# Sedimentation Stress and Population Density of Zooxanthellae in Some Corals Along the Egyptian Red Sea Reefs

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## ABSTRACT

The temporal variations of coral zooxanthellae populations were studied in six sites at Sharm El-Sheikh area, Northern Red Sea, on four scleractinian species (*Acropora humilis* Dana, *Pocillopora verrucosa* L., *P. damicornis* Ellis and Solander, and *Stylophora pistillata* Esper). For this purpose, coral samples were collected monthly from March 2001 to May 2002. In addition, other fourteen sites were chosen along the Egyptian Red Sea reefs to determine the spatial variations of the coral zooxanthellae population. Samples for this purpose were taken during October 2002 from a similar depth contour of 5m at all sites. The population densities of coral zooxanthellae varied widely from coral species to other. The highest zooxanthellae density was recorded in the tissue of the coral *A. humilis* (annual average: $1.529 \times 10^6$ cell/cm$^2$) and the lowest occurred in the tissues of the coral *S. pistillata* (annual average: $0.649 \times 10^6$ cell/cm$^2$). The maximum densities of zooxanthellae in the four coral species were recorded at sites with moderate Secchi disk reading and TSS. However, the minimum densities of coral zooxanthellae were recorded at sites with Secchi disk readings and TSS exceeded than 5.75 m and 147.5 mg/L, respectively. Concerning the seasonal variations, the maximum zooxanthellae densities in the four coral species were recorded during the period of late autumn-early winter, while the minimum densities were counted during summer.
**Key words:** Coral reef, Red Sea, TSS, zooxanthellae density

## INTRODUCTION

Zooxanthellae are marine dinoflagellates, found in many tropical invertebrates, including reef-building corals (Taylor, 1974). They supply energy to their host in the form of fixed carbon compounds (Muscatine *et al*., 1984; Klump *et al*., 1992), and are essential to the host's growth and survival under nutrient-limited conditions (Bé *et al*., 1982).

Because of the dependency of coral on zooxanthellae, any wide-decrease in algal productivity causes a requisite drop in the nutrition, growth, reproduction and depth distribution of corals (Richmond, 1993). Such stress has also been shown to decrease growth rates due to the disruption of the coral-algal relationship, which is essential in the calcification process (Pastorok and Bilyard, 1985). These symbiotic algae (i.e. zooxanthellae) are restricted to the gastrodermis of the adult corals, but at least, temporarily observed in the endoderm of the planulae of some hard and soft corals (Szmant-Froelich *et al*., 1985; Benayahu and Schleyer, 1998).

The number of zooxanthellae per unit area in the tissues of reef-building corals ranges between 0.5 and $5\times10^6$ cell/cm$^2$ (Drew, 1972; Kawaguti and Nakayama, 1993; Muscatine, 1980; Falkowski and Dubinsky, 1981; Porter *et al*., 1984; Muscatine *et al*., 1985; Stimson, 1997; Aamer, 2005). The density of zooxanthellae within coral tissues is not necessarily constant throughout the year; irradiance, nutrient availability, sedimentation stress and temperature have been experimentally shown to alter densities, and all these factors can or do changes through the year (Houck, 1978; Thinh, 1991; Stimson, 1997; Aamer, 2005). Furthermore, algal density within the colony showed un-formality occurrence throughout the colonies of the same coral species (Gladfelter *et al*., 1989).

Several studies reported that, among zooxanthellate cnidarians, the density varies temporally (Stimson, 1997; Fitt *et al*., 2000) across species (Drew, 1972), habitat/depth (Dustan, 1979), and with position in colony (Lasker, 1977 and 2003; Berner *et al*., 1987). No previous detailed studies on the population density of zooxanthellae in the corals along the Egyptian Red Sea reefs were carried out. Gohar (1940) reported that, in some soft corals off Hurghada (Xeniidae), the main zooxanthella recorded was the dinoflagellate *Gymnodinium microadriaticum*. Moreover, Shukr (1997) recorded the symbiotic dinoflagellate *Symbiodinium microadviaticum* in the tissues of a cnidarian sea anemone in the Egyptian Mediterranean Sea coast. A number of studies have addressed the adaptations of corals and their symbiotic zooxanthellae to light and shade at the northern part of the Gulf of Aqaba (Falkowski and Dubinsky, 1981; Rinkevich and Loya, 1983). But all these studies were concerned with one dominant coral species, *Stylophora pistillata*. Recently, Aamer (2005) made the first attempt on the density of zooxanhellae in some hard corals along the Egyptian Red Sea coast throughout a complete year.

## MATERIALS AND METHODS

The temporal variations of coral zooxanthellae populations were studied in six sites (sites 1-6; Figure 1) at Sharm El-Sheikh area in four scleractinian species (*Acropora humilis*, *Pocillopora verrucosa*, *P. damicornis* and *Stylophora pistillata*). For this purpose coral samples were collected regularly every month from March 2001 to May 2002. In addition, other fourteen sites of the Egyptian Red Sea reefs were studied to carry out the spatial variations of the coral zooxanthellae populations. Samples were taken during October 2002 from a similar depth contour of 5m at all

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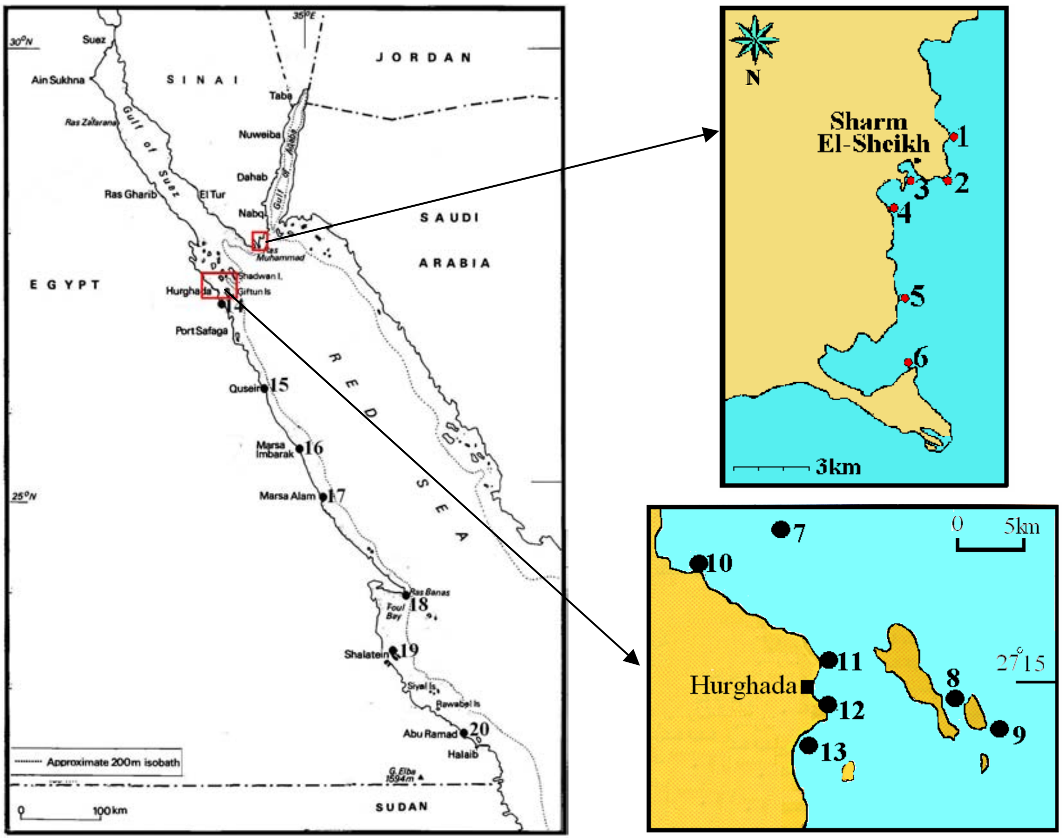


**Figure (1):** Map of the sampling sites along the Egyptian Red Sea coast.

sites. Five branches were collected from each of three colonies of each coral species at each site. The branches were immediately placed in 10% formalin in seawater. After 24h of fixation, branches were decalcified in 1:1 formic acid-Sodium citrate solution. A disk of tissue with 11.5 mm diameter was cut from a flat area of the decalcified tissue of each branch using a cork borer. The tissue disk was ground in a ground-glass tissue grinder with 1ml of water and the density of cells in the homogenate was placed in Sedjwek Rafter cell and examined under compounded microscope. The count of zooxanthellae was calculated from the average of three counts and expressed as cells/cm$^2$. The total suspended solids (TSS) and transparency were measured at all sites (i.e. sites 1-20) during October 2002 along the Egyptian Red Sea coast. A quadratic regression model was performed to know the effects of the total suspended sediments on the density of coral zooxanthellae.

## RESULTS

### Suspended solids and transparency

The TSS ranged between 12 mg/L at site 6 (Ras Mohamed) and 210 mg/L at site 13 with an average of 58.7 mg/L (Table 1). As shown in Table (1), 20% of the sites contained TSS higher than 100mg/L, 25% of the sites have values more than 50mg/L, 20% have more values than 25 mg/L, and more than 30% of the sites contained less than 25mg/L of TSS. The Secchi disk readings (i.e. transparency) at the study sites were generally high and fluctuated throughout the coast according to the level of the anthropogenic effects (i.e. sedimentation stress) occurred at each site. The highest transparency values were recorded at sites away from anthropogenic effects (sites 6, 5, 18, 8 and 9) (Table 1), while the lowest values of Secchi disk readings were recorded at sites neighbouring anthropogenic activities (such as sites 13, 16 and 19). A strong negative correlation was found between the total suspended solids and the transparency ($r = -0.84$).

### Spatial variations of the zooxanthellae populations

The population densities of zooxanthellae in the four target coral species differed widely among sites (Table 2). ANOVA analysis revealed that, there was no significant difference in the density of zooxanthellae among the branches of the same colony, nor between colonies of the same species at the same site. However, there was significant differences in the density of zooxanthellae in the four coral species ($P < 0.00001$).

The population density of zooxanthellae in the tissues of the coral *A. humilis* varied widely at different sites, with a mean value of $1.894 \times 10^6$ cell/cm$^2$ (SD $\pm 0.352 \times 10^6$ cell/cm$^2$) for the whole study area (Table 1). The highest density was recorded at site 15, while the lowest one appeared at site 13. It is to be mentioned that 50% of the sites contained zooxanthellae of >1-2 $\times 10^6$ cell/cm$^2$,

**Table (1):** Spatial records of Secchi disk reading (m), total suspended solids (mg/L), and population density of zooxanthellae ($\times 10^6$ cell/cm$^2$) in the tissues of the four coral species during October 2002 along the Egyptian Red Sea coast.

| Site | Secchi disk (m) | TSS (mg/L) | *A. humilis* | | *P. damicornis* | | *P. verrucosa* | | *S. pistillata* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **1** | 22 | 17 | 1.358 | 0.226 | 1.601 | 0.124 | 1.355 | 0.156 | 0.573 | 0.117 |
| **2** | 20 | 28 | 1.310 | 0.087 | 1.620 | 0.099 | 1.109 | 0.147 | 0.513 | 0.076 |
| **3** | 17 | 29 | 1.787 | 0.621 | 2.322 | 0.076 | 2.531 | 0.283 | 0.818 | 0.098 |
| **4** | 15 | 28 | 2.084 | 0.634 | 1.625 | 0.102 | 2.191 | 0.216 | 0.800 | 0.077 |
| **5** | 25 | 13 | 1.611 | 0.252 | 1.660 | 0.134 | 1.207 | 0.143 | 0.521 | 0.106 |
| **6** | 26 | 12 | 1.593 | 0.252 | 1.535 | 0.087 | 1.238 | 0.139 | 0.489 | 0.078 |
| **7** | 12 | 65 | 2.795 | 0.537 | 2.735 | 0.179 | 3.451 | 0.570 | 1.275 | 0.156 |
| **8** | 24 | 22 | 1.365 | 0.226 | 1.573 | 0.104 | 1.086 | 0.147 | 0.520 | 0.074 |
| **9** | 24 | 16 | 1.379 | 0.141 | 1.668 | 0.098 | 1.216 | 0.143 | 0.515 | 0.088 |
| **10** | 10 | 110 | 1.209 | 0.198 | 2.098 | 0.114 | 2.451 | 0.190 | 0.951 | 0.073 |
| **11** | 12 | 47 | 2.526 | 0.547 | 2.068 | 0.109 | 1.368 | 0.365 | 0.972 | 0.057 |
| **12** | 20 | 70 | 2.756 | 0.262 | 2.368 | 0.111 | 1.183 | 0.196 | 1.445 | 0.210 |
| **13** | 2 | 210 | 0.374 | 0.333 | 0.040 | 0.012 | 0.078 | 0.012 | 0.036 | 0.022 |
| **14** | 19 | 65 | 2.443 | 0.511 | 2.884 | 0.107 | 3.352 | 0.237 | 0.770 | 0.069 |
| **15** | 6 | 63 | 3.331 | 0.324 | 2.866 | 0.079 | 3.023 | 0.201 | 1.645 | 0.397 |
| **16** | 7 | 120 | 3.200 | 0.923 | 2.153 | 0.084 | 2.643 | 0.369 | 1.025 | 0.147 |
| **17** | 9 | 70 | 3.270 | 0.413 | 3.045 | 0.098 | 2.398 | 0.237 | 1.105 | 0.257 |
| **18** | 25 | 25 | 1.628 | 0.252 | 1.543 | 0.147 | 1.271 | 0.139 | 0.495 | 0.078 |
| **19** | 6 | 150 | 0.437 | 0.170 | 0.058 | 0.019 | 0.096 | 0.021 | 0.049 | 0.032 |
| **20** | 23 | 13 | 1.425 | 0.123 | 1.448 | 0.162 | 1.212 | 0.122 | 0.610 | 0.078 |
| **Mean** | **16.6** | **58.7** | **1.894** | **0.352** | **1.723** | **0.202** | **1.845** | **0.102** | **0.756** | **0.115** |

**Table (2):** One way ANOVA performed on the effect of months and sites on the population density of zooxanthellae in the four coral species at Sharm El-Sheikh area.

| Species | Source of variations | df | Mean of square x $10^6$ | F | Significance |
|---|---|---|---|---|---|
| *A .humilis* | Month | 11 | 0.101 | 1.38 | 0.0204 |
| | Site | 5 | 0.797 | 35.03 | 0.0002 |
| *P. damicornis* | Month | 11 | 0.517 | 13.91 | 0.0009 |
| | Site | 5 | 0.308 | 3.18 | 0.012 |
| *P. verrucosa* | Month | 11 | 0.428 | 1.83 | 0.067 |
| | Site | 5 | 2.60 | 30.18 | 0.0007 |
| *S. pistillata* | Month | 11 | 0.080 | 4.18 | 0.0001 |
| | Site | 5 | 0.202 | 13.09 | 0.0007 |

25% contained > 2-3 × $10^6$ cell/cm$^2$ and three sites only contained more than 3 × $10^6$ cell/cm$^2$. On the other hand at two sites, the tissues of the coral *A. humilis* had densities less than 1 × $10^6$ cell/cm$^2$. In the regression model, the quadratic term of TSS is significant and $R^2$ value indicates that the TSS content explains 44% of the total variance of zooxanthellae density in the tissues of the coral *A. humilis* (Table 3). The significance of the quadratic term indicates curvilinearity of the relation (Figure 2), where the density of zooxanthellae in the tissues of *A. humilis* increases with increasing TSS until reaching a stress value (88.75mg/L) at which with further increase causes decrease of zooxanthellae density. At the stress point mentioned above, the density of zooxanthellae in *A. humilis* reached its highest value (i.e. 2.563 × $10^6$ cell/cm$^2$).

The mean population densities of zooxanthellae in the tissues of the coral *Pocillopora damicornis* ranged between 0.040 × $10^6$ cell/cm$^2$ at site 13 and 3.045 × $10^6$ cell/cm$^2$ at site 17 with a total mean of 1.723 × $10^6$ cell/cm$^2$ (Table 1). Over all the area, 45% of the samples

**Table (3):** Quadratic regression model for zooxanthellae density of the four coral *species.* Y = density of zooxanthellae. $P \leq 0.0001$ for all regressions.

| Species | $R^2$ | Quadratic regression equation | F |
|---|---|---|---|
| *A. humilis* | 0.44 | Y= 1.027744 + 0.034615 (TSS) - 0.000195 (TSS)$^2$ | 117.2 |
| *P. verrucosa* | 0.65 | Y= 1.198239 + 0.029596 (TSS) - 0.000181 (TSS)$^2$ | 274.7 |
| *P. damicornis* | 0.44 | Y= 0.820697 + 0.033796 (TSS) - 0.000189 (TSS)$^2$ | 118.1 |
| *S. pistillata* | 0.55 | Y= 0.310642 + 0.017386 (TSS) - 0.0000957 (TSS)$^2$ | 180.7 |

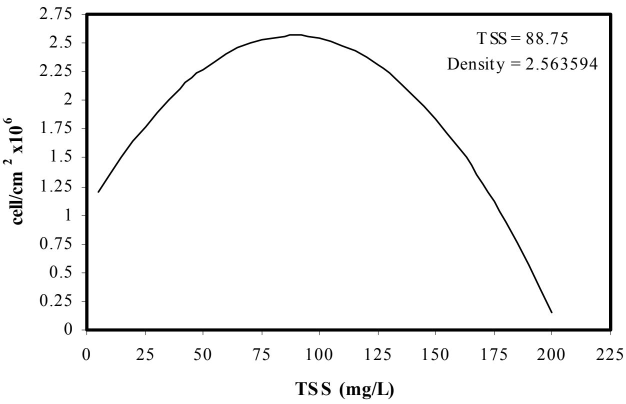


**Figure (2):** Spatial variations of zooxanthellae density in the coral *A. humilis* versus TSS contents over the whole sites during October 2002. The curve fitted is a significant quadratic regression.

contained zooxanthellae densities of 1-2 × $10^6$ cell/cm$^2$ and 45% contained 2-3 × $10^6$ cell/cm$^2$. The second power regression model showed that at a TSS value of 81.75 mg/L, the densities of zooxanthellae in the tissues of *P. damicornis* reached its highest value (i.e. 2.408 × $10^6$ cell/cm$^2$). Higher than this TSS value, the densities of zooxanthellae decreased sharply (Figure 3). The $R^2$ value indicates that the TSS content explains 65% of the total variance of zooxanthellae density in the tissues of the coral *P. damicornis* (Table 3).

The mean density of zooxanthellae in the tissues of the coral *Pocillopora verrucosa* was 1.845 × $10^6$ cell/cm$^2$. The highest density was recorded at sites 7 and 14, which were associated with the same TSS contents, while the lowest densities were found at sites 13 and 19, accompanied by the highest (Table 1). The second power regression model showed that, any increase in the TSS above 89.4 mg/l, caused a decrease of zooxanthellae count in the coral tissues (Figure 4). The regression curve is significant ($P$<0.0001) and explains 44% of the variance (Table 3). At 50% of the sites zooxanthellae density in the coral tissues fall within the range of 1-2 × $10^6$ cell/cm$^2$, 25% contained densities between 2-3 × $10^6$ cell/cm$^2$ and 15% contained densities more than 3 × $10^6$ cell/cm$^2$.

The reef-building coral, *Stylophora pistillat*a, had the lowest population density of zooxanthellae in their tissues among the four coral species varying between 0.036 × $10^6$ cell/cm$^2$ and 1.645 × $10^6$ cell/cm$^2$ at sites 13 and 15, respectively. The lowest zooxanthellae densities were recorded at sites with the highest TSS contents (sites 13 and 19). The regression model showed that the population densities of zooxanthellae in *S. pistillata* reached its highest value (i.e. 1.099 × $10^6$ cell/cm$^2$) at TSS of 99.55mg/L, but with increasing TSS value, the densities of zooxanthellae decreased (Figure 5). This means that, *S. pistillata* is more adaptable to the highest TSS contents than the other species. The $R^2$ value indicates that the TSS content explains 55% of the total variance of zooxanthellae density in the tissues of the coral *P. damicornis*.

**Seasonal variations of zooxanthellae populations**

The population density of zooxanthellae in the tissues of the four coral species varied temporally. Table (4) summarizes the seasonal average densities of zooxanthellae in the four coral species at Sharm El-Sheikh area during the period of study. In the four coral species, the lowest population densities of zooxanthellae were recorded during summer season. On the other hand, high densities of zooxanthellae in *A. humilis* and *S. pistillata* were recorded during winter, and in *P. damicornis* and *P. verrucosa* during autumn.

One way ANOVA showed that significant differences in the population density of zooxanthellae in the coral *A. humilis* among sites ($P$ = 0.0002) and non-significant among months ($P$ = 0.02) (Table 2). In contrast, differences in zooxanthellae densities of *P. damicornis* appeared to be significant among months ($P$ = 0.0009), while they were non-significant among sites ($P$ = 0.012). On the other hand, there were significant difference in zooxanthellae counts in the tissue of *P. verrucosa* throughout the sites ($P$ = 0.0007) but on the monthly scale the difference was less significant ($P$ = 0.067). In the tissue of *S. pistillata*, the variance among population densities of zooxanthellae was large; indicating significantly higher counts in some months and sites than others. One way ANOVA identify a distinct series of months and sites with uniformly greater zooxanthellae differences ($P$ = 0.0001 and 0.0007 for months and sites, respectively). The population densities of zooxanthellae in the tissues of the four coral species at Sharm El-Sheikh area were much lower during summer season than during autumn

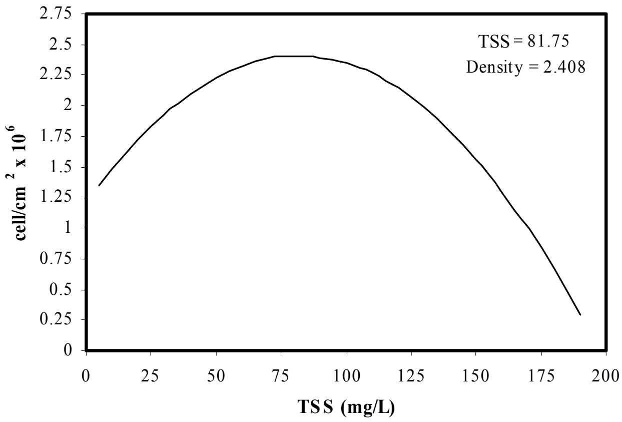


**Figure (3):** Spatial variations of zooxanthellae density in the coral *P. damicornis* versus TSS contents over the whole sites during October 2002. The curve fitted is a significant quadratic regression.

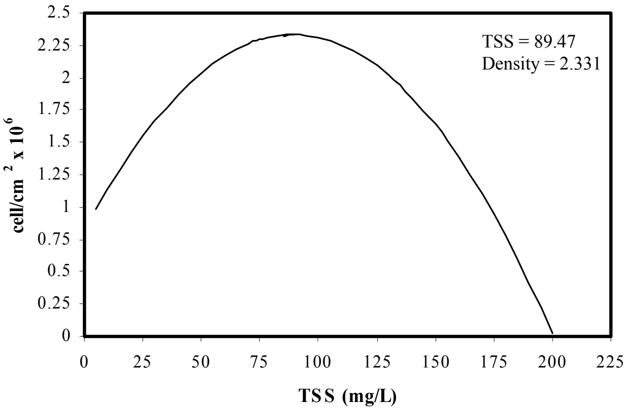


**Figure (4):** Spatial variations of zooxanthellae density in the coral *P. verrucosa* versus TSS contents over the whole sites during October 2002. The curve fitted is a significant quadratic regression.

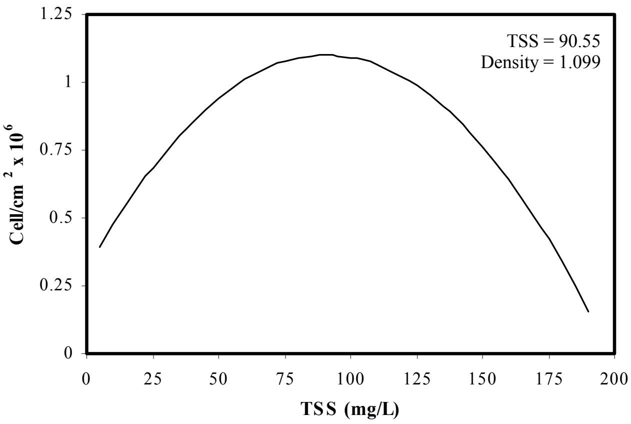


**Figure (5):** Spatial variations of zooxanthellae density in the coral *S. pistillata* versus TSS contents over the whole sites during October 2002. The curve fitted is a significant quadratic regression.

and winter. These patterns describe the effect of the illumination (i.e. light) during summer months on the population densities of zooxanthellae.

**Variations of zooxanthellae populations according to coral species**

The population densities of coral zooxanthellae varied widely from a coral species to anther. The highest zooxanthellae density was recorded in the tissue of the coral *A. humilis* (annual average: $1.529 \times 10^6$ cell/cm$^2$) and the lowest occurred in the tissues of the coral *S. pistillata* (annual average: $0.649 \times 10^6$ cell/cm$^2$). On the other hand, the highest population densities of zooxanthellae in the tissues of the four coral species were recorded at site 3 and the lowest densities occurred at site 6 for the corals *A. humilis*, *P. damicornis* and *S. pistillata* and at site 2 for the coral *P. verrucosa*. Concerning the monthly variations, the maximum zooxanthellae densities in the four coral species were recorded during the period October-December, while the minimum densities were counted during summer (July-August). The population densities of coral zooxanthellae varied significantly according to water clarity (Secchi disk readings and TSS). The maximum densities of zooxanthellae in the four coral species were recorded at sites with moderate Secchi disk reading and TSS. However, the minimum densities of coral zooxanthellae were recorded at sites with Secchi disk and TSS exceeded than 5.75 m and 147.5 mg/L, respectively (Table 5).

## Discussion

The stress responses of reef-building corals to a variety of environmental perturbations appear to originate in their symbiotic algae (Brown *et al.,* 1995). Coral bleaching occurs when corals loose their symbiotic zooxanthellae, either through the direct loss of the algal symbionts (Brown *et al*., 1995) or via the loss of host gastrodermal cells containing them (Gates *et al*., 1992). Offshore coral reef environments are generally regarded as being adapted to low turbidity and low-nutrient conditions. In contrast, near shore and coastal reef systems have evolved in relatively turbid environments where suspended sediment and turbidity are primarily influenced by local wind and wave action rather than by sediment supply. However, excessive inputs of sediment from land to coral reefs can lead to reef destruction through burial, disruption of recruitment success or deleterious community shifts. Sediment affects coral by smothering when particles settle out (sedimentation), reducing light availability (turbidity) and potentially reducing coral photosynthesis and growth.

Despite the variability of the present data, it is apparent that the population density of zooxanthellae in the tissues of the four coral species showed spatial variations and annual cycle. It is not clear, which factor or interacting factors are responsible for the seasonal changes in the density of these corals zooxanthellae.

The total suspended solids and water transparency along the Egyptian Red Sea varied widely according to the level of anthropogenic effects. Ras Mohamed (i.e. sites 5 and 6) considered as the clearest area with the highest Secchi disk reading and the lowest total suspended solids content. Consequently, the population density of zooxanthellae in the tissues of the four coral species showed healthy levels in this area. The dramatic decrease in the densities of zooxanthellae in the corals at sites 13 and 19 referred to the highest load of sediment at these sites.

The population density of zooxanthellae in the four coral species was affected by the content of total suspended solids in sea water. A significant quadratic regression was found between total suspended solids and zooxanthellae density in the four species. The highest population density of zooxanthellae of the four

**Table (4):** The seasonal average density of zooxanthellae ($\times 10^6$cells/cm$^2$) in the four coral species during the period of study.

| Species | *A. humilis* | | *P. damicornis* | | *P. verrucosa* | | *S. pistillata* | |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Mean** | **± S.D** | **Mean** | **± S.D** | **Mean** | **± S.D** | **Mean** | **± S.D** |
| **Spring** | 1.574 | 0.233 | 1.517 | 0.200 | 1.502 | 0.513 | 0.717 | 0.141 |
| **Summer** | 1.426 | 0.250 | 1.106 | 0.091 | 1.097 | 0.356 | 0.510 | 0.100 |
| **Autumn** | 1.631 | 0.293 | 1.766 | 0.212 | 1.606 | 0.507 | 0.634 | 0.127 |
| **Winter** | 1.714 | 0.234 | 1.668 | 0.176 | 1.573 | 0.529 | 0.735 | 0.141 |
| ***Mean*** | ***1.586*** | ***0.252*** | ***1.514*** | ***0.170*** | ***1.444*** | ***0.476*** | ***0.649*** | ***0.127*** |
| **Spring 2002** | 1.581 | 0.262 | 1.483 | 0.294 | 1.338 | 0.431 | 0.731 | 0.095 |

**Table (5):** Mean values of Secchi disc readings, TSS and zooxanthellae densities at all sites and four coral species.

| Sites | Mean Secchi disk | Mean TSS | **Mean zooxanthellae density** ($\times 10^6$ cell/cm$^2$) | | | |
|---|---|---|---|---|---|---|
| | | | *A. humilis* | *P. verrucosa* | *P. damicornis* | *S. pistillata* |
| **10, 13, 16, 19** | 5.75 | 147.5 | 1.31 | 1.32 | 1.09 | 0.52 |
| **7, 12, 14, 15, 17** | 15.2 | 66.6 | 2.92 | 2.68 | 2.78 | 1.25 |
| **1, 2, 3, 4, 5, 6, 8, 9, 11, 18, 20** | 21.2 | 22.7 | 1.64 | 1.43 | 1.70 | 0.62 |

coral species occurred at the sites with TSS values ranging between 60-70 m/L. At a stress point of TSS for all species, the zooxanthellae may be degraded or expelled from its coral host, and so, the density decreased dramatically. In *A. humilis*, tolerable concentration of TSS for zooxanthellae was 88.8 mg/L, whereas the higher values lead to a decrease in zooxanthellae count. Similarly, *P. damicornis* showed approximately the same tolerant capacity to TSS content (89.4 mg/L), while, *P. verrucosa* had the lowest tolerant ability to TSS load (81.7 mg/L). On the Other hand, *S. pistillata* considered as the most tolerant species to TSS load, the zooxanthellae density inside their tissues begin to leave the host at a TSS point of 99.5mg/L. Titlyanov *et al*. (2001) stated that *S. pistillata* is able to acclimate to changes in light intensities by two reactions: 1) changes in chlorophyll concentrations in zooxanthellae, and 2) changes in population density of zooxanthellae in corals. Other field investigations confirm that *S. pistillata* is able to dwell in both bright and extremely low light (Falkowski and Dubinsky, 1981; Porter *et al*., 1984; Titlyanov and Latypov, 1991; Titlyanov *et al*., 2000). Porter *et al*. (1984) analyzed whole coral colonies of *S. pistillata* (not exterior branches as studied by Titlyanov *et al*., 2000) and concluded that there was no significant change in zooxanthellae density with decrease in light levels. On the basis of investigations by Porter *et al*. (1984), Titlyanov *et al*. (2001), assumed that exterior branches of shaded colonies contained higher zooxanthellae density than exterior branches from well-illuminated colonies. At the same time, interior branches of shaded colonies lost zooxanthellae because of extremely low light intensity invoked by self-shading. The latter was shown by analyses of four orders of branches from colonies of *P. damicornis* and *P. verrucosa* living in shaded habitats in Sesoko, (Okinawa, Japan) (Titlyanov *et al*., 1988). Dubinsky and Jokiel (1994) examined *S. pistillata* colonies in northern Gulf of Aqaba from 66m depth, and found that zooxanthellae were only present in the upward facing portions of the colonies; there were no zooxanthellae in the downward facing portions, Titlyanov *et al*. (2000) found that the upward facing portions of *S. pistillata* colonies, taken from 2 to 3m depth, had approximately $12 \times 10^3$ zooxanthellae per polyp and about $25 \times 10^3$ zooxanthellae per polyp in colonies from 40m depth. However, the downward facing portions of the colonies taken from 40m depth harboured only $11 \times 10^3$ zooxanthellae per polyp.

The present study revealed that, the acclimation of the four studied coral species to sediment stress (i.e. low light intensity) varied among species. Significant changes in the population density of zooxanthellae appeared to be related to TSS, whereas zooxanthellae count increase with increasing TSS to a certain limit and then the relationship between the two variables become inverse due to the escape of zooxanthella under the stress of heavy load of TSS. The present annual average density of zooxanthellae showed variation among species and sites. The highest density (i.e. $1.529 \times 10^6$ cells/cm$^2$) was recorded in the tissues of the coral *A. humilis*, while the lowest (i.e. $0.648 \times 10^6$ cells/cm$^2$) was counted in the coral *S. pistillata*. The population density of zooxanthellae in the tissues of the four studied species in Sharm El-Sheikh area was more or less comparable with the same species in other regions around the worlds (Table 6). On the average, the highest density of zooxanthellae in all species was recorded mainly at site 3, which has the highest sedimentation rate (i.e. 4.8 mg /cm$^2$ /year) and TSS values (i.e. 40 mg/L), and the lowest transparency (i.e. 12m). All these three parameter are a function of low light intensity and irradiance. The present data are coincided with the results obtained by Titlyanov *et al*. (2001), who stated that in an aquatic environment with decreasing light intensity, corals responded by increasing cell division of zooxanthellae. On seasonal bases, zooxanthellae density in the tissues of the four studied corals exhibited a maximum peak during autumn (i.e. October-November) and a minimum values during summer months (July-August). This is in good agreement with findings of Fagoonee *et al*. (1999) for coral *A. formosa*, and Stimson (1997) for *P. damicornis*. On the other hand, the low density of zooxanthellae in the corals of the study area may be attributed to high temperature and water transparency. Gleason and Wellington (1993) observed a decrease in density of zooxanthellae in *Montastrea annularis* after 21 days of transfer to shallower waters in the Great Barrier Reef, and they experimentally demonstrated that this decrease is specifically in response to increased light. Similarly, Kinzie (1993) observed experimentally that colonies of *Montipora verrucosa* exposed to high irradiance for 62 days had significantly lower densities of zooxanthellae

**Table (6):** Variation in zooxanthellae density in some corals in different regions

| Species | Region | Zooxanthellae density x$10^6$ cell/cm$^2$ | Reference |
|---|---|---|---|
| *Acropora formosa* | Mauritius | 1.7 ± 2.4 | Fagoonee *et al*., 1999 |
| *A. humilis* | Sharm El-Sheikh | 1.529 ± 248 | Present work |
| *P. damicornis* | Kaneohe Bay, Hawaii | 1.2 ± 0.473 | Stimson, 1997 |
| *P. damicornis* | Sharm El-Sheikh | 1.514 ± 0.16 | Present work |
| *P. verrucosa* | Timor Sea, Timor | 0.9 4± 0.05 | Titlyanov *et al*., 1983 |
| *P. verrucosa* | Sharm El-Sheikh | 1.44 ± 0.466 | Present work |
| *S. pistillata* | Great Barrier Reef | 0.688 ± 0.02 | Titlyanov *et al*., 1981 |
| *S. pistillata* | Sharm El-Sheikh | 0.648 ± 0.119 | Present work |

than did colonies exposed to lower irradiance. Furthermore, increased water temperature has also been reported to result in lower densities of zooxanthellae in various cnidarians (Lesser *et al*., 1990; Stimson, 1997). The annual cycle of zooxanthellae density observed in the tissues of the four studied species could be also resulting from a combination of a constant growth rate of zooxanthellae population combined with a seasonal variation of skeletal/coral-tissue growth. In a season of high coral tissue/skeletal growth (i.e. summer), the growth of colony surface-area could exceed the growth rate of the symbiotic algal populations, resulting in a low algal density within the coral tissue. Alternatively, in seasons where tissue growth is low, algal densities could be higher. Stimson (1997) reported the same results in the coral *P. damicornis* in Kaneohe Bay (Hawaii).

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# إجهاد الترسيب وكثافة عشائر الزوزانثيلا فى بعض المرجانيات على طول شعاب الساحل المصرى للبحر الأحمر

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## الملخص العربـــى

تم دراسة الإختلافات الشهرية لكثافات الزوزانثيلا داخل أربعة أنواع من المرجان الصلب فى ستة مواقع للشعاب حول منطقة شرم الشيخ وذلك خلال الفترة من مارس 2001 وحتى مايو 2002 وهذه المرجانيات هى أكروبورا هيوميليس وبوسيلوبورا فيريكوزا وبوسيلوبورا داميكورنيس وستيلوفورا بيستيلاتا. بالإضافة إلى ذلك تم اختيار 14 موقع على طول الساحل المصرى للبحر الأحمر وذلك لدراسة الإختلافات المكانية لكثافات الزوزانثيلا ومدى تأثرها بزيادة محتوى المواد الصلبة العالقة.

وقد اختلفت كثافة الزوزانثيلا إختلافاً كبيرا من نوع لأخر من المرجان حيث سجلت أعلى كثافة لها داخل أنسجة المرجان أكروبورا هيوميليس (متوسط سنوى: 1.529 مليون خلية/سم$^2$)، فى حين سجلت أقل كثافة داخل أنسجة المرجان ستيلوفورا بيستيلاتا (متوسط سنوى: 0.649 مليون خلية/سم$^2$). وعلى الجانب الأخر كانت أعلى كثافات للزوزانثيلا داخل المرجان فى المواقع ذات الشفافية المتوسطة، وكذلك تركيزات متوسطة من المواد الصلبة العالقة، فى حين تزامنت أقل كثافة لها فى المواقع ذات شفافية أعلى من 5.75 م ومحتوى 147.5مج/لتر من المواد الصلبة العالقة. وبالنسبة للتغيرات الموسمية فقد سجلت أعلى كثافة للزوزانثيلا داخل أنسجة الأنواع الأربعة من المرجان فى الفترة من أكتوبر حتى ديسمبر بينما رصدت أقل كثافة فى فصل الصيف (يوليو- أكتوبر). ولقد توصلت الدراسة إلى أن لكل نوع من المرجان الصلب قدرة معينة على تحمل الزيادة فى تركيزات المواد الصلبة العالقة تتغير بموجبها كثافة الزوزانثيلا داخل المرجان.