

Coral Reef Reproduction and its features in the Arabian Gulf (Jebel Ali, UAE)

Ahmed Al-Hashmi*, Waleed Hamza, Gaber Ramadan

United Arab Emirates University, UAE

Abstract

Very little information is known about coral species reproduction in the Arabian Gulf. The present study has chosen the area of Ghantoot reserve in Jebel Ali (Saih Al Shaib- Dubai at UAE), which has a high biodiversity in both fauna and flora, to study the reproductive patterns, timing and degree of synchrony in spawning of coral species living at the coastal area of Jebel Ali. It also aimed to determine the impact of environmental parameters variations on gametogenesis and length of the reproductive season of the coral by finding out the proportion of their population with mature eggs. In that regard, four species (*Acropora downingi*, *Cyphastrea micropthalma*, *Platygyra daedalea* and *Porites harrisoni*) were selected as the most dominant ones and studied along a period of one-year round (August 2008 - August 2009). The results obtained have shown that three of the studied species were hermaphroditic and the other was gonochoric. Ovaries and spermaries were seen clearly by the histological section. The physical environmental factors showed a strong relation with the reproduction. Water temperature was the main factor affecting the reproductive cycle of all the species. The present study has also documented the coral spawning in field and reported to happen in the period extending from March to May. Moreover, the oogenesis lasted for 6-8 months, while the spermatogenesis extended for only two months. This study can be considered as a baseline for the coral reproduction studies in this region. It also opens new horizons for future investigations regarding the coral reefs management in the region and to alert decision makers toward the need of conserving such valuable natural resource.

Keywords: *Scleractinian corals, Environmental impact, Corals' reproduction, Arabian Gulf*

1. Introduction

Studies on coral reproduction have been conducted in different places in the world and revealed many interesting information describing the different strategies of reproduction in corals. These studies were conducted in Japan (Hayashibara, 1993), Australia (Harrison, 1984; Babcock, 1986, Wilson and Harrison, 2003), Caribbean (Szmant, 1986), Central Pacific (Kenyon, 1995), Red Sea (Shlesinger et al, 1998), Kenya (Mangubhai and Harrison, 2008) and Arabian Gulf (Fadlallah, 1996). It helped in better understanding the ecology of the corals, their response to the

surrounding environment and its changes and finding some solutions in order to ensure their sustainability although very little information is known about the Arabian Gulf species. The Arabian Gulf is characterized by its harsh environmental conditions such as high water temperature and salinity (Coles 1988; Sheppard, 1991; Coles and Fadlallah, 1991; Sheppard, 1992). The targeted site coordinates for the present study was N24° 58' 18.192", E54° 57' 59.0034" which is the Jebel Ali reef known as Saih Al-Shaib, opposite to Ghantoot reserve (Figure 1). This area

* Corresponding author: buhumdan@hotmail.com

has a high biodiversity in both fauna and flora. Recently many coastal construction development and industrial projects took place in the area and imposed a serious threat on the reefs sustainability.

This induced the scientists' interest including this research in investigating the impacts of these projects on the continuity of the ecosystem.

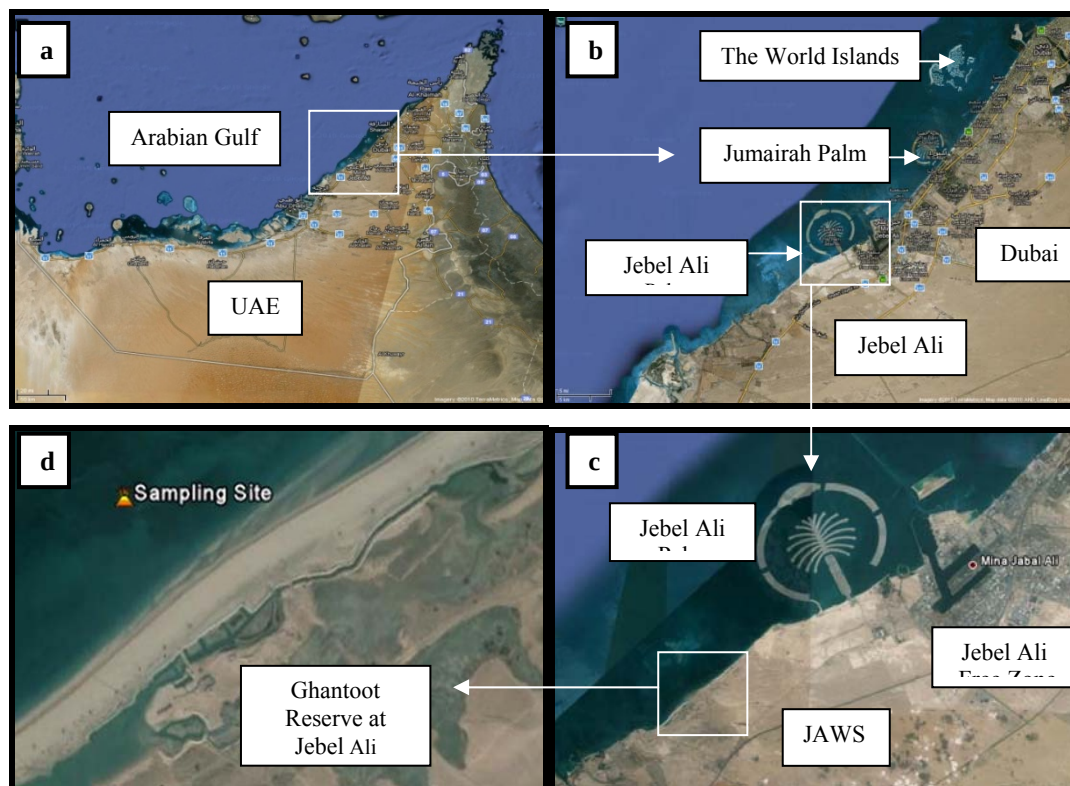


Figure 1: Detailed zooming on the sampling site

The objectives of this research were to study the reproductive patterns, timing and degree of synchrony in spawning of coral species living at the coastal area of Jebel Ali, and to determine the impact of environmental parameters variations on gametogenesis, length of the reproductive season of the coral by finding out the proportion of their population with mature eggs. In that regard, four species (*Acropora downingi*, *Cyphastrea microphthalma*, *Platygyra daedalea* and *Porites harrisoni*) were selected as of the most dominant ones and studied along a period of one-year round (August 2008 - August 2009). These four species belonged to Acroporidae, Faviids and Poritidae families. The reasons of choosing this study area are: (a) the dominance and high diversity of the reef species and (b) the existence of previous studies on these areas (Riegl, 1999 and Burt,

2008). The average depth of the site ranged between 4-6m.

2. Materials and Methods

Monthly ten samples of each of the four species were collected and analyzed, while environmental parameters (e.g. temperature, salinity, turbidity, chlorophyll-*a* and dissolved oxygen) data were measured and recorded on daily basis in the environment surrounding the corals. Samples were collected in situ usually from 9:00AM to 12:00PM prior to the full moon of each month and then preserved in 10% formaldehyde sea water for 24 hours followed by a rinse with running tap water for ½ hour to remove the excess fixative before storing in 70 % ethanol solution for further

analyses. Samples were then processed for paraffin technique (Shlesinger and Loya (Shlesinger and Loya, 1985; Fadlallah, 1996; Shlesinger et al, 1998).

Histological and dissecting analyses were carried out to study the sexuality, the timing and the reproductive patterns of the corals. *Acropora downingi* and *Cyphastrea microphthalma* were analyzed by microscopical analysis with more than 360 polyps. On the other hand, *Porites harrisoni* and *Platygyra daedalea* were analyzed by histological techniques (Guest, 2004). Samples were then processed for Paraffin technique. Tissue samples were oriented in paraffin blocks to obtain polyps longitudinal sections. Serial sections (5-7 μ) were produced by automatic Microtome (MICROM HM 315), mounted on slides and stained with Hematoxylin and Eosin for further examination.

Gametes of *Porites harrisoni* found in this study follow the description given by Glynn et al. 1994; and Muramatsu and Silveira, 2008. The number of the oocytes, their diameter and percentage of the colonies having the reproductive organs were recorded and calculated in order to find out the effect of the physical environmental factors on the coral reproduction.

Water Quality parameters include temperature, salinity, turbidity, chlorophyll-*a* and dissolved oxygen were monitored during the study period by using the combined WetLabs' fluorometer-turbidity sensor and Sea-Bird's multi-parameter. WQM is deployed on strategic locations around 5m of depth during the study period (September 2008 - July 2009).

Data were statistically analyzed using the SPSS for Windows (version 18, 2010) that used to measure the strength of association between two variables and used to investigate the most effective environmental parameters on the production and productivity of the different species during the study period.

3. Results and Discussion

The studied coral species, *Acropora downingi*, *Cyphastrea microphthalma* and *Platygyra daedalea*, were known to be hermaphrodites and reproduce in Jebel Ali with gametes development

having oocytes and spermaries intermingled on the mesentery. The only species that was found to be gonochoric is *Porites harrisoni*. Since spawning was not observed directly in the field, we indicated the approximate spawning time by the disappearance of the oocytes in the dissecting analysis and the histological sections of the reproductive organs. It has been found that all the four studied species have a single annual cycle of gametogenesis.

The timing of gametogenesis and spawning is thought to be controlled by a number of factors, which can be divided into the underlying evolutionary causes ('ultimate factors') and the mechanisms ('proximate cues') responsible for controlling reproductive patterns (Tranter, 1982; Oliver et al, 1988; Richmond and Hunter, 1990; Harrison and Wallace, 1990; Hayashibara, 1993; Wilson and Harrison 2003; Rosser and Baird, 2008; Baird et al, 2009).

Synchrony is also affected by many factors such as the temperature of the sea surface (SST) that has a major effect on the physiology of the spawning species in a certain location (Tranter, 1982, Rosser and Baird, 2008, Baird et al, 2009).

The four studied species have shown to be broadcast spawners as evidenced by: (a) the presence of large spermaries in polyps and mature pigmented oocytes seen in situ in *Acropora downingi* and *Cyphastrea microphthalma*. While, for the *Porites harrisoni* and *Platygyra daedalea* the oocytes were seen only in vitro by the histological sections, and (b) the lack of planulae in all samples.

The oogenesis of the *Acropora downingi* in the Arabian Gulf extends over a period of 7 to 8 months same as found in *Acropora variabilis* in the Red Sea (Shlesinger et al, 1998). For the *Acropora downingi* it is predicted to spawn in the Arabian Gulf during the period between Mar/Apr. Where, the percentage of the colonies containing reproductive organs dropped from 70% in March to 20% in April which indicates a major spawning in April (Table 1). On the other hand, another spawning had occurred in April as the oocytes disappeared in May. This showed that *Acropora downingi* has major and minor spawning events. Similarly to *Acropora downingi*, the oogenesis of the *Cyphastrea* species in the Arabian Gulf and in the Red Sea extended for the same period

(Shlesinger et al, 1998). The smallest detectable oocyte had a mean diameter of 160 μ m in September 2008 (Figure 2). The mean diameter of oocytes at maturity was 636 μ m in April with a pink to orange color prior to spawning (Table 2). The October samples were lost and this might be because they were not well preserved.

Table 1

Percentage (%) of colonies with gonads of the four studied species throughout the study period from Jul 08/ Jul 09

Year	2008				2009						
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
<i>Acropora downingi</i>	40	-	60	80	100	100	80	20	-	-	-
<i>Cyphastrea microphthalma</i>	-	-	60	100	80	100	100	100	100	-	-
<i>Platygyra daedalea</i>	-	-	50	70	50	50	80	50	30	-	-
<i>Porites harrisoni</i>				20	70	90	70	100	100	-	-

Table 2

Monthly mean of the oocyte diameter in micrometer (μ m)

Year	2008				2009						
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
<i>Acropora downingi</i>	164	-	290	336	326	428	545	636	-	-	-
<i>Cyphastrea microphthalma</i>	-	-	90	81	99	126	143	259	321	-	-
<i>Platygyra daedalea</i>	-	-	39	61	75	81	112	159	240	-	-
<i>Porites harrisoni</i>	-	-	-	11	12	20	63	95	104	-	-

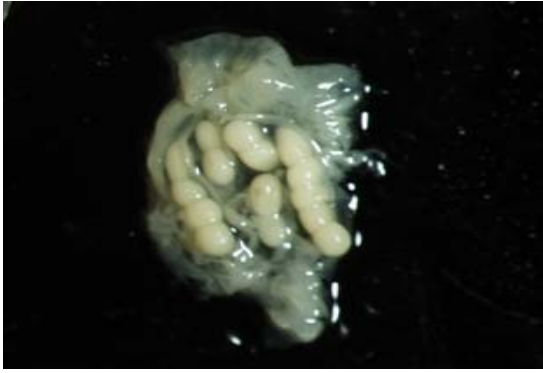


Figure 2: *Acropora downingi* ovaries and oocytes

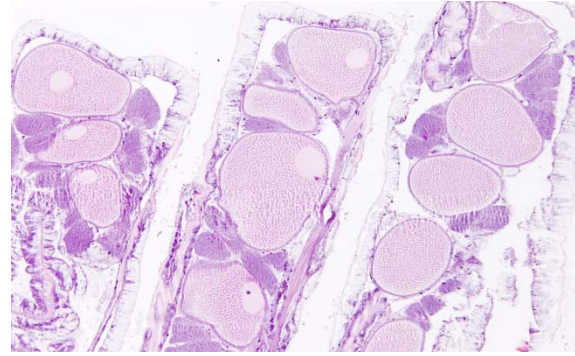


Figure 5: *Platygyra daedalea* oocytes integrated with the spermaries



Figure 3: *Cyphastrea microphthalma* polyps and the ovaries containing the oocytes

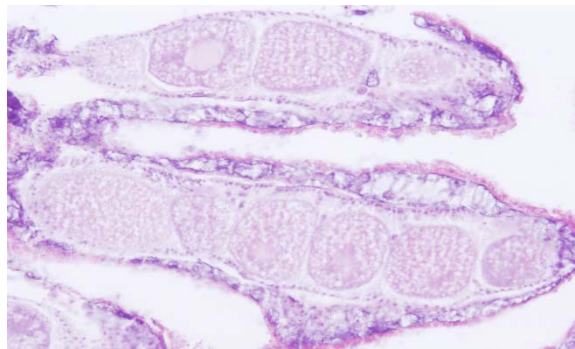


Figure 6: Female organs of *Porites harrisoni* (oocytes)



Figure 4: *Platygyra daedalea* orange colored eggs during spawning

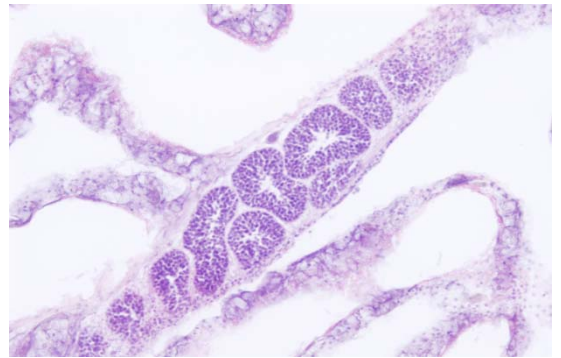


Figure 7: Histological dissection of the male organs of *Porites harrisoni* (spermaries)

On the other hand, around three colonies of *Cyphastrea microphthalma* were seen spawning on the same day of *Platygyra daedalea* spawning. The smallest detectable oocyte of *Cyphastrea microphthalma* had a mean diameter of 60 μm in November 2008 (Figure 3). The mean diameter of oocytes at maturity was around 320 μm in May, 2009 (Table 2).

Regarding *Platygyra daedalea*, the oocytes appeared in some colonies as early as November, but were low in abundance until May, indicating that the oogenic cycle may last for six to seven months similar to *Platygyra daedalea* in Kenya (Mangubhai and Harrison, 2008), whereas spermatogenesis lasted for two months (Table 1). *Platygyra daedalea* and *Cyphastrea micro-*

phthalma were recorded their spawning in May the day of the full-moon and one day after. Around five colonies of *Platygyra daedalea* were seen with orange colored eggs (Figure 4). The oogenesis occurred for 6-7 months from November 2008 - May 2009 and spermatogenesis occurred for 2 months from April to May 2009 (Figure 5). The minimum mean oocyte diameter for *Platygyra daedalea* was 39µm and the maximum mean was 240µm (Table 2).

In the literature, there were no studies about *Porites harrisoni* species. The only close species that was found in details were *Porites lutea* and *Porites lobata*. Studies on reproduction of *Porites lutea* have been done in the Great Barrier Reef (GBR), Heron Island (23°S) (Kojis and Quinn, 1981), Singapore (1°N) (James, 2004) and the Northern Red Sea at Eilat (29°N) (Shlesinger et al, 1998). In all of these studies, *Porites lutea* was gonochoric and a broadcast spawner. Reproductive characteristics, such as the length of the gametogenic cycle in this study, were different from those found for *Porites lutea* and *Porites lobata* on the Great Barrier Reef (Kojis and Quinn, 1981; Harriott, 1983; Babcock et al, 1986) and in the Red Sea (Shlesinger et al, 1998). *Porites harrisoni* in the Arabian Gulf spawn in May. In addition, the duration of the gametogenesis extended for 4 to 6 months for the oogenesis and two months for the spermatogenesis (Figure 6,7). The minimum mean oocyte diameter found in

Porites harrisoni was 11µm and the maximum mean was 104 µm (Table 2).

The obtained results have confirmed water temperature as a significant factor determining the general timing of annual spawning at high-latitudes (e.g. Shlesinger and Loya, 1985; Van Woesik, 1995; Wilson and Harrison, 2003; but see Babcock et al, 1994). However, global comparisons of coral spawning times and Sea Surface Temperatures (SSTs) showed that there were a number of inconsistencies in this relationship. A dramatic increase in the average size of both oocytes and testes in the studied species, over a 3 month period from January to April in 2009, coincided with a rise in the mean of the monthly SST of 5°C (from 23-28°C) (Table 3), therefore the main spawning times occurred when SSTs were rising. These findings are consistent with those from other regions, where the final maturation of gametes and spawning coincided with the period when SSTs are warming (Harrison and Wallace, 1990; Richmond and Hunter, 1990). These data lend support to the hypothesis that gamete maturation in corals is regulated by a rapid change in SSTs (Babcock et al, 1986). Orton's rule predicts that breeding in marine invertebrates should be continuous above some critical temperature (Orton, 1920). The mass spawning occurs after the spring temperature rise when the temperature is well below the summer maximum (Harrison & Wallace 1990). This is found in the Red Sea and the Arabian Gulf as well.

Table 3

Monthly water measurements of the temperature, salinity, turbidity, dissolved oxygen and chlorophyll-a

Year	2008				2009						
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Temperature (C°)	31.4	29.8	26.3	22.6	20.4	20.2	22.9	24.6	28.46	31.0	31.9
Salinity (PPT)	40.2	40.1	40.8	40.6	41.4	41.1	41.3	40.0	40.4	41.1	41.4
Turbidity (NTU)	1.7	1.3	1.8	2.5	2.3	1.6	2.1	1.4	1.4	1.5	1.0
Dissolved Oxygen (mll-1)	3.7	3.3	3.8	4.0	4.3	4.0	3.8	4.0	3.7	3.7	3.6
Chlorophyll-a (ugl-1)	1.7	1.6	1.8	1.9	1.9	1.3	1.5	1.3	1.0	1.4	1.3

The high salinity during the winter may be due to the retreats of the front water masses of the Arabian Gulf towards the Strait of Hormuz as suggested by Kämpf in 2006, while in summer the increase of water temperature may lead to an increase in the water evaporation rate and the salinity as well (Table 3). The statistical results showed no relation between the salinity and any factor of the coral reproduction patterns. However, it is hard to think of any reasonable biological basis for salinity as a seasonal reproductive cue in corals. That is especially if we know that such species are living in the Arabian Gulf since a long times and they became adapted to its salinity fluctuations (WCMC, 1991).

The increase in turbidity during the winter could be due to the strong currents affecting the area, while the other peak recorded in March might be caused by the action of Shamal wind and/ or the nearby human activities represented by dredging operations related to coastal constructions projects in the area. The results showed that colonies with reproductive organs of *Acropora downingi*, while the average number of oocytes per polyp of *Acropora downingi* was the only affected stage, whereas the *Porites harrisoni* was not affected by the turbidity. The spawning was seen to occur when the turbidity drops from 1.8 to 1.3 NTU (Table 3).

Satellite monitoring showed that the region of the Arabian Gulf is characterized by a constantly low Chlorophyll-*a* with a maximum in winter and a minimum in spring-early summer (Nezlin, 2007). However, the critical chlorophyll change that induces spawning was when its value dropped from 1.5 to 1 $\mu\text{g l}^{-1}$. It has been concluded from the statistical results that the chlorophyll-*a* is a cofactor acting synergistically with the temperature to affect the percentage of colonies containing reproductive organs of *Acropora downingi* and *Porites harrisoni* (Table 3).

Dissolved oxygen (DO) levels are usually inversely proportional to the water temperature (Table 3). The DO was shown to exert a positive effect on the percentage of the colonies with reproductive organs in all the species. The strong positive correlation may be because the oxygen had played an important role in the growth and the development of the early stages of the oocytes

before the zooxanthella had appeared and entered the oocytes membrane at the late stages (Kojis and Quinn, 1981; Heyward, 1986; Tomascik and Sander, 1987). Although this conclusion has never been cited elsewhere by any of the published literatures, our statistical analyses have supported such finding, which may have an ecological sound basis in the present study.

According to our results, it has been found that the temperature was the main environmental factor affecting the reproduction of almost all coral species with a minor exception of *Porites harrisoni*. Studies showed that there was a temperature increase by 2°C between 1996 and 1998 where *Acropora* species were highly bleached in Dubai (Riegl, 1999; George and John, 1999; Sheppard and Loughland, 2002), while Poritidae were much less vulnerable and damaged.

Coral Reef Management

Studying of coral reproductive cycles is an important part of our understanding base on the ecological processes of coral reefs and, by itself, is essential for their management and conservation. Successful coral reproduction is necessary for getting new colonies to a reef and the recovery of destroyed sites by natural or anthropogenic turbulence. An understanding of coral reproductive cycles and the impact of environmental factors on reproduction is for that reason vital in comprehending the potential of this important part of the life cycle. That's why it important to conduct some regular monitoring and surveys for coral reefs reproduction, recruitment, ecosystem etc... to understand their behavior and what the main threats are. It is believed that this study will help to select the best time for any marine project or coral translocation. As we found that during summer (June – August), corals don't have any reproductive spermaries or oocytes. However, in summer the hot weather and temperature should be considered. Also, it shows us the main environmental factors that play a role in reproduction and we need to consider them during the projects such as: temperature and dissolved oxygen concentrations.

4. Conclusion

The present study has documented the coral spawning in field and reported that it happens in the period extending from March to May. Moreover, the oogenesis lasted between 6-8 months for the four studied species (September – May), while the spermatogenesis extended only for two months (April - May). To this extent, it has been found that this study can be used as a baseline for the coral reproduction studies in this region. The fact that the four unrelated species had almost identical seasonal reproductive patterns indicates that there may also be a high degree of multi-species reproductive seasonality and synchrony (i.e. other scleractinian species may respond similarly to seasonal cues), both in terms of gamete maturation and in terms of spawning. It also opens new horizons for future investigations regarding the coral reefs management in the region and to alert decision makers toward the need of conserving such valuable natural resource.

References

- Babcock R.C., G. D. Bull, P. L. Harrison, A. J. Heyward, J. K. Oliver, C. C. Wallace and B. L. Willis (1986), "Synchronous spawnings of 105 scleractinian coral species on the Great Barrier Reef", *Marine Biology*, Vol. 90, pp. 379-394
- Babcock R.C B. L. Wills and C. J. Simpson (1994), "Mass spawning of corals on a high latitude coral reef", *Coral Reefs*, Vol. 13, pp. 161-169
- Baird A., James R., Guest, and Bette L. Willis (2009), "Systematic and Biogeographical Patterns in the Reproductive Biology of Scleractinian Corals", *Annual Review Ecology Evolution Systematic*, Vol. 40, pp. 551–71
- Burt J, Bartholomew A, Usseglio P. (2008), "Recovery of corals a decade after a bleaching event in Dubai, United Arab Emirates", *Marine Biology*, Vol. 154 No. 1, pp. 27-36
- Coles S.L. (1988), "Limitations of reef coral development in the Arabian Gulf: temperature or algal competition", *Proceeding of the 6th International Coral Reef Symposium, Townsville, Australia*, Vol. 3, pp. 211-216
- Coles, S.L. & Fadlallah, Y.H. (1991), "Reef coral survival and mortality at low temperatures in the Arabian Gulf: new species-specific lower temperature limits", *Coral Reef*, Vol. 9, pp. 231-237
- Fadlallah YH (1996), "Synchronous spawning of *Acropora clathrata* coral colonies from the western Arabian Gulf (Sudia Arabia)", *Bulletin of Marine Science*, Vol. 59 No. 1, pp. 209-216.
- George J, John D. (1999), "High sea temperatures along the coast of Abu Dhabi (UAE), Arabian Gulf—their impact upon corals and macroalgae". *Reef Encounter*, Vol. 25, pp. 21–23
- Glynn, P. W., S. B. Colley, C. M. Eakin, D. B. Smith, J. Cortes, N. J. Gassman, H. Guzman, J. B. Del Rosario, and J. S. Feingold. (1994), "Reef coral reproduction in the eastern Pacific: Costa Rica, Panama and Galapagos Islands (Ecuador). II. Poritidae". *Marine Biology*, (Berl.) Vol. 118, pp. 191-208.

Acknowledgements

This research project would not have been possible without the support of many people. In that concern, I would like here to express my appreciation to the Biology Department, Faculty of Science - United Arab Emirates University for supplying all technical support and laboratory facilities. I would also like to convey thanks to the Head of the Emirates Marine Environmental Group (EMEG) Major Ali Saqer Al Suwaidi for providing the logistical support in the field and the Dubai World – EHS (Trakhees) for the laboratory facilities in Jebel Ali. This work is partially financed by the United Nation University (UNU), through the scholarship grant agreed with UAE University.

- Guest J. R. (2004), "Reproductive Paterns of Scleractinian" Unpublished PhD thesis, National University of Singapore
- Harriott V. J. (1983), "Reproductive ecology of four scleractinian species at Lizard Island, Great Barrier Reef", *Coral Reefs*, Vol. 2, pp. 9-18.
- Harrison PL, Russell C. Babcock, Gordon D. Bull, James K. Oliver, Carden C. Wallace, Bette L. Willis (1984), "Mass Spawning in Tropical Reef Corals", *Science, New Series*, Vol. 223, No. 4641, pp. 1186-1189
- Harrison PL, Wallace, C.C. (1990), "Reproduction, dispersal and recruitment of scleractinian corals. In: Dubinsky", (ed.) *Ecosystems of the world*, Vol. 25, *Coral Reefs*. Elsevier Science Publishers, Amsterdam, pp. 133-207
- Hayashibara T., Shimoike K., Kimura T., Hosaka S., Heyward A., Harrison P, Kudo K., Omori M. (1993), "Patterns of coral spawning at Akajima Island, Okinawa, Japan", *Marine Ecology Progress Series*, Vol. 101, pp. 253-262
- Heyward AJ (1986), "Sexual reproduction in five species of the coral Montipora. In: Jokiel P. L., Richmond R. H., Rogers R. A. (ed.) *Coral Reef Population Biology*. Hawaii Institute of Marine Biology, Hawaii, pp. 170-178
- James, R. G. (2004), "Reproductive patterns of scleractinian corals on Singapore's reefs" *Unpublished PhD thesis*, National University of Singapore.
- Kämpf, J. and Sadrinasab, M. (2006), "The circulation of the Persian Gulf: a numerical study", *Ocean Science*, Vol. 2, pp. 27-41
- Kenyon J.C. (1995), "Latitudinal Differences between Palau and Yap in Coral Reproductive Synchrony", *Pacific Science*, vol. 49, No. 2, pp. 156-164.
- Kojis BL, Quinn N. J. (1981), "Reproductive strategies in four species of Porites (Scleractinia)". *Proceedings of the 4th International Coral Reef Symposium*, Manila, Vol. 2, pp. 145-151
- Mangubhai, P. L. Harrison (2008), "Gametogenesis, spawning and fecundity of *Platygyra daedalea* (Scleractinia) on equatorial reefs in Kenya", *Coral Reefs*, 27, pp. 117-122
- Muramatsu D. and Silveira F. I. (2008), "Gametogenesis in *Madracis Decactis* Lyman, Ilha Grande Bay (Rio De Janeiro), Southeastern Brazil", *Brazilian Journal of Oceanography*, Vol. 56 No. 4, pp. 297-305
- Nezlin P. N. Igor G. Polikarpov and Faiza Al-Yamani (2007), "Satellite-measured chlorophyll distribution in the Arabian Gulf: Spatial, seasonal and inter-annual variability", *International Journal of Oceans and Oceanography*, Vol. 2 No 1, pp. 139-156
- Oliver J. K., Babcock R. C., Harrison P. L., Willis B. L., (1988), "Geographic extent of mass coral spawning: clues to ultimate causal factors". *Proceeding of the 6th International Coral Reef Symposium*. Vol. 2, pp. 803-10
- Orton J. H., (1920), "Sea temperature, breeding and distribution in marine animals", *Marine Biology*, Assoc UK, Vol. 12, pp. 339-336
- Richmond, R. H., Hunter, C. L., (1990), "Reproduction and recruitment of corals: comparisons among the Caribbean, the tropical pacific, and the Red Sea", *Marine Ecology Progress Series*, Vol. 60, pp. 185-203
- Riegl B. (1999), "Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality", *Coral Reefs*, Vol. 18, pp. 63-73
- Rosser N.L., A.H. Baird (2008), "Multi-specific coral spawning in spring and autumn in far north-western Australia". *Proceedings of the 11th International Coral Reef Symposium*, Ft. Lauderdale, Florida, Session number 11
- Sheppard C. R. C, Sheppard A. L. S (1991), "Corals and coral communities of Arabia", *Fauna of Saudi Arabia*, Vol. 12, pp. 3-170

- Sheppard CRC, Price P, Roberts C. (1992), "Marine Ecology of the Arabian Region", London, Academic Press, pp. 347
- Sheppard C, Loughland R. (2002), "Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf", *Aquatic Ecosystem Health Management*, Vol. 5, pp. 395–402
- Shlesinger. Y., Loya, Y. (1985), "Coral community reproductive patterns: Red Sea versus the Great Barrier Reef", *Science*, Vol. 228, pp. 1333-1335
- Shlesinger Y, Goulet TL, Loya Y. (1998), "Reproductive patterns of scleractinian corals in the northern Red Sea". *Marine Biology*, Vol. 132, pp. 691-701
- Szmant A. M. (1986), "Reproductive ecology of Caribbean reef corals", *Coral Reefs*, Vol. 5, pp. 43- 53
- Tranter P. R. G., Nicholson D. N. and Kinchington D., (1982), "A description of the spawning and post-gastrula development of the cool temperate coral *Caryophyllia smithi* (Stokes and Broderip)", *Marine Biology*, Vol. 62, pp. 845-854
- Tomascik T, Sander F. (1987), "Effects of eutrophication on reef building corals III. Reproduction of the reef-building coral *Porites porites*". *Marine Biology*, Vol. 94, pp. 77- 94
- Van Woesik R., (1995), "Coral communities at high latitude are not pseudopopulations: evidence of spawning at 32°N, Japan", *Coral Reefs*, Vol. 14, pp. 119-120
- WCMC (World Conservation Monitoring Centre), (1991), *Gulf War Environmental Information Service, Impact on the Marine Environment*, World Conservation Monitoring Centre
- Wilson J.R. P. L. Harrison (2003). "Spawning patterns of scleractinian corals at the Solitary Islands - a high latitude coral community in eastern Australia", *Marine Ecology*, Vol. 260, pp. 115–123