrophyllia cornigera* and *Desmophyllum dianthus*) at anomalous warmer temperatures as high as 17 °C (Naumann et al., 2013) much higher than their normal temperature range in the ocean. Some field studies have also shown that DWC can live in environments where the temperatures exceed 17 °C (Castric-Fey, 1996; Forsterra and Haussermann, 2003; Freiwald et al., 2009). Our observations, and the previous study in the central Red Sea (Roder et al., 2013), clearly demonstrate that some DWC can survive at temperatures in excess of the highest recorded elsewhere in the ocean or aquaria.

Acknowledgments

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