The coral reefs of the Northern Arabian Gulf: stability over time in extreme environmental conditions?

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Abstract The coral reefs of Kuwait, Northern Arabian Gulf, are developed in extreme environmental conditions, in particular with respect to very high (in summer) and very low (in winter) seawater temperatures. A number of other factors, including anthropogenic pressure also influence the composition of such reef communities. Despite an adaptation to extreme environmental conditions, several episodes of coral mortality affecting in particular some of the main reef dwellers (e. g. the genus *Acropora*) have been recorded over the last twenty years. Three offshore reefs in the Kuwaiti waters, Umm Al-Maradem, Kubbar and Qaro were surveyed in 1986 by Downing, for major benthic categories, including scleractinain corals. In 2002 and 2003 we re-surveyed the same reefs, at the same stations, using the same methods used by Downing, enabling direct comparison of the data collected. Although coral mortality episodes may have induced significant year-to year variation, similarity of our results with that of Downing suggests that the coral communities in the reefs of the Northern Arabian Gulf display a remarkable stability over time in their composition.

Keywords
Kuwait, coral reefs, environmental factors, disturbances, stability

Introduction

Coral reefs are found throughout the Arabian Gulf, including Kuwait waters, in the northernmost area of the Gulf. Such reefs experience environmental conditions which can be qualified as typically extreme (Kinsman, 1964; Sheppard et al., 1992): Very high seawater temperatures in late summer (up to 33.9°C), very low temperatures in winter (down to 13.2°C), both temperature extremes being able to trigger bleaching episodes (Downing, 1985, 1989). Other environmental factors which may limit coral development or even cause coral mortality are elevated salinities (up to 42 parts per thousand), aerial exposure during abnormally low tide, the input of nutrient rich waters from the Shatt Al-Arab, turbid water (partly resulting from continuous and extensive prawn trawling), natural crude oil seepage, man-induced accidental pollution (including the largest ever recorded oil spill during the 1991 Gulf war) (Downing 1992; Price et al. 1994) and, more generally, anthropogenic stress. Such factors are at least in part responsible for the presence of a reduced zooxanthellate coral fauna, with only 29 species recorded (Carpenter et al, 1997). The limited coral fauna present in the Gulf is essentially an impoverished Indo-Pacific fauna, with very few endemics. It can be assumed that the twenty nine species found in the reefs of Kuwait have a very large ecological tolerance to the the above-mentioned factors or, like the ones in Oman (Coles, 1993), have adapted to the extreme character of many environmental conditions. However, the various tolerance thresholds can even be exceeded in some unpredictable circumstances (e.g. abnormally high or low temperatures), leading to varying degrees of bleaching or even coral mortality of variable importance (Shinn, 1975; Fadlallah et al., 1995; Riegl, 1999).

Over the last twenty years (before and after the Gulf war), the coral reefs of the Northern Gulf, including those of Kuwait, have been surveyed with respect to coral diversity and abundance, other major benthic categories and, in some instances, *Echinometra* abundances by Downing (1989, 1992) Price et al. (1994), Vogt (1995) and the authors (surveys in 2002 and 2003, unpublished reports). Comparison of the results obtained at the same sites , using the same techniques, allows ascertaining the degree of stability over time of coral and reef communities of reefs experiencing extreme conditions. In this paper, we will present coral data, comparing our own results to that collected by Downing in 1986 (Downing, 1989).

Material and methods

Geographic setting

The three off-shore reefs surveyed for the present study are Umm Al-Maradem, Kubbar and Qaro (Fig. 1). They are platform reefs situated in Kuwait waters at distances varying from 25 km (Umm Al-Maradem) to 42 km (Qaro) from the shoreline. All three reefs are roughly elliptical in outline, approximately 1.3 x 1.1 km, with an extensive reef flat on which an emersed sand cay forming an island, has developed. The island at Qaro is the smallest and is unvegetated. The reef flat extends seawards to a gently to moderately inclined slope where coral colonies are dominant. The reef slope gives way to an almost horizontal or gently sloping sedimentary substrate at depths varying between 6-8m (Umm Al-Maradem, leeward side) and 14-16 m (Qaro, windward side). Additional information on the general reef morphology and ecological characteristics of these reefs is given in Carpenter et al. (1997).

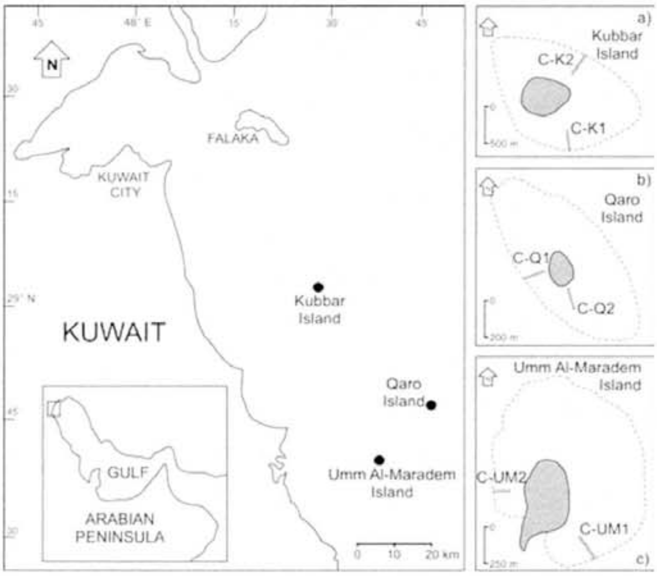

Fig. 1. Map of the North West Arabian Gulf, with the location of the three study reefs and position of the stations, a) Kubbar, b) Qaro and c) Umm Al-Maradeem.

Methods

The sampling methodology used during the surveys of 2002 and 2003 was the point intercept transect method (PIT). The major reason for selecting this method is that in Kuwait, it had been used by Downing (1989) on the reefs of Umm Al-Maradem (UM), Kubbar (K) and Qaro (Q). Thus a direct comparison of the results was possible.

In our 2002 and 2003 surveys, 50 m PIT lines were laid on the substratum, at right angle to a baseline transect perpendicular to the shoreline (C) where fixed pegs were placed in 2002 as transect starting points. At all sites the deeper end of the baseline transects was marked by a metallic fence picket driven into the substratum. The direction of each baseline transect was defined by a compass heading and was, in general, perpendicular to the reef slope. The position of the baseline transects set in 2002 and 2003 was mantained as close as possible to that of Downing (1989) using the fixes Downing provided. For each baseline transect the four line transects consisted of two shallower ones, on the gently inclined upper slope (between 1.5 and 3 m depth), and two deeper ones, closer to the bottom of the slope, where the inclination is steeper before reaching the sedimentary bottom (between 6 and 9 m depth).

The nature of the benthos under the PIT tape was recorded under every 1 m mark. The biotic and abiotic recorded categories included corals, dead corals, turf algae, encrusting coralline algae, sponges, zoanthids, echinoderms, sediment (sand) and rubble. For each 50 m PIT surveyed, it was then possible to extract a list of coral species and the percentage substratum cover for each coral species and the other major benthic categories. Each transect consisted of 50 point intercept observations.

The two baseline transects (C) surveyed in 2002 (Fig. 1) at Umm Al-Maradem (C-UM1 and C-UM2, Fig. 1a) and Kubbar (C-K1 and C-K2, Fig. 1b) reefs, and the one at Qaro (C-Q1, Fig. 1c), were re-surveyed in 2003. An additional baseline transect at Qaro (C-Q2) was set in 2003, and two line point transects (C-Q2-1 and C-Q2-2) surveyed.

The 2002 and 2003 percentage cover dataset was analysed by means of multivariate statistics in order to find out if any significant difference in coral community structure could be detected between the two survey years. The Primer v.5.2.9 (Primer-E Ltd. Plymouth, UK) statistical package was used to generate non metric Multi Dimensional Scaling (MDS) plots, and analysis of similarity (ANOSIM). The analysis of similarity (ANOSIM) (Clarke and Warwick, 1994) was used to test whether there is a statistically significant difference between group of samples. ANOSIM is built on a non-parametric permutation procedure applied to the rank similarity matrix. The same approach was used to investigate and characterize possible differences in coral community structure between reefs (Umm Al-Maradem, Kubbar and Qaro) and between position of the 50 m point sampling transects (respectively grouped in shallower and deeper transects depending on their depth and distance from shore).

In order to ascertain whether changes had occurred since the last pre-war survey which was carried out in September 1986 (Downing 1989), we compared Downing's data with the 2002 and 2003 percentage cover of the two categories defined by Downing as 'living cover' and 'non-living cover', as well as the average generic diversity for scleractinian corals for the three reefs, at the five sites. Detailed comparisons with Downing's pre 1990-1991 Gulf War results (Downing 1989) could only be made in general terms, due in particular to the lack of high level accuracy in the positioning of the transect lines.

Results

Benthic assemblages

The total percentage living cover for each transect at each reef in 2003 is shown in Fig. 2. It can be seen that in Umm Al-Maradem the total living cover is around 56% in the shallower transects (3 and 4) at both UM1 and UM2, and around 63% at the shallow transects in K1. An opposite trend is shown at K2 where the highest living cover (approximately 60%) is found at the deeper transects (1 and 2) and drops to 38% at shallower transects. In no transect at either Q1 or Q2 a total living cover higher than 44% was found. The average living cover in the six examined transects in Qaro is 39.3% ± 1.7 S.E.. The lowest living cover is found at UM2-1 (12%) and UM2-2 (20%), where the dominant category is sediment. The highest living cover is found at K2-2 where it reaches 68%.

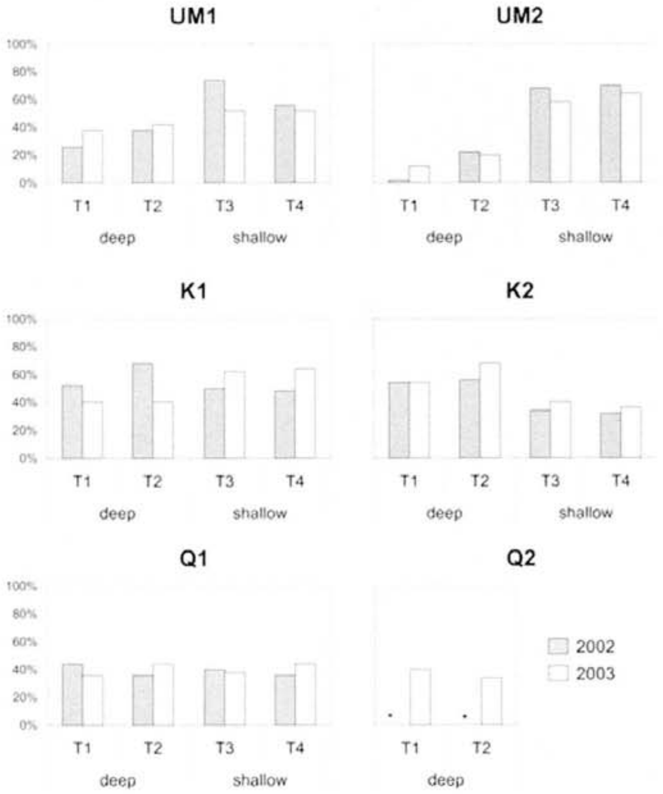

Fig. 2. Total living percentage cover of the 2002 and 2003 surveys for each transect at the 6 monitoring radials coded as follows: UM = Umm Al-Maradem; K = Kubbar; Q = Qaro; the number following the island abbreviation indicates the radial; T = transect; number from 1 to 4 following T indicates the transect number for the considered radial; * no survey in 2002.

No significant differences in frequencies between the 2002 and 2003 surveys were found for each of the major benthic categories The overall benthic assemblages composition showed no major change from 2002 to 2003 (Fig. 3a). It is likely that the recorded differences recorded in the point transect data are due to the methodology more than to an effective change in benthic composition.

In terms of percentage cover, corals were the dominant category on 9 transects (UM1-2, UM1-3, UM1-4, UM2-3, UM2-4, K1-3, K1-4, K2-1 and K2-2). On 12 of the other transects, the sediment and rubble category is dominant. The category 'dead corals' ranks 1st on one transect (Q1-3), second on two transects (Q1-4 and K1-2) and third on another 11 transects. It should be remembered, however, that in the absence of reef rock or pavement above the surface of the reef slope sedimentary deposits, dead corals provide the substratum for the other benthic categories (zoanthids, turf algae, encrusting coralline algae and, to a large extent, sponges and sea urchins). Percentage cover did not go over 6% for sponges (K1-2), 12% for echinoderms (Q1-4), while zoanthids were present on only 5 transects, reaching a maximum dominance of 4% at Q1-1.

The ANOSIM test showed no significant differences in the overall benthos and substrate composition between 2002 and 2003 (R=0.259; P=0.698), and this can be also clearly seen from the overlap of data in the MDS plot (Fig. 3a).

Considering the 2002 and 2003 transects as replicates, and looking at the same MDS plot where samples (transects) were marked per site, Umm Al-Maradem seems to show some distinctive multivariate pattern from the other two islands (Fig. 3b). A two way ANOSIM on factors site and transect position revealed highly significant differences in benthos and substrate composition between sites across position (R = 0.545; P = 0.001), and between shallower and deeper transects across sites (R = 0.432; P = 0.001) (Fig. 3c).

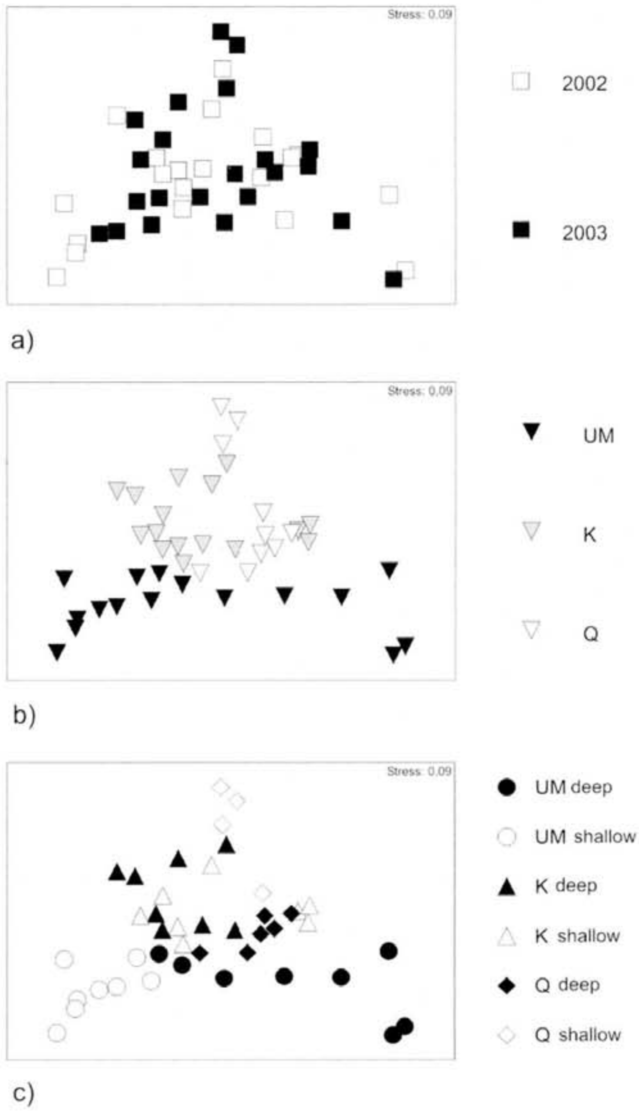

Fig. 3. MDS plot for the 2002 and 2003 multivariate benthic cover data set (symbol corresponds to a transect in a given year) showing a) transects marked per sampling year; b) per island (UM = Umm Al-Maradem, K = Kubbar, Q = Qaro); c) per depth and per island.

ANOSIM pairwise test results (Table 1) confirm that benthic assemblages in Umm Al-Maradem are significantly different in composition from those in Kubbar (R = 0.304; P = 0.001) and Qaro (R = 0.207; P = 0.027). Benthic assemblages in Kubbar and Qaro show a less significant difference (R = 0.181; P = 0.04). Figure 4 shows for shallow and deep transects in both years that the high mean living coral cover in shallow assemblages (60 ± 3.16 S.E.) and low in deep assemblages (20.5 ± 5.12 S.E.), the low turf (1.25 ± 0.77 S.E.) and encrusting (0.25 ± 0.25 S.E.) algae cover, and the lack of zoanthids under the transect lines are the factors that most differentiate Umm Al-Maradem from the other reefs.

Table 1 ANOSIM pairwise test R values for benthic assemblages at different depths at different sites (UM = Umm Al-Maradem; K = Kubbar; Q = Qaro). *P* values in brakets, n.s. = not significative.

		deep			shallow		
		UM	K	Q	UM	K	Q
deeper	UM						
	K	0.463 (0.002)	-				
	Q	0.499 (0.008)	0.455 (0.005)	-			
shallower	UM	0.665 (0.001)	0.786 (0.001)	0.959 (0.001)	-		
	K	0.261 (0.031)	0.065 (0.19) n.s.	0.01 (0.352) n.s.	0.675 (0.001)	-	
	Q	0.233 (0.04)	0.542 (0.006)	0.802 (0.005)	1 (0.002)	0.415 (0.008)	-

Differences between shallower and deeper transects across sites in the study area are due primarily to live coral and sediment cover differences. Shallow benthic assemblages at all reefs show a higher mean percentage cover in live coral (38.4 ± 4.7 S.E.) and a lower mean percentage cover in sediment (34.1 ± 2.4 S.E.) then those found in deeper water (live coral mean % cover = 25.8 ± 2.4 S.E.; sediment mean % cover = 47.3 ± 4 S.E.). All groups, reflecting shallower (transects 3 and 4) or deeper (transects 1 and 2) benthic assemblages at the various sites, are significantly different from each other with the exception of Kubbar shallower and deeper assemblages on the one hand, and Kubbar shallower and Qaro deeper assemblages on the other hand. Overall, the most important categories of benthos recorded on the 50 m transects were: live scleractinian corals, sediment and rubble, dead corals, and turf algae.

The 2003 data confirmed that no significant difference in living coral cover was found between Downing's data and the 2002 and 2003 surveys from our study at UM2, K2 and Q1 (Fig. 5). Although no significant differences in living cover were found at UM1 between the 2002 and 2003 surveys, and between the 1989 and 2002, in 2003 a significantly higher percentage of living cover was found than in 1989. At K1 living coral cover for 2002 and 2003 are not different, but both are significantly higher than for Downing' data.

Scleractinian corals

Overall between 2002 and 2003, 17 species of scleractinian corals belonging to 7 families were recorded at the studied sites (Table 2). This is slightly more than half the number (29) of zooxanthellate (reef building) corals known to exist in Kuwait waters (Carpenter et al., 1997), and all species recorded are cited by these authors. *Leptastrea transversa* and *Turbinaria reniformis* which were not recorded under the transect lines in 2002, were found in 2003 and conversely, *Siderastrea savignyana* and *Favia speciosa*, recorded in 2002 were not found in 2003. This could be due to the fact that the position of the line between the two years might not be identical on account of different water current conditions.

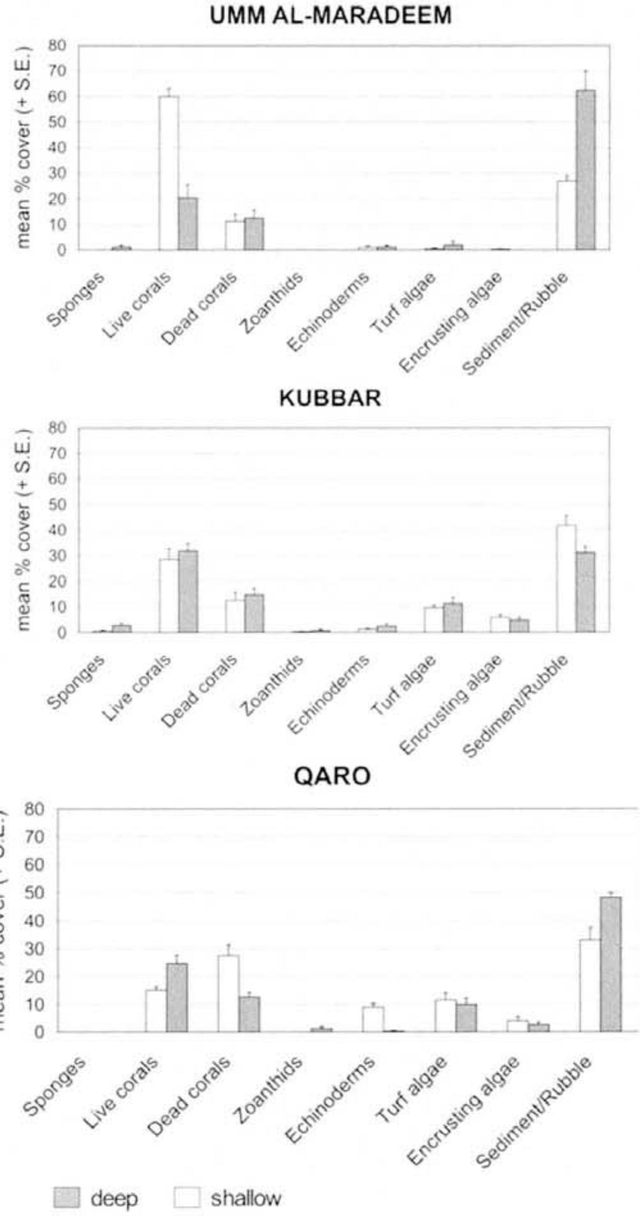

Fig. 4. Mean percentage cover (+ S.E.) for all benthic categories averaged across the two survey years (2002 and 2003) in shallow and deep assemblages at the three offshore islands of Umm Al-Maradem, Kubbar and Qaro.

Scleractinian corals were present on all 20 transects, with a species richness varying from 2 (transects UM2-1 and UM2-3) to 8 (transects UM1-2, Q2-1 and Q2-2). Species richness is expressed here in terms of the number of species per transect. Although several diversity indices could be calculated, this is not necessary in the present situation, given the very small number of species involved. Further, Loya (1972) and Pichon and Morrissey (1981) have shown that, for scleractinian coral distribution at least, the number of species per transect was strongly correlated to e.g. the Shannon and Weaver diversity index (Shannon and Weaver,1948).

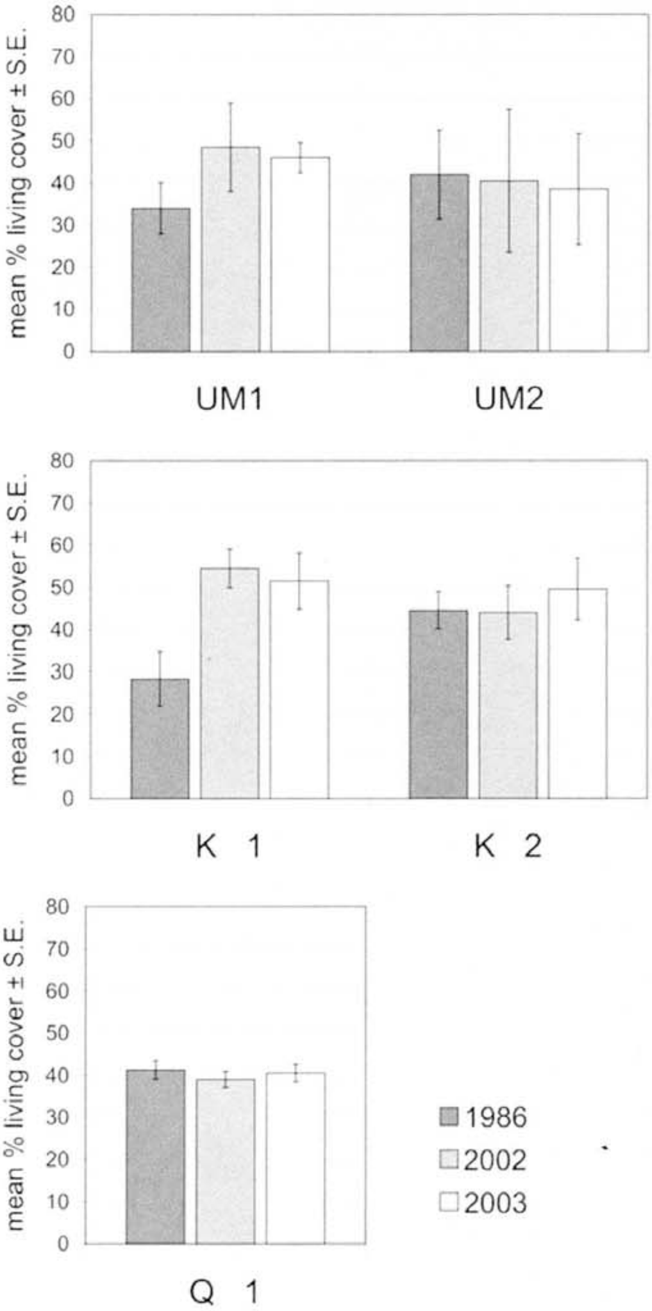

Fig. 5. Percentage living cover per radial, averaged across transects and across years (± S.E.) at a) Umm Al-Maradem, b) Kubbar; and c) Qaro. Living cover values are reported for each radial in 1986 (Downing 1989), 2002 and 2003. UM = Umm Al Maradem; K = Kubbar; Q = Qaro; the number following the island abbreviation indicates the radial.

At each site, coral species richness shows no significant difference with depth (the overall depth range, from 1.5 to approximately 8 m is very small, and one could not expect a major change in community structure along reef slopes of limited depth range).

Table 2 List of the recorded species of Scleractinia (*: species not recorded under the transect line in 2003; **: species not recorded under the transect line in 2002).

Family THAMNASTERIIDAE	
	Psammocora contigua (Esper, 1797)
	Psammocora superficialis Gardiner, 1898
Family ACROPORIDAE	
	Acropora arabensis Hodgson and Carpenter, 1995
	Acropora downingi Wallace, 1999
Family AGARICIIDAE	
	Pavona decussata (Dana, 1846)
Family SIDERASTREIDAE	
	**Siderastrea savignyana* Edwards and Haime, 1850
	Coscinarea columna (Dana, 1846)
Family PORITIDAE	
	Porites harrisoni Veron, 2000
	Porites lutea Edwards and Haime, 1860
	Goniopora lobata Edwards and Haime, 1860
Family FAVIIDAE	
	Favia pallida (Dana, 1846)
	**Favia speciosa* (Dana, 1846)
	Favites pentagona (Esper, 1794)
	Platygyra daedalea (Ellis and Solander, 1786)
	Cyphastrea sp.
	***Leptastrea transversa* Klunzinger, 1879
Family DENDROPHYLLIIDAE	
	***Turbinaria reniformis* Bernard, 1896

Overall, the two "key" species are *Acropora downingi*, (frequency 68%) which is preferentially characteristic of the shallower part of the reef slopes, particularly at Umm Al-Maradem, and *Porites harrisoni* (frequency 59%), which is more evenly distributed with depth than *A. downingi.* The latter produces large plate-like colonies, up to several metres across, and is the dominant species on 10 transects (UM1-1, UM1-2, UM1-3, UM1-4, UM2-3, UM2-4, K1-3, K1-4, Q1-2 and Q1-4), with a percentage substratum cover of 56% at UM2-3. Overall, this species is characteristic of the upper part of the reef slopes, where it is the major component of the coral community. *Porites harrisoni*, in contrast, is a typically massive species. Unlike *Acropora downingi, Porites harrisoni* produces large, massive colonies with a knobby surface. It is the dominant species in terms of substratum cover on another 4 transects (K2-1, K2-2, K2-3 and Q1-1). The remainder of the coral fauna, with the exception of *Acropora arabensis* and *Pavona decussata* is composed of species producing small massive colonies.

After updating the coral identifications in Downing (1989), comparisons at generic or, in some instances, specific levels can be made.

At Kubbar, taxa found by Downing and not recorded in the present study include *Leptastrea, Plesiastrea* and *Turbinaria peltata* (but the latter was observed outside the line transects at both Umm Al-Maradem and Kubbar). Conversely, we recorded *Siderastrea savignyana* (only in 2002), *Pasmmocora contigua* and *P. superficialis*, none of which are cited by Downing.

At Umm Al-Maradem, we did not record *Pavona varians* which is mentioned by Downing. Downing's record of *Pavona varians* is likely to be a misidentification (for *P. explanulata*?) as it is not mentioned by Carpenter et al. (1977) and we did not observe it, even away from the transect lines. In contrast, we recorded *Pavona decussata, Siderastrea savignyana* and the two species of *Psammocora*, none of which are referred to by Downing. Lastly, at Qaro, Downing recorded the genera *Cyphastrea* and *Favia*, which we also found, but only in 2003.

Table 3 Mean percentage living cover and average generic diversity per radial found in 1966 (Downing 1989), 2002, and 2003 (this study). UM = Umm Al-Maradem; K = Kubbar; Q = Qaro; the number following the island abbreviation indicates the radial for the considered island

	Percentage living cover			**Generic diversity**		
	1986	*2002*	*2003*	*1986*	*2002*	*2003*
UM1	34	48,5	46	6,67	5,5	5,75
UM2	42	40,5	38,5	4,5	2,2	3
K1	28,4	54,5	51,5	4,8	6	6
K2	44,5	44	49,5	6,25	4,25	4,75
Q1	41,3	39	40,5	3	2,25	2,25

Discussion and conclusions

The coral community composition and structure of the three reefs investigated is characteristic of reefs developed in extreme environmental conditions (Downing 1985, 1989). It is clear that some widespread Indo-Pacific species have adapted to such conditions (Coles and Fadlallah 1991) and can normally develop in the most northwest part of the Gulf. It is also equally obvious that the limited ability of reef dwellers to construct a massive framework (in part due to the low coral species diversity and in part to the low incidence of encrusting algae, the main reef binders) places the reef formations developed in Kuwait waters in a state of fragile equilibrium.

More than 16 years have elapsed since Downing's survey, carried out in 1986 (Downing, 1989). This time period is sufficient (e.g. Endean 1976, Pearson 1981, Harmelin-Vivien 1994).to allow return to equilibrium for coral communities which may have experienced widespread damage following catastrophic events such as, for instance, cyclones, severe bleaching or *Acanthaster* infestations (the latter so far not recorded in the northern Arabian Gulf).

The differences found between Downing' coral data and the 2002 and 2003 surveys refer to taxa which have low frequency indices, low percentage cover and, in general, have small-sized colonies. It is therefore possible that their presence or absence on the transects in the two survey programmes which are compared be totally spurious and this does not imply a change in the coral fauna during the time period considered.

With respect to living cover, mean values of percentages obtained during the present survey are either higher (UM 1, K 1) or similar (UM 2, K2, Q 1) to that recorded in 1986 (Table 3). Changes in average generic diversity are more variable (an outcome partly due to the survey technique employed) but do not indicate a major shift in the composition of coral reef communities (Table 3). These results suggest that no major long term damage to, or degradations of, the coral reefs resulted from the Gulf War. These findings are in agreement with the conclusions drawn by Downing (1993) and Vogt (1995) following post-war surveys on the reefs of Kuwait (July 1991) and Saudi Arabia (June-July 1991, 1992 and 1993). Both authors report that the reefs survived the conflict and the largest oil spill on record "virtually" (Downing) or "remarkably" (Vogt) unscathed. Indeed, Downing (1993) indicates a clear increase in percentage cover, for *Acropora* and a slight decrease for *Porites* at Qaro, from 1987 to 1991. At Umm Al-Maradem, the percentage cover by living *Porites* increased from 25.0 to 43.3, and from 23.1 to 57.1 at Kubbar.

Mass bleaching events, due to abnormally high temperatures and causing variable, and in some instances severe mortality are reported for the Arabian Gulf for the years 1996, 1998 and 2002. Our 2002 survey, however, conducted in September, at the end of the summer period, did not reveal any evidence of bleaching at all on the offshore reefs of Kuwait. Mortality episodes resulting from a combination of abnormally low tide conditions (which happen in winter time) and unusually low air and sea surface temperatures are also known to occur in the Arabian Gulf (Coles and Fadlallah, 1991) and have been reported from Kuwait both before and after the Gulf war. Such an episode occured in 1992 and caused widespread coral mortality, at least in the shallow parts of the reefs, with an almost 100% mortality for *Acropora downingi* including large colonies several metres across (Jaubert, pers. com.). By 2002, i.e.within a 10 year time period, numerous large (up to ca. 4 m in diameter) healthy colonies of the same species were observed in large numbers at all three reefs. This observation would suggest that the reef building species which have adapted to the environmental conditions of the North-West Arabian Gulf, can not only withstand their extremeness, but also grow very rapidly, allowing for a quick recovery following major disturbances. If, in such a case the reefs can show significant year to year variations of abundance for corals, the above mentioned observation and the comparison of our data with that collected in 1986 by Downing suggest that at a decadal scale these reefs show a remarkable stability in their composition and community structure.

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