Temporal variations in coral reef health at a coastal industrial site on the Gulf of Aqaba, Red Sea

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Abstract

A detailed ecological study was conducted for three years (2001–03) on a 5 km stretch of well-developed coral reef facing an industrial site in the southernmost section of the Jordanian coast of the Gulf of Aqaba, Red Sea. The degree of modification associated with the prevailing ecological factors was assessed with respect to species diversity and abundance of the major groups of the macrobenthic community: corals, bivalves, hydrozoans, echinoderms, sponges and macroalgae. Three locations of two depths each – 6 and 12 m – were selected and surveyed using the visual census point-intercept method. The actual area of the survey covered about 2250 m^2.

Macrobenthic communities occurring close to the industrial jetty were characterized by low diversity and the obvious dominance of soft coral (16–30%

cover). In the deep transects (12 m) hard coral cover was higher than that in the shallow transects (30–55%). Correlation analyses indicated that species richness increased with increasing distance from the industrial jetty. Species richness of other macrobenthos was also higher as depth increased. The results revealed that the distribution and abundance of coral, echinoderms, hydrozoans and macroalgae were correlated with the relative importance of bottom modification within the various locations in the entire study area. However, no distinct influence of location or depth on the identities of most macrobenthic species was indicated.

1. Introduction

The industrial site at the southern end of the Jordanian coast of the Gulf of Aqaba has a special significance for coastal managers and decision-makers. Being a site hosting a fertilizer plant, power station and chemical storage facilities makes it, theoretically at least, extremely susceptible to anthropogenic factors. The entire Jordanian coast is only about 30 km long. In the north it is sandy with seagrass beds as the main benthic habitat, but towards the south it becomes rocky with a coral reef bottom. The industrial site is on part of this rocky habitat, characteristic of the southern section of the Jordanian Gulf of Aqaba. Tidal levels and the steep slope of the area have produced a distinctive intertidal zone (Hulings, 1989). The reef flat and the reef front at this locality are very rich in hard corals that continue down to a depth of more than 40 m. At the same time, the reefs are close to land, which may cause them to be exposed to industrial and other human agencies.

The physicochemical variables at the industrial site are relatively stable, shaped mainly by the natural annual cycle; the sea state is mostly calm, with mean temperature and salinity amplitudes of 21–27°C and 40.2–40.7 PSU respectively. Nutrient and chlorophyll *a* concentrations are extremely low in summer but moderate in winter (Badran & Foster 1998, Manasrah et al. 2004, Al Rousan et al. 2004, Badran & Al-Zibdah 2005). There is a distinct stratification of the seawater in the upper 200 m of the water column during summer, whereas mixing is dominant during winter and spring (Genin et al. 1995, Badran et al. 2005).

Improper planning of the construction and operation of coastal industrial sites has led to degradation of coral reef ecosystems; this is already well documented. In Jordan, however, environmental regulations regarding coastal investments are generally adhered to. A significant aspect of these regulations is that EIA studies must be implemented prior to the construction of an industrial plant on the coast, and that thereafter the adjacent coastal habitats must be monitored continuously. Both private enterprise and state authorities accept this responsibility.

This study aimed to examine the status of marine benthic habitats in relation to industrialization at the southernmost end of the Jordanian coast of the Gulf of Aqaba. Coral reefs, some macrobenthic communities as well as abiotic components like rock, rubble and sand were investigated over three successive years (2001–2003).

2. Material and methods

Three locations (zones) covering about 2250 m^2 of sea bottom area were studied (Figure 1). The three zones were classified as follows: Zone I (ZI) is located between the inflow channel of the Thermal Power Station and the cooling water outflow of the Jordan Fertilizer Industry (JFI). Zone II (ZII) starts from the outflow cooling pipe and extends as far as the northern section of the Industrial Jetty, and Zone III (ZIII) begins at the southern section of the Industrial Jetty and ends about 150 m to the south of the beginning of an abrupt, steeply sloping valley. Two depths, the shallow reef slope (6 m) and deep reef slope (12 m) were selected in each zone. The bottom habitats intended for inclusion in the present study, i.e. rocky, sandy, and seagrass beds, were first inspected and identified by snorkelling

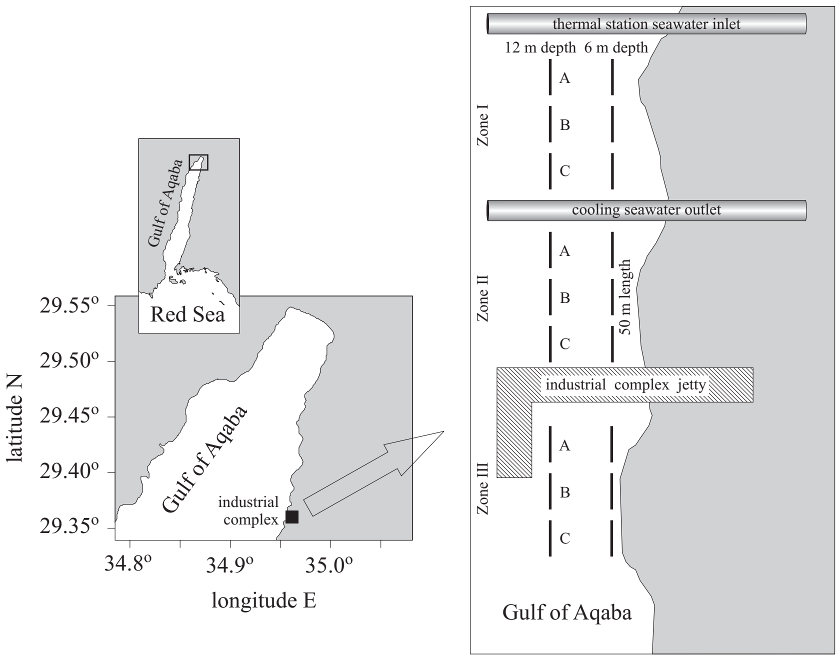

Figure 1. Map of the Jordanian coast of the Gulf of Aqaba showing the industrial area; schematic diagram of the three zones investigated

and SCUBA diving along the three specified zones. The benthic cover of the reef was assessed using a combination of line-intercept transects (English et al. 1994) and the point-intercept method (Loya & Slobodkin 1971, Mohammed et al. 2000). The macrobenthos, including hard and soft corals, ascidians, giant clams, urchins, anemones, macro-algae and sea grass beds, was assessed along three belt transects 50 m long and 5 m wide at each zone and depth. Observations and records were conducted by visual census at 50 cm point intervals by Scuba diving. To avoid bias, two divers carried out field observations simultaneously. The divers swam along the transects, recording all the macrobenthic communities encountered in a 2.5 m wide belt either side of the line.

The mean percentage cover was estimated for the living hard corals and soft corals, in addition to different benthic fauna and flora (macroalgae, seagrass, sea anemone, bivalves (giant clams), sea urchins (mainly *Diadema* sp. and *Tripeunestis* sp.), sponges and ascidians). The abundance of benthic fauna and flora was apparently very low, an observation not previously reported. The cover of non-living substrata, such as recently dead coral (RDC), rock, rubble and sand was also estimated. Data from the three different zones were analysed statistically by ANOVA (SAS corp.).

3. Results

The number of living hard coral species was counted in the whole study area (Table 1): over the three years (2001–03), a total of 46 were recorded. *Acropora* spp., *Montipora* spp., *Favia* spp., and *Fungia* spp. were the most abundant. The bottom habitat is mainly rocky – this is typical of coral reef sites. Structural modifications, due largely to construction activities, were noticed at certain localities in the study area, and hard coral abundance and cover were found to be slightly disturbed. The manoeuvring of ships and port activities may also have contributed to these modifications.

3.1. Mean percentage cover (MC) of benthos at 6 and 12 m depths

Data on coral and other macrobenthic fauna and flora were pooled from the three years (Figure 2). Results showed that the trends in the cover profile were similar at the two depths investigated. However, the coverage of hard and soft corals was significantly higher at 12 m than at 6 m. A similar profile was also recorded in the abiotic substrata at the two depths, with a significantly higher percentage cover in shallow water. However, there was no significant difference in the mean percentage covers of all the investigated

Table 1. List of the observed scleractinian corals species at the study site

Acropora, 7 species	*Montipora*, 6 species	*Favia*, 5 species	*Fungia*, 4 species	*Pavona*, 4 species	
A. cf. *nasuta*	*M. informis*	*F. favus*	*F. fungites*	*P. explanulata*	
A. digitifera	*M. retiformis*	*F. laxa*	*F. sp.*	*P. varians*	
A. eurystoma	*M. monasteriata*	*F.* cf. *maxima*	*F. sp. 2*	*P. venosa*	
A. granulosa	*M. sp.*	*F. pallida*	*F. sp. 3*	*P. decussate*	
A. hemprichii	*M. sp. 2*	*F. peresi*			
A. squarosa	*M. spongeosa*				
A. valida					
Cyphastrea, 2 sp.	*Goniastrea*, 2 sp.	*Porites*, 2 species	*Leptastrea*, 2 sp.	*Platygyra*, 2 sp.	*Echinopora*, 2 sp.
C. chalcidicum	*G. australensis*	*P. lutea*	*L. inaqualis*	*P. daedalea*	*E. fruticulosa*
C. microphthalma	*G. edwardsi*	*P. solida*	*L. purpurea*	*P. sinensis*	*E. gemmacea*
Stylocoeniella guentheri	*Astreopora myriophthalma*	*Coscinaraea monile*	*Echinophyllia aspera*		
Merulina scherii	*Pocillopora damicornis*	*Galaxea fascicularis*	*Psammocora haimeana*		

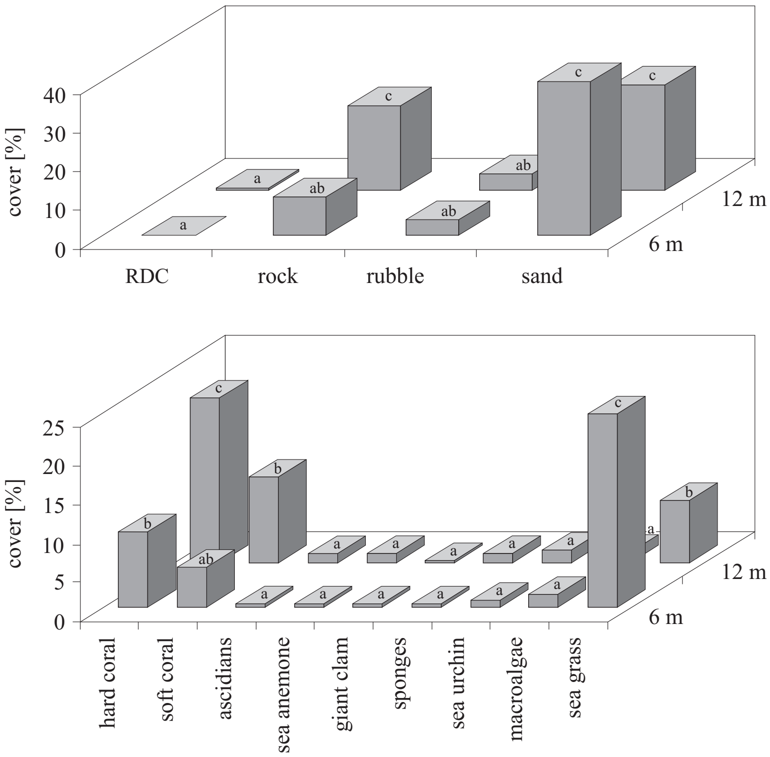

Figure 2. Comparison between the two study depths 6 m and 12 m of the average percentage cover of hard coral, soft coral and other macrobenthic fauna and flora, as well as the abiotic substrata in the three study zones in 2001–03. Bars marked with different letters are significantly different at $p < 0.05$

macrobenthic fauna and flora between the two depths. The coverage of both is very low (0.1–2%).

3.2. MC of benthos at the three zones in the study area

From the collective three-year records, the MC of all the benthos investigated was very low – between 0.2% and 3% in the three zones (Figure 3). Hard coral was more abundant in Zone II, with a coverage of c. 24%, a figure significantly different from the other two zones ($p < 0.05$). Soft coral was more abundant in Zone III; the difference between this and the other two zones was highly significant ($p < 0.01$). The MC of abiotic substrata, including recently dead corals (RDC), was minimal in Zone I. The mean percentage cover of hard coral over the whole study area at both depths was the highest (c. 15%), followed by the soft coral (8%). The cover of other components, however, was much lower (0.2–3%). The profile of the abiotic substrata was similar (Fig. 3).

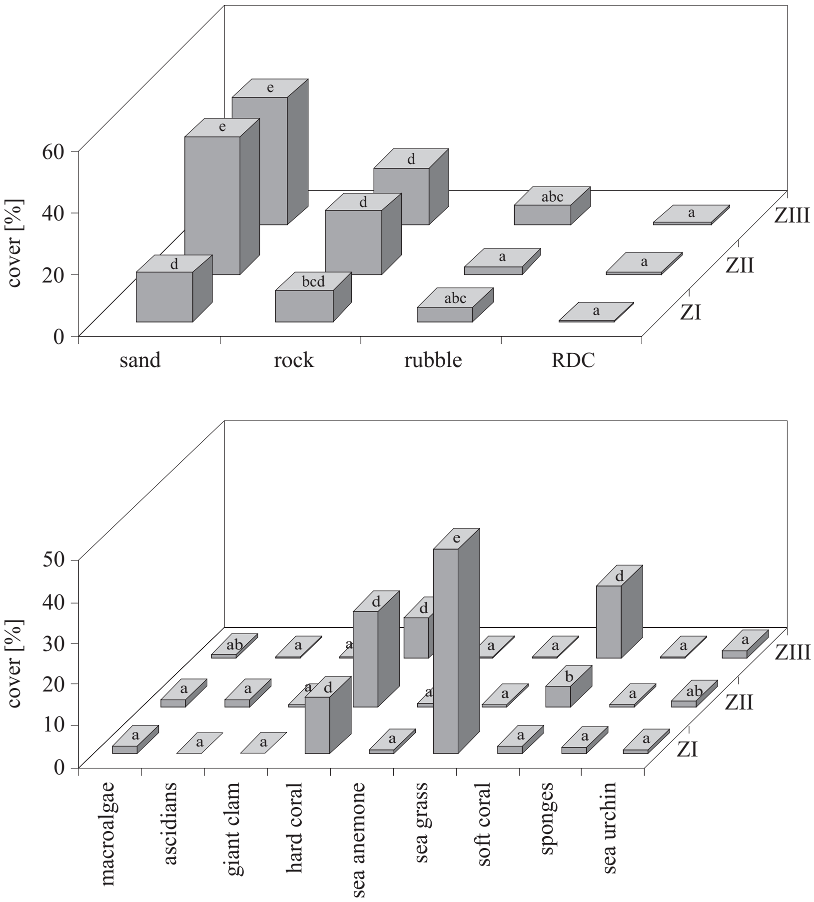

Figure 3. Comparison between the three study zones of the average percentage cover of hard coral, soft coral and other macrobenthic fauna and flora, as well as the abiotic substrata for the two study depths in 2001–03. Bars marked with different letters are significantly different at $p < 0.05$

3.3. MC relationships between hard and soft coral at the two depths

The most obvious difference was in the mean percentage cover of hard and soft corals in zones II and III at both 6 m and 12 m depths. For hard corals the highest values were measured at 12 m depth in Zone II, for soft corals they were measured at 6 m depth in Zone II. The lowest values were in Zone III at both depths.

MC values at 6 m in 2002 revealed that Zone I, which is located to the north of the industrial site, exhibited the lowest value of the three zones (Figure 4). The cover reached about 5%, whereas the percentage cover in

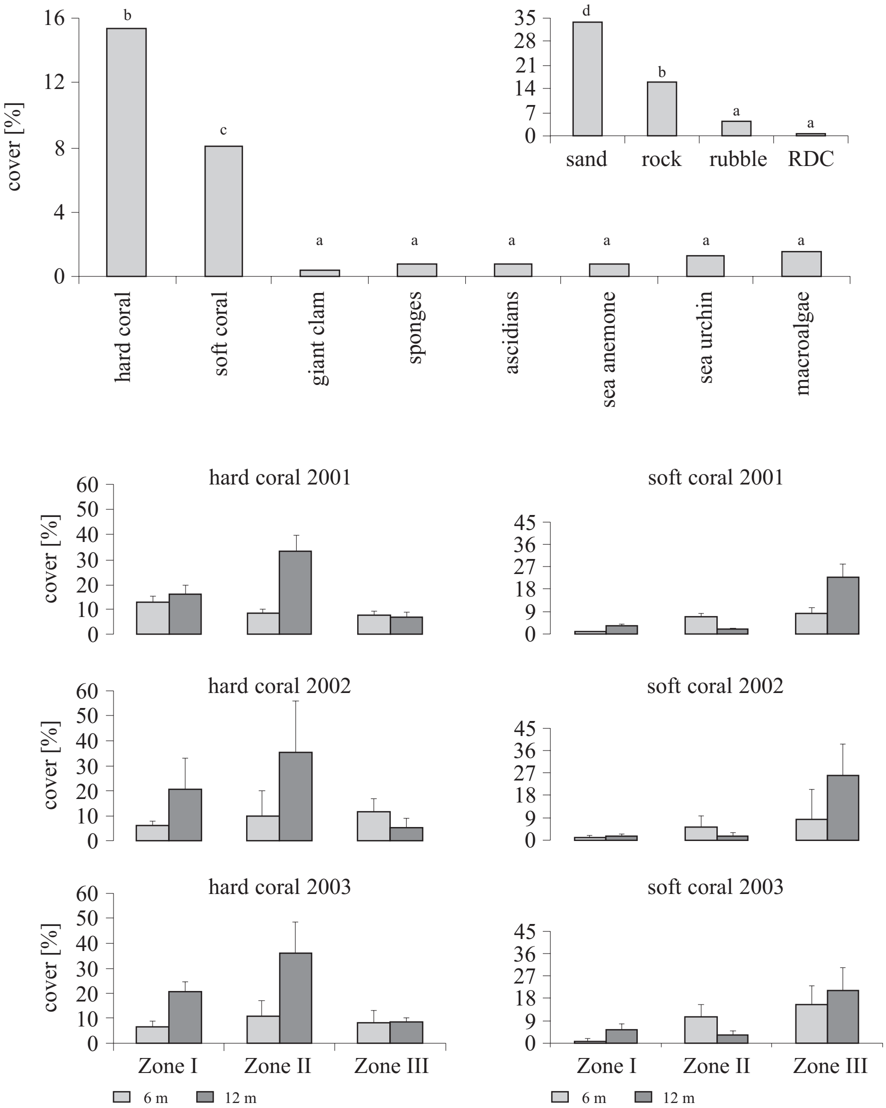

Figure 4. Overall average percentage cover of hard coral, soft coral and other macrobenthic fauna and flora, as well as the abiotic substrata; year-by-year comparison of the hard coral and soft coral percentage cover at the three study sites and two depths

zones II and III was a little higher (7–11%). The differences at both depths in comparison to MC values from 2001 and 2003 were insignificant. At 12 m, the differences in MC values between the three years in each zone were also insignificant. However, significantly higher MC values of hard coral were recorded in Zone II during the three years than in the other two zones: the cover reached about 35% in 2002, whereas in zones I and III it was almost similar for the three years, reaching about 20% and 8% for zones I and III, respectively.

Soft coral coverage in shallower water was quite similar to that in deeper water within the three zones. However, the maximum cover (21%) was recorded at 12 m in Zone III, followed by a 3% cover at the same depth in Zone II. The considerable cover of more than 21% at 12 m in Zone III is about 1.5 times that observed at 6 m in Zone III. The soft coral cover in the shallow water of Zone II (about 10%) was considerably higher than in the deep water (c. 3%).

3.4. Cover of rock and sand on the sea bottom

The percentage cover of rock (non-living biotope) at 12 m in the three zones was significantly higher than that in the shallow water, where the bottom is mostly sandy. In zones II and III, the percentage cover of sand at 6 m was similar, whereas in Zone I it was higher, reaching a maximum of 72% at 6 m. In the deep waters the sand cover was distributed evenly (16–37%).

Estimation of the percentage cover of recently dead coral (RDC) was mostly dependent on the newly dead coral colonies (bleached areas). Coral death was mostly negligible at 6 m in 2002 but was slightly higher in 2003. A similar pattern was observed in the deeper water, where in the two years RDC cover ranged from 0.5% to 2.3% in the three zones.

4. Inter-annual comparative study of the different benthic fauna

Hard and soft coral as well as some other benthic fauna were compared in three zones and at two depths for three years – 2001–2003 (Fig. 4). Hard coral decreased significantly at 6 m depth during the three successive years, especially in Zone I, but remained almost unchanged at 12 m in all three zones. Soft coral showed an increasing tendency during the study period, reaching a significantly higher value at 12 m depth in Zone I and at both depths (6 m, 12 m) of Zone II in 2003. Other fauna (hydrozoans, sponges, ascidians) and sea grass exhibited obvious variability in 2002 and 2003: some of these were either reduced or disappeared in 2003. Hydrozoans were absent at 6 m in 2003; sponges, too, had disappeared at 6 m in 2003. At 6 m in Zone III ascidians showed zero % cover in 2003 but increased significantly in Zone I. The seagrass abundance diminished to a very small cover in Zone I in 2003. This zone was the only locality with seagrass beds in the entire study area.

5. Discussion

The coral reef ecosystem is a very complex environment that is subject to considerable variability. Therefore, if studies are to be reliable, they should be based on long-term observations. The industrial area extends to the north as well as to the south of the industrial jetty in the southernmost section of the Jordanian Gulf of Aqaba. For the purpose of our study, we divided the whole site into three zones. This allowed us to conduct seasonal and temporal comparisons of the coral reef ecosystem over three years in the entire area.

Hard coral represents the most important component of the entire coral reef ecosystem along the Gulf of Aqaba coast. The soft coral cover fluctuates seasonally; its presence in considerable amounts at a particular locality and certain time may be indicative of certain anthropogenic disturbances. The hard coral cover did change slightly during the study period, but maintained the same trend with a highest cover of 35%. The site is historically regarded as an area of well-developed coral reefs, but the coral cover there appears to be considerably lower than at other sites, such as the Tourist Camp, Marine Reserve and the Clinker Port along the Jordanian coast, where coral covers range from 50% to 65%. These values are very close to those from other parts of the Gulf of Aqaba (Veron 1993, Te 1992, Fouda 1998). The probable reason for the decrease in coral cover at the industrial site is coral destruction during the port's construction.

The abundance of hard coral competitors, such as soft coral, corallimorpharians and algae, was more significant in Zone III than in the zones more distant from the industrial jetty. It appears that there has been a shift in species abundance in favour of *Montipora*. Other benthic categories contributed little during the three years of the study. The relative cover of the examined benthic organisms did not appear to have changed much. Zone II of the present study exhibited the highest percentage cover of hard and soft coral. But it is interesting here to note the shift from soft corals to hard corals as we go deeper into the water (Figure 5).

Surprisingly, the densities of macro-invertebrates – hydrozoans, sponges and bivalves – were very low. Soft corals that compete with hard corals have replaced hard corals in only very limited areas, for example in Zone III. Parts of the dead coral skeleton have been taken over by soft corals, especially where the water current is relatively strong around the cooling water outlet. The increase in fleshy algae in all zones was not very obvious. The density as well as the diversity of reef fish seemed to have decreased slightly in the entire area (Khalaf & Kochzius 2002). The deposition of solid waste in the shallow water of the industrial complex and the use of simple handling facilities are likely to endanger the structure and composition of

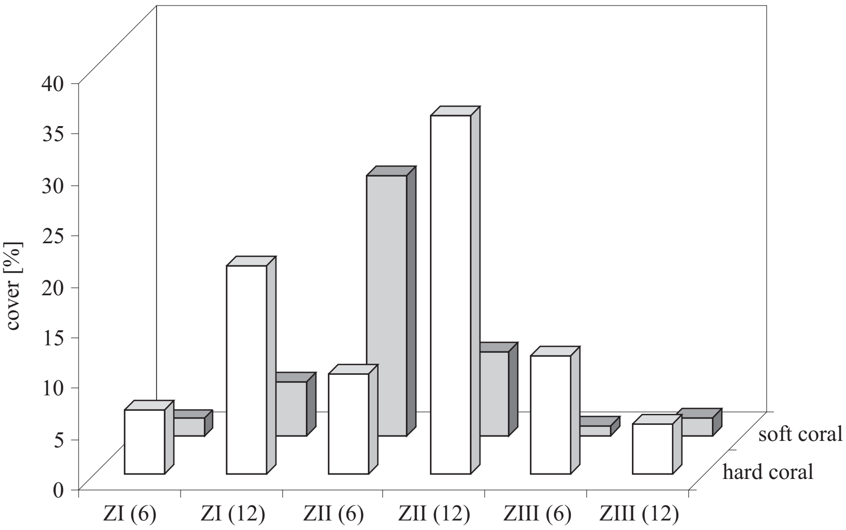

Figure 5. Depth effect on the average percentage cover of hard corals and soft corals at all study sites and depths during the study period (2001–03). Note the substantial difference in hard coral and soft coral covers with depth in Zone II

coral reefs. Johnstone et al. (1998), Ngoile & Horrill (1993) and Muhando (1995) have attributed the general degradation of the coral reef environment and its resources to coral mining, pollution, coastal construction and other misuses.

The settlement of new coral larvae at this site under the operational conditions of the thermal power station, the fertilizer facilities and port activity, needs thorough investigation. Pollution is one of the major factors affecting coral distribution, cover and survival. The rate of death of the scleractinian coral *Stylophora pistillata* was 4–5 times greater at the polluted site of a phosphate port adjacent to the main port of Aqaba compared with a healthy reef in the south (Walker & Ormond 1982). The reason for death was attributed to phosphate dumping during the loading of crude phosphate. Coral recovery is possible, however, owing to the favourable environment of intact coral skeletons, clear water and the availability of recruits in the area (personal field observations). Coral settlement occurs mainly in crevices and under reef structures (Franklin et al. 1998), indicating that successful settlement and growth of corals could be influenced by the structural complexity of the reef. The three zones at the industrial complex accommodate a typical fringing reef habitat with considerably good coral cover of up to 35% in Zone II. These values are very close to other known localities in the Gulf of Aqaba (Fouda 1998). The highest coral cover and diversity were reported between 10 and 20 m, and the cover does indeed increase southwards (Schuhmacher et al. (eds.) 1995). During our observations the largest coral cover was found in waters deeper than 12 m. This has implications for the number of species. Such an assumption was supported by our results at the industrial site, which showed maximum coral cover at a somehow not directly affected area within the study site (e.g. Zone I), reaching up to 40% hard coral cover. But within the port (Zone III) the maximum coral cover is less than 15%. Being dominated by coral reef habitats, the study area showed no link between the percentage cover of RDC and HC, which also indicates that coral mortality is due to natural decline. In conclusion, the conditions of the benthic community with regard to species composition and distribution at the industrial site are similar to those found at other parts along the Jordanian coast of the Gulf of Aqaba.

Port activities appear to have an impact on hard coral, especially in shallow waters and close to the jetty area. Industrial discharges may negatively affect coral health. Turbidity due to industrial activity may increase total suspended matter, decrease light availability and limit space for new larval settlement. At the same time, it enhances mucus production by corals, which is an energy-consuming process (Te 1992). Comparison of seawater quality between the study area and the other reference coastal sites offshore using the relative modification approach revealed significantly increased concentrations of reactive phosphate in seawater at the industrial site (Badran & Foster 1998). Those authors found no significant increase in chlorophyll *a* concentration. They attributed the result to the slow dissolution of spilled phosphate powder and final fertilizer products. However, nitrogen species are unlikely to accumulate, because nitrogen is the limiting nutrient in the waters of the Gulf of Aqaba (Badran 2001, Badran et al. 2005). The conditions in deep water (> 15 m) look better and were not directly affected.

In summary, the coral degradation found in some parts of the industrial site was highest in areas directly affected by port activities. Invertebrate counts including sea urchins, sponges, bivalves, tunicates and ascidians were relatively stable in spite of the increase in substrates for the growth of fleshy algae. Macro-invertebrates were probably few due to their natural distribution. Nevertheless, a more focused management policy needs to be implemented at the industrial site, especially as there are plans to move most of the port's components to this site. Research and monitoring are important and must be included when setting up management strategies. Base-line studies like this one are required to keep the coral reef ecosystem under continuous watch. The expansion of several industries on the southern Jordanian coast of the Gulf of Aqaba is already in progress, and several other industries are at the planning or licensing stages. It is worth mentioning that Jordan does apply careful environmental impact assessment studies as a part of the licensing process of industrial activities.

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