SUMMARY AND CONCLUSION

Summary and conclusion

The effects of different human activities on coral reefs were investigated at seven selected locations along the northern Red Sea of Egypt. Reef surveys indicated that all observed coral damage (coral death, coral breakage, algal overgrowth and coral diseases) was most frequent within the upper ten meters depth. The anthropogenic disturbance of various sorts was the main cause of reef damage because severe oceanographic and climatic changes are extremely rare in the area of study. Sixteen physico-chemical variables were assessed in the present study. Mean water temperature ranged from 23.89 ± 2.31 °C at location IV to 26.27 ± 2.45 °C at location VII, while mean salinity was flactuated between 39.64 ± 0.2 ‰S at location VII and 42.65 ± 0.17 ‰S at location I. Thus, salinity increases towards the north. The maximum mean concentration of dissolved oxygen 6.53 ± 0.17 mg O_2 L^{-1} was recorded at location VII, whereas the minimum mean 5.14 ± 0.19 mg O_2 L^{-1} was recorded at location II. Values of pH showed no obvious variation among the sampled locations.

The common indicators of eutrophication in the studied sites are increased nutrient and phytoplankton (as indicated by chlorophyll *a*) concentrations in the water column. The highest mean concentration of chlorophyll *a* (0.28 ± 0.02 µg L^{-1}) occurred at location III, whilst the lowest value was observed at locations VI and VII (0.14 ± 0.07 and 0.14 ± 0.04 µg L^{-1}, respectively). Nutrient concentrations showed relatively similar trend, whereas the mean concentrations of total dissolved inorganic nitrogen (nitrite + nitrate + ammonia) and dissolved phosphate were highest at location III (5.02 ± 0.95 and 0.42 ± 0.1 μM, respectively) and lowest at location V (2.07 ± 0.37 and 0.06 ± 0.02 μM, respectively).

Enhanced sewage discharge, seepage of wastewater and terrestrial sediment input seems to be the main causes of enhanced nutrient concentrations at location III (Marine Biological Station). Impacts of eutrophication on coral reefs are increased dominance of macroalgae which compete with corals for substrate space and overgrow living coral tissue, and increased concentration of total suspended particulate matter in the water column.

Concentration of total suspended particulate matter (SPM) was significantly different among the investigated reef sites. Site I (El-Ain Al-Sukhna) showed the highest mean concentration of SPM (12.52 ± 1.18 mg L^{-1}), while the lowest value (5.52 ± 0.31 mg L^{-1}) was reported at site V (Sha'b Abu-Galawa). Elevated concentration of SPM affecting reef corals directly by physical smothering or indirectly through a reduction of light levels available for zooxanthellae photosynthesis. The probable causes of high levels of SPM in the area of El-Ain Al-Sukhna are enhanced terrestrial sedimentation and resuspension of bottom sediments due to human trampling on reef flats.

Sedimentation rate exhibited high significant difference among the investigated reef sites. Maximum mean of sedimentation rate 317.76 ± 73.73 mg cm^{-2} day^{-1} was found at site II (Ras Za'farana), while the minimum mean 3.71 ± 0.67 mg cm^{-2} day^{-1} was found at site IV (Sha'b Saad). Excessive sedimentation can adversely affect the structure and function of the coral reef ecosystem by altering both physical and biological processes. Heavy sedimentation was associated with a significant reduction of live hard coral cover, hard coral density, species richness, species diversity, evenness index and population density of zooxanthellae, and increased coral mortality and coral diseases. It is suggested that landfilling concomitant with building activities, beach enhancements and land reclamation were the most significant

anthropogenic factors responsible for increased terrestrial sedimentation at the northwestern Gulf of Suez (locations I and II).

Total carbonate and organic matter (TOM) contents in reef sediments were significantly varied among the studied locations. Location V showed the maximum mean percentage of total carbonates (90.66 ± 1.85%), while location II showed the minimum value (42.44 ± 1.92%). Increased sedimentation rate is significantly correlated with decreased carbonate content in reef sediments. This would probably because the enhanced terrestrial sediment accumulation which are poor in carbonate content significantly reduce the net production of total carbonates by corals. The highest mean percentage of TOM 12.15 ± 1.29% was determined at location I, whereas the lowest value 2.94 ± 0.82% was determined at location V. The significant positive relationship between increased TOM content and enhanced trace metal concentrations in reef sediments demonstrated that organic matter is a significant concentrator of these metals. Generally, increasing TOM content in reef sediments was accompanied with increasing trace metal concentrations, which is adversely affected on coral population.

The mean concentration of total dissolved and dispersed petroleum hydrocarbons (DDPH) in seawater ranged between 7.24 ± 1.14 $\mu g\ L^{-1}$ at location IV and 34.83 ± 26.57 $\mu g\ L^{-1}$ at location II. Concentration of total petroleum hydrocarbons in reef sediments (TPH) showed significant variation among the sampled locations, where the highest mean concentration (52.85 ± 8.33 $\mu g\ g^{-1}$) was measured at location II and the lowest value (1.40 ± 0.01 $\mu g\ g^{-1}$) was measured at location V. The higher levels of petroleum hydrocarbons reported at locations II and I were probably attributed to the massive oil spillage associated with the different petroleum activities in the Gulf of Suez. On the other hand, the lower concentrations of petroleum hydrocarbons in the area of Hurghada

(locations III, IV, V and VI) may be attributed to the fact that this area is protected from the prevailing southerly currents which presumably carry the oil with it, by projected head lands and cluster of islands. The increasing oil concentration was significantly accompanied with decreasing live hard coral cover, hard coral density, species richness, species diversity, evenness index and zooxanthellae density, and increasing dead coral cover.

A survey of 10 heavy metals in seawater and reef sediments of the sampling locations indicated high levels of heavy metal pollution were found in the northwestern part of the Gulf of Suez (locations I and II). This probably is attributed to increasing environmental contamination resulted from intensive petroleum activities, increased terrestrial sediment input, sewage discharge, and the antifouling and anticorrosive paints that coated the hulls of travelling or waiting ships. The effect of heavy metals on reef corals is still unclear but the results revealed that the enhanced heavy metal concentrations might partially contribute to increased dead coral cover, decreased hard coral density and lowered species diversity indices.

Coral community structure was analyzed using belt quadrat sampling method, with an emphasis on reef-building corals, to determine the response of coral community structure to the human disturbance. SCUBA gear was used throughout the entire study. A total of 83 hermatypic coral species were encountered during this study. Ras Zafarana (Location II) showed the lowest number of species (12.0), species richness (2.48), species diversity (1.54) and hard coral density (3.65 ± 0.90). On the other hand, Sha'b El-Fanadir (location VI) had the largest number of species (43.0) and species richness (7.60), whereas the greatest species diversity (3.21), evenness index (0.89) and hard coral density (10.23 ± 1.88) were reported at location IV (Sha'b Saad).

There were significant differences in live hard coral cover and dead coral cover among the surveyed reef sites. The lowest percentage cover of live hard corals (30.56 ± 4.71%) and the highest percentage cover of dead corals (28.70 ± 3.89%) were recorded at site II. On the contrary, the maximum percentage cover of live hard corals (56.65 ± 9.17%) was found at site IV, and the minimum percentage cover of dead corals (9.43 ± 2.78%) was found at site V. It is suggested that the synergistic effects of heavy terrestrial sedimentation, higher levels of oil and heavy metal pollution, and increased SPM in the Gulf of Suez (locations I and II) may explain the lower number of species, species richness, species diversity, evenness index, hard coral density and live hard coral cover, in addition to higher cover of dead corals registered in these areas.

The high dominance of *Stylophora pistillata*, *Acropora pharaonis* and *Acropora forskali* in terms of percentage cover at site II may be mainly ascribed to the fact that these branching corals showed greater resistance to higher levels of sedimentation rate, SPM and oil pollution than massive and encrusting coral growth forms. Similarly, this probably explain the dominance of *Acropora pharaonis* in terms of percentage cover at El-Ain Al-Sukhna (site I). Moreover, *Stylophora pistillata* is suggested to be an opportunistic species, which may be expected to invade temporarily vacant ecological niches or relatively harsh and unpredictable environments on the reef. *Galaxea fascicularis* was the most dominant species at Marine Biological Station (site III) and the second dominant species at site I in terms of percentage cover. This possibly because *Galaxea fascicularis* showed high resistance to excessive sedimentation by evolving some cleaning mechanisms and able to tolerate the occasionally severe low tide.

Coral breakage was found to be significantly higher in the reefs with high visitor frequency (locations I, V and VI) than reefs with low

visitor frequency (locations II, IV and VII). Boat anchoring and grounding, SCUBA diving, trampling, and destructive fishing practices were the major causes of coral breakage in the area of study. Species of genus *Acropora*, *Millepora dichotoma*, *Stylophora pistillata* and *Pocillopora damicornis* were the most frequently affected corals with breakage.

Soft corals and macroalgae were the major space competitors with hermatypic corals in the investigated reefs. There were significant variations in the percentages of soft coral cover and macroalgal cover among the locations. The higher percentages of soft coral cover were obtained at locations I and II (18.51 ± 3.35% and 18.13 ± 4.79%, respectively), whilst the lower percentages were obtained at locations VII and III (3.37 ± 1.39% and 3.77 ± 1.04%, respectively). It is hypothesized that soft corals exhibited higher tolerance to higher levels of sedimentation and chemical pollution than reef building corals, which are more vulnerable to increased sedimentation and chemical pollution (a condition at locations I and II). Macroalgal cover ranged from 1.64 ± 0.75% at site V to 17.73 ± 2.60% at site III. The high significant correlation existed between live hard coral cover and macroalgal cover demonstrated the damaging effect of algal overgrowth. The high nutrient enrichments associated with both of increased sewage discharges and landfilling were probably accounted for the highest percentage of macroalgae on the reef near Hurghada (site III).

Sea urchins were the main coral skeleton bioeroders in the present study. Two species were dominant in the sampled locations, *Echinometra mathaei* and *Diadema setosum*. The former was dominant in the Gulf of Suez (locations I and II), while the latter was the major skeleton bioeroder in the Red sea proper (other locations). The drastic increase in the population density of sea urchin was thought to be partly due to a

dramatic decline in the population of their predators, large trigger fishes and large puffer fishes, which mostly were overfished for aquariums and marine curio trade. Furthermore, increased terrestrial sedimentation due to land reclamation and building activities, and installation of breakwaters may contributed to enhanced sea urchin density.

Population density of zooxanthellae was investigated in the tissue of *Stylophora pistillata*. The greatest density of zooxanthellae $1.08 \times 10^6 \pm 0.03 \times 10^6$ cells cm^{-2} was recorded at Sha'b Abu-Galawa (location V), whereas the smallest density $0.70 \times 10^6 \pm 0.03 \times 10^6$ cells cm^{-2} was recorded at location II. The synergistic effects of high sedimentation and oil pollution were the most important anthropogenic factors responsible for lower densities of zooxanthellae at locations I and II. Population density of zooxanthellae can be used as indicator of stresses on corals.

Occurrence and distribution of coral diseases were determined using semi-quantitative belt method (underwater time-count technique). Four coral diseases were surveyed in this study: Tissue Bleaching (TBL), White Band Disease (WBD), Black Band Disease (BBD) and Bacterial Infection (BIN). The present results suggested that elevated water temperature and man-made influences might act jointly to enhance the growth of TBL and WBD. The species of genera *Favites*, *Acropora* and *Platygyra* were found to be the most susceptible corals to TBL. The effects of the WBD were most severe among *Acropora* spp., *Goniastrea retiformis*, *Platygyra* spp., *Favites* spp. and *Echinopora gemmacea*. High nutrient enrichments at location III was probably accounted for the progress of BBD in this area. Susceptibility to BBD seems to be restricted in family Faviidae, with *Platygyra* and *Goniastrea* species are the heavily afflected corals. Since BIN takes place when corals protect themselves against outside stress by a layer of mucus (being a glycopeptide) which can be used by a wide variety of marine bacteria as a source of nutrients,

the anthropogenic stresses may increase the incidence of BIN. This would explain the frequent occurrence of BIN at locations II and III.

The significant anthropogenic disturbances that have affected coral reefs throughout our study region can be summarized as follows: 1) excessive terrestrial sedimentation caused by landfilling and construction activities accompanied with tourism expansion; 2) massive spillage of petroleum; 3) nutrient enrichments as a result of increased sewage discharge, seepage of wastewater and terrestrial sedimentation; 4) bottom sediment resuspension due to reef walkers; 5) physical damage resulted from recreational activities (such as boat anchoring, SCUBA diving, snorkelling, trampling on reef flats etc..) and destructive fishing practices; 6) disturbing the ecological balance inside the reef through heavy collection of reef fishes, shells, corals and other reef invertebrates for aquariums and curio trade.

Finally, it is difficult to separate the effects of specific anthropogenic stress from the other stresses. So, it can be concluded that the coral reef damage in the studied sites might be ascribed to the synergistic effects of several factors.