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Response to Increased Sediment Load by Three Coral Species from the Gulf of Suez (Red Sea)

M.L. Ebeid, M.H. Hassan and Y.A. Geneid
National Institute of Oceanography and Fisheries, Attaqa, P.O. Box 182, Suez, Egypt

Abstract: This study examines the hypothesis that sedimentation, as a result of anthropogenic activities, has a measurable effect on the growth rate (in terms of linear extension) of branching corals of a subtropical site in the northern Gulf of Suez. Three of the dominant branching coral species; *Stylophora pistillata* (Esper) 1792, *Acropora pharaonis* (Milne Edwards and Haime) 1860 and *A. hemprichi* (Ehrenberg) 1834 were chosen for monitoring their growth rate after the cessation of construction works. At the beginning of the study, the three study species had very low rates of growth in response to increased sediment load. Over time sedimentation rates decreased significantly while linear extension rate per branch of the three study species showed a significant gradual increase. The study reaches the conclusion that coral growth is negatively related to sedimentation.

Key words: Corals, sedimentation, growth rate, linear extension, Gulf of Suez, Red Sea

INTRODUCTION

Pollution of the marine environment by sedimentation is an accelerating problem throughout the World that increasingly threatens the valuable coral reef resources (Hodgson, 1990). Sedimentation occurs naturally as a result of terrestrial run-off and wave action and artificially as a result of many human activities (mainly coastal constructions). Normal sedimentation rates have been estimated to be at most 10 mg/cm^2/day (Rogers, 1990).

Sediment both reduces water clarity and requires an increased expenditure of energy by corals for cleaning activity, resulting in lower growth rates (Dodge *et al*., 1974). High sediment load (>10 mg L^{-1}) can smother benthic organisms, prevent the larvae from settling and reduce light availability for the symbiotic zooxanthellae. The ability of corals to resist the harmful impact of high sedimentation rates depends on the overall health of the colony and the presence of other stress factors (Brown, 1997; Jimenez and Cortes, 2003).

Environmental conditions in the Gulf of Suez approaches the tolerance limits for the existence of coral reefs (Sheppard *et al*., 1992). This high latitude shallow sea is subject to a combination of more than one extreme condition, e.g., high temperatures and salinities which exceed those experienced by corals elsewhere. The shallowness of the Gulf promotes high turbidity due to re-suspension of bottom sediment by waves (Sheppard *et al*., 1992).

Impacts of industrial sedimentation on corals of tropical reefs were studied by Macdonald and Perry (2003) and Crabbe and Carlin (2007). These impacts on sub-tropical reefs received much less attention (Harriott, 1998). The main objective of the present study was to test the hypothesis that sedimentation, as a result of anthropogenic activities has a measurable effect on the growth rate (in terms of linear extension) of branching corals of a high-latitude site in the Gulf of Suez.

Corresponding Author: Yasser Ali Geneid, National Institute of Oceanography and Fisheries, Attaqa, P.O. Box 182, Suez, Egypt Fax: +2062/3360016

MATERIALS AND METHODS

Study Site

The area of Beer Odeeb is located at the Northern Gulf of Suez (Lat: 29° 40' 58.82" N, Long: 32 ° 21' 54.93" E). The site is used as a berth, composed of one big platform accepting vessels serving the production of petrochemicals industry. The marine ecosystem at this site is generally poor. There are no corals around the berth. Heading south (about 150m from the berth) coral colonies are found composed mainly of three successive shallow patches. The first patch is the largest (150 m long and 20 m wide). The second patch is smaller (90 m long and 15 m wide) and the third patch is 50 m long and 20 m wide). The water depth ranged between 4 and 6 m, decreased southward to reach about 2 to 3 m deep where the corals are found (Fig. 1).

During September and October 2000, several operations were conducted by the Oriental Petrochemical Company to reuse the site. The company used the old berth for accepting vessels and reloading propylene gas. Dredging works were conducted around the berth to reach a safe depth for vessels. As a result heavy sediment load was released to the surrounding area.

Data Collection

The current study started in April 2001 (6 months after the dredging) to evaluate the impact of the dredging work and increased sediment load on coral colonies near the berth and to measure the response of coral growth to decreasing rates of sedimentation over time. Data were collected during five visits starting in April 2001, then July 2001, September 2001, April 2002 and August 2002. Three transects were fixed on each coral patch running parallel to the shoreline. The percentage cover of different coral species was recorded inside each transect.

Sedimentation Rates

Sedimentation rates were assessed using an experimental design (Rogers *et al*., 1994). Sediment traps consisting of straight sided plastic jars with a height of 24 cm and a diam of 8 cm (height to diameter ratio was approximately 3:1) were deployed in groups of three at three different locations inside each transect. Another group was deployed in a control area 800 m from the berth. All the traps were placed at a depth ranged from 2 to 3 m sec^{-1}. The sediment traps were left *in situ* for 7 days and were replaced after they were retrieved on two occasions resulting in three replicates over time. The traps were capped underwater, carefully brought upright to the surface and transported to the laboratory.

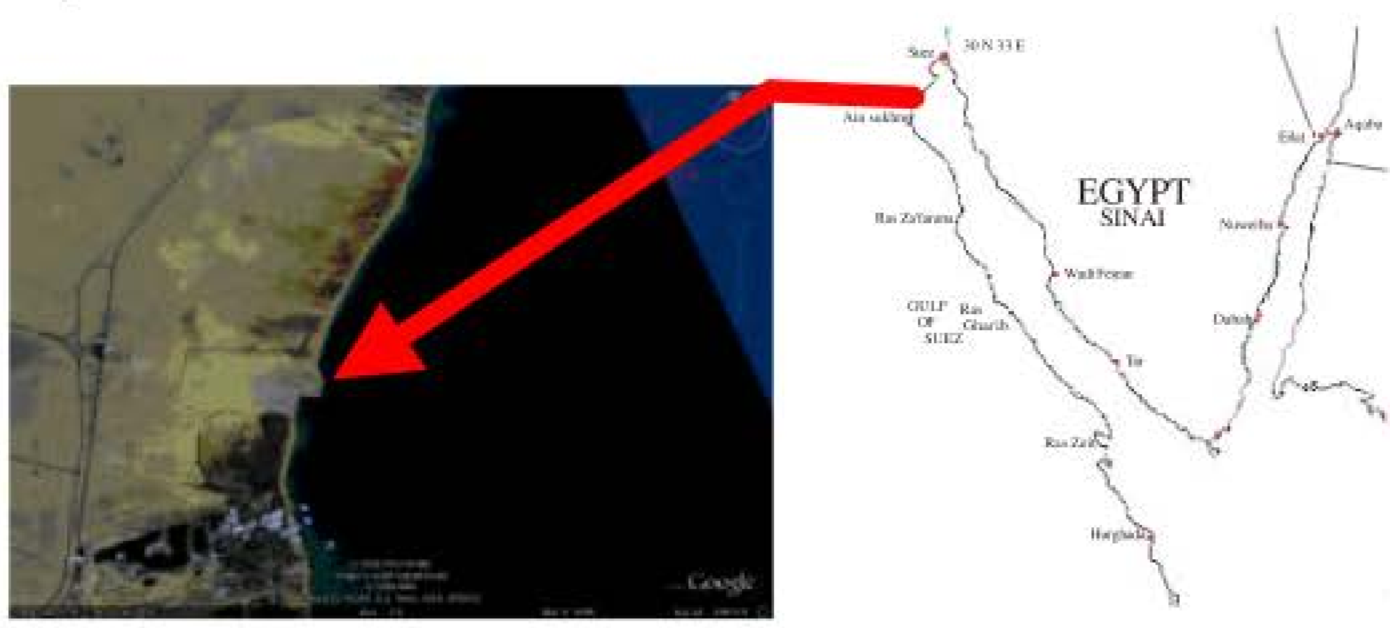

Fig. 1: Map of the Gulf of Suez showing the study area

Each trap was allowed to stand for 1 h, after which the sea water in the trap was siphoned off until approximately 100 mL remained to avoid disturbing the sediments that settled on the bottom. The settled contents were then removed and washed several times with distilled water to remove salts. The supernatant distilled water was also siphoned. The settled sediments were allowed to dry at 60°C till reaching a constant weight. The sedimentation rates were expressed as mg dry weight/cm^2/day.

Growth Rate

Three of the dominant coral species (*Stylophora pistillata*, *Acropora pharaonis* and *A. hemprichi*) were chosen for monitoring their growth rate. Fifteen coral colonies of each species were tagged to determine the changes in growth and the percentage of mortality in each colony. Care was taken to ensure that the chosen colonies were the healthiest ones in the study site. Coral colonies were tagged using thin copper threads and the distance between the thread and the top of the coral branch was accurately measured using a calliper. The position of tagged colonies was marked on a map of the site for future measurements. After each time interval, each of the fifteen coral colonies was identified and the change in their growth was calculated by measuring the distance from the copper thread to the growing tip of the branch again. The initial distance was subtracted from the new distance to calculate the growth. The growth rate was then expressed as the number of millimeters gained per time.

Data Analysis

By using the software SPSS (version 11.5), the following statistical analysis were preformed:

- Analysis of Variance (ANOVA) were conducted to detect the differences between sedimentation rates along the study sites and the surrounding area
- Growth rate of each study species and the sedimentation rate were compared using regression
- The t-test was used to compare the differences between coral cover among study sites

RESULTS

Sedimentation Rates

At the beginning of the study period, the rates of sedimentation at the study site were significantly higher than those of the control area '800 m away from the berth' (23.14 mg dry weight cm^2/day for the study site vs. 5.61 mg dry weight cm^2/day for the control, ANOVA: $F = 28.94605$, $df = 6$, $p<0.0001$). Sedimentation rates then decreased significantly over the total period of the study (ANOVA: $F = 8.036$, $df = 4$, $p<0.01$). Figure 2 shows the values of the sedimentation rates of the study sites over time.

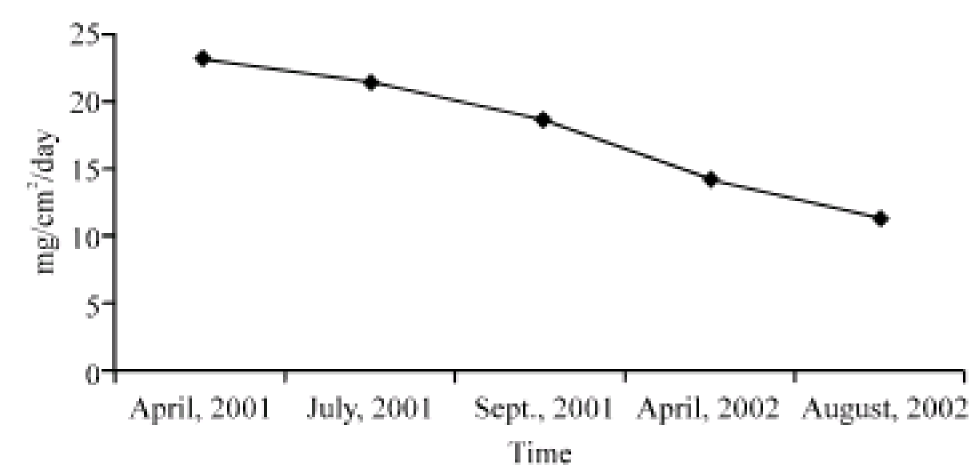

Fig. 2: Sedimentation rates over time in the study area

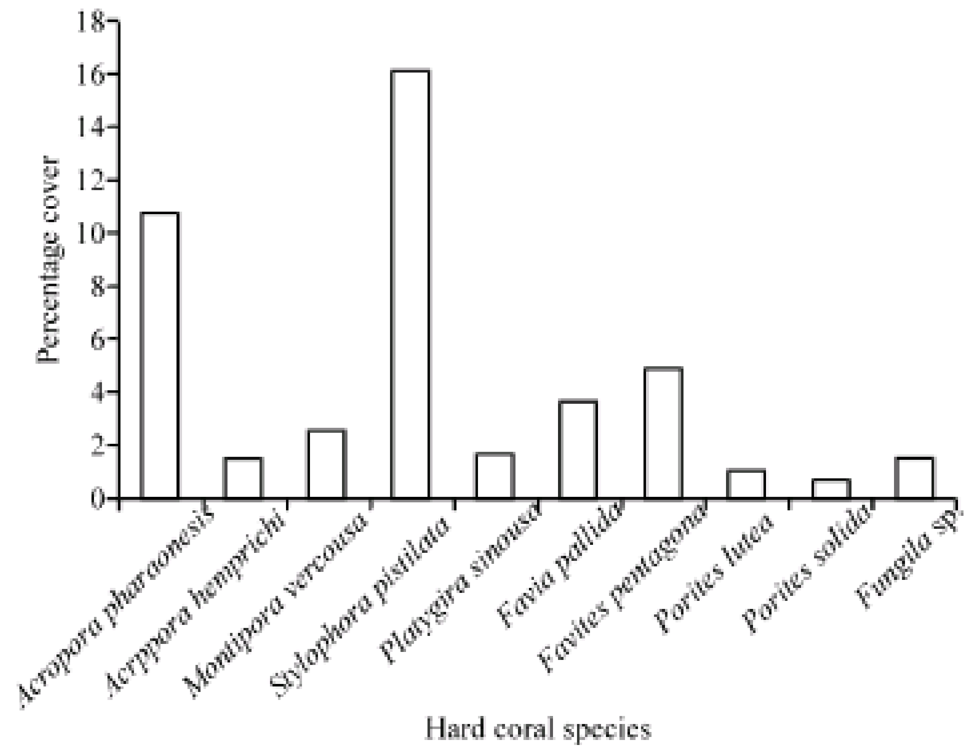

Fig. 3: The most common hard coral species at the study site

Table 1: Average linear extension rates (mm) of each study species during the study period

Time interval	*Stylophora pistillata*	*Acropora pharaonis*	*Acropora hemprichi*
Apr-July 2001	5.8±0.33	0.9±0.3	1.3±0.4
July-Sep. 2001	6.3±0.37	7.0±0.5	3.7±0.7
Sep-Apr. 2002	7.3±0.26	6.8±0.7	4.6±0.5
Apr-Aug. 2002	8.5±0.22	8.3±0.6	7.6±0.6

Coral Communities

The study area had significantly higher dead coral cover (82.7%) compared to live coral cover (Mean = 17.3% (t-test: df = 2, p = 0.00857)). Of the remaining live coral cover, branched corals were the dominant growth form (33%), while massive corals constituted only 13.7% of the live coral cover. Ten species of scleractinian corals were identified within transects (Fig. 3). The most abundant species was *Stylophora pistillata* with the highest percentage cover in the study area (16.1%).

Growth Rate of Corals

Stylophora pistillata had the highest rate of linear extension over the total period of the study (27.9±1.9 mm). Branches of *Acropora pharaonis* increased linearly by 23±5.5 mm and those of *A. hemprichi* increased by 17.1±2.5 mm over the study period.

Over the sixteen months period of the study, linear extension rate per branch showed significant increase in *Stylophora pistillata* (from 5.8±0.3 mm in July 2001 to 8.5±0.2 mm in August 2002, F = 15.854, $p<0.001$) and in *Acropora pharaonis* (from 0.9±0.3 mm in July 2001 to 8.3±0.6 mm in August 2002, $p<0.001$). *Acropora hemprichi* had a similar trend of increasing extension rate from 1.3±0.4 mm in July 2001 to 7.6±0.6 mm in August 2002 (Table 1).

At the beginning of the study period, the linear extension of the three study species was slower due to higher sedimentation rates (in April 2001, sedimentation rates were 23.14 mg cm^{-2}). As sedimentation rates decreased over time (in August 2002, sedimentation rates were 11.21 mg cm^{-2}), linear extension of the three study species showed a significant gradual increase-with only one exception in the case of *A. pharaonis* which had a slower growth rate during Sep-Apr 2002 than the previous time interval (Fig. 4).

Figure 5a-c show regression plots for the relationship between the growth rate of each study species and the rate of sedimentation. All three species showed a negative relationship with sedimentation rate. Linear extension increased as sediment load declined over time.

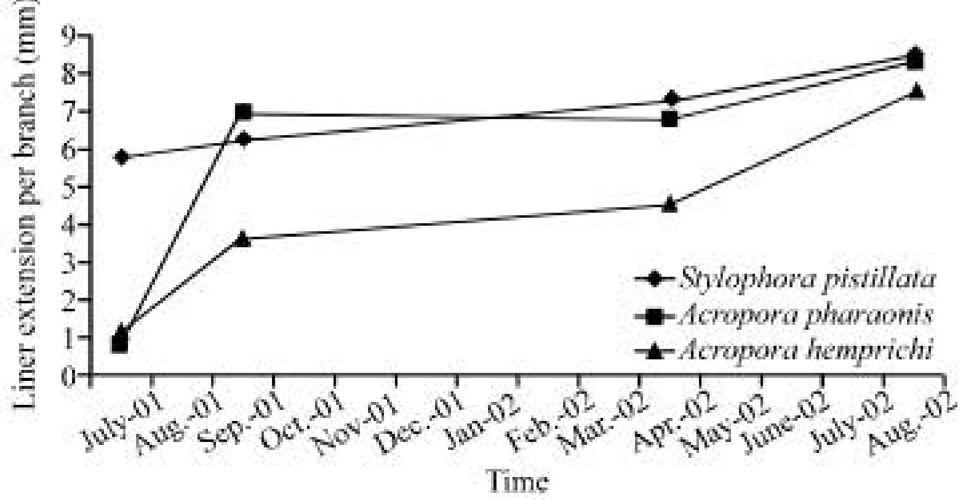

Fig. 4: Linear extension rates of the three studied coral species over time

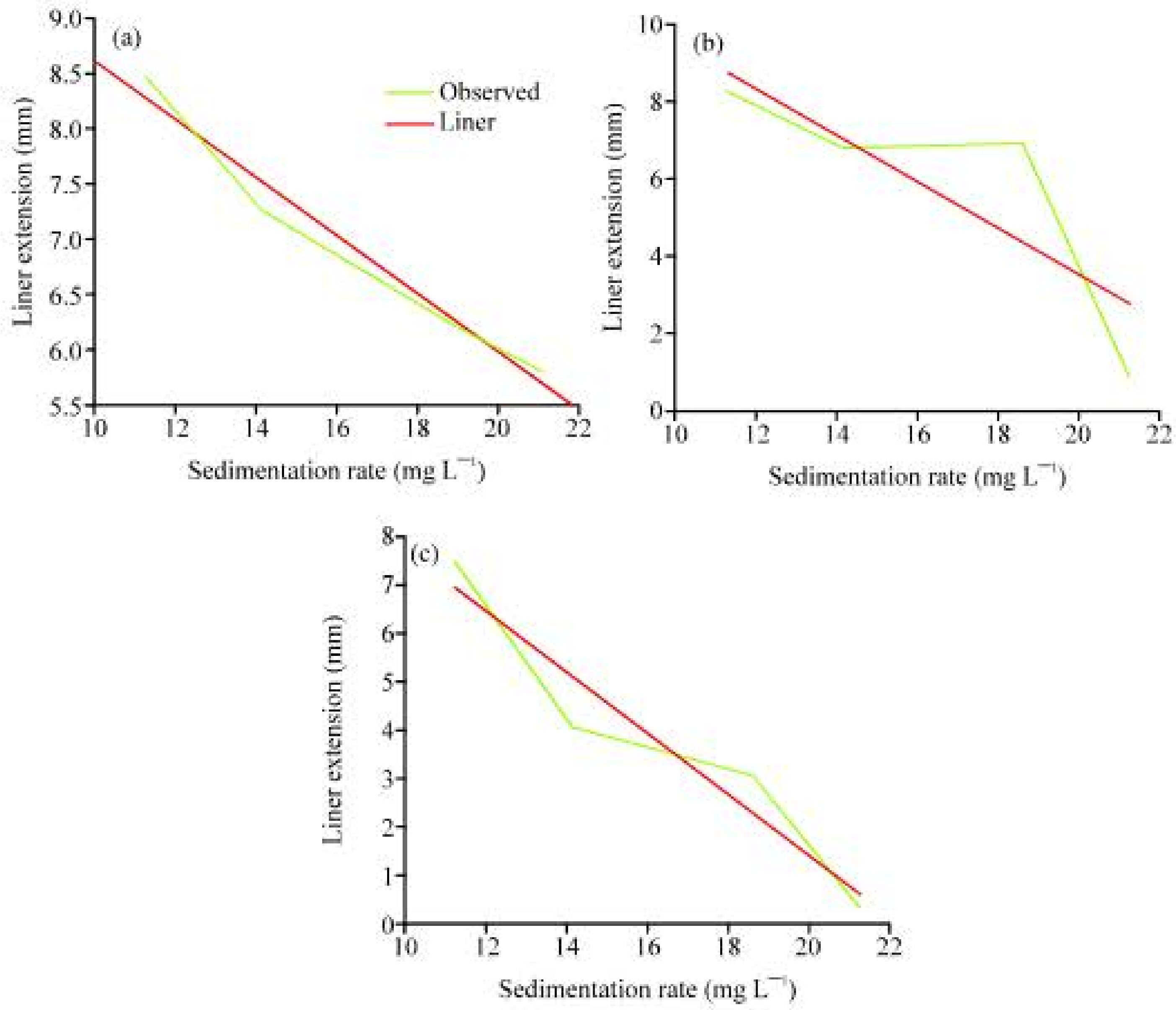

Fig. 5: Regression plots between growth rate of each study species and the sedimentation rate, (a) *Stylophora pistillata*, (b) *Acropora pharaonis* and (c) *Acropora hemprichi*

For *S. pistillata* and *A. hemprichi*, the regression relationship was significant ($R^2 = 0.97198$, $F = 69.38267$, $p<0.05$ and $R^2 = 0.92419$, $F = 24.38022$, $p<0.05$, respectively). For *A. pharaonis*, there was no significant impact ($R^2 = 0.67506$, $F = 4.15504$, $p>0.05$).

DISCUSSION

The present study showed that species diversity of corals is relatively poor in the study area (an average of ten species per transect compared to 18 species per transect reported from shallow reefs of the southern Gulf of Suez (El-Ganainy *et al*., 2008). In addition, live coral cover was significantly reduced in the study area (17.3% compared to 59.9% recorded from reefs of the southern Gulf of Suez). This decline in abundance and diversity of corals might be typical for high-latitude reefs. Corals of higher latitudes (e.g., the Northern Gulf of Suez) may suffer from reduced growth rates, lower ability to compete with algae, lower reproductive viability and higher rates of mortality. Grigg (1981, 1982) reported that growth rate of *Porites lobata* declined with increasing latitude along the Hawaiian Archipelago. Stimson (1996) reported an inverse relationship between latitude and growth rate for *Pocillopora damicornis* and tabulate *Acropora* sp. On the other hand, Smith (1981) reported that the growth of *Porites* sp. was not depressed at a high-latitude site, while changes in environmental parameters (temperature, salinity and turbidity) can influence not only growth rate (Crabbe and Smith, 2005) but also abundance and diversity of corals (Lirman *et al*., 2003). The dependence of coral growth on environmental conditions is well documented (Oliver *et al*., 1983).

The impact of increased sedimentation is probably the most common and serious anthropogenic influence on benthic organisms, particularly corals (Brown, 1997).

The present study showed very low growth rates for the three species examined. The coral growth rate-expressed in terms of linear extension - was significantly influenced by sediment levels. This accord with a number of studies on different species from different localities. For example, Harriot (1998) reported significantly greater linear extension rates for *Acropora formosa* in protected areas than more exposed reef slope sites. An earlier study by Kendall *et al*. (1985) showed that the growth rate and many other physiological parameters of *Acropora cervicornis* were adversely affected by increases in turbidity and sedimentation. A recent study by Crabbe and Carlin (2007) reported that *Acropora cervicornis* and *Siderastrea siderea* had significantly lower radial growth rate and linear extension on a site with a chronic sedimentation problem (linear extension rate for *A. cervicornis* of 2.51±2.2 cm year^{-1} at the lagoonal site, compared to 10.95±2.72 cm year^{-1} at a less-impacted fore-reef site. And a radial growth for *S. siderea* of 2.0±1.7 mm year^{-1} in the lagoonal site, compared to 6.6±2.2 mm year^{-1} at the fore-reef site).

Acroporid corals are important components of patch reefs of the Gulf of Suez (Sheppard *et al*., 1992; personal observations). The success of these species in penetrating habitats with extreme environmental conditions is largely due to their rapid growth. In Acropora, growth is achieved in a very short time. *Acropora cervicornis* may be the most rapidly growing coral in the world in terms of linear extension (Gladfelter *et al*., 1978). Linear extension rates for this species were as great as 26.4 cm year^{-1} in Jamaica. Crossland (1981) reported growth rates for *Acropora formosa* in a subtropical site which were substantially lower than the same species at tropical sites. Further examinations for changes in coral growth at multiple sites along latitudinal gradients would more precisely reveal the aspects of the influence of environmental parameters on coral growth and reef health.

In many species of branching corals, there is an extreme variability in the growth rates from branch to branch on the same colony and from season to season on the same branch (Porter, 1987). The present study revealed that one of the study species (*A. pharaonis*) had a slower rate during Sep. - Apr. 2002 than the previous time interval. The reason for this decrease might be attributed to lower temperatures during this time. On the other hand, some species did not show any variability in their growth rates. This was the case in *Montastrea annularis*, the growth rate of which was relatively consistent regardless of temperature, reef zone, or geographical area. Mean growth rate for this species was 6.55 mm year^{-1} (Weber and White, 1977).

In conclusion, although growth rates for the three study species in the Northern Gulf of Suez are much lower than the wide range of values for other species reported from tropical sites due to a combination of natural environmental conditions and anthropogenic activities, their linear extension increased as sediment load declined over time.

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