

GROWTH RATES OF THREE REEF-BUILDING CORAL SPECIES IN THE NORTHERN RED SEA, EGYPT

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ABSTRACT

Growth rates as linear extensions were measured for three species of reef-building corals in four different seasons and at three different depths (5m, 15m, and 30m) in Na'ama Bay, south of Sinai, northern Red Sea, Egypt. Alizarine-Red-S-stain was used as skeletal marker to stain the colonies alive *in-situ*. Comparison with similar studies elsewhere in the tropical regions shows consistency in growth patterns of the studied species regardless of depth and season, while they were different than others. The estimated annual rates of linear growth for the three corals considered at the different depths (5m, 15m, and 30m) were 9.24, 7.48, and 6.51mm/y for *S. pistillata*; 6.34, 9.24, and 5.90mm/y for *A. granulosa*; and 7.40 and 6.6mm/y for *P. damicornis*, respectively; *P. damicornis* was not found at 30m depth. Analysis of the data shows that it is not simple to detect the effect of either temperature or light level on the coral growth and they are simultaneously controlling the coral growth beside other factors, which could interfere as well. The present work could serve as a database for the future environmental monitoring of the marine life in Na'ama Bay, which is one of the tourist destinations in the Egyptian Gulf of Aqaba Protectorates.

INTRODUCTION

Scleractinean corals are considered the major reef builders while the coral reefs are the result of a complex interaction of constructive processes that build solid framework, and destructive processes that alter and remove that material. Of primary importance in understanding the overall forces that shape the reef, is a quantification of the individual contributions made by the carbonate-

producing organisms that live in and on it (Sheppard & Ssheppard, 1991).

Skeletal growth of stony corals is one of the important ecological and biological subjects, which essentially can help as an indicator for the calcification rate of the reef. Measurements of skeletal linear extension (LE) of corals within a distinct period by means of skeleton markers are one of the methods used (Rahav *et al.*, 1991; and Dullo *et al.*, 1995). These markers indicate the beginning of the newly grown skeletal extension during the time interval. Several methods have been used such as, plastic coated wires (Charuchinda & Hylleberg, 1984; and Oliver, 1984), Alizarin-Red-S-stain in order to stain the respective coral colonies alive (i.e. Gladfelter, 1984; and Dullo *et al.*, 1995), spikes were also driven into the coral skeletons as markers (Shinn, 1976), and direct interval photographs of the coral colonies have been used (Rahav *et al.*, 1991) as well. A variety of different methods have been used especially to measure the width of the annual growth rings in massive corals as an indicator of LE such as, X-ray (Gladfelter, 1984; Logan & Tomascik, 1991; Fang & Chou, 1992; and Bosscher, 1993).

One of the most conspicuous and universal aspects of coral growth is its variability (Buddemeier & Kinzie, 1976). The physiology of growth and skeletal deposition by scleractinian corals has been the subject of experimentation and speculation for more than a hundred years (Chalker, 1983). It is known that annual coral growth can be affected by different physical factors such as temperature (Gladfelter, 1984; and Vago *et al.* 1997), light and depth "as a function of light intensity" (Strömngren, 1987; Gattuso *et al.* 1993; and Dullo *et al.*, 1995), salinity (Charuchinda & Hylleberg, 1984), sedimentation rates (Yap & Gomez, 1981), water movements (Brown *et al.*, 1985), predation (Richmond & Hunter, 1990), and oil pollution (Dodge *et al.*, 1984). In addition coral growth may be affected by biological factors, e.g. food availability (Dullo *et al.*, 1995), endogenous zooxanthellae rhythms (Gattuso *et al.*, 1993; and Dullo *et al.*, 1995) and reproductive cycles (Richmond & Hunter, 1990).

Normally, the interference of a complex set of factors, either biotic or abiotic, is responsible for the skeletal deposition and growth mechanisms (Buddemeier & Kinzie, 1976; Logan & Tomascik, 1991; and Dullo *et al.*, 1995), which makes it difficult to investigate the effect of each factor separately.

The present study aims to investigate the growth rate of three of the most dominant scleractinian coral species in the Red Sea. In addition, the study attempts to throw light on the effects of the major environmental conditions (i.e. light and temperature) on their growth in different seasons and at different depths. Such effects are obscured if growth is integrated over the whole year. It is worth to mention that the present study follows the same procedures used by Kotb (1996), where the same experiment was done during 1992, and this allows to follow and monitor the growth rates of the respective species since that time.

MATERIALS AND METHODS

The study covers growth increments of three coral species namely: *Stylophora pistillata* (Esper, 1797); *Pocillopora damicornis* (Linnaeus, 1758); and *Acropora granulosa* (Edwards & Haime, 1860), which are predominant in the northern Red Sea reefs especially in the Egyptian region. Growth rates as LE of the investigated species at different depths (5m, 15m and 30m) were measured during the different seasons of 1998 for the purpose of comparison.

Study area:

The study was conducted on the fringing reef of Na'ama Bay along the south-eastern coast of the Sinai Peninsula (Fig.1). The bay is located near Sharm El-Shiekh on southern Sinai, facing the Red Sea proper. This area is a typical example of a Red Sea fringing reef (Sheppard & Sheppard, 1991). The site experiences an intermediate level of exposure to waves and has fairly low sedimentation in shallow waters. The fore-reef is covered with a dense cover of corals while the back-reef and the reef slope are relatively impoverished (Dotan, 1990). Two sandy plates interrupt the reef slope at 5m and 15m depths. The depth level of 30m experiences poor light conditions due to the steep slope angle and its orientation towards the west (Kotb, 1996). Dense communities of fishes usually inhabit the sandy plate at 15m depth (especially trigger and surgeon fishes).

Staining method:

The living coral colonies were stained *in situ* with Alizarin-Red-S-stain. Staining periods of 4 hours as recommended by some authors (Dustan, 1975 and Gladfelter *et al.*, 1978) gave no coloured

marks in the coral skeletons. After a pilot experiment, a staining period of 24 h was found to be suitable for marking the skeletons.

Three to Five colonies of each species at each depth (5m, 15m and 30m) were collected and stained at the respective depth of collection. Colony size varied from 10 to 15cm in diameter and the corals were removed from the bottom with great care. For the underwater staining procedure, plastic bags each with 25 litres capacity were prepared with 0.25 g of stain, which was securely tied off in one of its corners. The colonies were placed in the plastic bag, which was fully inflated to ensure that it contained 25 litres of seawater. Then it was tightly closed with cotton string and the stain was allowed to release from the corner of the bag and mix with the water inside it by shaking the bag slowly once or twice, taking care not to damage the colonies inside. The final concentration of the stain in the bags was about 10-15mg / l seawater, as used by Dustan (1975) and Gladfelter *et al.* (1978).

Afterwards, the plastic bags were securely fixed with strings to a protected location on the bottom for 24 h (colonies were in the normal growth position). Then colonies were carefully removed from the bags and tied to a horizontal aluminium rod, which was fixed to the bottom at the respective depth (Fig.2). The stained corals were allowed to grow for a period of about 3 months (i.e. a season). This procedure was carried out repeatedly at each season during 1998. The season timing followed the investigation of Kotb (1996) for the sake of data comparison being; 53, 95, 88, and 86 days for winter, spring, summer, and autumn respectively.

Preparation of skeletons and growth measurements:

After each growth period, corals were taken out of water and macerated in closed plastic containers containing seawater for one week. The remaining tissues were removed from the skeleton with a fresh water jet, and then the skeleton was air-dried. Skeleton added during the growth period appeared as a white portion at the tip of each branch over the old pink skeleton, due to staining process (Fig. 3). The rate of linear extension (LE) of the newly grown skeleton was determined for each species in each season at each depth and the means of LE [mm / day] were calculated.

LE measurements were taken as the mean of $n =$ (individual measurements of 10 branches per colony and 3-5 colonies per species). Branches were selected randomly and sectioned longitudinally into 2 halves along the vertical growth axis of the

branch, using a diamond saw (width of blade 0.3mm). Distances between the staining mark and the edge of the newly grown material were measured (Figure 4) using a dissecting microscope with ocular micrometer. Three measurements of LE were taken along the growth direction of each branch and the longest was recorded (Fig. 4). The seasonal mean LE rates were calculated as mm/day for each season. It should be noted that annual growth data were collected over a period of 322 days. Finally, the LE rate was extrapolated for the whole year for each species at each depth by adding the 4 means of seasonal growth figures. The "growth rate" used in the present work means the "linear extension rate (LE)" and the vice versa.

Other measured parameters:

Bottom temperatures were measured weekly at the respective depths, during inspection dives over the investigation period using a normal laboratory mercury thermometer.

Plankton samples were collected monthly from the water surface in the study area (from February 1998 to January 1999). Their abundance per m³ of seawater was recorded and plotted to show the monthly variations and peaks of plankton abundance in the area.

Statistical treatment of data:

LE rates of the respective scleractinian corals were compared with reference to depth and season. Furthermore, comparison of the whole year growth of the different species at different depths was also investigated.

Data of LE for each species were tested in each season at each depth, to satisfy the normality and homogeneity of variance assumptions. One-way analysis of variance (ANOVA) was applied to test significant differences in the LE data between different species in different seasons and depths. Where the F-value given by ANOVA was significant, a Bonferroni multiple comparison test of the post-hoc contrasts with a significance level of 0.05 was used to indicate which groups of seasons or depths are differed significantly.

It is worth to mention here that the "growth rate" used in the present work means the "linear extension rate (LE)" and the vice versa.

RESULTS

Table (1) gives the monthly temperature fluctuations at the various depths, as well as the planktonic abundance at the surface water of the study site. Temperatures presented a normal profile of highest values

during summer and lowest values during winter (Figure 5). However, seasonal temperature did not vary over depth except for the 30m station, where a decrease was observed in spring and autumn.

The annual distribution of plankton (No. of individuals /m³ seawater) at the water surface in the study area showed four peaks over the year (Figure 6). One peak occurred at the end of each season. The highest peak was in winter, while the lowest one was in summer.

The LE growth rates obtained in this study are summarised in Table (2) with the maximum and minimum recorded values. It is worth to mention that *P. damicornis* was the only species not occur at 30m depth in the study site.

***Stylophora pistillata*:**

S. pistillata showed its highest growth rates during the warm periods of summer and autumn at the shallowest depth of 5m (Fig.7), while at the cold periods of winter and spring, the highest growth rates were at the intermediate depth of 15m. The analysis of variance (ANOVA) revealed that there are statistically significant differences ($p < 0.05$) in the growth rates of *S. pistillata* among depths in all seasons except in winter according to Bonferroni test (Table 3A). Furthermore between seasons, the growth rate at 5m depth was significantly higher in summer than in other seasons, while at 15m depth, growth showed the significantly highest rates in spring (Table 3B).

***Pocillopora damicornis*:**

P. damicornis had almost similar growth patterns at 5 and 15m depths during the different investigated seasons (Fig. 8). The seasonal growth rates at each depth were alike and ANOVA test showed no significant differences among the measured rates (Table 4B).

***Acropora granulosa*:**

A. granulosa showed variable growth rates at the different depths during the studied seasons (Fig. 9) with two peaks of growth in autumn and spring. The growth pattern of this species was significantly higher at 15m depth than the shallower depth of 5m in all seasons. ANOVA test had detected significant differences in the growth rates between depths during different seasons, and Bonferroni test gave these depths (Table 5A). Generally, the 30m depth showed significantly lower growth rates than 15m depth in all seasons except in winter, while the growth at both 5m and 15m did not differ significantly except in summer (Table 5A). Furthermore, there were significant differences between the growth rates of *A. granulosa* in the studied seasons at each depth ((Table 5B).

Annual growth of the studied species:

Table (6) presents the annual growth data, as accumulated values from the seasonal growth rates for each species at each depth. The table also includes the numbers of replicates (N) for each species at each depth.

Growth rates according to depth and species showed usual patterns, with higher rates in shallow water and decreased by depth for both *S. pistillata* and *P. damicornis* (Fig.10), while *A. granulosa* had different pattern with highest growth rate at the intermediate depth (i.e. 15m). The highest growth rates were recorded for *S. pistillata* and *A. granulosa* at 5m and 15m, respectively (Table 6), while the highest growth rate at 30m depth was recorded for *S. pistillata*.

DISCUSSION

The growth rates obtained in the present study showed different pattern than that recorded in other areas. Loya (1985) studied the LE of *S. pistillata* in the northern Gulf of Aqaba and he recorded lower LE of almost 0.003mm/day in summer and 0.001mm/day in winter at 5m depth, than the recorded rate in the present study (0.035, and 0.019mm/day, respectively). Glynn (1977) studied the growth rate of *P. damicornis* within 7m depth in the Gulf of Panama and the Gulf of Chiriqui (Pacific coast of Panama). He found mean annual growth of 3.08 and 3.86mm/y respectively and related that higher growth to the higher temperature in the Gulf of Chiriqui. His growth data are much lower than the present work values for the same species (6.53 and 5.75mm/y, at 5 and 15m, respectively).

On the other hand, the present results of the growth rates are similar to those recorded by Kotb (1996), while there was considerable variation between the maximum and minimum growth values of each species at the same depth and in the same season. The earlier findings of other authors, e.g. Isdale (1977) and Strömngren (1987), may help to explain these differences. These authors found that colonies of the same species may grow at different rates at the same depth and time, depending on the surrounding conditions.

Temperature in the study area showed normal patterns of variation at such latitudes, and similar seasonal variations have been

recorded in the area by Hulings (1979); Dotan (1990); and Kotb (1996). Fricke and Schuhmacher (1983) found that light intensity along the Sinai coast on the Red Sea varied seasonally and decreased with depth to about 80%, 60% and 50% of the surface light intensity at 10m, 20m and 30m respectively. A marked drop in water transparency was reported in February-March due to increased plankton productivity (Levanon-Spanier *et al.*, 1979; and Fricke & Schuhmacher, 1983). This phenomenon was confirmed by the fieldwork in this study, where the highest levels of temperature and light could be recorded in summer and lowest levels in winter.

The LE rates of *S. pistillata* at 5m depth tend to follow the patterns of temperature and light over the year. LE rates increased with increasing temperature level and light intensity. Conversely at 15m depth, the pattern of LE rates was inversely affected by temperature and light profiles (with the highest rate in spring).

The reproduction of *S. pistillata* in the Gulf of Aqaba and the Red Sea has been observed during the period of December-July by some authors (e.g. Loya, 1985; and Richmond & Hunter, 1990). Also, the reproduction time of one species may differ with depth within the same reef coral community (Richmond & Hunter, 1990). Therefore, the more probable explanation is that *S. pistillata* reproduced between December and July, but not simultaneously at the different depths. Reproduction could take place in winter at 5m depth, and in summer at 15m depth. At the times concerned, the colonies invested their energy in reproduction mechanisms rather than in growth.

Furthermore, the effects of the hard winter conditions (i.e. low temperature, low light intensity and water turbulence caused by waves) should not be ignored. They affect the shallowest depth more than the deeper depths. Therefore, the LE rate of *S. pistillata* at 5m depth was lower in winter than in the other seasons. In contrast, the more favourable light and temperature conditions lead to the highest LE rate in summer at that depth. This could provide further evidence that the LE rate depends on light and temperature. These conclusions are in accordance with Kotb (1996) who found the same variation of growth with depth.

P. damicornis had its highest LE at 5m depth in autumn and lowest in winter. This autumn trend reveals that high temperatures and light intensity in summer may have inhibited growth at those shallow depths. The lowest growth rate in winter may be due to the

rough winter conditions. Davies (1991) had similar pattern of growth when he studied the effect of light intensity on the energy budgets of *P. damicornis* at 5m depth in Hawaii. He found that the coral energy budget increases with increasing light.

An overview of the growth at all depths in all seasons shows different patterns between the studied species. However, it is meaningful to say that each species reacts differently to the surrounding conditions.

At 5m depth, *S. pistillata* skeletons grew more rapidly in terms of linear extension than the other species during harsh winter conditions and during the most favourable conditions of summer (i.e. highest illumination levels and temperatures). On the other hand, the three species showed similar skeletal extensions at the same depth in autumn and spring seasons with moderate illumination levels and temperatures. Therefore, it can be deduced that *S. pistillata* could survive more successfully in extreme conditions than *P. damicornis* and *A. granulosa*. On the other hand, the highest recorded LE rate at 15m depth in all seasons except winter was for *A. granulosa*. Also, it may be deduced that *A. granulosa* preferred the depth of 15m, which receives sufficient light for photosynthesis production and is away from the water turbulence at the surface. The fact that *A. granulosa* had the lowest LE rate of all the species in winter may suggest that *A. granulosa* is the most sensitive species to harsh winter conditions.

As mentioned before, temperature was similar along the depth profile over the year. Therefore, light intensity was the major environmental factor varied by depth. The annual growth patterns of the species with reference to depth could be related directly to light intensity differences.

Each species exhibited similar relationship between light intensity and both seasonal and annual growth. The annual LE rates of *S. pistillata* and *P. damicornis* decreased with depth, accordingly, the LE mechanism of these species may depend on light. *A. granulosa* reached its highest annual LE rate at 15m depth, which may indicate that *A. granulosa* needs moderate light conditions (as at 15m depth) for its maximum extension rate. Gladfelter (1984) showed through a series of lab experiments on *A. cervicornis* that LE occurred as results of micritic crystals, which were deposited more at night than in the daytime. She concluded that temperature controlled the LE mechanism more than light.

Comparing the annual growth rates, *A. granulosa* and *S. pistillata* had the highest annual LE of 9.24mm/y. It is noticeable that *A. granulosa* and *S. pistillata* grew more successfully in the study area than *P. damicornis*. The dominance of both species over the *P. damicornis* in the Egyptian Red Sea reefs was recorded by Kotb *et al.* (1991) in Ras Mohamed reefs and by Kotb *et al.* (2000) in the southern reefs of Egypt from Hurghada until the Egypt/Sudan borders.

From the present study it is obvious that several factors govern the skeletogenesis of the corals *S. pistillata*, *P. damicornis* and *A. granulosa* in varying degrees. Therefore, perhaps a better insight on the processes of linear extension and calcium carbonate accretion involved in the growth of the skeletons could be reached by longer-term investigations (i.e. over several years), using a larger number of test samples and by bathymetrical exchange of cloned colonies.

CONCLUSIONS

Finally, it could be concluded that light and temperature control the linear extension growth of corals simultaneously, while other factors such as reproduction may interfere to some extent. Furthermore, high light intensity and temperature may inhibit the LE growth of corals.

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Table 1: Monthly variation of temperature (°C) and plankton abundance (no. of individuals.m⁻³ seawater) measured and estimated during the study period.

Months	Temperature			Plankton abundance
	5 m depth	15 m depth	30 m depth	
Jan	18	18	18	274
Feb	21	21	21	500
Mar	22	22	22	1800
Apr	22	22	22	410
May	25	25	20	157
Jun	26	26.5	20	1118
Jul	28	28	28	41
Aug	26	26	26	514
Sep	26	26	26	736
Oct	25	25	25	160
Nov	22	22	20	368
Dec	18	18	18	1048

Table 2: Mean linear extension (L.E) rates of the studied species with reference to depths and seasons. L.E = mm/day and all the values are ± SD, while N=number of sampled branches. The sign (-) indicate that no data due to the absence of this species at that depth.

Season	Species	<i>S. pistillata</i>				<i>P. damicornis</i>				<i>A. granulosa</i>			
		Depth	mean L.E	Max.	Min.	N	mean L.E	Max.	Min.	N	mean L.E	Max.	Min.	N
Summer	5m	0.035 ± 0.01	0.08	0.02	50	0.021 ± 0.01	0.06	0.01	45	0.016 ± 0.01	0.04	0.01	50
	15m	0.016 ± 0.01	0.03	0.01	39	0.018 ± 0.01	0.06	0.01	47	0.028 ± 0.01	0.06	0.02	48
	30m	0.020 ± 0.01	0.07	0.01	47	-	-	-	-	0.012 ± 0.0	0.03	0.01	50
Autumn	5m	0.027 ± 0.01	0.06	0.03	39	0.025 ± 0.01	0.04	0.02	45	0.025 ± 0.01	0.04	0.01	47
	15m	0.019 ± 0.01	0.03	0.01	44	0.021 ± 0.01	0.04	0.01	44	0.033 ± 0.01	0.06	0.02	39
	30m	0.021 ± 0.01	0.05	0.01	46	-	-	-	-	0.022 ± 0.01	0.05	0.01	50
Winter	5m	0.019 ± 0.01	0.04	0.01	48	0.017 ± 0.01	0.03	0.01	48	0.008 ± 0.0	0.03	0.01	44
	15m	0.023 ± 0.0	0.03	0.01	33	0.019 ± 0.01	0.03	0.01	48	0.013 ± 0.01	0.04	0.02	47
	30m	0.018 ± 0.01	0.04	0.01	49	-	-	-	-	0.018 ± 0.01	0.04	0.01	50
Spring	5m	0.024 ± 0.01	0.05	0.01	39	0.021 ± 0.01	0.03	0.01	47	0.023 ± 0.01	0.05	0.02	39
	15m	0.027 ± 0.01	0.04	0.01	48	0.017 ± 0.0	0.03	0.01	49	0.031 ± 0.02	0.07	0.01	43
	30m	0.015 ± 0.01	0.03	0.01	47	-	-	-	-	0.015 ± 0.01	0.04	0.02	48

Table 3: Bonferroni multiple comparison test of the post-hoc contrasts for *S. pistillata* between: A) mean growth rates for depths at each season, and B) seasonal growth rates at each depth. Ns=no significant difference, *—significant (*P* < 0.05) difference.

		Summer			Autumn			Winter			Spring		
		5m	15m	30m	5m	15m	30m	5m	15m	30m	5m	15m	30m
<i>S. pistillata</i>	5m	.	.	.	.	.	.	.	.	.	.	.	.
	15m	*	.	.	*	.	.	ns	.	.	ns	.	.
	30m	*	ns	.	ns	ns	.	ns	ns	.	*	*	.
		5m				15m				30m			
Season		Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp
Summer		.	.	.	.	.	.	.	.	.	.	.	.
Autumn		*	.	.	.	ns	.	.	.	ns	.	.	.
Winter		*	*	.	.	*	ns	.	.	ns	ns	.	.
Spring		*	ns	ns	.	*	*	*	.	ns	ns	ns	.

Table 4 : Bonferroni multiple comparison test of the post-hoc contrasts for *P. damicornis* between: A) mean growth rates for depths at each season, and B) seasonal growth rates at each depth. Ns=no significant difference, *=significant ($P < 0.05$) difference.

P. damicornis	A												
	Summer			Autumn			Winter			Spring			
	Depth	5m	15m	30m	5m	15m	30m	5m	15m	30m	5m	15m	30m
5m	.			.			.			.
15m	ns	.		.	.		ns	.		ns	.		
30m	-	-	.	-	-	.	-	-	.	-	-	.	

	B			
	5m		15m	
Season	Su	Au	Wi	Sp
Summer	.			.
Autumn	ns	.		ns
Winter	ns	*	.	ns
Spring	ns	ns	ns	ns

Table 5 : Bonferroni multiple comparison test of the post-hoc contrasts for *A. granulosa* between: A) mean growth rates for depths at each season, and B) seasonal growth rates at each depth. Ns=no significant difference, *=significant ($P < 0.05$) difference.

A. granulosa	A												
	Summer			Autumn			Winter			Spring			
	Depth	5m	15m	30m	5m	15m	30m	5m	15m	30m	5m	15m	30m
5m	.			.			.			.
15m	*	.		ns	.		ns	.		ns	.		
30m	ns	*	.	ns	*	.	*	ns	.	*	*	.	

	B					
	5m		15m		30m	
Season	Su	Au	Wi	Sp	Su	Au
Summer	.			.	.	
Autumn	*	.		ns	.	
Winter	ns	*	.	*	*	.
Spring	*	ns	*	.	ns	ns

Table 6: The annual linear extension (LE) rates of the studied species at different depths. LE = mm / y, N = number of measured branch tips, and (-) indicate that no data .

Depth	<i>S. pistillata</i>	N	<i>P. damicornis</i>	N	<i>A. granulosa</i>	N
5m	9.24	176	7.392	185	6.336	180
15m	7.48	164	6.6	188	9.24	177
30m	6.512	189			5.896	198

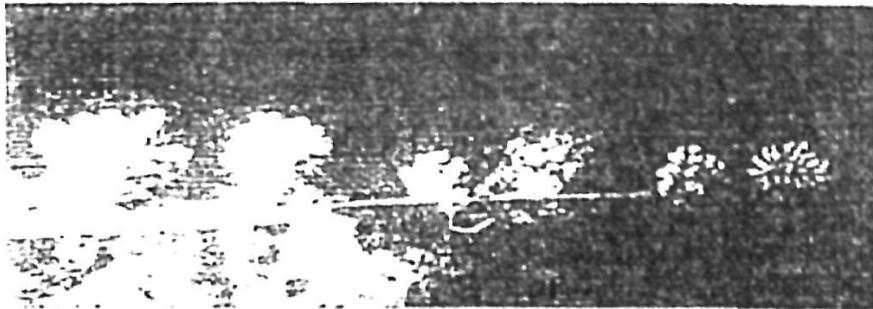


Figure 2: Branch of *Acropora* sp. cemented fixed to an aluminium rod.

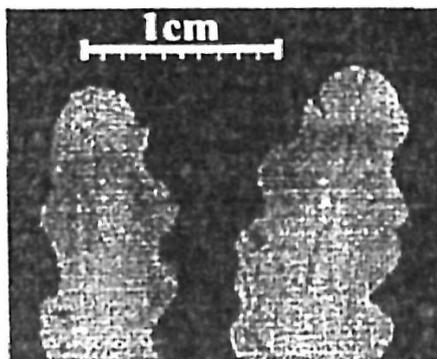


Figure 3: Branch of *Acropora granulos* after maceration, cleaning and cutting into 2 cm slices with the newly grown material (white) above the stained skeleton (dark piece).

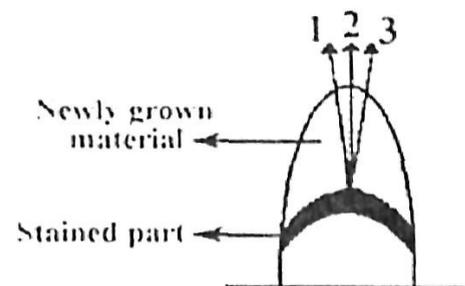


Figure 4: The measured linear growth axes (1,2,3).

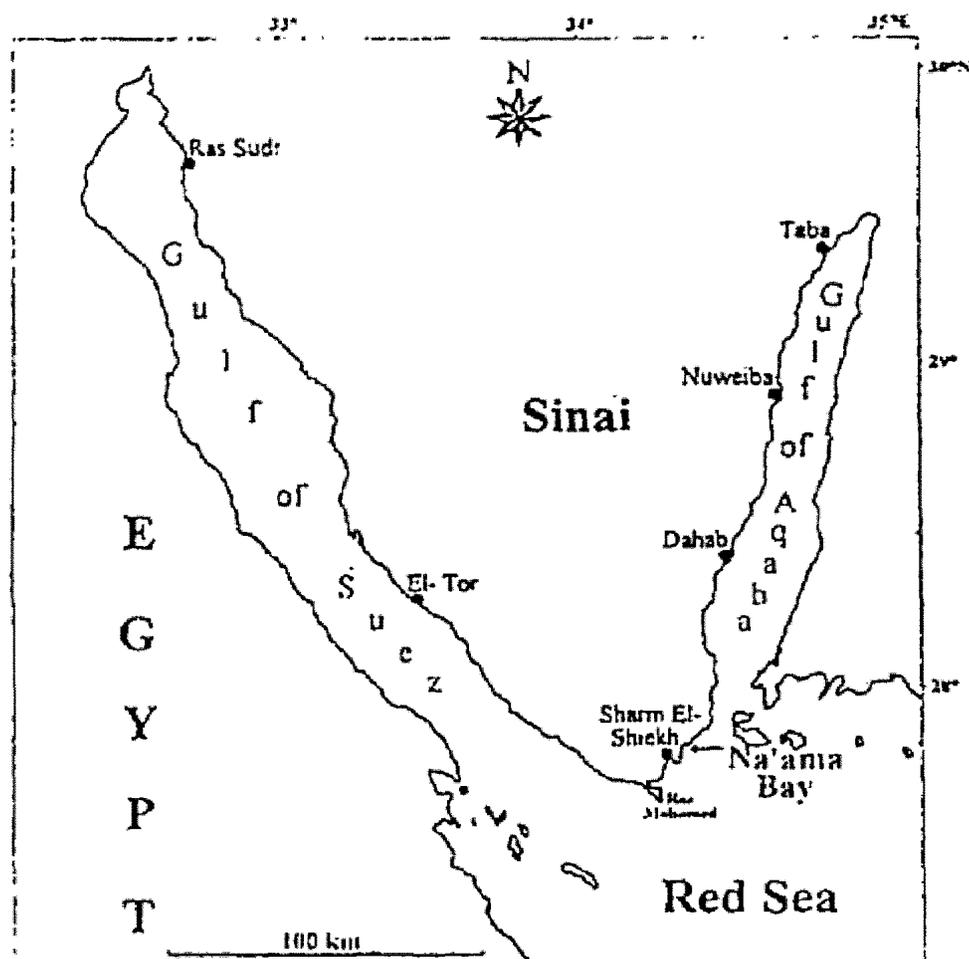


Figure 1: The location of the study site (Na'ama Bay) in Sharm El-Shiekh Area at the southern Sinai Peninsula.

GROWTH RATES OF THREE REEF-BUILDING CORAL SPECIES IN THE NORTHERN RED SEA, EGYPT

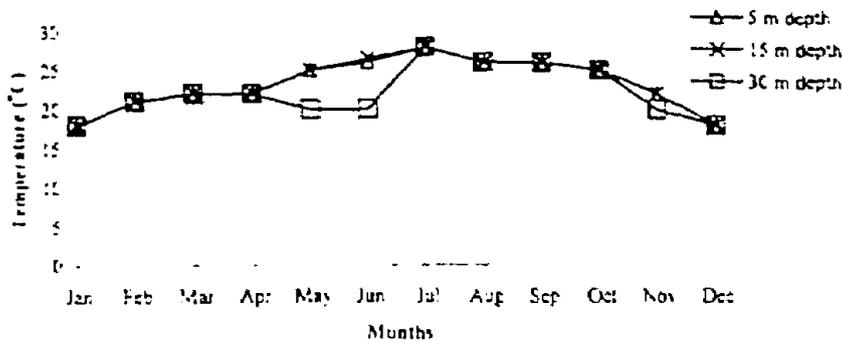


Figure 5: Monthly variation of temperature measured at the investigated depths in the study area

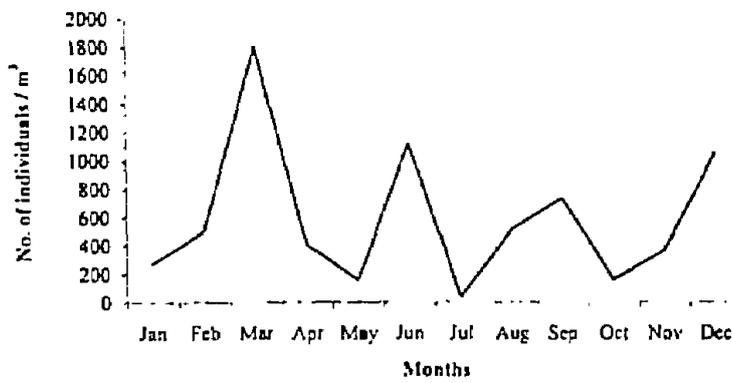


Figure 6: Monthly variation of plankton abundance at the surface water of the study area.

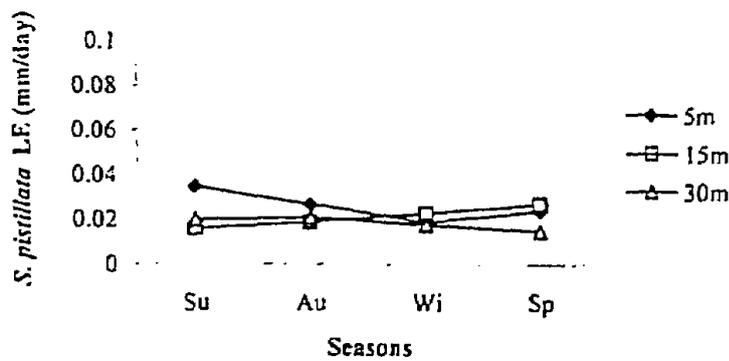


Figure 7: Linear extension rates of *S. pistillata* in different seasons at different depths. Su = summer, Au = autumn, Wi = winter, and Sp = spring.

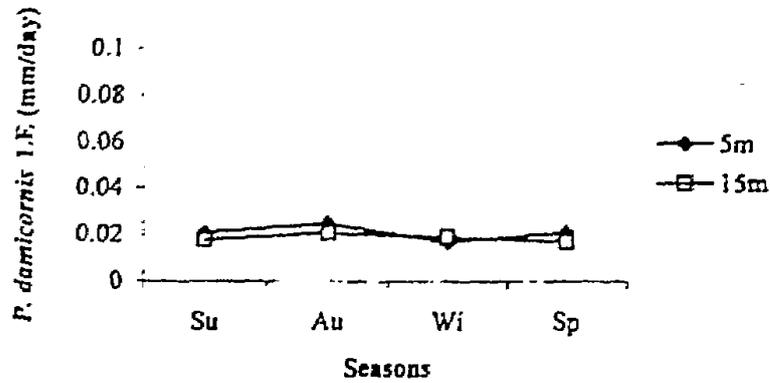


Figure 8: Linear extension rates of *P. damicornis* in different seasons at different depths. Su = summer, Au = autumn, Wi = winter, and Sp = spring.

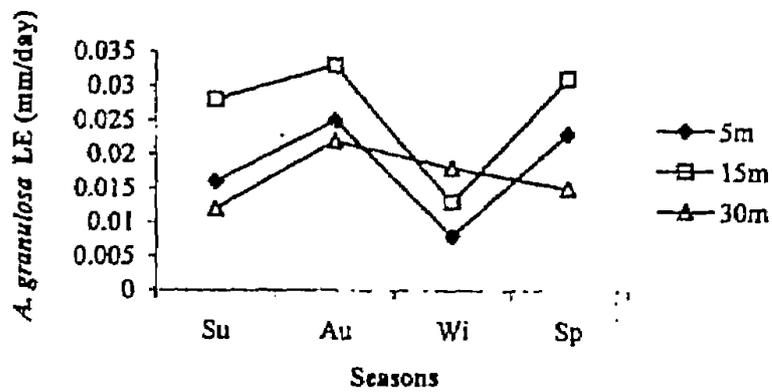


Figure 9: Linear extension rates of *A. granulosa* in different seasons at different depths. Su = summer, Au = autumn, Wi = winter, and Sp = spring.

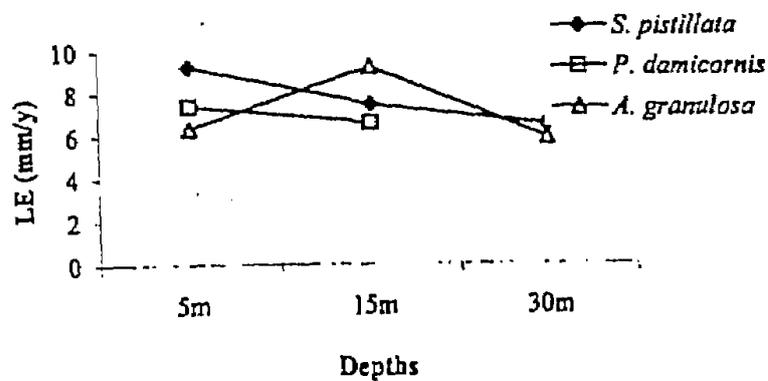


Figure 10: Annual linear extension rates of the different studied species at different depths.