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Coral Growth and Skeletal Density Relationships in Some Branching Corals of the Red Sea, Egypt

Tarek A. A. Mohammed Mahmoud A. Dar
National Institute of Oceanography and Fisheries, Hurghada, Egypt

Abstract

The coral reefs at the exposed zones are exhibited to strong wave action, renewable water masses, clear seawater and small temperature variations, however, in the sheltered zones they exposed to high turbidity, high temperature variations and protected from the surge waves and currents. ***In situ*** measurements of seasonal and annual growth rates and the branch thicknesses using Varner Caliber and the laboratory measurements of skeletal densities using Archimedes's Principle were done in four branching coral species growing in the exposed and sheltered zones of Hurghada and Hamrawin at the northern Red Sea. *Acropora humilis* recorded the highest seasonal and annual growth rates at all zones; 0.68±0.02, 0.76±0.03, 0.66±0.03 and 0.69±0.02mm/month and 7.25±0.20, 7.96±0.33, 7.10±0.11 and 7.34±0.14mm/yr respectively. *Pocillopora damicornis* recorded the highest averages of skeletal density at the different zones of Hurghada and Hamrawin; 2.04±0.35, 1.64±0.26, 2.64±0.66 and 1.96±0.18gm/cm^3 respectively and the highest averages of the branch thicknesses at the exposed and sheltered zones of Hurghada (1.66±0.42cm^2, 1.51±0.30cm^2) while, *A. humilis* recorded the highest average of the branch thicknesses at the exposed and sheltered zones of Hamrawin (1.49±0.16cm^2, 1.14±0.08cm^2). *A. humilis* was the fastest growing species in the worm season at the exposing and sheltered zones of Hurghada and Hamrawin, while *P. damicornis* was the slowest growing species because of it tends to form thick and dense branches. The oceanographic and local conditions as; temperature variations, aragonite saturation, turbidity, effects of surge waves and light intensity are responsible about the differences in the skeletal parameters of the studied species.

Keywords: Branching corals – Growth rates - Skeletal density – Branch thicknesses – exposed and sheltered zones.

INTRODUCTION

Scleractinian corals have a complex porous skeleton containing more or less dense structure lattice. Branching corals grow rapidly at their branch tips (Hughes, 1987; Tunnicliffe, 1983), but they are often easily broken during storms and trampling (Woodly *et al.,* 1983; Hawkins and Roberts, 1994) or bleached by the interaction of the physical conditions and/or biological effects (Mohammed and Mohammed, 2005). Skeletal density of corals is a growth mode that has been studied by many authors as a function of increasing in height and volume of the newly grown skeletons (Oliver, 1984; Hughes, 1987; Ammar *et al.,* 2005). Kotb (2002) pointed out that the linear extensions and skeletal densities of corals are independent growth modes. The growth and skeletal deposition mechanisms are making the effect of each factor investigation separately very difficult (Loya, 1985). Coral growth or skeletogenesis is driven by calcification, the process whereby calcium (Ca^{+2}) and carbonate (CO_3^{-2}) ions obtained from seawater precipitate beneath the calcioblastic ectoderm (CE) of the coral polyp to form crystals of the calcium carbonate ($CaCO_3$) mineral polymorph, aragonite (Wooldridge, 2013). Growth rates are inherently variable among different corals species, partly in accordance with differences in gross morphology, skeletal structure and polyp size (Hall and Hughes 1996). Spatial, temporal and taxonomic differences in coral growth play an important role in the ecology and dynamics of coral reef ecosystems, affecting reef productivity, heterogeneity, and growth (Anderson *et al.,* 2012).

The annual growth rates and the skeletal densities can be affected by different physical factors such as temperature (Klein *et al.,* 1993), light and depth (Davies, 1991), reproduction (Tarrant *et al.,* 2004), salinity and sedimentation rates (Charuchinda and Hylleberg, 1984), water movement and wave actions (Bottjer, 1980; Brown and Howard*.,* 1985; Rodgers *et al.,* 2003) in addition to the interference of a complex set of biotic or abiotic factors (Mohammed *et al.,* 2007). The changes in temperature, salinity, and sedimentation can influence not only growth but also diversity and abundance of corals (Lirman *et al.,* 2003), often, high energy and high sedimentation together can reduce growth (Cruz-Pinon *et al.,* 2003).

The present work aims to study the effects of oceanographic and local conditions on the growth rates, skeletal densities and branch thicknesses of the branching corals species at the exposed and sheltered zones of the Red Sea.

MATERIALS AND METHODS

1- Geomorphic and environmental settings of the studied localities

Two localities with different environmental settings and anthropogenic effects at Hurghada and Hamrawin in the northern Red Sea (Fig., 1) were selected to study the coral growths, skeletal densities and branches thicknesses of four branching coral species; *Acropora humilis, Acropora hyacinths, Stylophora pistillata* and *Pocillopora damicornis*. These coral species inhabit the exposed and sheltered zones of the localities of investigation. The exposed zones were characterized by strong surge waves and current, renewable water masses, clear seawater and small temperature variations as well as these corals didn't suffer from exposing during low tide time. The corals in the sheltered zones are protected from the surge waves and currents but they are intensively suffering from high turbidity rates, high temperature variations as well as the solar radiations during the low tide time.

The sheltered zone at Hurghada is in front of NIOF (National Institute of Oceanography and Fisheries) is sheltered from the surge waves, strong currents and direct wind effects but slightly affected by overfishing and touristic activities (diving and snorkeling). It is also suffered from the neap tide events, long time of areal exposure during the semidiurnal tidal regime (Mohammed and Mohammed, 2005), direct sunlight exposure, retain high temperature in summer and low temperature in winter inside their basins, high sedimentation rates, landfilling, fishing and tourist activities (Dar *et al.,* 2012). The second zone at Hurghada is in the lee side of El Fanadir Rocky Islands directly exposed to intensive surge waves, wind induced waves and marine currents. Also it was intensively used for diving and snorkeling activities (Fig., 1b).

Hamrawin is a phosphate harbour and mining occupation located about 120km to the south of Hurghada along the Red Sea coast. It lies directly on small embayment to the south (Dar, 2005) at the downstream of Wadi Hamrawin that was used as navigation basin for shipping phosphate raw materials. Throughout the shipment processes, the transferring raw materials are exposing in most days to intensive winds, subsequently, the finest particles are smothering then fall down to sea. In the reverse wind days, the amount of volatized dusts geminates reaching to the embayment and the southern tidal area is about four or five folders due to the generated eddy winds. The sheltered zone of Hamrawin was inside the southern shipping embayment while the exposed zone included in the back and fore reef areas (Fig., 1c).

Materials and Methods

Sampling and *in situ* measurements were carried out in the shallow reefs using SCUBA diving at the exposed and sheltered zones of Hurghada and Hamrawin. Five colonies of each species of; *Acropora humilis*, *A. hyacinthus, Stylophora pistillata* and *Pocillopora damicornis* were chosen and marked at depth between 3 to 5m of each zone to study the growth rates. Five branches from each colony were tagged by plastic string at about 1.5-2.0 cm apart from the tip. The growth rates of the tagged branches were investigated by measuring the increasing in length (linear extension) bi-seasonally in winter and summer, from the plastic string to the tip of the branch (Mohammed, 2003) then the annual growth rates were calculated. After one year of the experiment, five fragment specimens of each species at each zone were collected and cleaned from the adhered materials then dried to study the skeletal densities and the branches thickness. The skeletal densities were measured using Archimedes's principle by weighting them then suspended briefly from an analytical balance into water (Graus and Macintyre, 1982; Ammar *et al.* 2005) while, the branch thicknesses were measured using vernier caliper of 0.01 mm accuracy (Mohammed *et al,* 2007; Dar and Mohammed, 2009). Some of the physico-chemical parameters were measured *in situ* at each location using Hydrolab (Hanna Model).

Results and Discussion

1- Oceanographic parameters of the studied sites

Seawater temperature at Hurghada was varied between 19.56ºC in winter and 29.38ºC in summer and at Hamrawin, it was changed between 18.89ºC in winter and 29.03ºC in summer (Table 1). Salinity was fluctuated between 39.75‰ and 42.43‰ at Hurghada and from 40.18‰ to 42.15‰ a Hamrawin. The pH Values shows the great variation at Hurghada in summer (7.83 – 8.61) and at Hamrawin in winter (7.7 – 8.05). The relatively high values of salinity and pH at Hurghada were due to shallowness the sheltered zone, the exposing to high temperatures for long time and dismissing the continuous water mixing.

2- Annual and Seasonal Growth rates

The annual linear growth rates of *Acropora humilis* shows an average of 7.25±0.20mm/yr at exposed zone and the average of 7.96±0.33mm/yr at the sheltered zone of Hurghada. At Hamrawin, it recorded the average of 7.10±0.11mm/yr at the exposed zone 7.34±0.14mm/yr at the sheltered zone (Table 2). *A. hyacinthus* recorded an average of 6.60±0.24mm/yr and an average of 6.88±0.23mm/yr at the exposed and sheltered zones of Hurghada. At Hamrawin, it was recorded the averages of 5.20±0.20mm/yr and 6.04±0.21mm/yr at the exposed and sheltered zones. According to Attalla *et al.,* (2011), the linear growth rates of *A. humils* varied significantly according to the sheltering condition, with an overall mean of 8.89 and 6.98mm/year in exposed and sheltered sites of Hurghada, Red Sea. They added, the highest linear growth rate of *A. humilis* was estimated at the exposed site of Gotta Abu Ramada, being 9.17mm/year, while the lowest rate of 6.61mm/year was recorded at the sheltered site of El-Fanadir Reef at Hurghada. Mohammed *et al.,* (2007) founded that *Acropora humilis* have the higher growth rates (7.49 mm/y) than *Stylophora pistillata* (6.87mm/y). Aamer (2004) recorded linear growth rates of *A. humilis* at Sharm El-Shiekh, northern Red Sea between 6.17mm/year and 9.80mm/year, while

Davies (1989) reported that *A. humilis* in Caribbean Sea varied between 2-13.3mm/year at 2m depth. Yap *et al.,* (1992) documented that the *Acropora hyacinthus* consistently exhibited the lowest growth rates among the studied species in a northern Philippine.

The annual linear growth rate of *Stylophora pistillata* at the exposed zone of Hurghada recorded the average of 6.17±0.24mm/yr and at the sheltered zone recorded an average of 6.27±0.31mm/yr. At Hamrawin, *S. pistillata* showed the average of 6.02±0.19mm/yr at the exposed zone and 6.48±0.02mm/yr at the sheltered zone. *P. damicornis* showed annual growth rate averages of 6.37±0.15mm/yr and 7.13±0.21mm/yr at the exposed and sheltered zones of Hurghada. At Hamrawin *P. damicornis* linear growth rate averages were 5.97±0.13mm/yr at the exposed zone and 6.36±0.11mm/yr at the sheltered zone. Kotb (2001) recorded that 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 *Acropora granulosa;* and 7.40 and 6.6mm/y for P. *damicornis,* respectively; *P. damicornis* was not recorded at 30m depth at Na'ama Bay, south of Sinai, northern Red Sea. Vago *et al.,* (1997) documented that the relative growth rate of *S. pistillata* does not remain constant throughout its lifetime, meaning that in this species, growth accelerates with colony size and age, probably until a certain size and age of incipient senescence are reached.

Seasonally, *Acropora humilis* shows the average of linear growth rate reaching 0.68±0.02mm/month through summer season and 0.53±0.02mm/month through winter season at the exposed zone of Hurghada. At the sheltered zone, it showed the averages of 0.76±0.03mm/month in summer and 0.56±0.04mm/month in winter. At Hamrawin, *A. humilis* recorded the growth rate averages 0.66±0.03mm/month and 0.52±0.02mm/month in summer and winter seasons respectively at the exposed zone, and at the sheltered zone the averages were 0.69±0.02 mm/month in summer and 0.54±0.01mm/month in winter. The linear growth rate of *A. hyacinthus* showed the averages of 0.58±0.03mm/month and 0.52±0.03mm/month in summer and winter seasons at the exposed zone and it was averaged 0.64±0.04mm/month and 0.51±0.01mm/month in summer and winter seasons at Hurghada. At Hamrawin, the linear growth of *A. hyacinthus* recorded the averages of 0.50±0.02mm/month and 0.37±0.02mm/month through summer and winter seasons at the exposed zone and the averages of 0.55±0.0mm/month and 0.46±0.04mm/month through the same seasons at the sheltered zone respectively (Table 2).

S. pistillata linear growth averaged of 0.56±0.01 and 0.47±0.04 mm/month in summer and winter at the exposed zone and 0.58±0.03 and 0.47±0.04 mm/month in summer and winter at the sheltered zone of Hurghada. At Hamrawin, *S. pistillata* recorded the averages of 0.55±0.02, 0.46±0.02, 0.56±0.00 and 0.52±0.00mm/month in summer and winter seasons at the exposed and sheltered zones respectively. *P. damicornis* showed the averages of 0.58±0.02mm/month in summer and 0.48±0.01mm/month in winter at the exposed zone and 0.61±0.02mm/month in summer and 0.57±0.03mm/month in winter at the sheltered zone of Hurghada. At Hamrawin, the averages of linear growths were; 0.51±0.01, 0.48±0.01, 0.56±0.00 and 0.50±0.01mm/month in summer and winter seasons at the exposed and sheltered zones respectively. Gillette (2012) recorded that *P. damicornis* showed the highest skeletal extension rates under optimal (26°C) temperatures. Jokiel and Coles (1977) found that the skeletal growth in *P. damicornis* in Hawaii is greatest at about 26–27ºC. Piniak and Brown (2008) documented that, *P. damicornis* growth rates in Ma‘alaea Harbor were highest in the summer, when both light and temperature were at their maximum. Anderson *et al*., (2012) found that, *P. damicornis* was the slowest growing corals (0.54-1.20 mm/month) at Lord Howe Island and the linear extension for *P. damicornis* were 29-68% lower when compared to the summer growth rates at the Solitary Islands (Harriott 1999) because of *P. damicornis* is allocating most of its energy for reproduction in the summer accounting for the reduced summer growth. Inversely, Al-Sofyani and Floos (2013) found that the highest skeletal growth rate of *P. damicornis* was during winter whilst the lowest value was during summer but the difference was not significant.

Changes in environmental conditions may have both positive and negative effects on coral growth. Most corals are adapted to local environmental temperature (Hughes *et al.* 2003), and typically bleach and die if the local temperature exceeds the normal summer maxima by >1°C for 3 to 4 weeks (Hoegh-Guldberg, 1999). Branching corals are generally considered to be much more susceptible to extreme temperature (Marshall and Baird 2000), compared to massive coral species (Anderson *et al.,* 2012). Small changes in temperature can cause significant (up to 50%) changes in growth rates (James *et al.,* 2005). In general, the studied species were develop well in the worm season at the sheltered zones than those in the exposed zones whereas the temperature degree of the seawater around the average of 28ºC. Anderson *et al.,* (2012) reported that the coral growth is currently limited by the cool winter temperatures and climate related increases in ocean temperature may extend the summer growing period. Marshall and Baird (2000) pointed out that the elevated temperatures have been shown to have a greater affect on branching species, such as *Acropora* and *Pocillopora*. Crossland (1981) documented that the greater skeletal elongation with increasing temperature is observed seasonally in the subtropics and the rising global temperatures could support greater subtropical coral growth rates. At some subtropical reefs, coral growth is currently limited by cool winter temperatures (Harriott 1999; Crossland 1981), whereby coral growth is negligible during winter months (Anderson *et al.,* 2012). Anomalously low (below 18 °C) and high (much above 30 °C) seawater temperatures can impair coral physiology (Tambutté *et al.,* 2011). Gladfelter (1984) Correlated skeletal growth of *Acropora cervicornis* and four environmental parameters; temperature, daylight hours, sun hours, plankton abundance. She found that linear extension does not change during the year with the possible exception of April. It is suggested that temperatures outside an optimal range (ca. 26°–29°C for staghorn *Acroporas*) might cause a decrease in linear extension.

A. humilis recorded the highest increasing percentage in the seasonal growth among the studied coral species at the exposed and sheltered zones of Hurghada (29.13% and 35.85% respectively) and sheltered zone of Hamrawin (28.48%), *A. hyacinthus* recorded the highest growth percentage at the exposed zone of Hamrawin (34.54%) and the lowest seasonal growth percentage at the exposed zone of Hurghada (9.82%). *S. pistillata* recorded the lowest seasonal growth percentage at the sheltered zone of Hamrawin (7.30%), while *P. damicornis* recorded the lowest growth percentage (7.52% and 6.66%) at the sheltered zone of Hurghada and the exposed zone of Hamrawin respectively (Fig., 2). *A. humilis* was the fastest growing species in the worm season at the exposing and sheltered zones of Hurghada and Hamrawin, while *P. damicornis* was the slowest species in growth rate under the different conditions because of *P. damicornis* tends to form thick and dense branches relative to the other species especially under the sheltered conditions. Veron and Pichon (1976) reported that the growth forms typically show a gradual transition from a compact shape, under exposed (high energy fore-reef) conditions, to a thinner branching shape under sheltered (low energy back reef or lagoonal reefs) conditions. Such morphological variations are reflected in the annual extension and density pattern of the growth forms, where linear extension rates are lowest and bulk densities highest at the exposed reef sites (Scoffin *et al.,* 1992; Logan and Tomascik 1994). Harriott (1998) suggested that the high growth rate and trend towards thinner branches for the lagoonal sites is consistent with the appearance of colonies in such habitats. She added, the lagoonal basins are frequently dominated by monogeneric stands of staghorn corals, which are tall with fine-branching structure. Such habitats are protected from prevailing weather conditions with little water movement. Muko *et al.,* (2013) attributed the decline in growth rates of *Acropora* in the exposed sites to the physical disturbances and in the sheltered sites to the thermal stresses. Guzman and Cortes (1989) suggested that the seasonal growth, which is greater during the dry season, may be affected by variations in available light, cloud cover, turbidity, salinity and reproductive time rather than temperature changes. Anderson *et al*., (2012) documented that the growth rates of *Acropora* corals at Lord Howe Island recorded (4.15-3.40mm/month) which are much greater than the recorded in the present study and the growth rates recorded by Harriott (1999) at the Solitary Islands; 0.46 mm/month for *A. cytherea* and 0.80 mm/month for *A. valida.* Lough (2008) reported that the average linear extension and calcification rates in the massive coral *Porites* are significantly linearly related to average sea surface temperature (SST). Brachert *et al.,* (2013) concluded that the predicted SST rise over the next decades is likely hazardous to coral health because precipitation of the calcareous skeleton depends primarily on SST.

3- Skeletal densities

The different coral species recorded the highest averages of the skeletal densities and branch thicknesses at the exposed zones of Hurghada and Hamrawin. *P. damicornis* recorded the highest averages of skeletal density at the different zones of Hurghada and Hamrawin (Fig., 3); 2.04, 1.64, 2.64 and 1.96gm/cm^3 respectively, *A. hyacinthus* recorded the lowest averages of skeletal density at exposed and sheltered zones of Hurghada (1.13, 1.09 and 1.26gm/cm^3) and the sheltered zone of Hamrawin, while *S. pistillata* recorded the lowest skeletal density average (1.62gm/cm^3) at the exposed zone of Hamrawin (Table 3). Skeletal densities at exposed zone were higher than the sheltered zone of Hurghada with percentages between 1.6% in *S. pistillata* and 32.20% in *A. humilis*. At Hamrawin, the exposed zone species were higher in the skeletal densities than the sheltered zone species by a percentage varied between 26.46% in *S. pistillata* and 34.52% in *P. damicorins.* Also, the species of exposed zone of Hamrawin were denser than those in the exposed zone of Hurghada with a percentage fluctuated between 26.79% in *A. humilis* and 66.54% in *S. pistillata* and the species of the sheltered zone of Hamrawin were denser than the species in the sheltered zone of Hurghada by a percentage varied between 16.91% in *A. hyacinthus* and 38.35% in *S. pistillata* (Table 3). Tambutté *et al.,* (2011) found up to a 4.5% increasing in calcification with a 1°C elevation in seawater temperature. Harriott (1998) demonstrated that coral calcification rate was positively and significantly correlated (R=0.8) to seawater temperature. According to Lough and Barnes, (2000), a 1°C increase in mean annual temperature increased mean annual coral calcification rate by about 3.1%. Brown and Howard (1985) reported that the corals in exposed areas can have denser skeletons and hence may be more resistant to breakage than those in more sheltered areas. The high-extension, low density and skeletal growth are the common sclera-chronological signal of combined sedimentation and eutrophication effects on corals (Edinger *et al.,* 2000; Carricart-Ganivet and Merino, 2001). Harriott (1997) examined variability of skeletal density in *Acropora formosa* between sites within the Houtman Abrolhos - Australia, and between the Abrolhos and a more tropical site. She found that corals from more protected sites at the Abrolhos were less heavily calcified than corals from more exposed sites, and that corals from the tropical site were less heavily calcified than those from Houtman Abrolhos. A detailed study of bulk density of *Acropora formosa* showed that porosity varies significantly with degree of exposure at Houtman Abrolhos, with lagoonal corals being more lightly calcified than those from more exposed sites.

4- Branch thicknesses

P. damicorins showed the highest averages of the branch thicknesses at the exposed and sheltered zones of Hurghada (1.66cm^2, 1.51cm^2), *A. humilis* recorded the highest average of the branch thicknesses at the exposed and sheltered zones of Hamrawin (1.49cm^2, 1.14cm^2), *A. hyacinthus* recorded the lowest branch thicknesses at the exposed and sheltered zones of Hurghada (0.87cm^2, 0.70cm^2) and *S. pistillata* showed the lowest averages of branch thicknesses (0.82cm^2 and 0.67cm^2) at the exposed and sheltered zones of Hamrawin respectively (Fig., 4). *S. pistillata* recorded the highest variation percentage in branch thickness (53.33%), while *P. damicornis* showed the lowest variation percentage (13.09%) between the exposed and sheltered zones of Hurghada. At Hamrawin, *P. damicornis* recoded the highest variation percentage (40.29%) in branch thickness between the exposed and sheltered zones and *A. hyacinthus* recorded the lowest variation percentage (20.29%). Dar and Mohammed (2009) found that, *Acropora humilis* and *Stylophora pistillata* have thicker branches at the exposed sites than those at the sheltered sites, indicating to that the coral species are developing well under the effects of sea currents and surge waves. Harriott, (1998) pointed out, in protected habitats, linear extension is faster, but branches are more lightly calcified, so that net accretion of calcium carbonate does not vary greatly between habitats. Where water movement is high, thicker, shorter, more heavily calcified branches are produced which would be more resistant to damage from wave action.

The relatively higher growth rates, skeletal densities and branch thicknesses of the studied species in the exposed and sheltered zones of Hamrawin than those at Hurghada may also be affected by the phosphate particulates in the water column that are scavenged and introduced to the skeletal frameworks of the different species. This process may reduce the required energy to buildup the framework of the corals from the ionic forms of calcium and carbonates. Godinot *et al.,* (2012) found that skeletal growth rate increased by 31% between un-enriched and P-enriched corals, whereas, phosphate-enriched corals incorporated 1.7 times more phosphorus into their skeleton than did un-enriched corals. They added that phosphate enrichment mainly affected the coral symbionts, by increasing their carbon, nitrogen, and phosphorus contents and their specific growth rate. Phosphate enrichment also affected the skeletal compartment, by increasing the skeletal growth and the P/Ca ratio. Dunn *et al.,* (2012) found linear extension and tissue growth increasing for *Acropora muricata* exposed to phosphate levels of 0.09, 0.20, and 0.50 mg L^{-1} for four months and the growth rates were highest at a phosphate concentration of 0.50 mg L^{-1}. They suggested that the phosphate enhanced growth was due to increased zooxanthellar populations and photosynthetic production within the coral. Skeletal density reduction may be due to phosphate binding at the calcifying surface and the creation of a porous and structurally weaker calcium carbonate/calcium phosphate skeleton. Increased phosphate concentrations, often characteristic of eutrophic conditions, caused increased coral growth but also amore brittle skeleton.

The high sedimentation levels limit light availability and consequently reduce the coral growth (Barnes and Lough, 1999; James *et al.,* 2005). On the other hand, these sediment particles in water column may increase the aragonite saturation of seawater that may also help in skeleton formation. Aragonite saturation declines with increasing latitude and climate induced ocean acidification may further reduce the capacity for growth of calcifying organisms at the latitudinal limits of reef growth (Anderson *et al.,* 2012). Ohde and Hossain (2004) found direct relationship between aragonite saturation in the seawater and the coral calcification. They reported, such coral calcification plays an important role in constructing reefs in warm shallow-water in which many organisms grow. Since a decrease in coral calcification leads to a decrease in reef-building capacity of corals, it is important to elucidate factors controlling coral calcification. The calcium carbonate budget, and in turn skeletal density, varies over space and time as a function of location in water current (Le-Campion-Alsumard *et al.,* 1993), light intensity (Davies, l99l) or temperature (Tunnicliffe, I 983). Ohde and van Woesik (1999) suggested that coral calcification depends on the saturation state of surface seawater with respect to aragonite. The increasing in temperature during summer season increases aragonite saturation in the seawater, consequently the rate of calcification and coral growth increasing too. Silverman *et al.,* (2007) indicated that summer (April–October) and winter (November–March) in the northern Red Sea have average calcification rates of corals varied between 60±20 and 30±20 mmol.m^{-2}.d^{-1}, respectively. They added, in general, calcification increased with temperature and aragonite saturation state of reef water with an apparent effect of nutrients, which is in agreement with most laboratory studies and in situ measurements of single coral growth rates. Calcium carbonate accretion is most strongly correlated with number of sun hours (Gladfelter, 1984). Harriott (1998) pointed out that carbonates of *Acropora formosa* were deposited in similar amounts, but either as porous, rapidly ex-tending branches, or as denser branches which extended more slowly. Lough and Barnes (1997) observed an increase in calcification rate of 3.5% for every 1ºC rise in SST for the massive coral *Porites lutea* between 1906 and 1982 on the Great Barrier Reef, Positive relationships between temperature and calcification were also noted in studies that examined coral growth rates over latitudinal scales (Lough and Barnes, 2000; Carricart-Ganivet, 2004). Cooper *et al.,* (2007) defined an optimum temperature of 26.7ºC for extension and calcification of massive *Porites* on the Great Barrier Reef, with extension and calcification rates decreasing by 15% per 1ºC either side of this temperature. They also observed a decrease in calcification (~21%), linear extension (~16%) and bulk density (~6%) of colonies of the massive coral *Porites* on the northern Great Barrier Reef over a 16-year period (1988–2003) that also coincided with an increase in SST (0.24ºC per decade) over the 16 years examined. Tanzil *et al.,* (2009) suggested that the warmer sea temperature regime at Phuket is a factor associated with a more precipitous decline or whether the corals in each location are thermally acclimatized to their respective local regimes. They also found a decrease in only calcification and linear extension rates while bulk density remained unchanged. Gladfelter (1984) recorded the monthly rates of linear extension and calcification with environmental variables in *Acropora cervicornis* by, suggested that temperatures outside the optimal range might cause a decrease in linear extension while calcification was more influenced by light availability.

5- Growth rates, skeletal densities and branch thicknesses relationships

From the data, there inverse relationships were observed between the coral growth in a side with coral density and branch thickness in the other side in the studied coral species and positive relationships were observed between coral density and branch thickness with different significances. These relationships were clearly observed in *A. humillis* (r = -0.53, -0.50 and 0.54 respectively (Fig.5 2a,b,c) but they were decreased in their significances with the other species depending up on the continuous variability in the surrounding oceanographic conditions at the studied zones (Figs, 6a,b and 7). Also, the inverse relationships of the linear growth with coral density and branch thickness indicated that the more dense species and the thick branches at the exposed zones of Hurghada and Hamrawin are less porous than those in sheltered zones. The inverse relationships of skeletal density and extension rates are affected by light and temperature in the shallower areas (Lough and Barnes, 2000; smith *et al.,* 2007; Tanzil*, et al.,* 2009). Lough, (2008) found inverse relationship of the average skeletal density versus the linear extension rate and calcification rate whereas the linear extension is the main source of variability in calcification rate. He added, any effects of declining calcification on linear extension may also be offset by reductions in skeletal density. While the exposed areas are suffering from the high and surge waves and the observed high water currents, so they consumed some of their energies in the calcification process rather than the growth. So that, the branch thickness increases as a result of calcification and consequently their skeletal density increases. Rodgers *et al.,* (2003) pointed out that, the skeletal strength was correlated with the wave energy present in the environment in the region they inhabit; suggesting that structural strength of corals is an adaptive response to hydraulic stress. The great uncertainties observed in the different illustration figures attributed to the effect of the different oceanographic variables at the studied zone. Temperature, light, sedimentation rate, dissolved nutrients and wave energy were the most effective oceanographic variables that control coral growths, densities and branch thicknesses.

Conclusions

- Linear growth rates, coral densities and branch thicknesses were studied in four branch coral species; *Acropora humilis*, *A. hyacinthus, Stylophora pistillata* and *Pocillopora damicornis* at two localities under the exposed and sheltered conditions.
- The growth rates of the selected coral species were noticed biseasonally (winter and summer) throughout a year. After a year of the experiment, coral density and branch thicknesses were measured.
- *Acropora humilis* recorded the linear highest annual and seasonal growth rates the two localities under the different conditions, while *Stylophora pistillata* showed the lowest annual and seasonal linear growth rates Hurghada and *Acropora hyacinthus* at Hamrawin.
- *A. humilis* was the fastest growing species in the worm season at the exposing and sheltered zones of Hurghada and Hamrawin, while *P. damicornis* was the slowest species in growth rate under the different conditions because of *P. damicornis* tends to form thick and dense branches relative to the other species especially under the sheltered conditions.
- *P. damicornis* recorded the highest averages skeletal density at the different zones of Hurghada and Hamrawin, *A. hyacinthus* recorded the lowest averages of skeletal density at exposed and sheltered zones of Hurghada and the sheltered zone of Hamrawin, while *S. pistillata* recorded the lowest skeletal density average at the exposed zone of Hamrawin.
- *P. damicorins* showed the highest averages of the branch thicknesses at the exposed and sheltered zones of Hurghada, *A. humilis* recorded the highest average of the branch thicknesses at the exposed and sheltered zones of Hamrawin, *A. hyacinthus* recorded the lowest branch thicknesses at the exposed and sheltered zones of Hurghada and *S. pistillata* showed the lowest averages of branch thicknesses at the exposed and sheltered zones of Hamrawin.
- Inverse relationships were observed between the coral growth in a side with coral density and branch thickness in the other side in the studied coral species and positive relationships were observed between coral density and branch thickness with different significances. These relationships were clearly

observed in *A. humillis* but these relationships were decreased in their significances with the other species depending up on the continuous variability in the surrounding oceanographic conditions at the studied zones

- Temperature rates, aragonite saturation, phosphate particulates, sedimentation rates, effects of surge waves and light intensity are the main variables that controlling the coral growths, densities and branch thicknesses at the different zones.

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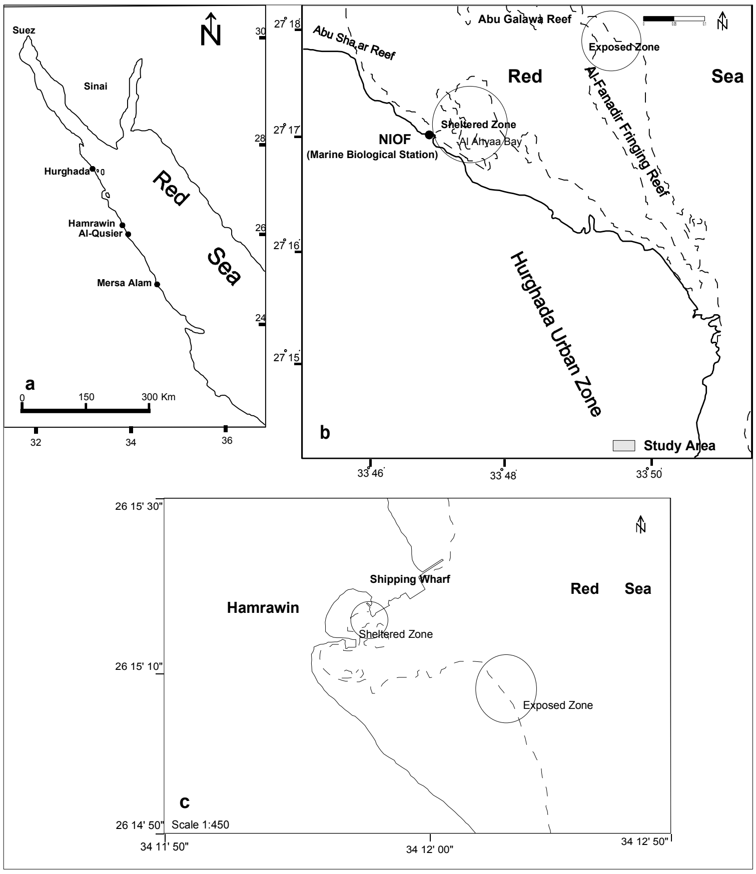

Fig. (1) Location map shows the exposed and sheltered zones at each locality.

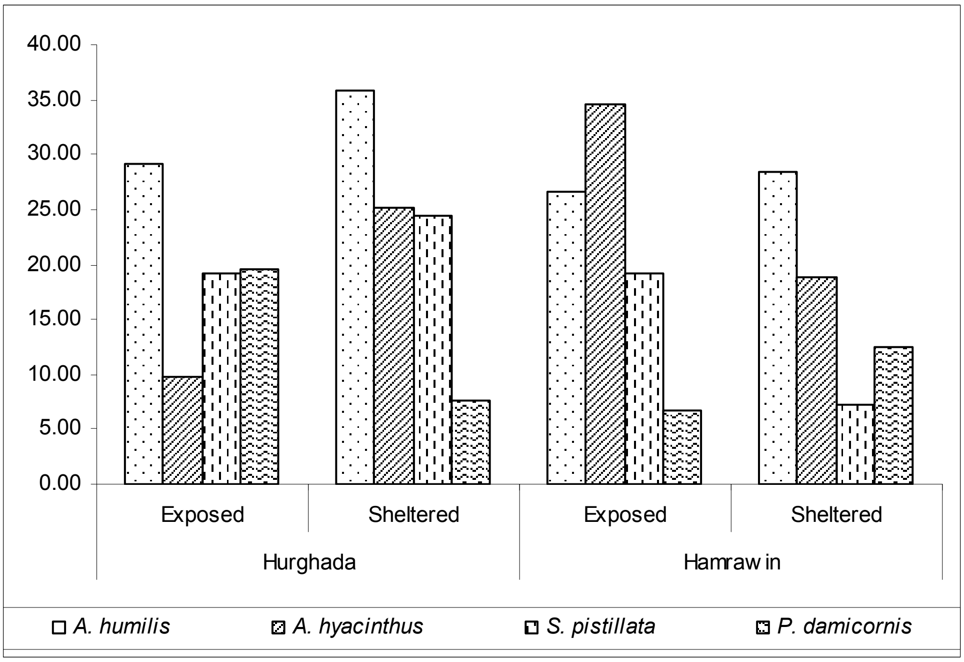

Fig., (2) Growth rate variations between summer and winter seasons of the different species at the different zones.

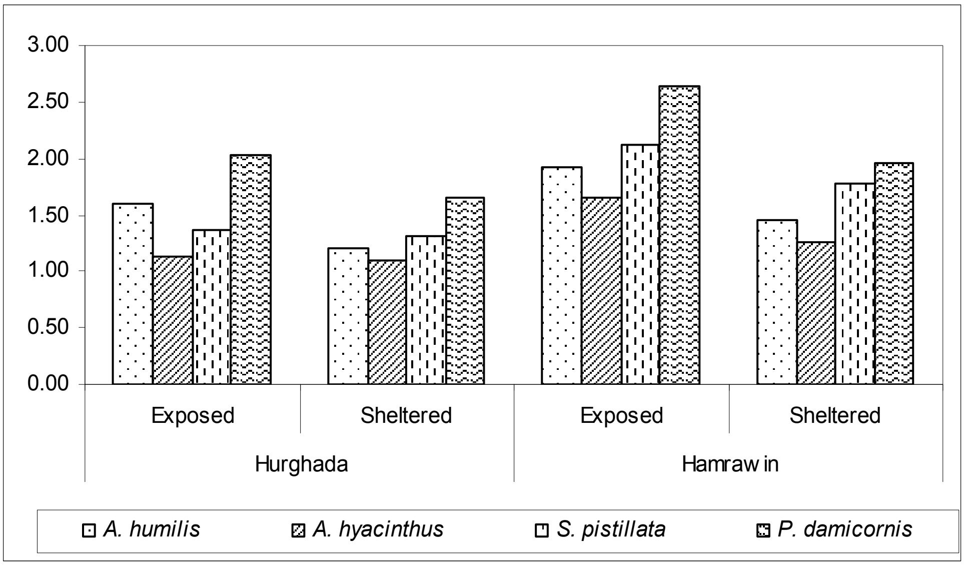

Fig., (3) the differences of skeletal density of the studied species at the different zones.

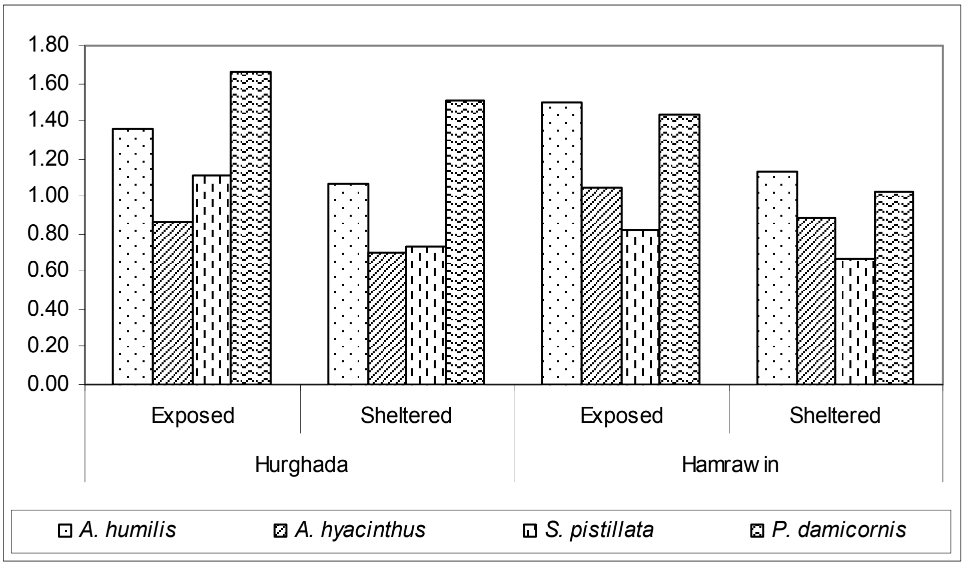

Fig., (4) Branch thickness variations of the studies species at the different Zones.

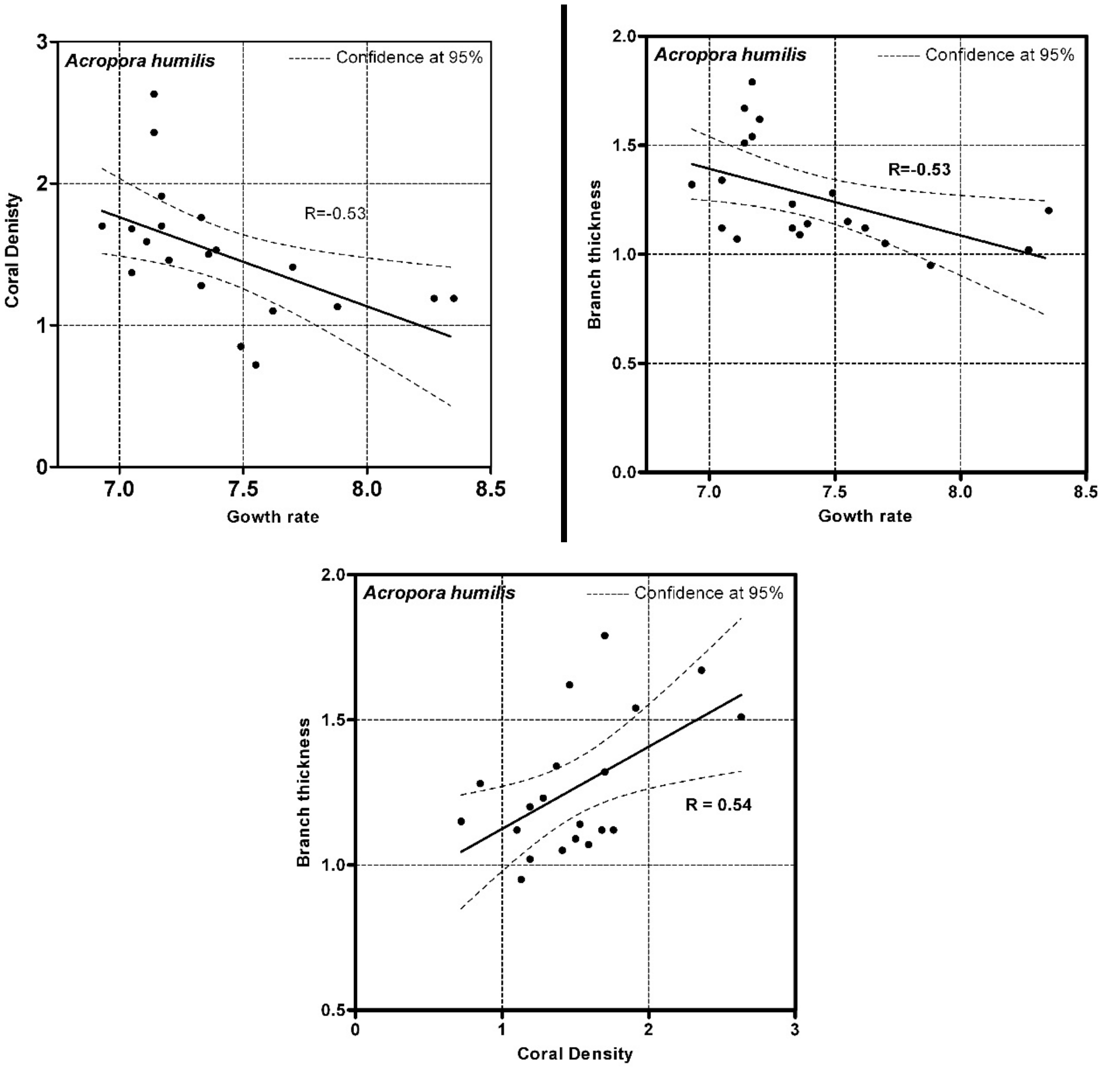

Fig., (5). Linear regression relationships of Growth rate, coral density and branch thickness in *A. humilis*.

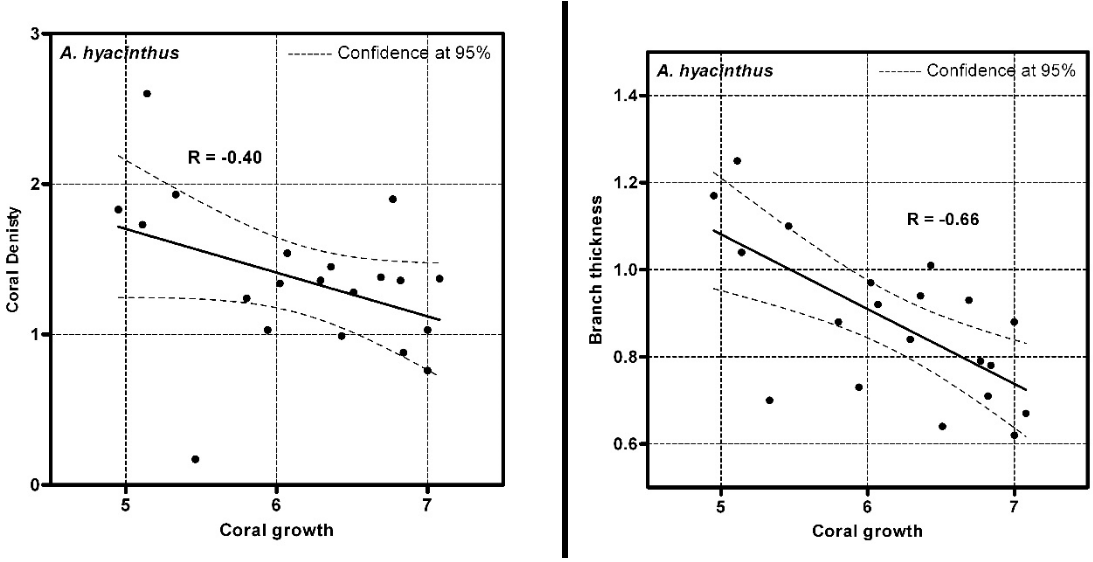

Fig., (6). Linear regression relationships of Growth rate against coral density and branch thickness in *A. hyacinthus*.

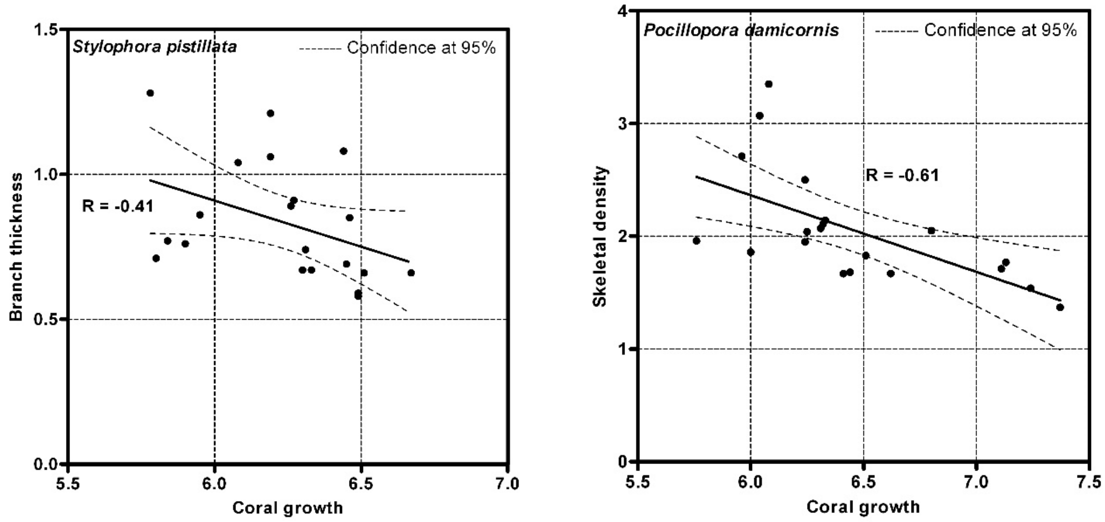

Fig., (7). The linear regression relationships of Growth rate against branch thickness and coral density in *S. pistillata* and *P. damicornis*.

Table (1): The means of some oceanographic parameters in summer and winter at the studied locations:

Locations	Season	Temperature (ºC)		pH		Salinity (‰)	
		Max.	Min.	Max.	Min.	Max.	Min.
Hurghada	Winter	21.94	19.56	8.6	7.98	41.18	39.75
	Summer	29.38	26.91	8.61	7.83	42.43	41.61
Hmrawin	Winter	23.57	18.89	8.05	7.7	40.92	40.18
	Summer	29.03	26.94	8.01	7.88	42.15	41.79

Table (2). The recorded seasonal and annual growth rates of the studied species at the studied zones of Hurghada and Hamrawin:

		Hurghada						Hamrawin					
		Exposed			Sheltered			Exposed			Sheltered		
		Summer	Winter	annual	Summer	Winter	annual	Summer	Winter	annual	Summer	Winter	annual
A. humilis	1	0.66	0.53	7.17	0.75	0.53	7.70	0.66	0.53	7.17	0.69	0.53	7.33
	2	0.66	0.53	7.14	0.80	0.59	8.35	0.66	0.53	7.14	0.69	0.54	7.36
	3	0.69	0.54	7.33	0.75	0.52	7.62	0.69	0.52	7.20	0.66	0.53	7.11
	4	0.68	0.50	7.05	0.78	0.60	8.27	0.68	0.50	7.05	0.70	0.53	7.39
	5	0.71	0.55	7.55	0.73	0.58	7.88	0.61	0.54	6.93	0.70	0.55	7.49
	Av.	0.68±0.02	0.53±0.02	7.25±0.02	0.76±0.03	0.56±0.04	7.96±0.33	0.66±0.03	0.52±0.02	7.10±0.11	0.69±0.02	0.54±0.01	7.34±0.14
A. hyacinthus	1	0.60	0.53	6.77	0.66	0.52	7.08	0.50	0.39	5.33	0.53	0.48	6.07
	2	0.61	0.53	6.84	0.62	0.52	6.82	0.50	0.35	5.14	0.54	0.46	6.02
	3	0.54	0.54	6.43	0.66	0.51	7.00	0.52	0.39	5.46	0.54	0.52	6.36
	4	0.57	0.48	6.29	0.58	0.50	6.51	0.50	0.35	5.11	0.55	0.42	5.80
	5	0.57	0.55	6.69	0.67	0.49	7.00	0.46	0.36	4.95	0.55	0.44	5.94
	Av.	0.58±0.03	0.52±0.03	6.60±0.24	0.64±0.04	0.51±0.01	6.88±0.23	0.50±0.02	0.37±0.02	5.20±0.02	0.55±0.01	0.46±0.04	6.04±0.21
S. pistillata	1	0.58	0.46	6.19	0.60	0.45	6.31	0.53	0.47	5.95	0.56	0.53	6.51
	2	0.57	0.50	6.44	0.61	0.50	6.67	0.57	0.49	6.33	0.56	0.52	6.49
	3	0.54	0.50	6.27	0.54	0.51	6.30	0.53	0.44	5.84	0.55	0.52	6.45
	4	0.56	0.47	6.19	0.58	0.47	6.26	0.55	0.43	5.90	0.57	0.52	6.49
	5	0.55	0.42	5.78	0.57	0.40	5.80	0.55	0.46	6.08	0.56	0.52	6.46
	Av.	0.56±0.01	0.47±0.04	6.17±0.24	0.58±0.03	0.47±0.04	6.27±0.31	0.55±0.02	0.46±0.02	6.02±0.19	0.56±0.00	0.52±0.00	6.48±0.02
P. damicornis	1	0.59	0.48	6.41	0.61	0.58	7.13	0.52	0.49	6.04	0.56	0.49	6.31
	2	0.57	0.47	6.25	0.62	0.59	7.24	0.53	0.48	6.08	0.56	0.48	6.24
	3	0.56	0.48	6.24	0.61	0.52	6.80	0.51	0.49	6.00	0.57	0.51	6.44
	4	0.56	0.50	6.33	0.59	0.60	7.11	0.51	0.49	5.96	0.57	0.52	6.51
	5	0.61	0.49	6.62	0.65	0.58	7.37	0.49	0.46	5.76	0.56	0.49	6.32
	Av.	0.58±0.02	0.48±0.01	6.37±0.15	0.61±0.02	0.57±0.03	7.13±0.21	0.51±0.01	0.48±0.01	5.97±0.13	0.56±0.00	0.50±0.01	6.36±0.11

Table (2). The recorded coral densities and branch thicknesses of the studied species at the studied zones of Hurghada and Hamrawin:

		Coral Density				branch thickness			
		Hurghada		Hamrawin		Hurghada		Hamrawin	
		Exposed	Sheltered	Exposed	Sheltered	Exposed	Sheltered	Exposed	Sheltered
A. humilis	1	1.70	1.41	1.91	1.76	1.79	1.05	1.54	1.12
	2	2.63	1.19	2.36	1.50	1.51	1.20	1.67	1.09
	3	1.28	1.10	1.46	1.59	1.23	1.12	1.62	1.07
	4	1.68	1.19	1.37	1.53	1.12	1.02	1.34	1.14
	5	0.72	1.13	1.70	0.85	1.15	0.95	1.32	1.28
	Av.	1.60±0.70	1.20±0.12	1.91±0.40	1.45±0.35	1.36±0.29	1.07±0.10	1.49±0.16	1.14±0.08
A. hyacinthus	1	1.90	1.37	1.93	1.54	0.79	0.67	0.70	0.92
	2	0.88	1.36	2.60	1.34	0.78	0.71	1.04	0.97
	3	0.99	1.03	0.17	1.45	1.01	0.62	1.10	0.94
	4	1.36	1.28	1.73	1.24	0.84	0.64	1.25	0.88
	5	1.38	0.76	1.83	1.03	0.93	0.88	1.17	0.73
	Av.	1.13±0.25	1.09±0.26	1.66±0.90	1.26±0.19	0.87±0.10	0.70±0.10	1.05±0.21	0.89±0.10
S. pistillata	1	1.96	1.46	2.11	2.20	1.21	0.74	0.86	0.66
	2	1.33	1.81	2.77	1.52	1.08	0.66	0.67	0.59
	3	1.08	0.87	2.13	2.04	0.91	0.67	0.77	0.69
	4	1.36	1.20	2.16	1.41	1.06	0.89	0.76	0.58
	5	1.01	1.58	1.62	1.68	1.28	0.71	1.04	0.85
	Av.	1.37±0.38	1.31±0.36	2.11±0.41	1.79±0.34	1.11±0.14	0.73±0.09	0.82±0.14	0.67±0.11
P. damicornis	1	1.67	1.77	3.07	2.07	2.20	1.71	1.43	1.09
	2	2.04	1.54	3.35	1.95	1.75	1.75	1.33	0.86
	3	2.50	2.05	1.86	1.68	1.15	1.73	1.77	1.28
	4	2.14	1.71	2.71	1.83	1.33	1.11	1.05	0.84
	5	1.67	1.37	1.96	2.11	1.88	1.25	1.63	1.08
	Av.	2.04±0.35	1.64±0.26	2.64±0.66	1.96±0.18	1.66±0.42	1.51±0.30	1.44±0.28	1.03±0.18