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ORIGINAL PAPER

Quaternary fossil coral communities in uplifted strata along the Balochistan coast of Pakistan: understanding modern coral decline in the Arabian Sea

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Abstract
Uplifted reefs due to being important palaeoclimate archives and a rich source of information on past physical and geochemical changes globally have become the centre of marine research. The uplifted fossil Quaternary coral communities of Jiwani and Gwadar are perfect places to study the palaeoclimatic and geological changes that have shaped the Balochistan coast. Studies on the palaeodiversity of corals along the Makran coast of Pakistan are lacking. In the present study, the samples collected using line intercept method from four uplifted sites (Balochistan coast: one at Gwadar and three at Jiwani) were analysed. The relative distribution and diversity of scleractinian fossil corals was determined, and the factors responsible for coral decline along Pakistan coast were compared with modern coral distribution and diversity. A total of 48 fossil coral species were recorded in nine families and 22 genera. High coral diversity was recorded in the uplifted landward sites of Jiwani and Gwadar headland. Terraces close to the shore at Jiwani had lower diversity. The corals seem to be Quaternary: most likely Pleistocene to Holocene. The modern fauna lacks many species recorded in the fossil community, thus suggesting a faunal turnover in diversity and redistribution of coral fauna which may be linked with past geological events and increasing anthropogenic pressure.

Keywords Quaternary fossil corals · Makran subduction zone · Arabian Sea · Balochistan · Gwadar · Jiwani

Introduction

Uplifted reefs serve as important palaeoclimate archives (Felis and Patzold 2003) and have great geologic and archaeological significance (Moursi et al. 1994; Walter et al. 2000).They are a rich source of information on the past physical and geochemical changes, biological diversity over large temporal scales and the response of living organisms to past and present climatic changes in their surroundings (Sepkoski 1997; Gagan et al. 2000; Honisch et al. 2004; Pandolfi and Greenstein 2007). Useful data on the significance and distribution of Quaternary corals is available on both the regional and global scales (e.g. Chappell 1974; Newton et al. 1987; Dullo 1990; Kora and Fattah 2000; Moustafa et al. 2000; Pandolfi and Jackson 2001; Bruggemann et al. 2004; Crabbe et al. 2006; Edinger et al. 2007; Greenstein and Pandolfi 2008; El-Sorogy et al. 2013; Mossadegh et al. 2013; Pellissier et al. 2014).

The Makran coast of Pakistan is a part of Makran Subduction Zone (MSZ; defines a 900-km long area located in the southern part of Pakistan and Iran) (Fig. 1) where the oceanic crust of the Arabian plate is being subduced northward below the Eurasian plate since at least the Cretaceous to the Recent, with a convergence rate of 4.2 cm year^{-1} in east Makran and 4 cm year^{-1}in west Makran (White 1982; Harms et al. 1984; Byrne et al. 1992; Burg et al. 2008). The 800-km Makran coast extends from NW of Karachi (Fig. 1) in the east to Gwatar Bay (Iranian border) in the west with a narrow tectonically active continental shelf (Haq 1988; Ali and

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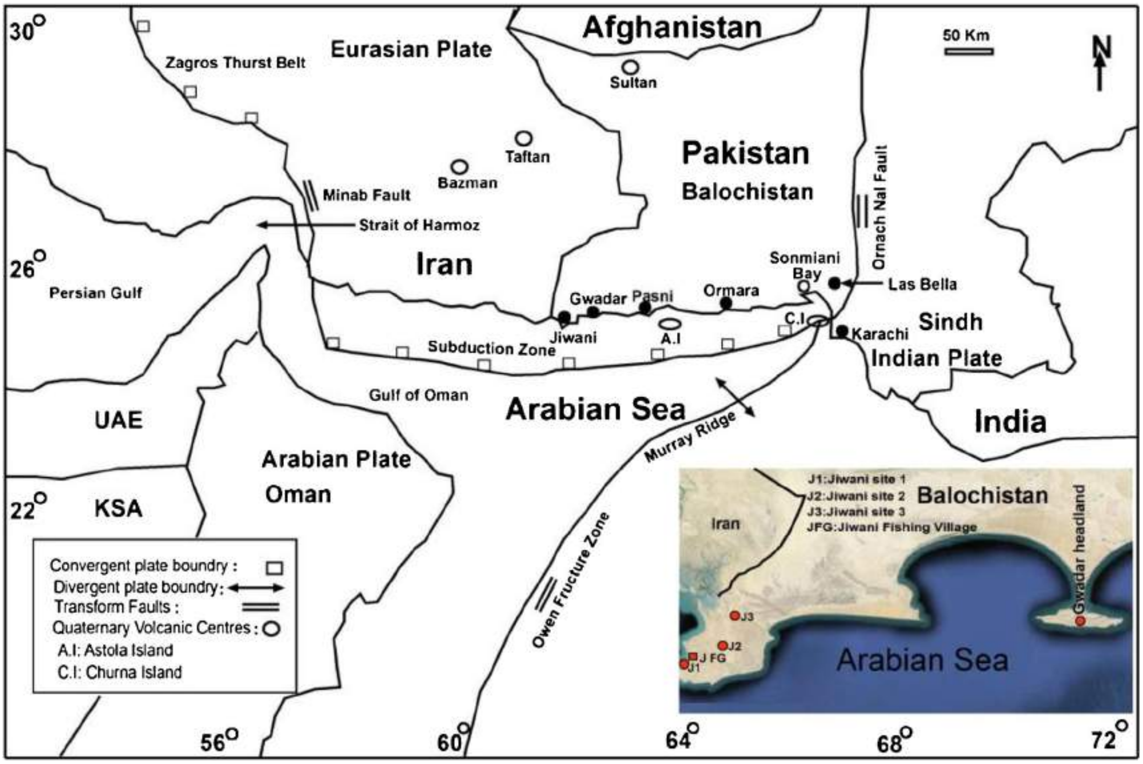

Fig. 1 Map showing Makran subduction zone (MSZ) in the coastal region of Pakistan and Iran and other structural features in northern Arabian Sea. Inset showing study sites at Gawadar and Jiwani, Balochistan coast

Memon 1995; McCall 1997). The principal geomorphic features of the Makran coast are cliffs, headlands, stacks, spits, terraces, raised beaches and mud volcanoes. Rocks exposed along the coast in the headlands, terraces and coastal cliffs are assemblages of sandstone and mudstone (Page et al. 1979; Ali and Memon 1995). The tectonic and stratigraphic history of MSZ has been described by Harms et al. (1984) and can be summarised as follows. As a result of jostling between the continental plates, complex geotectonic changes are divided into three significant stages relevant to this study: the middle Miocene, the late Miocene to middle Pliocene and the middle Pleistocene to Recent. During the middle Miocene, the deposition of turbidites dominated. The late Miocene to middle Pleistocene was dominated by progradation of the plains, shelf, slope and landward margin, as well as regional uplifting and folding. The middle Pleistocene to Recent phase was largely characterised by further uplift and faulting.

The uplifted Jiwani and Gwadar areas are perfect places to study Quaternary coral communities with respect to the palaeoclimatic and geological changes that have shaped the Balochistan coast of Pakistan. No significant studies have previously been undertaken in this area other than by Crame (1984) and Siddiqui et al. (2011). Crame (1984) and Ali and Memon (1995) reported the presence of Neogene and Quaternary molluscs and corals embedded in different lithostratigraphic units, but no taxonomic details were provided; Siddiqui et al. (2011) reported only 14 fossil coral species from uplifted reefs at Ras Gunz near Jiwani (see Appendix Table 3). Duncan (1880) reported 55 Miocene corals from Sindh province of Pakistan. Studies on the palaeodiversity of corals along the Makran coast of Pakistan are lacking, and this is one of the first studies of its kind in the region. Previous studies (Siddiqui et al. 2011; Ali et al. 2014) showed that modern fauna lacks many species recorded in the fossil community. The present study was carried out to further explore and compare recent and fossil coral distribution and to discuss the changes in coral communities with respect to the past geological history and increasing anthropogenic pressure in recent time.

Climate

Present climate

The climate of coastal areas of Pakistan is mainly dry to hyper dry (Salma et al. 2012) and is strongly affected by tropical cyclones, winter weather disturbances (cyclonic, anti-cyclonic and meridonal) in the `Mediterranean Sea, reversal of the monsoon and the cyclic migration of the Inter Tropical

Convergence Zone (ITCZ). Yearly rainfall is less than 254 mm (Snead 1968; Sheppard et al. 1992; Djamali et al. 2010; Rojas et al. 2013).

Past climate

Historically, great variations in monsoon patterns, temperature, productivity, turbidity, sedimentation rates and upwelling have been noted for the Arabian Sea. Overall, the monsoon was characterised by large temporal scale changeability. The south-west monsoon was stronger during interglacial and weakest during the last Glacial Maximum (Tiwari et al. 2011). During the glacial periods Marine Isotope Stage MIS 3 and MIS 8, sea surface temperatures were lower than during the interglacial periods (ten Haven and Kroon 1991). Productivity and turbidity in the Arabian Sea were high during MIS 13 and possibly associated with the beginning of a harsh meridional overturning circulation in the Atlantic Ocean at the end of the middle Pleistocene (Gupta 1999; Prins et al. 2000; Ziegler et al. 2010). The sedimentation rate in the Arabian Sea (northern Arabian Sea) was 1.2 mm/year for the last 5000 years (Prins and Postma 2000).

Materials and methods

Study sites

The study sites for the present work are located in the Gwadar and Jiwani Formations along the Balochistan coast (Fig. 1). On the basis of preliminary surveys, four sites were selected, one in the Gwadar headland and three in the Jiwani, located tens of meter above mean sea level.

Geological description of sites

Gwadar headland

The Gwadar headland is located ~ 543 km west from Karachi. The northern side of the headland is composed of thick shell and coquina beds, deposited in 15- to 20-m thick massive mudstone units. The upward trending lithologies are a succession of pebbly sandstones transitioning upwards to fine sands, interbedded with coquinas and conglomerates. The Gwadar headland is a part of the Gwadar Formation (20,000 and 30,000 years; Kazmi and Jan 1997) which extends eastward up to the Hingol River and to Jiwani in the west with variable thickness (Crame 1984).

Jiwani

Jiwani is located about 720 km from Karachi on the Balochistan coast of Pakistan and 60 km from Gwadar towards the west, close to the border of Iran. Folding, faulting and elevated terraces, possibly late Pleistocene time, are the major features of the formation (Hussain et al. 2002). The formation is largely comprised of porous shell fragments, hard and pebbly shale and limestone deposited in mudstone, interbedded with a conglomerate of rounded sandstone, pebbles, cobbles, limestone and red jasper, with bedding up to 3 m. The colour is mostly greyish brown to dark ferruginous brown. This study site is part of Jiwani Formation generally confined to the southern part of the Makran division (Hunting Survey 1961; Crame 1984; Shah 2009). The formation is considered as younger extending from late Pleistocene to Holocene (Crame 1984; Raza et al. 1991) compared to Gwadar Formation.

Field techniques

The sampling surveys were undertaken during September 2012 and October 2013. Position and general observations for each site were recorded (Appendix Table 4). Location and height above sea level was determined using a Garmin Etrex 10 GPS. At three sites in the Jiwani Formation, samples were collected using line intercept method (Loya 1972), a more effective method for reef slopes than quadrat method and is less time consuming (Ohlhorst et al. 1988; Beenaerts and Berghe 2005). Transects (50 m each) were laid considering the nature of the sites (e.g. topography, width, coral cover). One transect at Jiwani site 1 (J1), five transects at Jiwani site 2 (J2; large area about 1 km^2) and two transects at Jiwani site 3 (J3) were laid. Transects at J2 were at least 100 m apart, and at J3, they were separated by 10 m. Gwadar headland (GH) was ecologically disturbed due to the construction of a local infrastructure, and corals were counted and not recorded systematically. Each species was assigned a rank number (1–5) depending on its abundance: 6 = > 50 individuals, 5= > 40 individuals, 4 = 25–40 individuals, 3 = 16–24 individuals, 2 = 8–15 individuals and 1 = 1–7 individuals.

For detailed examination of identifiable taxonomic features, small samples were collected using hammer and chisel and carefully washed. The overall and magnified images were made of individual samples with the help of Canon Power Shot A1100IS digital camera for the identification of coral species following Veron (2000) and Bromfield (2013). Specimens are stored at the Centre of Excellence in Marine Biology, University of Karachi, for future reference. Skeletons of same taxa from fossil corals (this study) and modern corals (collected earlier; Ali et al. 2014) were compared to assess the effects of sediment stress and primary productivity following the methods described earlier by Klein et al. (1991) and Edinger and Risk (1994).

Table 1 List of fossil corals collected from uplifted strata at Gawadar (GH) and Jiwani (J1, J2, J3), along Balochistan coast of Pakistan. Values are relative abundance based on number of individual of each species in a sample

Fossil corals	GH	J1	J2					J3	
			J2 (1)	J2 (2)	J2 (3)	J2 (4)	J2 (5)	J3 (1)	J3 (2)
Family: Faviidae									
Blastomussa sp.			5	3				2	2
Caulastrea sp.					2			2	
Cyphastrea hexasepta			2	1					
Cyphastrea sp. 1			1					2	
Cyphastrea sp. 2			1						
Cyphastrea sp.3								1	
Echinopora sp.	2								
Favites complanata	1	4	2	3	3	2	2	3	3
Favites spinosa	2		1					3	
Favites cf. *abdita*	1					1		2	
Favites cf. *chinensis*								2	2
Favia pallida	2		4	2	3			4	4
Favia speciosa	2		4	2	3	2		4	2
Favia favus	2		4	2	3	1		4	2
Favia sp. 1			4	3					
Favia sp. 2			4	2	2			3	
Goniastrea columella								1	
Goniastrea aspera	2	4	4		2				
Goniastrea sp.			2					3	3
Leptastrea transversa			2						
Leptastrea sp.				2					
Platygyra pini	2		2	2	2			3	1
Platygyra sinensis	2		3	2	2	2	1	2	1
Plesiastrea versipora				1				1	
Family: Acroporidae									
Acropora sp. 1	2								
Acropora sp. 2	1			1				1	
Acropora sp. 3				1				1	
Acropora sp. 4			1	1	1			1	
Astreopora sp.1			1						
Astreopora sp. 2			2						
Astreopora sp. 3			1						
Astreopora sp. 4								1	
Family: Pociloporidae									
Pocillopora damicornis	2							1	
Pocillopora verrucosa	1		1					1	1
Pocillopora cf. *eydouxi*								1	
Stylophora pistillata	3		2	2	2			1	
Family: Poritidae									
Porites sp. 1			1						
Porites sp. 2	2								
Goniopora sp. 1			1						
Goniopora sp. 2			1	1					
Family: Merulinidae									
Hydnophora exesa	3		1				1	1	
Hydnophora microconis	2		1						
Family: Dendrophyliidae									

Table 1 (continued)

Fossil corals	GH	J1	J2					J3	
			J2 (1)	J2 (2)	J2 (3)	J2 (4)	J2 (5)	J3 (1)	J3 (2)
Turbinaria sp.								1	
Family: Fungiidae									
Cycloseris sp.			1						
Fungia sp.								1	
Family: Musidae									
Acanthastrea hillae								1	
Acanthastrea cf. *echinata*								1	
Family: Agaracidae									
Leptoseris cf. *mycetocoides*		1							
Total species	18	2	29	17	11	5	3	30	10

Data analysis

Based on presence and absence data and Bray and Curtis similarity index, cluster analysis was conducted using group average linkage techniques to investigate relationship between sites (Bray and Curtis 1957: Clarke 1993; Clarke and Warwick 2001). To map any decline or change in coral communities from the Quaternary to the present in Pakistan, a comparison was made using the Quaternary coral data from current study and Siddiqui et al. (2011) and data on modern coral distribution in Pakistan from Ali et al. (2014).

Further cluster analysis was conducted to compare the species and genera composition of Quaternary (current study and Siddiqui et al. 2011), modern corals (Ali et al. 2014) from Pakistan and Miocene corals reported from southern Iran (McCall et al. 1984). Analyses were done using PRIMER v6 software package (Clarke and Gorely 2006).

Results

A total of 48 species of fossil corals belonging to 9 families and 22 genera (Table 1; Fig. 2a, b) were recorded during this study. Among these, 18 were identified to species level, 25 up to genus level while there is some doubt about the identification of 5 species. The landward sites (J2, J3) had high diversity and density, compared to GH and the shoreward site J1. Skeletal comparison of fossil and modern corals showed no significant difference between corallite morphology (Fig. 3), whereas bioeroding effects were comparatively found high in fossil corals (Fig. 4). A cluster analysis of the coral communities at all sites showed that J2 (4) and J3 (2), J2 (2) and J2 (3), J2 (1) and J3 (1) and J1 and J2 (5) formed well-defined clusters at a similarity levels of about 55, 65, 67 and 40% while GH formed a separate cluster at a similarity level of about 45% respectively (Fig. 5).

Comparing fossil coral fauna with modern distribution (Table 2) indicated that diversity was high in the past (Pleistocene) in comparison with recent coral fauna suggesting a faunal turnover in coral fauna. For example, Faviidae and Acroporidae are well represented in the fossil fauna but show considerable extension. On the other hand, Poritidae, not abundant in the fossil fauna, is common in the recent fauna (Ali et al. 2014). Species comparison between three communities indicated that the Quaternary communities were more similar to Miocene communities (southern Iran) at a similarity level of about 42% than to the modern coral communities of Pakistan (about 29%) (Fig. 6). Regarding genera composition, the Quaternary coral communities were more similar to modern coral communities at a similarity level of about 45% than to the Miocene communities (about 15%) (Fig. 7).

Discussion

The term 'Quaternary communities' was assigned on the basis of different studies conducted on sediments and palaeodiversity (Crame 1984; McCall et al. 1984; Hosseini-Barzi and Talbot 2003; Hosseini-Barzi 2010; Kober et al. 2013) in southern Iran and coastal Makran (Pakistan). Proper dating of the strata from the coral sites is however required. A variety of factors including natural (earthquakes, cyclones, outbreaks of *Acanthaster planci*) and manmade (sedimentation due to coastal development, exploitation, pollution) influence coral growth (Sano et al. 1987; Wilkinson 1999; Edinger et al. 2001; Pandolfi 2002; Hughes et al. 2003; Pandolfi et al. 2003; Bahuguna et al. 2008), among them thermal stress (Warner et al. 1996; McClanahan 2004; McClanahan et al. 2007; Coles 2008; Crabbe 2008; Munday et al. 2012; Weber et al. 2012; Roth and Deheyn 2013; Mumby et al. 2014; Bozec and Mumby 2015) and sedimentation load (Rogers 1990; Riegl 1995; Erftemeijer et al. 2012; Bartley et al. 2014; Junjie et al. 2014; Perez et al. 2014; Jones

Fig. 2 **a** Diversity of fossil corals recorded from uplifted strata at Jiwani and Gwadar along Balochistan (Makran) coast, Pakistan.1 *Blastomussa* sp., 2 *Caulastrea* sp., 3 *Cyphastrea hexasepta*, 4 *Cyphastrea* sp. 1, 5 *Cyphastrea* sp. 2, 6 *Cyphastrea* sp. 3, 7 *Echinopora* sp., 8 *Favites complanata*, 9 *Favites spinosa*, 10 *Favites* cf. *abdita*, 11 *Favites* cf. *chinensis*, 12 *Favia pallid*, 13 *Favia speciosa*, 14 *Favia favus*, 15 *Favia* sp. 1, 16 *Favia* sp. 2, 17 *Goniastrea columella*, 18 *Goniastrea aspera*, 19 *Goniastrea* sp. 20 *Leptastrea transversa*, 21 *Leptastrea* sp. 22 *Platygyra pini*, 23 *Platygyra sinensis*, 24 *Plesiastrea versipora*. **b** Diversity of fossil corals recorded from uplifted strata at Jiwani and Gwadar along Balochistan (Makran) coast, Pakistan. 25 *Acropora* sp. 1, 26 *Acropora* sp. 2, 27 *Acropora* sp. 3, 28 *Acropora* sp. 4, 29 *Astreopora* sp. 1, 30 *Astreopora* sp. 2, 31 *Astreopora* sp. 3, 32 *Astreopora* sp. 4, 33 *Pocillopora damicornis*, 34 *Pocillopora verrucosa*, 35 *Pocillopora* cf. *eydouxi*, 36 *Stylophora pistillata*, 37 *Porites* sp. 1, 38 *Porites* sp. 2, 39 *Goniopora* sp. 1, 40 *Goniopora* sp. 2, 41 *Hydnophora exesa*, 42 *Hydnophora microconos*, 43 *Turbinaria* sp., 44 *Cycloseris* sp., 45 *Fungia* sp., 46 *Acanthastrea hillae*, 47 *Acanthastrea* cf. *echinata* 48, *Leptoseris* cf. *mycetocoides*

et al. 2015) are important. However, corals have some adaptations that enable them to cope with such stressors to a critical level (Sanders and Baron-Szabo 2005; Bellantuono et al. 2012; Doney et al. 2012; Erftemeijer et al. 2012). Corals adopt different strategies to response environmental stressors, i.e. photoadaptation ability, shuffling and moving of symbiots, feeding elasticity and polyp bail-out response. Every species have some specific morphologic response to environmental stress. Some have limited options while some have multiple options. For example, *Stylophora pistillata* has C1 type

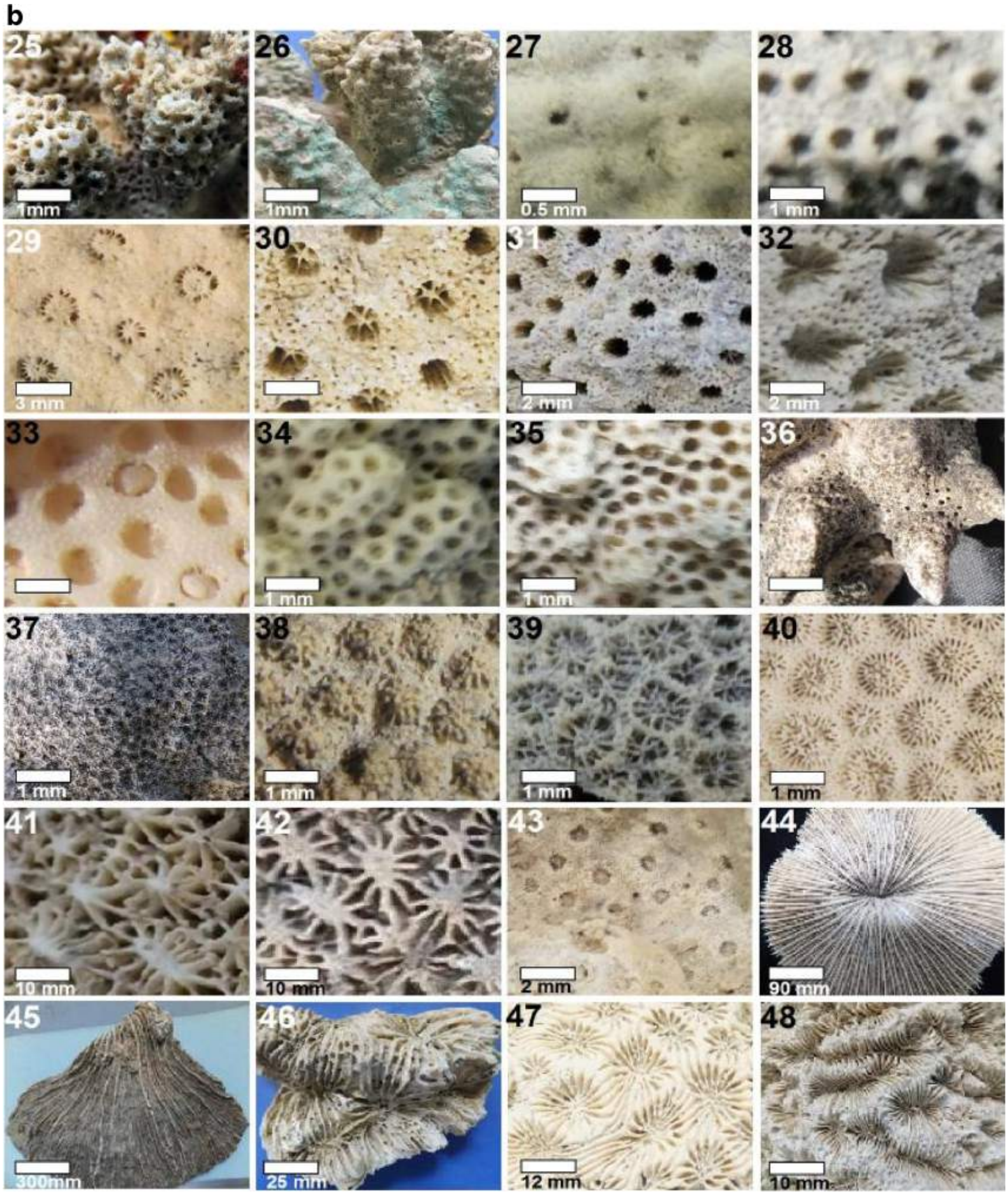

Fig. 2 (continued)

zooxanthella and less protein to act as barrier against thermal stress whereas *Montastraea annularis* and *Montastraea faveolata* hosts a number of zooxanthella. Some corals, i.e. *Montipora capitata*, cope with temperature extremes by increasing their feeding rates (Yonge 1935; Sammarco 1982; Brown and Howard 1985; Van Woesik et al. 1995; Rowan et al. 1997; McClanahan 2004; Grottoli et al. 2006; Baird et al. 2007; Fitt et al. 2009).

High coral diversity at landward sites might be due to less turbid environment. According to Prins et al. (2000) and Luckge et al. (2001), fluvial input increased between 5000 to 3000 years BP due to climatic and hydrological changes in this area. Lithogenic fluxes derived from the Makran were highest during the Pleistocene, and the sediment load increased as a result of uplifting and sea level fluctuations. Sedimentation rates during the Holocene were high in deeper parts of the Arabian Sea and on the upper continental slope during the last Glacial Maximum and remained high during the whole deglaciation (von Rad et al. 1999; Prins et al. 2000). Skeletal comparison indicated the presence of healthy

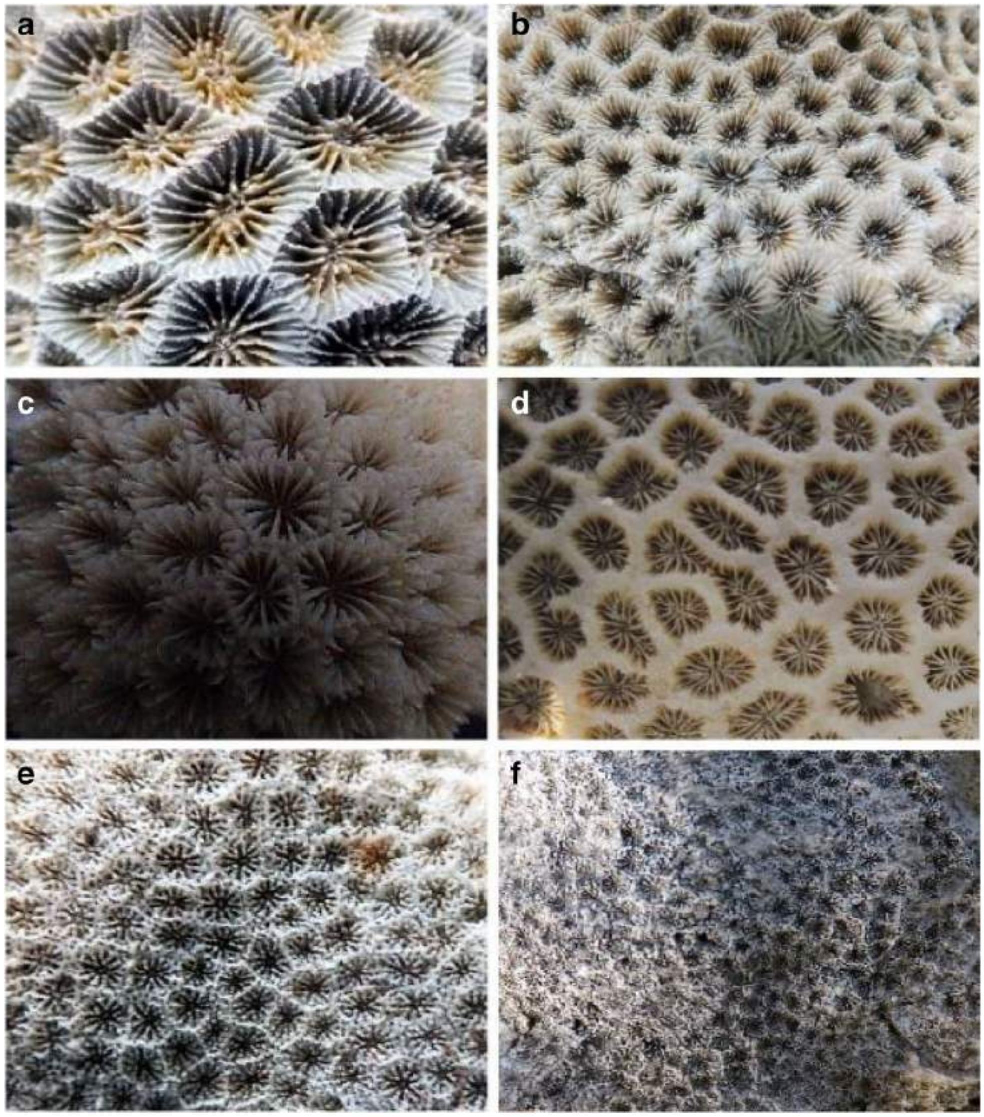

Fig. 3 Comparison of modern corals (**a**, **c**, **e**) collected from coastal waters with fossil corals (**b**, **d**, **f**,) from coastal uplifted strata (Makran, Balochistan), Pakistan. **a**, **b** *Favites* species, **c**, **d** *Leptastrea* species, **e**, **f** *Porites* species

environment as no significant signs of sediment stress was observed possibly due to the existence of Pleistocene corals for a short period of time (Edinger and Risk 1994). The size of a corallite is affected by sediment stress that ultimately affects septal growth (Ketcher and Allmon 1993). Further, some Pleistocene events made the environment less favourable for corals (Bromfield and Pandolfi 2012), although there were also periods of vigorous reef growth in the interglacials.

Comparing fossil coral fauna with modern distribution indicated a disappearance of some genera in the modern fauna. Among the faviids, the apparent disappearance of *Favia* and *Platygyra* from contemporary coral communities is interesting as some species in each genus are known to tolerate high sedimentation environments by virtue of having large calices (> 10 mm), which help in rejecting sediment more easily than species with smaller calices (Stafford-Smith and Ormond 1992; XiuBao et al. 2013). Individual species of coral can tolerate sediment stress up to critical levels, and there are contradictory tolerances among species (Fabricius 2005). Acroporidae has less ability to tolerate turbid conditions than Faviidae and Poritidae (Stafford-Smith 1993; Riegl 1999), which may explain why it is not found in modern fauna. Communities with higher sediment tolerance are known to replace coral communities composed of species with lower sediment tolerance (XiuBao et al. 2013), and this partially explains the faunal turnover observed on the Makran coast. Today, species of Poritidae (11 species) dominate coral fauna of Pakistan followed by Faviidae (6 species) and Siderastreidae (5 species), a fact also noted from other places in the Arabian Sea (Wilkinson 2004); whereas Acroporidae were under represented (Coles 2003). A gradual increase in sediment load due to frequent geological events may have caused replacement of corals having less sediment tolerance by more tolerant species. Similar changes have been seen in

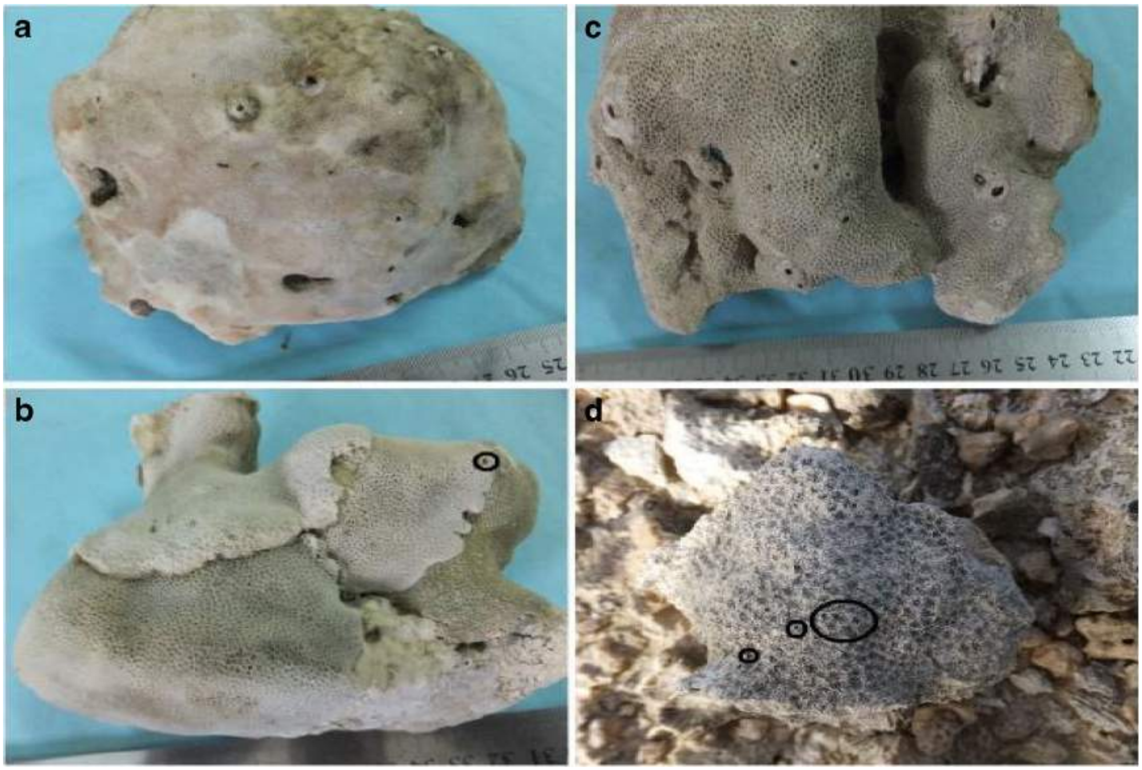

Fig. 4 Comparison of modern *Porites* species (**a**, **b**) collected from coastal waters with fossil *Porites* species (**c**, **d**) collected from coastal uplifted strata (Makran, Balochistan), to check the effects of bioerrosion

the Persian Gulf where *Platygyra* species were recorded as dominant during MIS 7.5 and MIS 7.1 at Kish Island, but are not prevalent in the modern coral fauna (Mossadegh et al. 2013). The hard coral diversity and distribution during their evolution to emerging modern forms appear to be linked with environmental and geological settings. Solitary and small to medium size corals (with corallites 3 to 8 mm) were dominant in turbid environments, while solitary and medium to large size (with corallites 8 to 15 mm) remained the characteristic of clear water conditions (Flugel 1982; Kiessling et al. 1999; Dupraz and Strasser 2002; Flugel 2002; Flugel and Kiessling 2002; Leinfelder et al. 2002; Perrin 2002; Wilson and Lokier 2002; Stanley 2003; Olivier et al. 2004; Sanders and Baron-Szabo 2005). Increase in sediment load reduces biotic area, species abundance, coral cover and irradiances (Rogers 1990; Fabricius 2005). Sedimentation is a continuous process along Makran coast and is a feature of dynamic plate margins (Prins and Postma 2000; Prins et al. 2000; Schluter et al. 2002; Grando and McClay 2007; Mouchot et al. 2010; Haghipour et al. 2012).

Tectonic factors may also be responsible for habitat destruction in the waters of Makran (Balochistan) coast. Abundant and active mud volcanoes on and offshore in coastal areas of Makran are reported at Haro Range, Chandragup

Fig. 5 Cluster analyses of similarities between fossil coral community composition at four sites (9 transacts), based on presence–absence data and Bray–Curtis similarities. JI Jiwani site 1, J2 (1–5) Jiwani site 2 (1–5), J3 (1–2) Jiwani site 3 (1–2), GH Gwadar headland

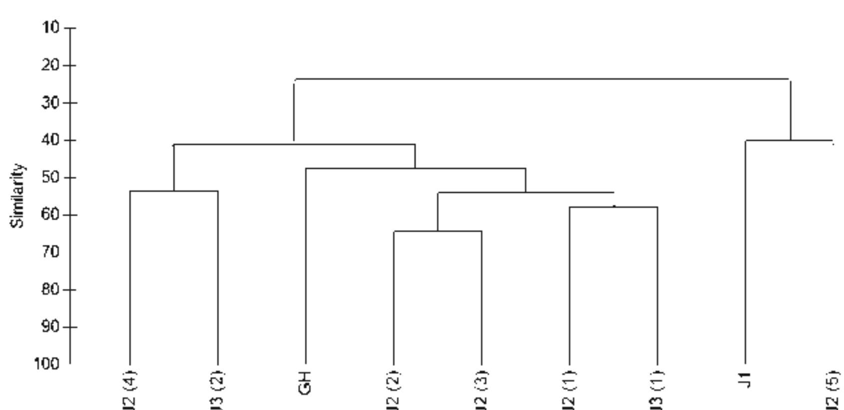

Table 2 List of families and genera of Quaternary and modern corals recorded in uplifted strata of Balochistan and coastal waters. Numbers of species found in each genus are also shown. A significantly high diversity is evident from Quaternary period compared to currently recorded live coral species

Family/Genera	Quaternary status[1]	Current status[2]
Family: Faviidae		
Blastomussa species	1	
Cladocora species	1	
Caulastrea species	1	
Cyphastrea species	5	
Echinopora species	1	
Favites species	6	3
Favia species	11	
Goniastrea species	4	
Leptastrea species	2	2
Platygyra species	3	
Plesiastrea sp.	1	1
Family: Acroporidae		
Acropora species	5	
Astreopora species	5	
Montipora species		1
Family: Pociloporidae		
Pocillopora species	3	1
Stylophora species	1	
Family: Poritidae		
Alveopora species		1
Porites species	2	5
Goniopora species	2	5
Family: Siderastreidae		
Coscinaraea species		2
Psammocora species		3
Family: Merulinidae		
Hydnophora species	2	
Family: Family:Dendrophyliidae		
Dendrophyllia species		1
Turbinaria species	1	1
Family: Fungiidae		
Cycloseris species	1	
Fungia species	1	
Family: Musidae		
Acanthastrea species	2	2
Family: Agaracidae		
Leptoseris species	1	
Pavona species		1
Total species	62	29

[1] Numbers of fossil corals also include species that have been mentioned in Siddiqui et al. (2011)

[2] Numbers of live coral species also include species that have been mentioned in Ali et al. (2014)

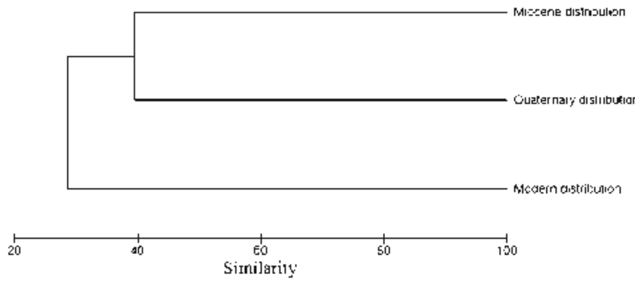

Fig. 6 Cluster analyses of species composition of Quaternary, modern and Miocene coral communities based on presence–absence data and Bray–Curtis similarities

area (Ormara), and in the vicinity of Gwadar. As a result of these eruptions, numerous ephemeral islands have appeared, and some have survived, e.g. Khandwari Mud Volcano, though many of these have disappeared due to strong wave action (Hunting Survey 1961; Snead 1964; Wiedickea et al. 2001; Delisle et al. 2002; Schluter et al. 2002; Delisle 2004; Grando and McClay 2007; Kassi et al. 2014). From 1668 to date, at least 28 earthquakes have been reported in this area with a magnitude of 7 or greater than 7 (Ambrasseys and Bilham 2003). Among them, the earthquake of 1945 with a magnitude of 8.1, occurred in the northern Arabian sea about 100 km south of Karachi largely destroyed the underwater habitats (Wadia 1981; Pacheco and Sykes 1992; Pararas-Carayannis 2006). A recent example is the emergence of a new island in 2013, near Gwadar, that also caused the uplift of hard and soft corals (see Kumar 2014). Uplift of reefs as a result of 2004 earthquake is also reported from Simeulue Island, Indonesia (Foster et al. 2006). Human impacts (industrial and domestic pollution, high sedimentation load due to coastal development, overfishing, spear fishing, boat anchor damage and habitat loss due to the sale of broken coral) due to rapid urbanization along the coast could be another factor responsible for coral deprivation. Arabian Peninsula including Pakistan remained a hot biodiversity spot including corals during the Eocene period. Habitat destruction caused by past geological events in the area, for example collision of Arabian

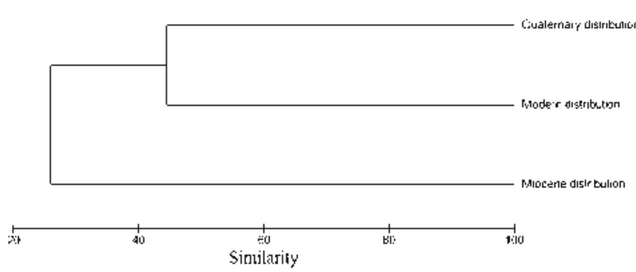

Fig. 7 Cluster analyses of genera composition of Quaternary, modern and Miocene based on presence–absence data and Bray–Curtis similarities

and Eurasian plate during middle to late Miocene, shifted biodiversity from this region (Kay 1996; Harzhauser et al. 2007; Renema 2007). Further Pleistocene changes such as formation of numerous palaeoshorelines, sedimentary sequence, habitat loss and changes in environmental settings on regional and global scale have occurred during sea level lowering stage (Lambeck 1996; Pandolfi 1999; Banerjee 2000; Prins and Postma 2000; Bruggemann et al. 2004; Kusky et al. 2005; Gharibreza and Motamed 2006; Mossadegh et al. 2013; Pain and Abdelfattah 2015). It might be possible that changes (reduction in continental shelf, habitat destruction, transition from sheltered to open water conditions) occurred gradually, thereby making the environment less favourable for corals, not only along the coast of Pakistan, but along the shores of Arabian Sea as a whole.

Comparing Pakistan's fossil fauna with Miocene corals reported from mountain range of southern Iran by McCall et al. (1984) indicated that Pakistani fossil fauna, of at least 62 species, was quite rich, although less than the 90 species reported from the Iran. However, the spatial scale of the Iran study was quite large compared to this report. This also indicates that fossil coral fauna reported form-uplifted strata along Balochistan coast of Pakistan is likely to be much younger (Late Pleistocene in age), could form a part of the expansion of Indian Ocean coral reefs occurred during the start of upper Pleistocene (Hopley 1982; Crame 1984) and existed in a less turbid environment as most of the Miocene fauna has been extinct and existed in turbid or calm water conditions (Edinger and Risk 1994; McCall et al. 1984).

Conclusions

The data obtained on fossil corals from the uplifted strata revealed that coral diversity in the past (62 species) was high than modern corals (29 species) along the coast of Pakistan. This suggests a faunal turn over due to habitat destruction caused by past geological events in the area, for example collision of Arabian and Eurasian plate during middle to late Miocene. Further Pleistocene events and present day anthropogenic impacts have rendered the environment less favourable for corals than in the past. However, many species occur in deeper depths and further investigation of a wide area and depth range are necessary before the absence of *Acropora* and other genera can be confirmed with more certainty. Regarding this, additional detail studies on a large scale in uplifted strata along the coast and in submerged habitats with emphasis on environmental, anthropogenic and geological parameters are recommended.

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Appendix

Table 3 List of fossil coral collected from an uplifted location at Ras Gunz near Jiwani, Balochistan. Taxa with a question mark were not identified with certainty. From Siddiqui et al. (2011)

Species	Family
Favia truncatus?	Faviidae
Favia lizardensis	
*Favia*sp.1	
Favia sp. 2	
Favia sp.3	
Favia sp.4	
Favites cf. *acuticollis*	
Favites sp.	
Goniastrea cf. *retiformis*	
Platygyra daedalea	
Cladocora cf. *caespitosa*	
Cyphastrea serailia	
Astreopora sp.	Acroporidae
Acropora sp.	

Table 4 General observations recorded at each site with GPS coordinates and elevations from sea level

Site name	Geographical position with elevation from sea level	General observations
Gwadar head-land (GH)	25^0 06. 017″ N, 62^0 19. 937″ E Elevation: 90 m	The habitat near the site was mostly rocky, composed of sandstone. The site was ecologically disturbed. Eighteen corals were recorded at this site. The dominant genera were *Favia* and *Favites* species.
Jiwani 1(J1)	25^o 02. 714″ N, 61^o 43. 954″ E Elevation: 2–4 m	The habitat was mostly rocky, consisting of sandstone and pebble beds. The coral cover was about 25%. Only two species (*Favites complanata and Favites spinosa*) were dominant, the majority of colonies scattered freely in coarse sand while few were tightly packed.
Jiwani 2 (J2)	25^o 04. 079″ N, 61^o 47 .443″E Elevation: 67 m	The coral colonies were scattered in large patches on about more than 1-km^2 area. The habitat was mostly rocky, composed of sand stones with fine and coarse sand, boulders and mudstone. Thirty coral

Table 4 (continued)

Site name	Geographical position with elevation from sea level	General observations
		species were recorded at this site. Many species were found scattered but a considerable proportion was tightly packed. Coral cover was about 33%. Prominent genera were *Favia* (11%) and *Favites* (4%).
Jiwani 3 (J3)	25° 06. 611″ N, 61° 48. 528″ E to 25° 06.635″ N, 061 ° 48.504″ E; Elevation: 4–26 m	This site was steeply sloped. The habitat mostly comprised of sandstone with fine sand, shale, limestone and boulders. Majority of corals were loosely packed. Thirty one coral species were recorded at this site. The coral cover was about 19%. The dominant genera were *Favia* (5%), *Astreopora* (3%), *Favites* (2%) and *Blastomussa* (2%).

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