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DISTRIBUTION AND ABUNDANCE OF THE GIANT CLAM TRIDACNA MAXIMA (BIVALVIA: TRIDACNIDAE) IN THE NORTHERN RED SEA

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Key words : giant clams, Tridacna, Tridacnidae, Bivalvia, Red Sea.

ABSTRACT

Giant clam populations were compared in 5 different sites, on the southern coast of the Sinai Peninsula, at the northern Red Sea. The sites varied in their substrata and in their exposure to the surface currents. Site 1 was the least in its exposure to the surface current, while site 5 was the most exposed site compared with the other sites. Eight depths (between the reef flat and 20 m deep) were surveyed in each site in which ***Tridacna maxima*** *was the dominant species, while* ***T. squamosa*** *was very rare. There were only 45 clams of the latter species, compared with 6709 clams of the former during the study. Clam abundance varied significantly among sites, depths and site-depth interaction (two-way-ANOVA, $P<0.0001$). Mean clam density varied between 1.6 and 0.1 clam m^{-2} between sites 1 and 5, respectively and these densities were found comparable to other places in the Indo-Pacific. About 95% of the clams were found between the reef edge and 5 m. Clam sizes were between 1 and 32 cm and there was a significant difference in sizes among different sites ($P<0.01$), and depths ($P<0.001$). Although site 1 has the most abundant population, it had the least empty shell mass due to the collection by man. Biomass of edible components in site 5 (preserved marine park) suggests the possibility of this animal to reach higher production in the other sites if protected from overfishing.*

INTRODUCTION

Among the different species of invertebrates colonizing the coral reefs in the Indo-Pacific area are the giant clams of the genus ***Tridacna***, which are dominant feature of the shallow waters where they are living (Rosewater, 1965). Giant clams are the largest bivalves that have ever existed and they are also of economic interest, since they are eaten in many countries and the adductor muscle has a high commercial value in South-East Asia, because of its high price (Munro, 1988). In addition to that, live clams are sold for aquaria traders in Europe and USA and shells have been sold for ornaments (Braley, 1992); and for tile industry in Indonesia (Firdausy & Tisdell, 1989). The lucrative trade in the world has lead to the clam overexploitation throughout much of their geographical range. Accordingly, all tridacnids were included in The IUCN Invertebrate Red Book as threatened species (Ballie & Groombridge, 1996).

Clam natural populations were investigated in many places in The Indo-Pacific region, such as Salvat (1971); McMichael (1975) on ***T. maxima***; Lewis *et al.*, (1988) ***on T. maxima*** and ***T. squamosa***; Hamner, (1978) on ***T. crocea***; Hardy and Hardy, (1969); Hester and Jones, (1974); Bryan & McConnell (1976); Pearson (1977); Hirschburger (1980); Munro (1988) on ***T. derasa*** and ***T. gigas***; Ledua ***et al.***, (1993) on ***T. tevoroa***. The distribution of the large species i.e. ***T. gigas*** and ***T. derasa***, has dramatically attenuated, either by exploitation or by some ecological factors (Munro, 1988).

The Red Sea is considered the northernmost extent of distribution of the giant clams, where there are two tridacnid species found, ***T. maxima*** and ***T. squamosa***. Mansour, (1946a, 1946b, 1946c, 1949) studied the morphological and biological peculiarities of ***T. elongata*** (***maxima***) and ***T. squamosa*** in the Red Sea. Hughes (1977) and Mergner and Mastaller (1980) confirmed the existence of the two-tridacnid species, mentioned before. While, Bodoy (1984) estimated the human impact on ***T. maxima*** near Jeddah, Saudi Arabia.

Although giant clams have not yet become scarce in The Red Sea as in The Pacific, their economical importance arose in the northern areas in the last 5 years. Here, the people have been collecting the most abundant species, ***T. maxima*** and export them to the European aquarium markets or selling their shells for ornaments in the local souvenir shops. So, in order to minimize the impact of those activities and to facilitate the fisheries management, stock assessment of the tridacnids has been investigated along The Red Sea coasts at the present time. Clam farming is also being tried in order to supply the traders with their needs, and to restock the depleted reefs.

The present study was planned to investigate distribution and abundance of tridacnids in the northern part of the Red Sea where 5 sites were selected along the western side of the Gulf of Aqaba, between Ras Nosrani and Ras Mohammed representing various environmental conditions and different degrees of human impact. Furthermore, the size structure and biomass of that clam were studied and compared with data pertaining to tridacnids from other areas in the world. This was done as a preliminary step of a long term plan to: a) study the clam stock assessment in the area; b) assess the potential of this tridacnid as an alternative fishery resource; and c) start farming the clams in order to supply the traders with their needs and to restock the depleted reefs.

MATERIALS AND METHODS

This study was carried out in January 1994. Five different sites were chosen at the southwestern shores of the Gulf of Aqaba, between Ras Nosrani and Ras Mohammed (Fig. 1). These sites were selected to provide a contrast in the environment in terms of substrates, reef width, degree of exposure to the surface currents and degree of human impact (mainly tourism activities).

Measurements:

Clam measurements were carried out using the belt transect survey method (Loya, 1972, Loya 1974, Mingoa and Minez, 1988). A propylene line of 30 m long was placed down on the bottom parallel to the shoreline at the given depth. An aluminum quadrate 1x1 m was put on both sides of the line to cover 60 m^2. Each of the clams found underneath the belt transect was counted after being identified and measured using a metal vernier caliper. Three transect replicates were measured, with 5 m interval in between, at each depth. Total area covered by this method was 180 m^2 at each depth and measurements were taken at different depths at each site. These depths are the reef flat, 3 m (Depth D), 5 m (Depth E), 10 m (Depth F), 15 m (Depth G) and 20 m (Depth H). Three different locations were surveyed on the reef flat, the back reef (Depth A), the mid reef (Depth B), and the reef edge (Depth C) Snorkeling was used when working on the reef flat, while SCUBA was necessary at deeper transects. Length-frequency histograms were constructed with 0.25 cm intervals to compare the size distribution between different sizes.

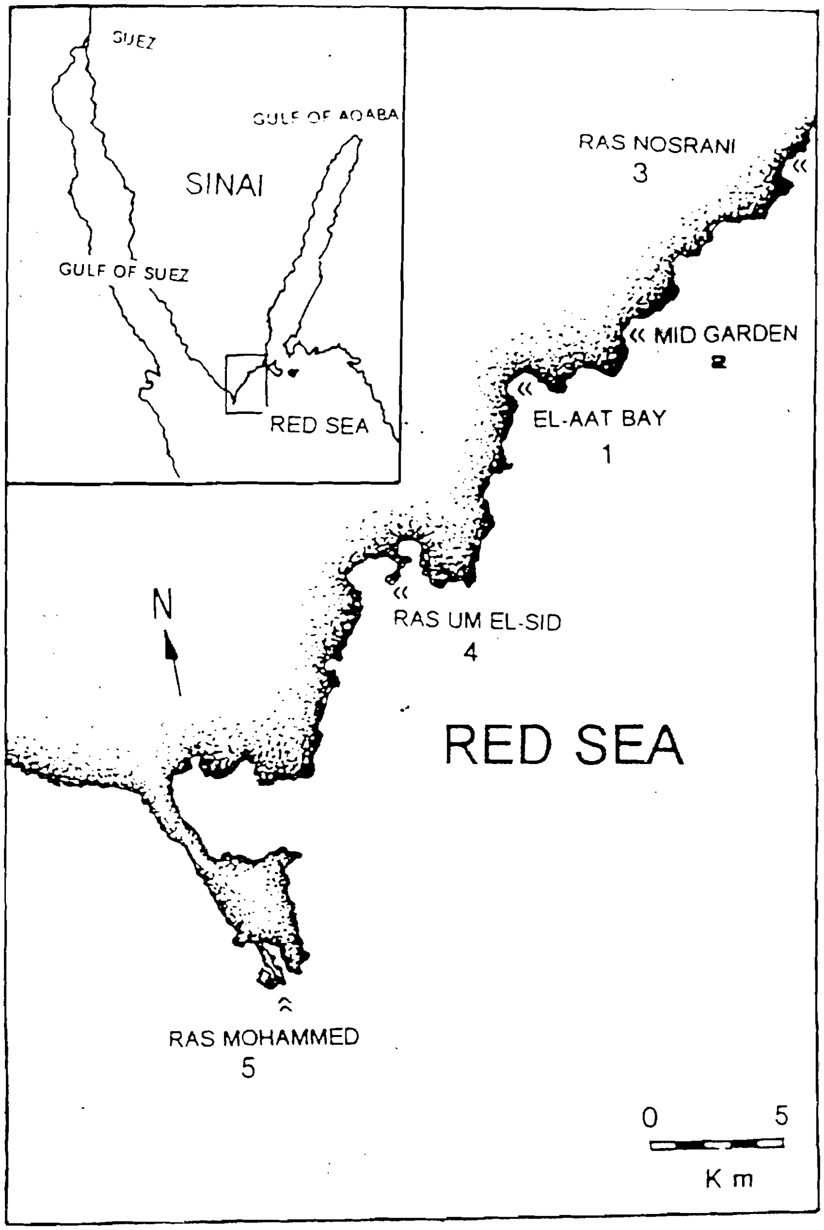

Fig. (1): Study area and sites

Biomass:

About 30 clams were collected every month (total 463 clams) from site 2 which chosen due to the high clam abundance that makes the removal of this number undestructive to the population. Clams were removed by cutting the byssal threads with a thin-bladed filet knife. After taking the animal to the laboratory, the maximum antero-posterior length was measured to the nearest cm using a vernier caliper and the wet weight was obtained by weighing the whole animal to the nearest gram, after water was drained from it. The clam was then dissected, and the flesh weight was separated and weighed to the nearest gram, then the adductor muscle was separated and weighed. Dry weight was determined to the nearest gram after drying the clam soft tissues at 85 ^{0}C in an oven, for 48 hour. The relationships between the clam length and each of the body total weight (wet weight), dry weight, adductor muscle weight and the empty shell weight were determined. The best fitting line in each relationship was calculated using the least squares regression analysis (SYSTAT, 1992). The equation was in the form:

$$Y = a * X^b$$

where Y is the weight of different body content (g), X is the clam length (cm), a and b are the intercept with the Y axis and the slope, respectively. The correlation coefficient (r) was determined with each parameter.

Statistical Analysis:

Statistical analyses to reveal differences in clam abundance and mean size among different sites and depths were performed using the General Linear Model procedure (SAS, 1993). Two-way-ANOVA was used to find the effect of site, depth and their interactions on the clam size and abundance. ANOVA was used after testing for normality with the Shapiro-Wilk statistic (SAS, 1993) and as a result, all analyses were run on the raw data.

Results:

In the present study, ***T. maxima*** were found to be the most abundant species among giant clams. Out of 6754 individuals recorded in the five sites under study, only 45 clams of the species ***T. squamosa*** were recorded. Most of which (23 clams or 51%), were encountered in site 1, the rest was distributed along sites 2, 3, and 4. None was found in site 5. ***T. squamosa*** was completely absent from Gulf of Aqaba North of 29 ^{o}N.

Abundance and Size Distribution:

The total number of ***Tridacna maxima*** found in the five sites was 6754 clams. Site 1 appeared to have the highest population density, where 2270 clams or 1.576 individual m^{-2}, while site 5 had the least abundance with 131 clams or 0.091 individual m^{-2} at all depths (Fig. 2). By comparing the clam abundance and number m^{-2} in each site and depth, it was found that the reef edge (Depth C) of site 1, had the maximum number (Fig. 2). There were significant differences between sites, depths and sites-depths interaction in the clam abundance and size, (Two-way ANOVA, $P<0.0001$, Table 1).

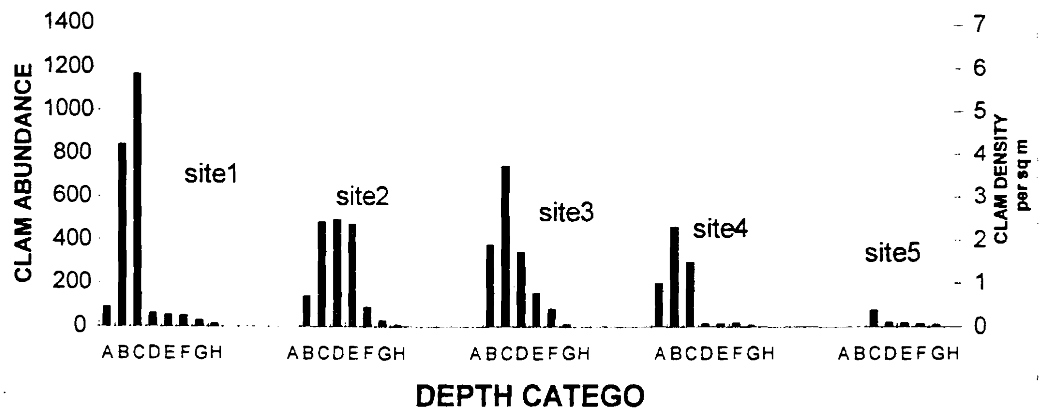

Fig. (2): *T. Maxima* total abundance and abundance m-2 over all depths in all sites. [A: Back Reef, B: Mid Reef, C: Reef Edge, D: 3m, E: 5m, F: 10m, G: 15m, H: 20m]

Length-frequency distributions from the five sites were constructed using size intervals of 0.25 cm (Figs. 3 a-e). Although site 1 had the highest density (2270 clams) at all depths, it lacked animals larger than 15 cm. Clam sizes in sites 2 and 3, were between 1 cm to 20 cm and 0.5 cm to 18 cm, respectively. Whereas, site 5 had the least clam abundance (131 clams), it had the largest animals recorded in the five sites.

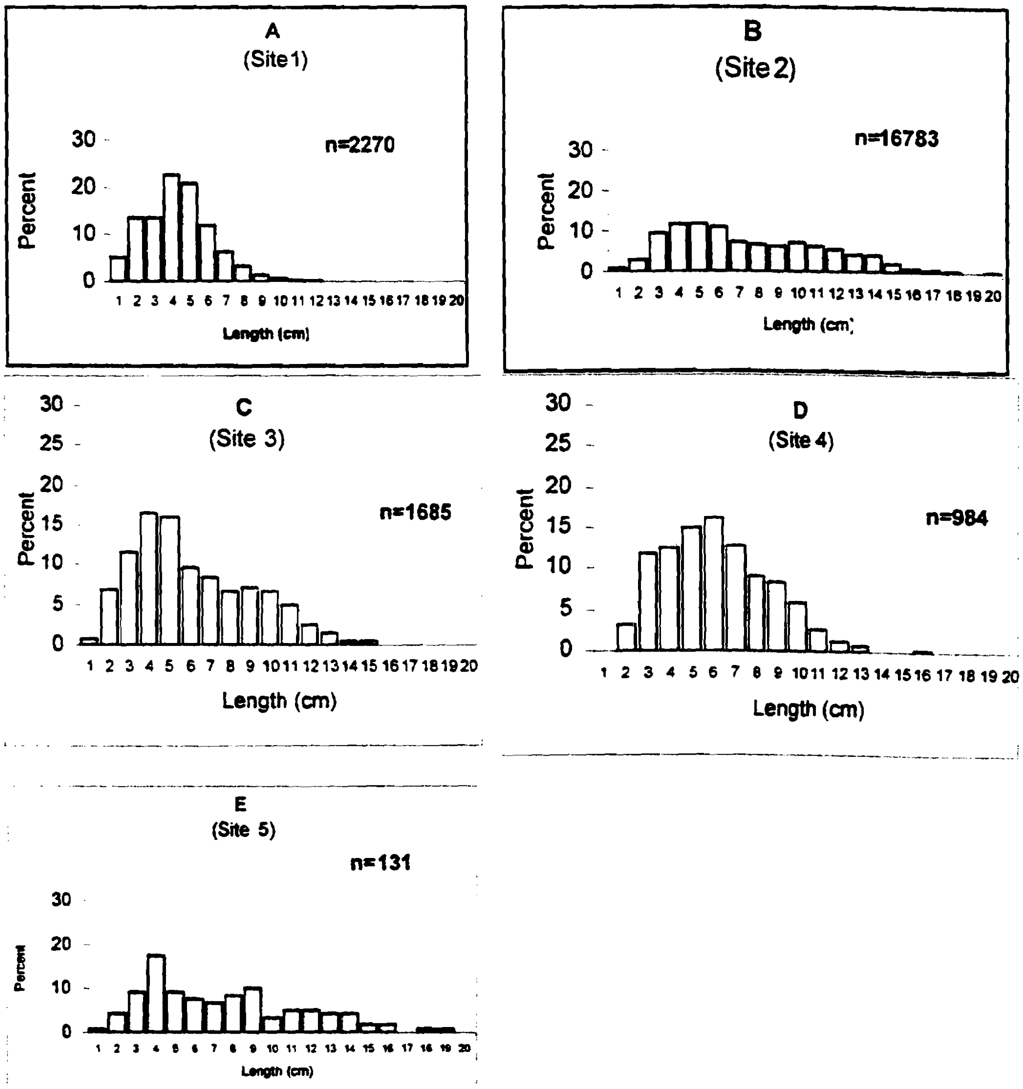

Fig. (3): Length-Frequency of T. maxima in all sites

Biomass:

Relationships between clam length (cm) and clam flesh weight, adductor muscle weight, and empty shell weight (g) were determined (Table 2). In each case the correlation coefficients a and b and the coefficient of determination (r) were estimated. Sites 2 and 5 had the highest and lowest estimated biomass, respectively. While site 1 had lower value in terms of empty shell, than in site 5.

Table (1A): Two-way-ANOVA on the effect of sites, depths and their interaction on the clam abundance. [DF: degrees of freedom; SS: sum of squares]

Source	DF	SS	Mean Square	F-value	P-value
Site	4	112029.03	28007.25	10.88	0.0001
Depth	7	435306.90	62186.70	24.16	0.0001
Site-Depth	28	387813.76	13850.49	5.38	0.0001
Error	80	205932.36	2574.15		

Table (1B): Two-Way-ANOVA on the effect of sites, depth, and their Interaction on the clam size distribution.

Source	DF	SS	Mean Square	F-value	P-value
Site	4	67.51	16.88	3.59	0.0096
Depth	7	311.33	44.47	9.45	0.0001
Site-Depth	28	387.77	13.84	2.94	0.0001
Error	80	376.32	4.70		

Discussion:

Distribution and Abundance:

The water movement in the northern part of the Red Sea is strongly influenced by southern winds which move large water masses towards the north, predominantly into the Gulf of Suez, and only partly into the Gulf of Aqaba. Over the shallow wide open Gulf of Suez, this water movement raises and transports large amount other sediments, thus reducing light penetration in the water (Sheppard *et al.*, 1992). This seems to be one of the factors that prevent development of intensive coral reef and associated organisms in this Gulf, at least along the Sinai coast. This is not observed in the Gulf of Aqaba, isolated from the Red Sea proper by the shallow and narrow Tiran Straits. This passage, of approximately 170 m depth, is crossed by two currents: the surface current moves water from the Red Sea into the Gulf of Aqaba, while the bottom current flows in the opposite direction. The narrow and steep littoral shelf of this Gulf, and its great depth, enable the rising and sinking of sediment only over narrow, isolated areas; thus the water in the Gulf remains clear and illuminated at great depths which enhance the flourishing of coral reefs and their associated fauna (Fishelson, 1971, 1980).

Table (2): .Relatioship between body length and different body weight parameters. Equations are given in the form: $y=a*x^b$ [All lengths and weights are in cm and gram, respectively, a and b: growth constants, r: coefficient of determination, n=465].

					95 % Confidence Intervals	
X	Y	A	B	r	LOWER	UPPER
Length	Wet Weight	0.24	2.93	0.94	2.81	3.05
Length	Flesh Weight	0.05	2.68	0.95	2.57	2.79*
Length	Shell Weight	0.19	2.91	0.94	2.79	3.03
Length	Adductor Weight	0.06	2.28	0.93	2.14	2.41*

*Not significant b<3

There are some vertical platforms of pleistocenic coral reef cliff formations in site 1 (Fishelson, 1971, Sheppard *et al.*, 1992) which rise to a height of 5-7 m, above the water line, facing the sea and protecting the shore from the prevailing winds. They might have given this site more shelter from the prevailing winds, compared with other sites. While site 2 and 3 are located in Tiran Strait, which weakens the southern current (Sheppard, *et al.*, 1992), on the other hand, site 4 is larval abundance with preferential survival. The seawater around the adult clams may stimulate competent larvae to settle or perhaps larvae actively settle near adult pseudofaeces. This hypothesis may well be applied on the present study. The original difference in the clam population abundance m^{-2} at different sites may be responsible for the continuous variation in the clam density between the five sites under study. The mean density in site 1 was 1.6 clams m^{-2} which is bigger than that at site 5 (0.[illegible] clam m^{-2}). Here, the distance between the clams, is greater than at site 1, which makes the animal response to the spawning stimulus more difficult, and as a result, the clam abundance will be always less.

The clam density m^{-2} in site 1 was found to be comparable to that in other parts of the Indo-Pacific sites. In the Eastern parts of the Red Sea, the abundance of ***T. maxima*** was found to be 0.22 clams m^{-2} (Bodoy, 1984). Other studies found different densities per m^2 in various sites (Table 3). The high abundant population in this area shows that natural characters can support the growth of tridacnid clams.

Clams were absent completely from the back reef (Depth A), at sites 2, 3, and 5. The sediments at these transects consist mainly of loose sands. This kind of substrate is very probably the reason for the lack of giant clams at these locations, since loose sands are thought to be not suitable for the settlement of the clam post-larvae. Hardy and Hardy (1969) attributed the absence of ***T. maxima*** from some sites to the presence of loose sediment, which is unsuitable for the byssal attachment of the clam. Most of the clams recorded in site 1 were found at the mid reef (Depth B) and reef edge (Depth C). Here the substrate consists mainly of calcified rocks, covered with dead and live corals mainly scleractinians (***Stylophora*** spp.) and hydrocorals (***Millepora*** spp.). Substrates suitable for the settlement and growth of giant clams were investigated by Rosewater (1965), Hardy and Hardy (1969), Hester and Jones (1974), Hirschburger (1980), Bodoy (1984), Brown and Muskanofola (1985), Richard (1985), Braley (1987a), Adams ***et al.*** (1988), Lucas (1988a), Juinio ***et al.*** (1989), and Munro (1989). The clam ***T. maxima*** attach itself firmly to the coral reef by its byssal filaments. Depending on the substrate, individuals may burrow deeply, although never becoming imprisoned as ***T. crocea*** (Rosewater, 1965, Lucas, 1988). Similarly, Munro (1989) found ***T. squamosa*** and ***T. maxima*** to be associated with coral reefs to which they are firmly attached by byssal threads throughout their adult lives. ***T. crocea*** erodes the coral heads to which it is attached and is normally embedded in the coral. On the other hand, ***T. gigas, T. derasa, Hippopus hippopus*** and subject to a strong southern surface current.. At the tip of Sinai, Ras-Mohammed (site 5), which faces the main Red Sea, the surface current is stronger, and this site is completely exposed to the southern current. Consequently, sites 1, 2, and 3 are considered to be more sheltered from strong surface currents, than sites 4 and 5, during most of the year. The difference in the strength and direction of the surface current may be responsible for the scarcity of the giant clams at site 5, as it results in dispersing the planktonic larvae. The currents' effect on the clam distribution in the Great Barrier Reef was found to be mainly on the planktonic larval stage. Braley (1984), Braley (1987a) and Braley (1987b) found that the larvae drift by the current patterns could be a factor accounting for the distribution of ***Tridacna gigas*** on the Great Barrier Reef. Also, Bodoy (1984) found that the clam distribution and growth may be affected by the velocity and direction of tidal currents. Similarly, Salvat (1972) encountered ***T. maxima*** on the windward side of the barrier reef of Gambier Islands. and thought that exposure could affect the clam quantitative distribution. Adams ***et al***. (1988) found that the distribution of ***T. derasa*** may be affected by the presence of enclosing reefs, the size of islands and associated with small islands. This may be due to the protection from wave action or a concentration effect on pelagic larvae. Accordingly, the fluctuation in the clam density over different sites may be attributed to the degree of exposure to the prevalent surface currents.

The giant clam abundance is stated by Wada (1952) to be related to the spawning mechanism. He found that a threshold concentration of gonad suspension could stimulate spawning response. Also he suggested that the possibility of fertilization occurring would decrease rapidly as the distance between the spawning adults increased. There is thus, a probability that a minimum population level exist at which no successful reproduction takes place even though adult clams are still present (Nash ***et al***., 1988). On the Great Barrier Reef, the results of nearest neighbor analysis on high natural population have shown clumping by species on some substrates Braley, (1984). Beckvar (1981) and Gwyther and Munro, (1981) found in some localities with low density populations of these clams, that the collection and placing of mature clams in close proximity to each other will assure greater success in fertilization. After fertilization, the larvae remain in the planktonic stage for 7-12 days after which they settle on the bottom (Beckvar, 1981). Juveniles may crawl for sometime till they find the suitable substrate to fix themselves permanently by the byssus filaments. The aggregation pattern of ***T. crocea*** (> 100 m^{-2}) on the surface of coral heads (Hamner, 1978) suggests a gregarious settling response or extreme

H. porcellanus are all free-living as adults and it is clear that a hard substratum is needed for settlement and attachment only in the juvenile stages (Adams ***et al.***, 1989, Munro, 1989). Similarly, Hester and Jones (1974), and Hirschburger (1980) thought that the habitat preferences in

Table (3): Comparison between the ***T. maxima*** abundance m^{-2} in different places in in the world and the present study.

Location	Number m^{-2}	Depth	Reference
Reao, Tuamotu Archipelago	50-70	-	Salvat, 1972
Northern part of the Red Sea (Site 1)	6.46	Reef edge	Present study
Takapoto lagoon, French Polynesia	1.5-6.7	<50 m	Richard, 1985
One Tree Island, Australia	0.8	Shallow	McMichael, 1975
Tuwwal, Saudi Arabia	0.22	-	Bodoy, 1984
Palau	0.031	2m	Hester & Jones, 1974
Cagayancillo Is., Philippines	0.009-0.026	0-15 m	Juinio ***et al.***, 1989
West Caroline Islands	0.014-0.025	-	Bryan & McConnell, 1976
Karimum, Indonesia	0.02	-	Brown & Muskanofola, 1985
Palau	0.005	<20m	Hardy & Hardy, 1969
Palau	0.002-0.082	-	Bryan & McConnell, 1976
Palau	0.003-0.04	-	Hirschburger, 1980

the giant clams would lead to patchy distribution. ***T. maxima*** was found in shallow water embedded in large brain corals and it can be distinguished by its more triangular shape; its byssus keeps it firmly anchored halfway deeply embedded than their normal half body depth, in coral and coral heads. While ***T. squamosa*** was noted to thrive in very diverse types of habitats which range from clear coral reef areas to turbid muddy-sandy bays with sparse stable substrates, the highest densities of ***T. squamosa*** were noted in sheltered (not exposed to strong currents) reefs (Hardy and Hardy, 1969, Juinio ***et al.***, 1989).

The effect of human impact on the giant clams population was observed in the variation of the clam abundance between sites 1 and 2 (Figure 3 a and b). The indiscriminate collection going on in some regions (e.g. Site 1) has resulted in reduced stocks of larger animals. Although this site is located close to site 2, the length frequency is clearly skewed to smaller sizes (Figure 5a and b) where site 1 (Naama Bay), with more than 10 hotels and villages, is more accessible than site 2, which is located at the end of a difficult rocky road. Site 1 suffers from heavy tourism activities like snorkeling and diving, that also impacts coral colonies. The tourists visiting this place tend to step on the coral colonies or collect giant clams in shallow waters. Some tourists were found to kill clams and feed them to fish and others kill clams for trophies or for food (Hawkins and Roberts 1993). People are attracted to the large size giant clams, especially those bigger than 9 cm. Flesh is used as bait, while shells are taken for ornaments.

Depth had a significant effect on the distribution of giant clams at all sites. Clam abundance was larger in shallow depths. About 95.40% of the total clams lying between the reef flat and 5 m deep. The depths at which the clam abundance was minimum at the back reefs (4.38% of the total number) and 20 m deep (0.37% of the clams). It was clear that the vertical distribution was mainly affected by the light intensity reaching the symbionts within the clam tissues. This symbiotic relationship has a profound effect on the ecology and morphology of the giant clams. Besides being phototrophic, they are also only found in shallow waters down to 15 m deep in clear conditions. They occur at less depths in turbid conditions (Hardy and Hardy, 1969, Fisher ***et al.***, 1985, Lucas, 1988a, Munro, 1989). Because of this kind of behavior, in the mariculture procedure and in the ocean-nursery phase, the clam juveniles are put in special trays between 0.3 m and 3.5 m deep. At these depths, the juveniles were found to grow faster than in deeper waters (Beckvar, 1981, Crawford ***et al.***, 1987, Braley, 1989, Hambrey and Lane, 1992). In a study on the nutrition of two species, it was found that the biggest giant clams; ***T. gigas*** satisfy all apparent carbon requirements from the combined sources of filter feeding and phototrophy (Klumpp ***et al.***, 1992).

Biomass

Site 2 was chosen to study the giant clam biomass, being one of the sheltered sites from human impacts and where clams attained a wide range of size. It is true that the abundance in site 1 was larger than in the other sites, but mean clam size was smaller. This was attributed to the more human impact in site 1 than in site 2. While in site 5, the clams are protected and grow to larger sizes, resulting in larger biomass even than site 1.

Giant clams have long been a part of the diet of the peoples in Indo-Pacific region where the entire flesh of these clams is edible, except for the kidney, and the adductor muscle is most sought after (Calumpong, 1992). The present study has found that the adductor muscle comprises about 35 % the wet flesh weight which is higher value than that recorded by Calumpong (1992), being only 10-15 %. As shown in the present investigation, the adductor muscle can reach 24.4 g m^{-2} and wet flesh weight 62 g m^{-2} (at 3 m deep in site 1), compared to 15.6 g m^{-2} of total wet weight of ***T. maxima***, recorded by Hardy and Hardy (1969) in Palau. The higher values obtained in the present study are outstanding and reflected the high production rates of some sites under study.

Schumacher and Zibrowius (1985) have emphasized on the importance of the giant clams in any reef comes from being a major source of the reef construction. In redefining the term hermatypic, these authors explained that marine animals that live in a symbiotic relationship with zooxanthellae and contributes in the reef building (as are the Tridacnidae) may be considered as hermatypic, even if it is non-scleractinian. In the present study, the estimated shell biomass was about $208.2x10^3$ g (in site 2) may act as a part of the reef wall. Site 1, on the other hand, makes only $27.9x10^3$ g of shell material due to smaller clam sizes there. In most of the studied sites, the giant clams are not overexploited but it should be clear that if this happens, it might cause a loss of a source of reef construction.

Conclusions:

The importance of this work comes from being the first study to be done on the distribution and abundance of giant clams in the northern Red Sea. In this area giant clams are represented by two species, ***Tridacna maxima*** and ***T. squamosa***, with the former being most abundant (more than 98 % of the clams found).

Comparison of ***T. maxima*** population in different sites has shown that this species is most abundant in site 1 and least in site 5. The clam size did not show the same trend, with mean size being larger in site 2 than in the other sites. With regard to depths, giant clams were more abundant on the reef edge but least at 30 m deep. Light intensity may be the main limiting factor in depth distribution, while the degree of shelter of any site from the prevailing currents may be responsible of the distribution over sites.

Clam abundance at depth C (reef edge) in site 1 (6.46 m^{-2}) was higher than those reported in other places in the Pacific (less than 4 m^{-2} in French Polynesia). Similarly, the maximum length recorded in sites 1 and 5 (25 m deep) was 32 and 35 cm, respectively, also larger than in some places in the Pacific.

Even though the most abundant population was found in site 1, the largest biomass was recorded in site 2. The edible parts in the clams (flesh and adductor muscle) may produce about 62 and 25 g m^{-2}, respectively. This may indicate the potential of this sites as a new and expensive source of fishery.

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