REPORT

B. Riegl

Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality

Abstract Reef coral communities in a non-reef setting on shallow, flat hardgrounds were quantitatively sampled in Dubai Emirate (UAE, Southern Arabian Gulf) before and after a coral mass mortality in 1996. The coral fauna consisted of 34 scleractinian species before and 27 after the event, which removed virtually all *Acropora*. No alcyonacea were recorded. Five community types were identified and characterized by the dominant species: (A) a sparse *Porites lutea* community in sandy areas, (B) a dense *Acropora clathrata* community in areas with little sand, (C) a faviid community in muddy areas, (D) a *Siderastrea savignyana* community in sandy areas, and (E) a *Porites compressa* community, which built a framework in sandy areas. These communities are comparable to those described from other areas of the Gulf, where a stable pattern of community differentiation appears to exist. The spatial distribution and dynamics of the coral communities appears to be strongly influenced by mass mortality events recurring every 15 to 20 y. A combination of extreme water temperatures and high sedimentation/turbidity appear to be the major cause of mortality.

Key words Coral community structure · Coral fauna · Mass mortality · Water temperature Sedimentation · Arabian Gulf

B. Riegl (✉)
Institut für Geologie und Paläontologie, Karl-Franzens-Universität Graz, Heinrichstrasse 26, A-8010 Graz, Austria

Introduction

Coral community structure studies are a valuable tool for assessing the severity of any given environment (Downing 1985; Sheppard 1988, Riegl et al. 1995). In particular in high-latitude reefs, important community shaping processes were identified by this method (Coles 1988; Sheppard 1988; Coles and Fadlallah 1991; Sheppard and Sheppard 1991; Riegl and Riegl 1996). Due to their depauperate fauna, high-latitude reefs sometimes show clearer patterns of zonation and more visible ecological partitioning than highly diverse tropical reefs. Zonation and ecological dynamics in high-latitude systems can be caused by recurring episodic events like mass mortalities (Coles 1988; Coles and Fadlallah 1991) and/or regular suppression of otherwise dominant species by, for example, wave action (Riegl and Riegl 1996).

Arabian Gulf coral communities exist in a harsh environment with respect to salinities, sea temperatures and extreme low tides (Coles 1988; Sheppard and Sheppard 1991; Coles and Fadlallah 1991; Sheppard et al. 1992). These factors have a profound influence on community structure by restricting the number of species in the area and by causing recurrent mortality among the dominant species (Coles and Fadlallah 1991; Fadlallah et al. 1995). While quantitative information exists for coral communities in the northern Arabian Gulf (Downing 1985; Coles and Fadlallah 1991; Fadlallah et al. 1993; Vogt 1996) and in Musandam in the Straits of Hormuz (Sheppard and Salm 1988), little work has been done in the southern Arabian Gulf. In this area, coral communities occur within a non-reef setting, which has so far only received limited attention (Fadlallah et al. 1993). Corals there grow on flat substrates with virtually no topographic differentiation, and they do not reach the surface. Therefore, they are not affected by extreme low tides, but are nonetheless subjected to temperature extremes and stress from turbidity and

sedimentation (Riegl 1995a; Riegl and Branch 1996, Riegl and Piller 1997).

This paper presents a quantitative account of coral community structure and species composition on shallow subtidal hard grounds in Dubai Emirate (United Arab Emirates), southern Arabian Gulf. Immediately after an initial census in spring 1996, a coral mass mortality event took place over the summer of 1996. Subsequently, the communities were re-sampled in early 1998 to ascertain the effects of this mortality event, which did not affect all taxa in a similar way. The results of this study are compared to published accounts of coral community structure in the Arabian Gulf. The goal is to determine whether community structure is primarily determined by (1) episodic mortality, (2) different substratum type and sedimentation regimes, or (3) a combination of these factors. The study also aims to determine the causes and frequency of mass mortality events.

Methods

Study area

The investigated area is a shallow subtidal sea-bed, sloping gently offshore to depths no greater than 9 m. No accentuated bottom topography exists over most of the area, except some low ridges, which rise less than 2 m above the surrounding, flat sea-bed. Corals are found in a belt between 200 and 2000 m offshore (Fig. 1) with a variable density, diversity and surface cover.

Most of the sea floor is sandy, underlain in wide areas by early diagenetically cemented calcarenites (Shinn 1969; Evans et al. 1973), also referred to as cap-rock or simply limestone, which provide substratum for coral settlement. Corals are only found in areas with rocky substratum. They can be best classified as coral carpets *sensu* Reiss and Hottinger (1984), Piller and Pervesler (1989) and Riegl and Piller (1997).

A Side-Scan Sonar survey gave preliminary information about the extent of the coral areas. Twenty-six evenly distributed, equidistant sample points were selected. The sample points were located by means of differential GPS fixes. In these localities two transect sampling methods were utilized because of highly variable coral cover and because we wanted to know which method described the communities better: (1) continuous intercept recording on 10 m line transects and (2) point intercept recording at 1 m intervals on 50 m line transects. The variability in coral cover made different transect lengths necessary in order to provide adequate sample size. The rationale for this was, that in areas of high coral cover, the short continuous transects would be more precise. In areas of low coverage, in order to avoid undersampling communities of small, widely spaced colonies, the longer, point recording transects would give better results. This hypothesis was verified in a set of trials conducted prior to the commencement of regular sampling. The first census conducted prior to the 1996 mortality event, set out to establish the structure and distribution of communities, therefore it employed both sampling methods. A second census, after the 1996 mortality event, evaluated changes in the most affected communities (determined by a visual survey) and therefore concentrated only on precise, small-scale, 10 m transects.

The intercepts of all underlying coral species, benthic invertebrates and macro-algae were recorded to the nearest centimetre along each transect. Also the type of substratum, classified as either sand, limestone, or rubble, was recorded. Groups of eight 10 m transects were arranged in a star-like fashion around 1 × 1 m iron frames permanently fixed to the substratum, which were used as survey markers. When the star-shaped arrangement of transects was inadequate for sampling community gradients, sets of randomly spaced transects were recorded along gradients between clearly visible communities. The 1998 re-sampling employed only random transects. Two 50 m point intercept transects were run due north

Fig. 1 Geographical location of the sampled coral areas in Dubai Emirate, United Arab Emirates (UAE) in the southern Arabian Gulf. Location names mentioned in the text are indicated. The discontinuous areas of dense coral growth are indicated in the lower map
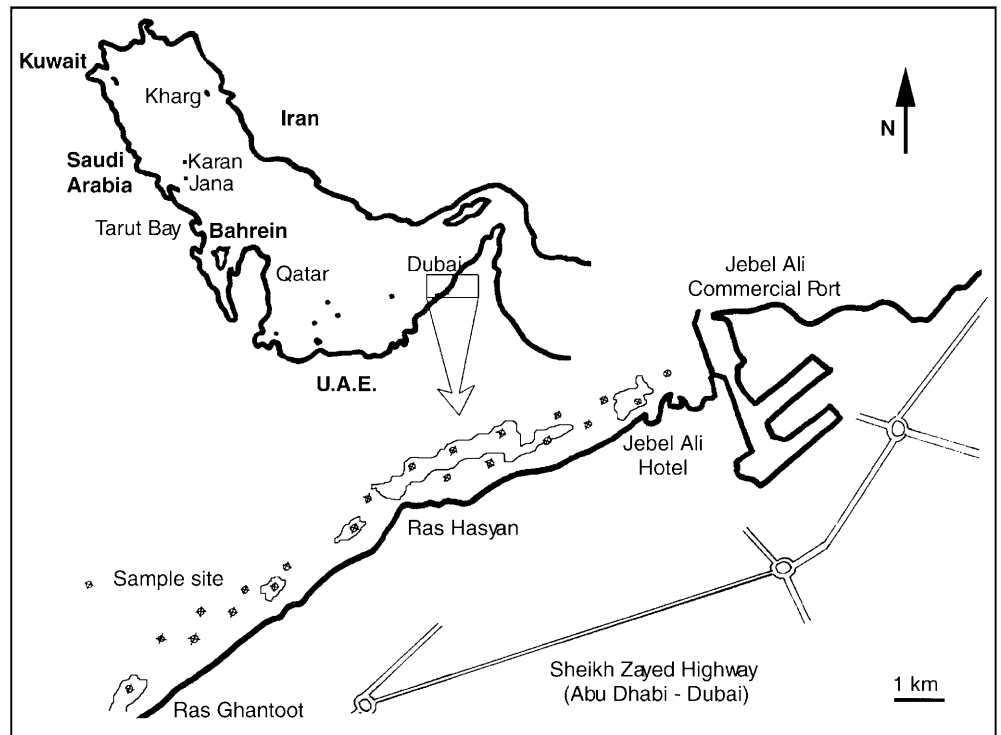
and south of the sample point markers established in 1996. The type of substratum and the species of benthic fauna or flora underlying the transect at each 1 m interval was recorded.

Two multivariate techniques were used to detect patterns within the data-set: agglomerative hierarchical cluster analysis and multidimensional scaling (MDS, Digby and Kempton 1984; Agard et al. 1993). MDS was preferred over PCA (principal components analysis) as the latter is better suited for the analysis of environmental data (continuous data) than species abundances (James and McCulloch 1990; Clarke and Warwick 1994). Furthermore MDS is not limited to the description of patterns within the community but has successfully been used to link community structure to environmental variables (Clarke and Ainsworth 1993; Agard et al. 1993) and to estimate the severity of disturbance (Warwick and Clarke 1993). By using MDS rather than other methods, studies can be standardized and compared. Both multivariate methods were used as it was not certain how distinct community structure would be between sites. Each of these statistical methods has advantages for delineating groups either in a very distinct community setting (cluster analysis) or in one with gradations between communites (MDS; Field et al. 1982; Kenkel and Orloci 1986; Warwick et al. 1988). If both analyses provide consistent results, it is likely that they represent natural groupings. The statistically obtained groupings were compared to the situation in the field, and when found to coincide, were used to describe community patterns. Data obtained from 50 m and 10 m transects were evaluated separately.

Ecological diversity of the samples was expressed using Margalef's index (Magurran 1988; Riegl and Velimirov 1994), $D = (S - 1)/\ln N$.

For the comparison of groups over time, community characteristics were compared using one-way analysis of similarity (Clarke and Green 1988). This analysis is built on a non-parametric permutation procedure applied to the same rank similarity matrix underlying the classification or ordination of samples. It is more applicable to the presently used data sets than a multivariate analysis of variance as it does not assume normality of data and allows for the dominance of zero counts in the typical transect data-set. It tests against the null-hypothesis that there are no differences in community composition between samples (Clarke and Green 1988). Analyses used the software packets PRIMER and SPSS.

Results

A total of 34 coral species (Table 1) were found. Prior to the mortality event, the most prominent species in terms of cover and frequency were *Acropora clathrata* and *Porites lutea*. *A. clathrata* had the highest cover in the 10 m transect line study (51% of the area covered by corals), followed by *P. lutea* (21%). However, *P. lutea* was the most frequently encountered coral in the 50 m transect study (25% of all encountered colonies), followed by *A. clathrata* (20%). Other species with high cover were *Porites lobata* (3%), *Platygyra daedalea* and *lamellina* (3%) and *Turbinaria reniformis* (2.5%). All other species occupied less than 2.5% of the total coral cover.

Analysis of the 1996, pre-mortality, 10 m transect data by hierarchical agglomerative cluster analysis showed data to separate into three major clusters, A, B, and C (Fig. 2a). The central cluster split into three further sub-clusters, B1-B3. The distance map produced by two-dimensional ordination by multidimensional scaling (MDS, Fig. 2b) supported this interpretation. Three distinct point clouds correlated to the clusters in
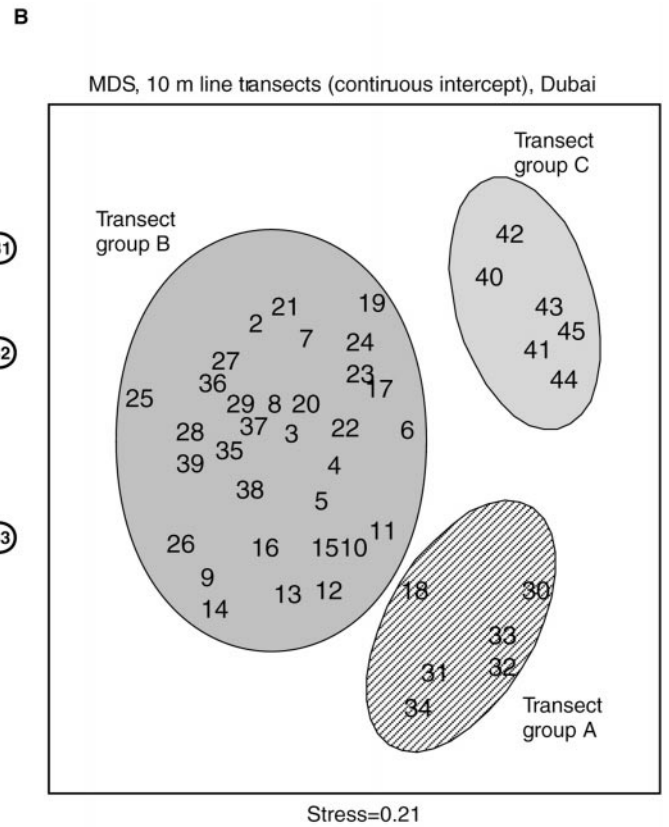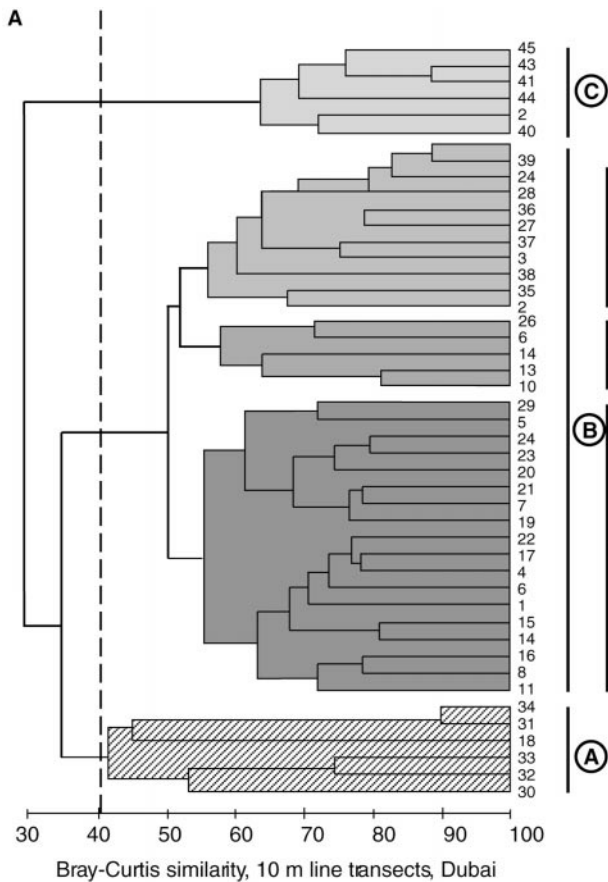
Table 1 Coral species list of the study area in Dubai Emirate, southern Arabian Gulf. Species marked "?" are based on preliminary identifications which may change once more material becomes available

Acropora clathrata (Brook, 1891)	1,2,3,4
Acropora pharaonis (Edwards and Haime, 1860)	1
Acropora horrida (Dana, 1846)	1,4
?*Acropora valenciennesi* (Edwards and Haime, 1860)	1
Acropora arabensis (Hodgson and Carpenter, 1994)	2,3,4
?*Acropora florida* (Dana, 1846)	*
Acropora valida (Dana, 1846)	3
Acropora tenuis (Dana, 1846)	*
Porites lutea Edwards and Haime, 1851	1,2,3,4
Porites solida (Forskaal, 1775)	*
Porites lobata (Dana, 1846)	*
Porites compressa Dana, 1846	1,2,3,4
Porites nodifera Klunzinger, 1879	1,2
Porites cf. mayeri Vaughan, 1918	*
Siderastrea savignyana Edwards and Haime, 1850	1,2,3
Pseudosiderastrea tayamai Yabe and Sugyama, 1935	1
Coscinaraea monile (Forskaal, 1775)	1,2
Psammocora contigua (Esper, 1795)	1,2,3,4
Favia pallida (Dana, 1846)	1,2,3
Favia favus (Forskaal, 1775)	1,2,4
Favia cf. rotumana (Gardiner, 1898)	1
? *Barabattoia amicorum* (Edwards and Haime, 1850)	*
Favites pentagona (Esper, 1794)	1,2,3,4
Platygyra daedalea (Ellis and Solander, 1786)	1,2,3,4
Platygyra lamellina (Ehrenberg, 1834)	*
?*Platygyra cf. crosslandi* (Matthai, 1928)	*
Plesiastrea versipora (Lamarck, 1816)	2,3
Cyphastrea microphthalma (Lamarck, 1816)	1,2,3,4
Cyphastrea serailia (Forskaal, 1775)	1,2,3
Leptastrea transversa Klunzinger, 18479	1,2,3
Turbinaria peltata (Esper, 1794)	2,3,4
Turbinaria reniformis Bernard, 1896	2
Stylophora pistillata (Esper 1797)	1,2,3,4
Acanthastraea echinata (Dana, 1846)	1,3

Identification follows Sheppard and Sheppard (1991) and Riegl (1995b) for *Acropora*. Previous published records from the Gulf: 1, Sheppard and Sheppard (1991); 2, Fadlallah et al. (1993); 3, Hodgson and Carpenter (1995); 4, Vogt (1996), *, new record

Fig. 2a. The biggest point cloud (transect group B, Fig. 2b) is not separable into sub-clusters, which indicates the similarity of the sub-communities included in cluster B (Fig. 2a).

Data obtained by 50 m point intercept sampling were subjected to similar analyses. When using Euclidean Distance instead of the Bray-Curtis Index, the biological characteristics of the resultant clusters were similar to those of the 10 m transects. In order to achieve constancy of the data evaluation process, only the clusters formed by the first 5 dichotomies (of greatest Euclidean Distance) were used. Results compared well to those obtained from the 10 m sampling routine. However, additional communities, which were previously not adequately sampled, were picked up (Fig. 3a). Also in this case, the MDS ordination supported our interpretation of best cluster size (i.e. best cut-off distance) and the identification of natural transect groups in the classification. Transect groups A, B-ex and D were not separable in the MDS distance

A

Bray-Curtis similarity, 10 m line tansects, Dubai

B

MDS, 10 m line tansects (continuous intercept), Dubai

Stress=0.21

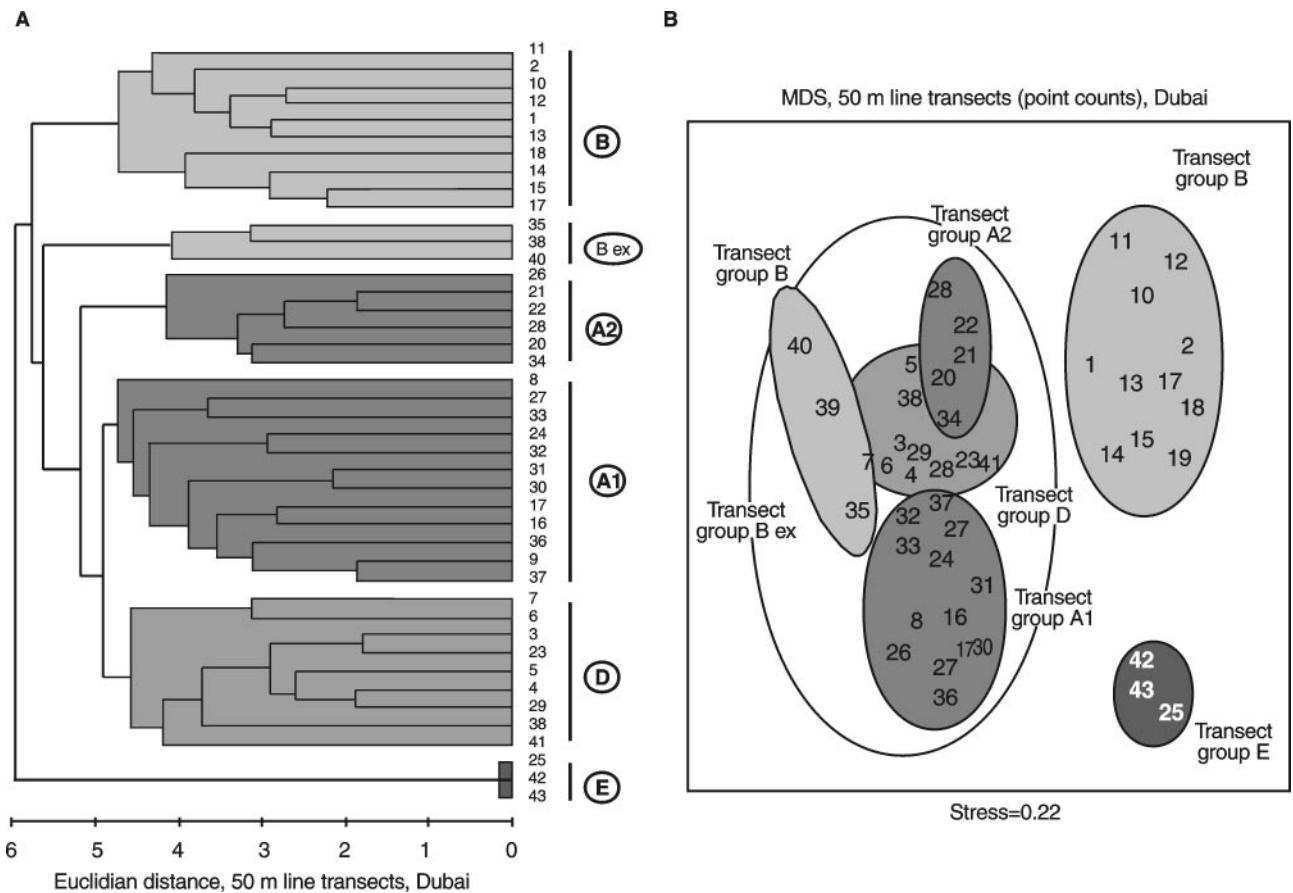map (Fig. 3b). Biological characteristics of transect groups are given in Table 3.

The classification of the 10 m transects gave detailed information on the subdivision of the complex *Acropora* dominated community B (Fig. 2a), which was intensely sampled. The analyses of the 50 m transects revealed the frequency of each community type on the reefs. Because sampling sites were spread evenly over the reefs, the frequency of each community type was expressed as a percentage of a total number of samples. Therefore, the biggest clusters contain the most widely distributed community (A followed by B and D).

The most widely distributed community was sampled in transect groups A (10 m transects, Fig. 2) and the equivalent A1 and A2 (50 m transects, Fig. 3). These groups were dominated by *Porites lutea* (Tables 2 and 3), but differed in contribution by other species to within cluster similarity. Coral cover was generally low (Tables 2 and 3) but individual colonies, particularly massive *P. lutea* and *P. lobata*, reached diameters of up to 4 m. The substratum surrounding the isolated corals had little coral growth and was typically sand. This community was found in most parts of the study area and graded laterally into several other communities, like B or C, or into sand. It was not affected by the 1996 die-off event. The few *Acropora* colonies that were present died, which did not lead to significant changes in community structure.

Fig. 2A Classification of the continuous intercept 10 m line transects. The last four dichotomies of lowest Bray Curtis similarity included ecologically interpretable clusters. Biological characteristics of these clusters are shown in Table 2. **B** Distance map of the same 10 m line transects, produced by multidimensional scaling

Transect cluster B (Figs. 2 and 3) included the areas of highest coral coverage and diversity, dominated by *Acropora*. The substratum was limestone with a thin cover in places by coarse sand. In subcommunities B1 and B2, dominance alternated between *Porites lutea* and *Acropora* (either *A. pharaonis* or *A. clathrata*). In B1, *Porites* occupied more space than *Acropora*, in B2 the opposite occurred. Living coverage was between 50 and 70% and the sub-communities were found at the periphery of dense *Acropora* areas. B2 laterally graded into B1, which in turn graded into an increasingly *Porites*-dominated system.

Subcommunity B3 was characterized by *A. clathrata* and had the highest space coverage (between 80 and > 100%). Although it appeared as if only one coral species completely dominated, the measured low coral diversity was partly an artifact, because numerous other small corals underneath the *Acropora* tables were not recorded in the transects. *Acropora pharaonis* covered most space. Other common *Acropora* were *A. valenciennesi*, *A. horrida*, *A. florida*, and *A. tenuis*. The substratum was caprock with a thin layer of coarse sand.

Fig. 3A Classification of the point intercept 50 m line transects. The last five dichotomies of highest Euclidean Distance included ecologically interpretable clusters. Biological characteristics of these clusters are shown in Table 3. **B** Distance map of the same 50 m point intercept transects, produced by multidimensional scaling. Some sample numbers are missing, which is due to superposition of several samples due to high similarity

Over 1996, all *Acropora* communities suffered total mortality of the dominant species. Subcommunities B1, B2, and B3 became *Porites* (*P.lutea, P. nodifera*) dominated systems with a strong faviid component (Tables 2 and 3). Even prior to the mass mortality event, a degraded *Acropora* community type B was sampled in transect cluster B-ex (Fig. 3). Poritids and faviids were an important component in *Acropora* dominated systems (particularly subcommunity B1). When these communities were degraded, *Acropora* died first, leaving the remaining faviids or poritids. Cluster B-ex of the 50 m transects represents a community with numerous dead *A. clathrata* tables, dominated by surviving *Porites* and faviids (Table 3). This community was found in a flat area where the limestone was covered by a thick layer of fine sand or mud.

The least widely distributed community was sampled in transect cluster C (Fig. 2), dominated by faviids (Table 2). This community occurred in deeper water (around 9 m depth) in areas of sand and/or fine sand. It was not affected by the die-off event.

The community in transect cluster D (Fig. 3) was made up of *Siderastrea savignyana* colonies on limestone in flat areas of low sand coverage. The coarse sand covering the limestone was usually arranged in ripple trains. *Siderastrea* were found in the valleys between the ripples, where they were frequently covered by ripples moving over them, but not killed. Other

important coral species in this community were *Pseudosiderastrea tayamai*, *Porites* cf. *mayeri* and *Coscinarea monile*. Coral cover and diversity were low (Table 3). This community was widely distributed in deep and shallow water and was not affected by the die-off event.

A spatially restricted community (cluster E, Fig. 3) which covered little space on the reefs consisted mainly of densely packed colonies of *Porites compressa* which built a small reef framework. Coral cover within the reef patches was around 80%. Within the *Porites* framework there was little loose sediment, and it was usually surrounded by limestone with thick sand cover. This community was also not strongly impacted by the mortality event.

The mortality event acted selectively, removing virtually all *Acropora* from the community, reducing species richness to 27 (Table 4). In total, only five partly surviving *A. clathrata* were encountered. Mortality in all other species was restricted to individual colonies and did not attain similar catastrophic levels.

Table 2 Biological characterization of the 10 m continuous intercept transect clusters obtained by hierarchical agglomerative cluster analysis and multidimensional scaling (Fig. 2). Percentages in brackets are the contribution (%) of the species to within cluster similarity. All other values are mean and standard deviation of the mean

Transect group	Dominant species in 1996	Total living cover (%)		Margalef diversity		Dominant typology	
		1996	1998	1996	1998	1996	1998
A	*Porites lutea* (66.3) *Coscinarea monile* (21.3) *Porites lobata* (5)	36 ± 15	35 ± 14	0.48 ± 0.31	0.40 ± 0.26	Massive	Massive
B1	*Acropora clathrata* (23.1) *Porites lutea* (24.6) *Plesiastrea versipora* (16.2)	47 ± 15	25 ± 8	1.15 ± 0.45	1.04 ± 0.32	Massive/ tabular	Massive
B2	*Acropora clathrata* (47.5) *Porites lutea* (38.9)	48 ± 28	16 ± 7	0.58 ± 0.19	0.49 ± 0.26	Tabular/ massive	Massive
B3	*Acropora clathrata* (48.9) *Acropora pharaonis* (28.7)	901 ± 12	10 ± 9	0.74 ± 0.31	0.48 ± 0.32	Tabular/ branching	Massive
C	*Favia favus* (24.6) *Coscinarea monile* (19.4) *Porites lutea* (19.3)	16 ± 4	16 ± 4	1.21 ± 0.33	1.14 ± 0.28	Massive/ branching	Massive

Table 3 Biological characterization of the 50 m point intercept transect clusters obtained by hierarchical agglomerative cluster analysis and multidimensional scaling (Fig. 3). Percentages in brackets are the contribution (%) of the species to within cluster similarity. All other values are mean and standard deviation of the mean. n.a. = not applicable, as not sampled in 1998

Transect group	Dominant species in 1996	Total living cover (%)		Margalef diversity		Dominant typology	
		1996	1998	1996	1998	1996	1998
A1	*Porites lutea* (40.2) *Cyphastrea serailia* (31) *Porites solida* (19.8)	23 ± 11	n.a.	1.83 ± 0.39	n.a.	Massive	Massive
A2	*Porites lutea* (42.2) *Plesiastrea versipora* (20.8) *Coscinarea monile* (10.4)	20 ± 11	n.a.	1.58 ± 0.46	n.a.	Massive	Massive
B	*Acropora clathrata* (34.8) *Porites lutea* (39.5)	54 ± 22	37 ± 15	1.91 ± 0.61	1.75 ± 0.49	Tabular	Massive
B-ex	dead *Acropora clathrata* (48.9) *Porites lutea* (39.5)	11 ± 5	n.a.	1.45 ± 0.52		Dead tables/ massive	Massive
C	not expressed in this analysis	—	—	—	—	—	—
D	*Siderastrea savignyana* (42.2) *Porites lutea* (20.8)	14 ± 7	n.a.	1.34 ± 0.28	n.a.	Massive	Massive
E	*Porites compressa* (12.9)	51 ± 2	n.a.	1.67 ± 0.15	n.a.	Columnar	Columnar

Table 4 Pre- and post-mortality characterists of the entire coral system at Jebel Ali, Dubai. n.s. = not significant, n.a. = not applicable.

	1996 mean ± SD	1998 mean ± SD	Test statistic	Significance level
Dead *Acropora* (% cover)	7 ± 17	38 ± 23	t = 6.65, df:82	P < 0.001
Non-*Acropora* (% cover)	9 ± 5	13 ± 4	t = 3.52, df:85	p < 0.001
Number of species	34	27	n.a.	n.a.
Margalef Diversity, non-*Acropora*	0.77 ± 0.36	0.76 ± 0.35	t = 0.17, df:79	n.s.
Margalef diversity, including *Acropora*	0.92 ± 0.43	0.76 ± 0.77	t = 1.56, df:83	n.s.

Consequently, space coverage by non-*Acropora* species had not decreased but increased significantly (Table 4, t = 3.52, df:85, df:82, P = 0.000). The most frequent coral and the one with the highest space coverage after the die-off event was *P. lutea*. Ordination by MDS including the non-*Acropora* components of each community prior to and after the mortality event, did not separate the samples (Fig. 4). Similarly the one-way ANOSIM did not detect any differences between the non-*Acropora* communities (R = 0.149, P = 0.2, Table 4).
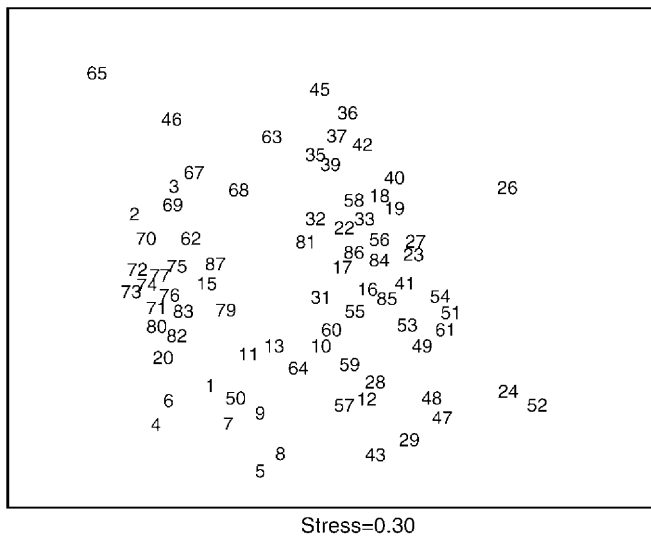
MDS. 10 m line transects from 1996 (1-65) and 1998 (66-85)

Stress=0.30

Fig. 4 MDS ordination of transects prior to and after the 1996 mortality event. Data include only non-*Acropora* members of the community

Discussion

Suitability of transect methods

Both transect methods sampled the communities adequately. For rapid, large-scale surveys, the 50 m point intercept recording method is adequate and gives a good estimation of the spatial distribution of coral communities. For more detailed ecological studies with an interest in expressing differing species diversities and small-scale patterns, or in the detection of patterns within individual coral groves, the 10 m transects yielded better results.

Coral fauna of the Arabian Gulf

The Dubai coral fauna, with 34 scleractinian species (of which eight are new records for the Gulf), is among the richest in the Gulf. The richest coral fauna has been recorded from Saudi Arabia, around the islands of Jana and Karan, (50 species, Basson et al. 1977). Fadlallah et al. (1993) subsequently recorded 23 and 19 species in specific sample sites on these two islands and suggested that species richness may actually be lower than suggested by Basson et al. (1977), which is supported by data in Vogt (1996). Species richness in Dubai's Jebel Ali area (Fig. 1) and possibly other areas of the Gulf as well, appears to be subjected to temporal fluctuations caused by mass mortality events which affect only certain sets of species. In our study area, six species of *Acropora* disappeared from the live fauna after the 1996 mass mortality (Table 4). Only one of the species

(*Acropora clathrata*) had a nearby viable population, 30 km to the east (Deira Corniche, Dubai).

The species composition of Gulf corals is typically Indo-Pacific, with most species occurring in a wide geographic area. One endemic *Acropora* species is known (*Acropora arabensis*, Hodgson and Carpenter 1994). The closest faunal proximity to other coral areas of the Indo-Pacific is to the Red Sea (Sheppard and Sheppard 1991) due to a shared paleoceanographic history of restriction during the last sea-level low stand and simultaneous flooding during the Holocene transgression (Sheppard and Sheppard 1991). While this has led to the marked development of local endemism in the Red Sea, it is less pronounced in the Arabian Gulf. The Dubai coral species, and those of the Gulf in general, are similar to those at the geographic periphery of reefs. The very common *Acropora clathrata* and *Porites lutea*, for example, are also dominant species on the southernmost reefs of the western Indian Ocean in South Africa (Riegl et al. 1995; Riegl 1996). However, the *Acropora* are different in their morphology from Red Sea and Indian Ocean specimens and clearly represent local subspecies sensu Veron (1986).

The Dubai coral fauna is entirely made up by scleractinia. No alcyonacean soft corals or reef building hydrozoa, which are common on other high-latitude reefs in the Red Sea and the Indian Ocean (Sheppard and Sheppard 1991; Riegl and Velimirov 1994) were found. However, soft coral cover also declines from the northern Red Sea to its southern basin (Sheppard et al. 1992), where conditions are more comparable to those in Dubai.

Notable absences in Dubai include *Montipora*, which is common in the Indian Ocean and reportedly also occurs in the Gulf (Sheppard and Sheppard 1991; Vogt 1996). Similarly, no *Pocillopora* were found, although *P. damicornis* is reported from the Gulf (Bahrain and Saudi Arabia) and is common in Tarut Bay, Saudi Arabia, (Fadlallah et al. 1993, Fadlallah et al. 1995). *Stylophora pistillata*, which dominates a zone on shallow reefs in Tarut Bay, Saudi Arabia (Fadlallah et al. 1995), is rare in Dubai. This is surprising, given the wide ecological tolerance and distribution of this species (Loya 1976 a,b). Among the poritids, *Goniopora* are absent, the nearest records being from Musandam (Straits of Hormuz; Sheppard and Sheppard, 1991). Also, all fungiids, agariciids, oculinids, and merulinids are completely absent. The pectiniids are depauperate with only *Acanthastrea echinata* being present in Dubai.

Coral assemblages: comparison to other areas in the Gulf

Many similarities exist between Dubai's coral communities and those in other areas of the Gulf. Comparable *Acropora clathrata* dominated communities (community B) have been described from Kharg Island, Iran,
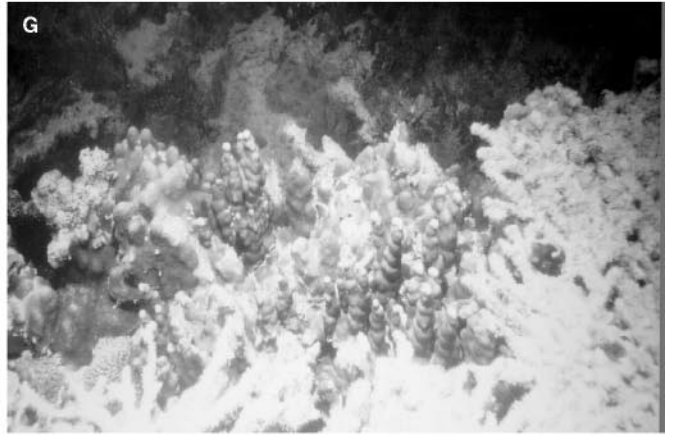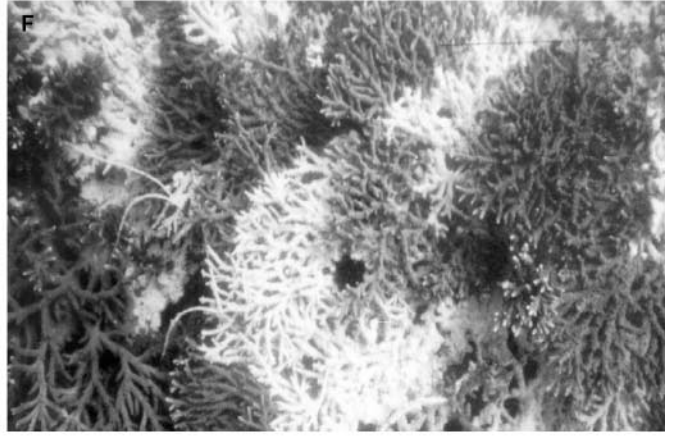
(Shinn 1976), Kuwait (Downing 1985; Fadlallah et al. 1993; Vogt 1995a,b), Tarut Bay, Saudi Arabia, (Coles and Fadlallah 1991; Fadlallah et al. 1995), Jana, Kurain, Karan and Abu Ali Islands, Saudi Arabia, (Basson et al. 1977; Fadlallah et al. 1993, Vogt 1996), and Bahrain (Sheppard and Sheppard 1991).

Areas of sparse *Porites lutea* growth (community A) have also been reported from other areas in the Gulf e.g. Bahrain (Sheppard and Sheppard 1991), where similar monospecific nodular *Porites compressa* stands (community E) also occur, and elsewhere in Saudi Arabia (Vogt 1996). In Dubai, this community frequently occurred within the same habitat, often adjacent to massive *Porites* or tabular *Acropora* communities without any notable environmental gradient being present, i.e. different salinities (Sheppard and Sheppard 1991). The deep, soft sediment surrounding some of these patches suggested that *P. compressa* is able to survive well in sedimented conditions.

Community differentiation in Dubai is most likely driven by similar factors as in the northern Gulf (Coles and Fadlallah 1991; Fadlallah et al., 1995), which has resulted in similarities in community structure (Fadlallah et al. 1993; Vogt 1996). Fluctuations of 20°C in sea-temperatures between summer and winter are reported from the southern Gulf (Kinsman 1964; Sheppard et al. 1992). Consequently, species-specific tolerances to low or high temperature (Coles and Fadlallah 1991; Sheppard et al. 1992) are highly likely to be a deciding factor in community differentiation all over the Gulf. Furthermore, differences in the substratum, most notably in the thickness and grain size of sand or mud overlying the limestone, are also an important factor shaping community composition (e.g. Riegl et al. 1995; Riegl 1995a). The different thickness of the sand overlying the rock basis may be the source of different sediment stress during stormy conditions. Sediment-resistant corals like faviids and poritids have an advantage in areas of high re-suspension and re-settlement, while acroporids, with a low tolerance to sediment, only dominate in areas with little resident sand and therefore lower re-suspension. The agents for sediment re-suspension are strong northerly winds, particularly the Shamal, which create big swells in the Gulf.

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Fig. 5A An *Acropora clathrata* dominated community B (subcommunity B3) in 1995. The fish is *Pomacentrus aquilus*; **B** Subcommunity B1, dominated by *Porites lutea* and *Acropora clathrata* in 1996. The fish in the centre is *Chaetodon melapterus*; **C** Community A, characterized by well-spaced *Porites lutea* in 1996 and 1998; **D** Community C, low coverage Faviid dominated community. **E** Community D, individual *Siderastrea savignyana* on sandy cap-rock. The algae are *Hormophysa cuneiformis*; **F** Mortality prior to the mass die-back was mainly due to coral diseases, which never killed entire populations; **G** *Porites compressa* (centre) survived the 1996 die-back, while all *Acropora* were dead in 1998. **H** A surviving *Favia favus* (top centre) among dead *Acropora* in 1998.

Is mass mortality a recurring event?

On a community scale, the aggressive *Acropora* species should, over time, outcompete slower growing, less aggressive species like *Porites* in areas where the substratum suits *Acropora* (Sheppard 1979, Hughes 1985; Thomason and Brown 1986). All communities B1 and B2 should terminate in a community B3. Yet B3 was not the community with the highest space cover, even prior to the 1996 mass mortality. In the study area, free space and early successional community stages, could only persist, if the coral growth was stunted repeatedly, i.e. if the mass mortality was a recurring event.

According to Holt Titgen (1982), previous mass mortality events like the one described here took place in the Dubai study area between July 1979 and February 1981. In this event, all *Acropora* also died over most areas, with only individual specimens surviving near the shore. Massive genera, particularly *Porites*, were not affected by the die-back event. This pattern is directly comparable to that observed in 1996. Holt Titgen (1982) speculated that either cold winter temparatures, or excessive sedimentation caused by the dredging of the nearby Jebel Ali port and hotel marina could have been the causes of this die-back. In 1996, abnormally high water temperatures over summer appear to have been the cause. Average air temperature in June and July 1996 were the highest encountered between 1984 and 1997 (two degrees above average) and sea water temperature reached 35°C (Dubai Municipality 1996), which is about 2°C above the usual maximum in Dubai. It can be speculated that another such die-off event could have taken place in 1964 as Shinn (1976) reports an *Acropora* overkill in Qatar caused by an unusually strong Shamal, which resulted in unusually low water temperatures. It is not unlikely that this mortality event would also have taken place in Dubai, where the same Shamal would have had a similar impact. Shinn (1976) speculates that die-offs may be a cyclical phenomenon and attributes water temperature as the driving agent. He also reports selective mortality, i.e. that primarily *Acropora* were affected.

Despite apparently repeated mass mortality events, the location and structure of the coral-covered areas between Jebel Ali and Ras Hasyan has seemingly changed little. The area containing corals mapped by Holt Titgen (1982) in 1980 was roughly the same as that in 1996. This indicates that the natural regeneration of species richness and space coverage comparable to that encountered in 1996 should occur within 10–15 y.

Extensive stands of young *Acropora clathrata* (diameter up to 50 cm) were encountered 30 km away, off the Deira corniche in 1998. This finding casts some doubt on the hypothesis that the mortality event at Jebel Ali was solely temperature-driven. Furthermore, corals in the Gulf at Abu Dhabi, Qatar and Saudi Arabia are exposed to up to 36°C (Kinsman 1964;

Shinn 1976; Coles 1988, 1997; Salm 1993) and in Oman routinely survive temperatures around 32°C (Quinn and Johnson 1996; Coles 1997). One possibility is, that some human influence such as sediment plumes from nearby dredging, may have contributed to the mass mortality at Jebel Ali. However, it is also possible that a combination of stresses under natural conditions would trigger mass mortality of susceptible species. A strong Shamal, for example would create sedimentation stress by re-suspending sediment, while at the same time lowering the water temperature. Similarly, high swells during an extremely hot period, could have the same effect of creating combined stresses.

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