Research Article

Some aspects of physiological studies of two reef building corals in the red sea

Yahya AM Floos[1]* and Abdulmohsin AAl-Sofyani[2]

[1]Faculty of Marine Science & Environment, Department of Marine Biology & Fishery, Hodeidah University, Republic of Yemen

[2]Department of Marine Biology, Faculty of Marine Sciences, King Abdulaziz University, Saudi Arabia

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Abstract

Some aspects of the physiology of the corals *Seriatopora hystrix* and *Lobophyllia corymbosa* described in this paper. At the study site, the lowest mean of seawater temperature is 27.42 °C and 27.17 °C at 5m and 10m depths respectively during winter, while the maximum mean of seawater temperature was 32.67 °C and 31.17 °C in 5 m and 10 m depths respectively during summer. *L. corymbosa,* had a lower number of zooxanthellae 0.05×10^5, 0.43×10^5, 0.06×10^5 and 0.46×10^5 mg^{-1} dry tissue weight than *S. hystrix* 0.19×10^5, 5.1×10^5, 0.27×10^5 and 9.59×10^5 mg^{-1} dry tissue weight in two season and two depths respectively. The mean respiration rate of whole colonies of *S. hystrix* was higher than that of *L. corymbosa* at the same depths both in summer and winter. The mean dark respiration rate decreases with increasing depths. The mean photosynthesis vs irradiance curves of *S. hystrix* and *L. corymbosa* were plotted to the hyperbolic tangent function (Chalker,1981) for summer and winter season. The growth rate was linear during each period of measurement during summer, the highest mean daily skeletal growth rate of *S. hystrix* was 2.3 ± 1.3 (20) mg.skel.d^{-1} in 10m depth and it was 1.6 ± 0.5 (21) mg .skel.d^{-1} at 5m depth. Whilst during winter, the lowest was 1.9 ± 0.96 (20) mg .skel. d^{-1} at 10m and also lowest (1.5 ± 0.7 (20) mg .skel. d^{-1}) at 5m depth. The growth rate of the two species was lower in the winter than in summer.

Introduction

Coral reefs are one of the most interesting environments due to their enormous biodiversity. Corals, which are members of the phylum Coelenterata, class Anthozoa, sub-class Hexacorallia and order Scleractinia [1-3], are the dominant species. The Scleractinia has been divided into hermatypic and ahermatypic. The terms are usually used by biologists to distinguish between corals with or without symbiotic algae (zooxanthellae) respectively [4]. The majority of hermatypes is reef building and live usually in shallow water, whilst the ahermatypes are non-reef building, and are often found in deep water.

Hermatypic corals are restricted to tropical and sub-tropical seas where the temperature is not lower than 18 °C, with optimal reef development between 25° and 29 °C this is

expressed in latitudinal patterns of coral reefs distribution and diversity [4-6]. Rising seawater temperature is one of the greatest threats to the persistence of coral reefs [7]. In 1998, an estimation of 16% of the world's living corals were eliminated in a single warming event related to El Niño [8], during this event, sea temperatures warmed to 2-3 C above long-term average summer temperatures and resulted in a catastrophic "bleaching" event that caused significant mortality of many species of coral. The impacts of this thermal event decrease the percent living coral cover of shallow reef worldwide (Hoegh-guldberg 1999). Coral reefs are under high threats including ocean warming and human disturbance, which together lead to widespread coral mortality [9,10].

There are three main metabolic processes in corals (i) photosynthesis (CO_2 consumption and O_2 release), (ii) respiration (O_2 consumption and CO_2 release) and the (iii)

biogeogenic process of calcification (deposition of CaCO$_3$). These processes are interconnected in corals [11].

Zooxanthellae of scleractinian corals have been grouped into clades. In recent studies, clade "D" was found in *P. verrucosa* from eastern Pacific reefs [12], while clade "C" was found in *P. damicornis* [13]. The work of Baker, et al. [14]. suggests that members of clades D may have greater thermal tolerances than clade C in their zoanthid samples of *Palythoa caribaeorum*. Clade A and B inhabit shallow water colonies, while clade C zooxanthellae are found in deeper water colonies, or in shaded areas of the same individual coral colony [15,16].

The term bleaching refers to the disruption of the coral-algae symbiosis caused by the loss of photopigments or endosymbiotic dinoflagellates from the animal tissues [17]. During the phenomenon of bleaching in August 1998 some coral species such as *P. damicornis* had less resistance against bleaching than *P. verrucosa* due to the unusual high seawater temperature and calm sea condition [18,19]. Nakamura, et al. [20] reported that the dark respiration rate of the coral species *Acropora pruinosa* was higher in winter than in summer, especially in the temperature range from 20–30 °C. Moreover, Coles & Jokiel [21] showed very high response in metabolic rate with temperature change in corals *Pocillopora damicornis*, *Montipora verrucosa*, *Porites compressa* and *Fungia scutaria* over the range 19–31° C in Hawaii and Enewetak.

Through previous studies, it is clear to us that different species of corals have different autotrophic photosynthesis and heterotrophic feeding abilities [22] in addition to different tissue biomass and lipid concentrations [23].

Growth of scleractinian corals can be divided in two mechanisms: first, skeletal growth due to the deposition of an external skeleton of calcium carbonate by the synthesis of an organic matrix, a process called as calcification, and the second one is the tissue growth. According to the light-enhanced calcification theory [24,25], the symbiosis with zooxanthellae is helping the process of skeletal growth. According to this theory, calcification of the coral host is enhanced by photosynthesis of zooxanthellae [26-28]. Certainly, on average, calcification in light is found to be around three times higher than calcification in darkness [25]. However, the growth rate of hermatypic corals is influenced by external factors such as light quality and intensity, temperature, and sedimentation and by internal factors such as reproduction, genetics, growth form of colony, number or type of zooxanthellae [29,30].

Photosynthesis and calcification are spatially separated processes (photosynthesis occurs in the oral tissue layer and calcification in the aboral tissue layer), they do share a common pool of inorganic carbon inside the coelenteron of the coral host, accounting for the interaction between these two processes, the exact mechanisms of the enhancement of calcification by photosynthesis are still a matter of debate [25]. Some of the proposed mechanisms include that: (1) photosynthesis provides energy for the energy-demanding processes associated with calcification, such as calcium transport and organic matrix synthesis and (2) photosynthesis raises intracellular pH and

intracellular saturation state of calcium carbonate, thereby favouring the precipitation of calcium carbonate [24,26].

The main objective of this study was, to compare the respiration, photosynthesis, growth and their sensitivity range of *Seriatopora hystrix* and *Lobophyllia corymbosa* to the environmental factors during two seasons (Summer and Winter). Results obtained this study will improve our knowledge on the ecology and physiology of Red Sea corals.

Materials and methods

The study was carried out in the onshore laboratory of the Faculty of Marine Sciences, King Abdulaziz University, Jeddah, which is located adjacent to the fringing reefs of an inlet, Obhur creek, away from the north of the city Creek (Figure 1). The study site was located at the mouth of the creek on its northern shore, at the water depths of 5 m and 10 m. Specimens of *S. hystrix* and *L. corymbosa* were collected at this depths.

Measurement of environmental parameters

Water temperature was measured *in situ* by using two maximum and minimum thermometers attached to the reef in a shaded location. They were read at monthly intervals from July 2009 to Jun 2010. Underwater down-dwelling UV temperature loggers (HOBO) launch devices (model UA-002-64) were setup in the lab using the HOBOware® Pro software. The sampling intervals were of 15 min and the total recording light is one day in summer 2010 and during winter 2010. The recording time start at 06:00 pm to 06:00 am measuring photosynthetically Active Radiation (P.A.R) between 400 and 700 nm.

Specimen preparation

All determinations were made using branch tips or "nubbins" [32-34]. Samples from *L. corymbosa & S. hystrix* were collected from the study area at 5m and 10m water depths. Samples were transported in shaded buckets to the laboratory. The nubbins from each collection depth were collected and transported to the laboratory in shaded buckets. Any debris or fouling organism that had settled on the tiles bearing the nubbins were carefully scraped off. The nubbins were then placed in the running seawater tank overnight. These were attached to pre-weighted 3×3 cm acrylic tiles, using a small quantity of cyanoacrylate adhesive. Similar-sized pieces of *L. corymbosa,* with more irregular growth form, were made in to nubbins in the same way. They were then placed on racks and returned to the reef to recover for at least once in a week.

Dark respiration

Respiration oxygen uptake of nubbins was measured in darkness using respirometer cell immediately before the commencement of a photosynthesis run. Respiration rate was linear with production of O$_2$ over the 100% to 90% saturation levels that were used for the determination. Dark respiration values were added to the net photosynthesis values to obtain gross photosynthesis.

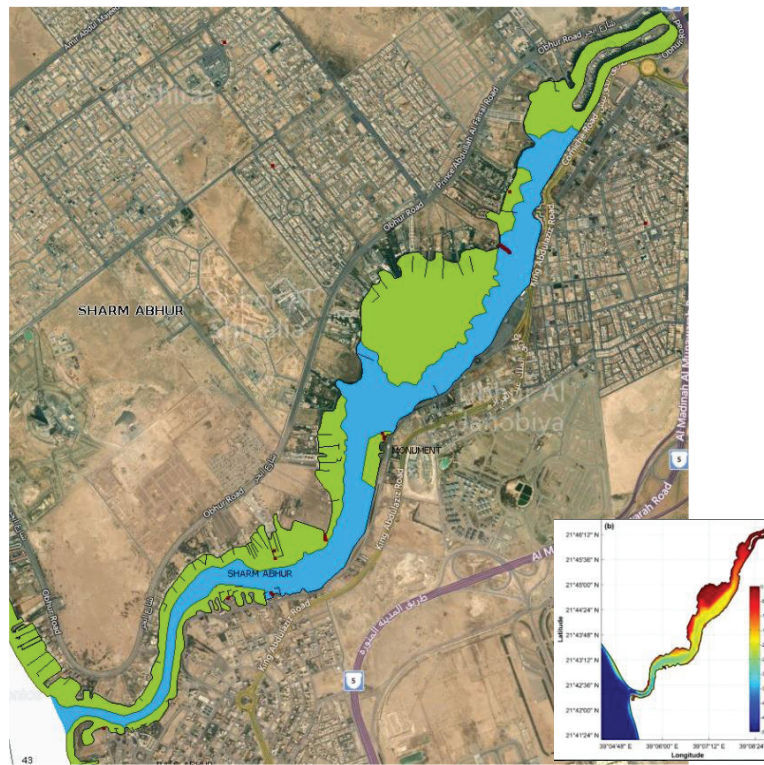Respiration rate of Zooxanthellae were determined on freshly isolated sample, from nubbins that had been

Figure 1: Red Sea Map and Location of Obhur Creek which lies in the north of Jeddah City with bathymetry (Madah, 2022). The Study Site is Marked (•) at the Entrance of Obhur Creek at 5 m and 10 m depths.

maintained in darkness for 12 h. Coral tissue was removed with a water pick, and the slurry was centrifuged at 2000 x g for 1 min. Further separation was achieved with a hand-held potter homogenizer, after which the suspension was centrifuged, washed with seawater thrice and re-suspended in 1 ml of filtered seawater. The rate of oxygen uptake was measured in darkness in an RC 300 respirometer cell (Strathkelvin instrument) with a 1302 paleographic oxygen electrode. Zooxanthellae concentrations within the cell were measured on a subsample using haemacytometer

Photosynthesis

Nubbins were placed in water-jacketed clear acrylic closed respirometer cell with a water volume of 128 ml. Oxygen flux was detected by a polarographic oxygen electrode (Strathkelvin Instruments, 1302) connected to a oxygen meter. Light was provided by a bank of overhead fluorescent lambs whose output was varied between 25 and 300 µE m^{-2} sec^{-1} by mean of a variable transformer. Net oxygen production rates were normalized to dry weight of coral tissue, mean values derived at each irradiance value and best fit curves for the plots of net (P v I) were obtained using a hyperbolic tangent function curve-fitting program [35].

Growth

Nubbins were placed on racks at 5 m and 10 m in the experimental sites on the fringing reef of *S . hystrix* and *L. corymbosa* , after taking the buoyant weight using a precise 120A balance [36]. They were returned to the laboratory for reweighing after intervals of approximately seven days. Growth

rates were determined in summer 2009 and winter 2010 and were expressed in mg skeleton d^{-1}.

Results

The monthly maximum and minimum mean temperatures of the study sites are given in Figures 2,3. The lowest temperature observed was 27.42 ± 0.80 °C and in March 2010 and the highest observed temperature was 32.67 ± 0.29 °C during August 2009. The mean difference between the maximum and minimum readings was 2.5 °C. The daily maximum variation of light intensity of photosynthetically active radiation (P.A.R) and the duration are shown in the Figures 4,5. The P.A.R of daily light curve was maximum in the summer (August 2010) with the value of 512 µE s^{-1} m^{-2} and minimum in the winter (February 2010) with a value of (389 µE s^{-1} m^{-2}).

Skeleton and Biomass Characteristics of *S. hystrix* and *L. corymbosa* are shown in (Table 1). The mean density of the skeleton of both species was identical at 2.5 ± 0.16 (10) g.cm^{-3} and 2.75 ± 0.05 (10) g.cm^{-3} respectively. The mean surface area (cm^2 g^{-1} skeleton) was higher in *L. corymbosa* 4.73 ± 2.31 (10) cm^2 g^{-1} skeleton than *S. hystrix* 3.58 ± 1.2 (10) cm^2 g^{-1} skeleton with no significant difference. The mean dry tissue weight g^{-1}skeleton in summer at 5m depth was higher in *L. corymbosa* 39.6 ± 24.9 (10) mg.d.t.g^{-1} skeleton than *S. hystrix* 24.9 ± 16.4 (10) mg.d.t.g^{-1} skeleton and was significantly different (t – test $p \le 0.03$). While in summer at 10m depth was higher in *L. corymbosa* 45.49 ± 14.00 (10) mg.d.t.g^{-1} skeleton than *S. hystrix* 24.9 ± 19.6 (10) mg.d.t.g^{-1} skeleton and was significantly different (t – test $p \le 0.01$). On the other hand the mean dry tissue weight per g. skeleton in winter at 5m depth was higher in *L. corymbosa*
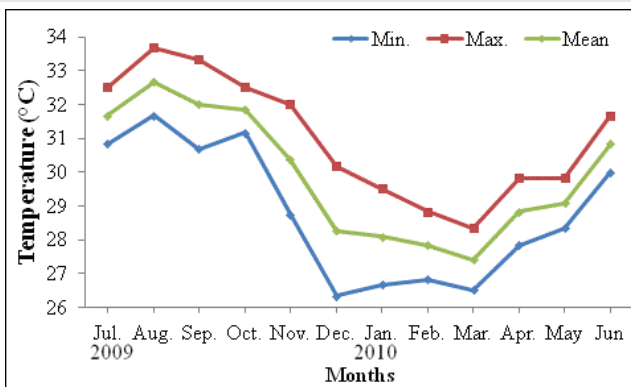
Figure 2: Monthly Mean Variation of Sea Water Temperature (°C) of Obhur Creek at 5 m Depth from July 2009 to Jun 2010.
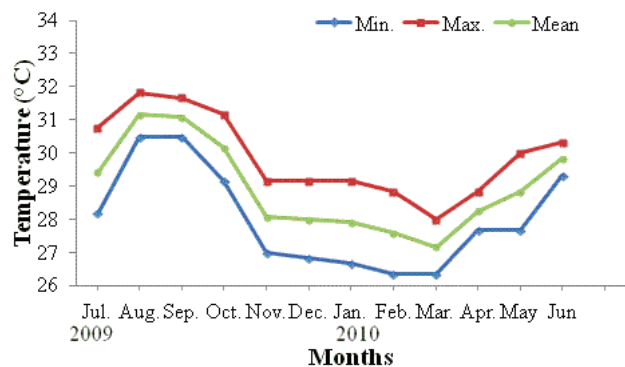

Figure 3: Monthly mean variation of sea water temperature (°C) of Sharm Ubhur at 10m depth, from July 2009 to Jun 2010.
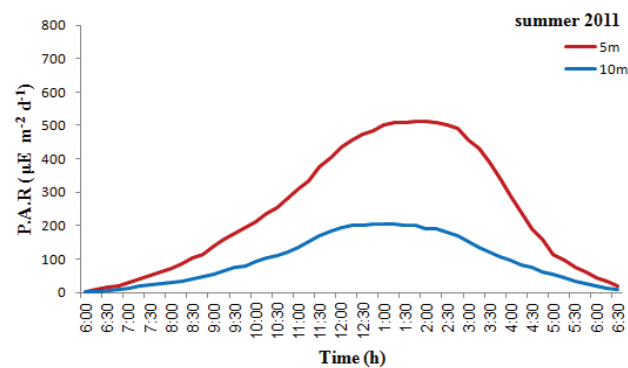

Figure 4: The irradiance intensity variation of Photosynthetically Active Radiation (P.A.R) in summer (August 2011), recorded at 5m and 10 m depths at Obhur creek.
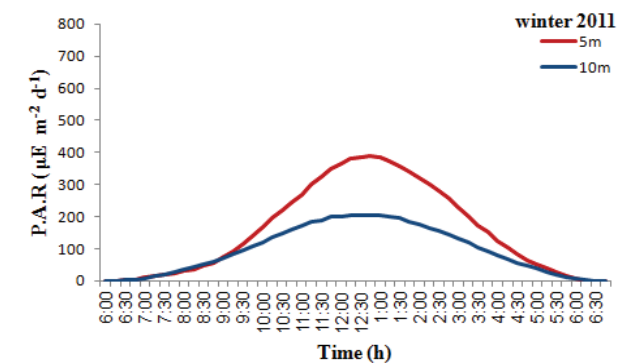

Figure 5: The irradiance intensity variation of Photosynthetically Active Radiation (P.A.R) in winter (February 2011), recorded at 5m and 10m depths in Sharm Ubhur.

36.9 ± 4.9 (10) mg.d.t.g⁻¹ skeleton than *S. hystrix* 13.3 ± 4.9 (10) mg.d.t.g⁻¹ skeleton and was significantly different (t – test $p ≤ 0.001$). While in winter at 10m depth was higher in *L. corymbosa* 44.1 ± 15.00 (10) mg.d.t.g⁻¹ skeleton than *S. hystrix* 11.7 ± 5.8 (10) mg.d.t.g⁻¹ skeleton and was significantly different (t–test $P ≤ 0.0001$) relative biomass between the two species and two season. The values remain significantly different when they were expressed on a surface area basis, i.e. 9.17 ± 3.97 (10) mg.d.t.cm⁻² higher in *L. corymbosa* than *S. hystrix* 7.81 ± 5.82 (10) mg.d.t.cm⁻² in summer at 5m depth and was not significantly difference. While in summer at 10m depth, it was higher in *L. corymbosa* 11.05 ± 4.91 (10) mg.d.t.cm⁻² than *S. hystrix* 7.7 ± 6.6 (10) mg.d.t.cm⁻² and was no significantly different. While in winter at 5m depth it was higher in *L. corymbosa* 8.16 ± 2.43 (10) than *S. hystrix* 4.14 ± 2.0 (10) mg.d.t.cm⁻² and was significantly different (t – test $p ≤ 0.001$). However, in winter at 10m depth it was higher in *L. corymbosa* 11.57 ± 7.26 (10) than *S. hystrix* 3.32 ± 1.6 (10) mg.d.t.cm⁻² and is significantly different (t – test $p ≤ 0.003$) between the two species and two season.

There was a significant seasonal difference in the numbers of zooxanthellae of both the species at two different depths on the basis of biomass and surface area (t – test $p < 0.005$). *L. corymbosa*, had a lower number of zooxanthellae 0.05×10⁵ , 0.43×10⁵ , 0.06×10⁵ and 0.46×10⁵ mg⁻¹ dry tissue weight than *S. hystrix* 0.19 ×10⁵ , 5.1 ×10⁵ , 0.27×10⁵ and 9.59×10⁵ mg⁻¹ dry tissue weight in two season and two depths respectively. *S. hystrix* had higher number of zooxanthellae in 5m depth both in summer and winter respectively (1.2×10⁵, 19.09×10⁵ cm⁻²) and in 10m depth it was 1.6×10⁵ and 25.7×10⁵ cm⁻² in summer and winter than the *L. corymbosa*. At 5m depth, the observed zooxanthellae of *L. corymbosa* was 0.50×10⁵ in summer and 3.51×10⁵ cm⁻² in winter and it was 0.58×10⁵ in summer and 4.42×10⁵ cm⁻² in winter respectively

Dark respiratio

- **Colony:** The colony respiration mean values of both species were estimated using tissue biomass and surface area studies and are given in (Table 2) and (Figures 6–9).

- **Species variations:** The mean respiration rate of whole colonies of S. hystrix was higher than that of L. corymbosa at the same depths both in summer 2009 and winter 2010. The difference was significant in all cases (Table 3). The difference significant was found when making similar comparisons on the rate of respiration of freshly isolated zooxanthellae at (t – test p ≤ 0.05).

- **Seasonal variations**

Seriatopora hystrix: In S. hystrix, the average rate of dark respiration was higher 4.56 ± 2.29 (10) µl O₂ mg⁻¹.d.t h⁻¹ during summer (32 °C) than winter (30 °C) season (3.164 ± 1.32 (11) µl O₂ mg⁻¹.d.t h⁻¹) at 5m depth. But the variation was not significant at this 5 m depth (Tables 3,4). The surface area value was lower (16.97 ± 8.54 (10) µl O₂ cm⁻² h⁻¹) during summer (32 °C) than the winter (30 °C) season (22.01 ± 9.194 µlO₂ cm⁻² h⁻¹). with no significant difference at the 5 m depth (Table 2). It was also higher in summer (31 °C) at 10 m depth 2.477 ± 1.143 (10) µl O₂

Table 1: The Mean Skeletal and Tissue Biomass Colony of *S. hystrix* and *L. corymbosa* at the Study Site Recorded at 5 m and 10 m Depths during Summer and Winter.

Characteristic		*S. hystrix*		*L. corymbosa*		*t* - test	*P* - value
Skeleton							
Skeletal density							
(g.cm^{-3})		2.5 ± 0.16	(10)	2.75 ±0.1	(10)	3.97*	0.001
Biomass Colony							
mg.d.t.g^{-1} skeleton	(5m)(in sum.)	24.9 ± 16.4	(10)	39.6 ± 11	(10)	2.34*	0.031
	(10m)(in sum.)	24.9 ±19.6	(10)	45.49 ±14	(10)	2.72*	0.014
mg.d.t.g^{-1} skeleton	(5m)(in wint.)	13.3 ±4.9	(10)	36.9±4.9	(10)	4.19*	0.001
	(10m)(in wint.)	11.7 ±5.8	(10)	44.1 ±15	(10)	6.33*	0.0001
cm^2 .g^{-1} skeleton	-	3.58 ± 1.2	(10)	4.73 ± 2.31	(10)	1.39	0.182
mg.d.t.cm^{-2}	(5m)(in sum.)	7.81 ± 5.82	(10)	9.17 ± 3.97	(10)	0.59	0.563
	(10m)(in sum.)	7.7 ± 6.6	(10)	11.02 ± 4.91	(10)	1.26	0.22
mg.d.t.cm^{-2}	(5m)(in wint.)	4.14 ±2.0	(10)	8.16 ±2.43	(10)	4.00*	0.001
	(10m)(in wint.)	3.32 ± 1.6	(10)	11.57 ± 7.26	(10)	3.51*	0.003
Zooxanthellae							
No.10^6 g^{-1} skeleton	(5m)(in sum.)	0.4 ± 0.17		0.19 ± 0.7		3.53*	0.0001
	(10m)(in sum.)	0.5 ± 0.17	(10)	0.23 ± 0. 7	(10)	5.37*	0.002
No.10^6 g^{-1} skeleton	(5m)(in wint.)	6.2 ± 2.3	(10)	1.4 ± 0.5	(10)	6.33*	0.0001
	(10m)(in wint.)	8.04 ±3.0	(10)	1.88 ±0.6	(10)	6.265*	0.0001
No.10^5 .mg^{-1} d.t	(5m)(in sum.)	0.19 ±0.09	(10)	0.05 ±0.02	(10)	6.61*	0.0001
	(10m)(in sum.)	0.27 ± 0.14	(10)	0.06± 0.02	(10)	4.15*	0.001
No.10^5 .mg^{-1} d.t	(5m)(in wint.)	5.1 ± 3.1	(10)	0.43 ± 0.18	(10)	4.41*	0.0001
	(10m)(in wint.)	9.59 ±7.1	(10)	0.46 ±0.16	(10)	4.23*	0.001
No. 10^5.cm^{-2}	(5m)(in sum)	1.2±0.6	(10)	0.50±0.27	(10)	3.32*	0.004
	(10m)(in sum.)	1.6 ±0.67	(10)	0.58 ±0.26	(10)	4.47*	0.0001
No. 10^5.cm^{-2}	(5m)(in wint.)	19.09±8.9	(10)	3.51±1.86	(10)	5.43*	0.0001
	(10m)(in wint.)	25.7±12.9	(10)	4.42±1.53	(10)	5.18*	0.0001

*significance (*p* ≤ 0.05) * sum: Summer; wint: Winter

Table 2: The mean dark respiration of whole nubbins and of freshly isolated zooxanthellae of *S. hystrix* and *L. corymbosa* at different depths (5 m, 10 m) and seasons (summer and winter) at Sharm Ubhur.

| Dark Respiration | Depth (m) | *S. hystrix* | | | | *L. corymbosa* | | | |
		Summer 2009	Winter 2010	*t* - test	*P* - value	Summer 2009	Winter 2010	*t* - test	*P* - value
Colony									
µlO$_2$mg^{-1}.d.t h^{-1}	5	4.563	3.164			1.035	0.844		
S.D±		2.296(10)	1.321 (11)	1.732	0.099	0.469 (10)	0.3823(11)	1.034	0.312
µlO$_2$cm^{-2} h^{-1}		16.974	22.01			8.082	5.871		
S.D±		8.544(10)	9.194 (11)	1.061	0.303	3.667(10)	2.135(10)	1.649	0.117
µlO$_2$mg^{-1}.d.t h^{-1}	10	2.477	1.432			0.618	0.471		
S.D±		1.143(10)	0.553 (10)	2.6*	0.018	0.113(14)	0.091(14)	3.07*	0.006
µlO$_2$cm^{-2} h^{-1}		8.09	9.958			5.761	3.167		
S.D±		3.728 (10)	3.842 (10)	1.103	0.284	1.054 (10)	2.128(11)	3.481*	0.003
Zooxanthellae									
µlO$_2$mg^{-1}.d.t h^{-1}	5	0.0675	0.7799			0.0865	0.2537		
S.D±		0.0308(10)	0.2746(10)	9.683*	0.0001	0.0156(10)	0.1633(10)	3.215*	0.004
µlO$_2$cm^{-2} h^{-1}		0.4671	2.881			0.724	1.982		
S.D±		0.2129(10)	1.0143(11)	7.365*	0.0001	0.130(10)	1.275(12)	3.09*	0.006
µlO$_2$mg^{-1}.d.t h^{-1}	10	0.0569	0.1918			0.0305	0.1264		
S.D±		0.0196(10)	0.098(10)	4.268*	0.001	0.0119(10)	0.0342(10)	8.371*	0.0001
µlO$_2$cm^{-2} h^{-1}		0.3939	4.669			0.303	1.177		
S.D±		0.1357(10)	2.391(12)	5.626*	0.0001	0.114(11)	0.325(10)	8.395	0.0001

*significance (*p* ≤ 0.05)

mg⁻¹.d.t h⁻¹, than the winter (29 °C), 1.432 ± 0.553 (10) µl O₂ mg⁻¹.d.t h⁻¹. The difference was significant at the 10m depth (t – test p ≤ 0.01). The surface area comparison studies revealed that it was lower (8.09 ± 3.728 (10) µl O₂ cm⁻² h⁻¹) during summer (31 °C) than the (9.958 ± 3.842 (10) µl O₂ cm⁻² h⁻¹) winter (29 °C). The surface area difference was not significant in the 5m and 10m depths (Table 2).

Lobophyllia corymbosa: The mean rate of the dark respiration was higher 1.035 ± 0.469 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹ during summer (32 °C) than winter (30 °C) 0.844 ± 0.3823 (11) µl O₂ mg⁻¹d. t. wt. h⁻¹, at 5m depth. The difference was no significant at depth (Table 2). On basis of surface area, the values show higher in summer (32 °C) 8.082 ± 3.67 (10) µl O₂ cm⁻². h⁻¹, and winter (30 °C), 5.871 ± 2.135 (10) µl O₂ cm⁻². h⁻¹, at the same depth, with no significant difference (Table 2). The mean rate of dark respiration on biomass and basis of surface area were considerably lower, 0.618 ± 0.113 (14) µl O₂ mg⁻¹ d.t.wt.h⁻¹, (5.761 ± 1.054 (10) µl O₂ cm⁻². h⁻¹), during summer (31 °C) than 0.471 ± 0.091 (14) µl O₂ mg⁻¹d. t. wt. h⁻¹, (3.167 ± 2.128(11) µl O₂ cm⁻²h⁻¹), during winter (29 °C) at 10m (Table 2).

- **Depth variations**

Seriatopora hystrix: The mean rate of dark respiration was significantly higher at 5m depth, 4.563 (summer 32 °C) and 3.164 (winter 30 °C) µl O₂ mg⁻¹ d. t. wt. h⁻¹ than at 10m 2.477 (summer 31 °C) and 1.432 (winter 29 °C) µl O₂ mg⁻¹ d. t. wt. h⁻¹(t – test p ≤ 0.005 summer and t –test p ≤ 0.001 in winter).

Lobophyllia corymbosa: The mean value of oxygen consumption decreases with increasing depth 1.035 ± 0.469 (10) during summer at 5m depth and 0.618 ± 0.113 (14) µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 10m and increasing with decreases depth 0.844 ± 0.3823 (11) and 0.471 ± 0.0.91 (14) at 5m and 10m during winter respectively. There was a significant difference during summer whilst during winter there was no significant difference.

- **Zooxanthellae**

The mean rate of dark respiration of zooxanthellae on the basis of tissue biomass and the surface area is shown in (Table 2).

(a) **Seasonal variation**

Seriatopora hystrix: On the basis of tissue biomass, the average rate of respiration was lower 0.0675 ± 0.030 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹ in summer (32 °C) than the winter (30 °C) 0.779 ± 0.274 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 5m depth. This results were significantly varied at 5m depth (Tables 3,4). In the case of surface area, the results were lower and significantly varied in summer (32 °C) 0.467 ± 0.212 (10) µl O₂ cm⁻² h⁻¹ than in winter (30 °C) 2.88 ± 1.014 (10) µl O₂ cm⁻² h⁻¹, at 5m depth (Table 2). In the case of 10m depth, the value was 0.0569 ± 0.0196 µl O₂ mg⁻¹ d. t. wt. h⁻¹ (10) in summer (31 °C) and 0.1918 ± 0.098 (11) µl O₂ mg⁻¹ d. t. wt. h⁻¹ in winter (29 °C) respectively. The difference in the value was apparently significant (Tables 3,4). In addition, the surface area was lower (0.39 ± 1.357 (10) µl O₂ cm⁻² h⁻¹) in summer (31 °C) season than (4.669 ± 2.39 (12)

µl O₂ cm⁻² h⁻¹) the winter (29 °C) at 10m depth. The surface area variation was a significantly different at 10m depth (Table 2).

Lobophyllia corymbosa: The average rate of zooxanthellae respiration was lower (0.0865 ± 0.015 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹) in summer (32 °C) and higher (0.2537 ± 0.16 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹) in winter (30 °C) at 5m depth. The seasonal difference of the zooxanthellae was significantly varied (Table 2). The surface area of value was significantly lower 0.724 ± 0.130 (10) µl O₂ cm⁻² h⁻¹ in summer (32 °C) and higher 1.982 ± 1.275 (12) µl O₂ cm⁻² h⁻¹ in winter (30 °C) in the 5m depth (Table 2). Similarly at 10m depth, the respiration value was lower 0.0305 ± 0.0119 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹in summer (31 °C) and higher 0.1264 ± 0.0342 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹ in winter (29 °C). This was also significantly varied as shown in the Table 3,4. In 10m depth, the surface area was lower 0.303 ± 0.114 (11) µl O₂ cm⁻² h⁻¹ in the summer (31 °C) higher 1.177 ± 0.325 (10) µl O₂ cm⁻² h⁻¹ in the winter (29 °C). There was significant difference observed between the summer and winter season (Table 2).

(b) Depth variations

Seriatopora hystrix: The mean dark respiration rate decreases with increasing depths. In summer, the value was higher 0.0675 µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 10m depth and lower 0.0569 µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 5m depth, but it was not significantly different. In winter at 5m depth, the dark respiration rate was higher 0.779 µl O₂ mg⁻¹ d. t. wt. h⁻¹ and lower 0.192 µl O₂ mg⁻¹ d. t. wt. h⁻¹at 10 depth. There was a significant difference between 10 m depth.

Lobophyllia corymbosa: The zooxanthellae of this species showed the same pattern of respiration rates which decrease with increasing depths, the rates was lower at 5m, during both season 0.0865 and 0.2537, and higher at 10m, 0.0305 and 0.1264 µl O₂ mg⁻¹ d. t. wt. h⁻¹ during summer and winter respectively. There was a significant difference between the two depths during summer but no significant difference in winter

- **Photosynthesis**

The mean photosynthesis vs irradiance curves of *S. hystrix* and *L. corymbosa* were plotted to the hyperbolic tangent function [35] for summer 2009 and winter 2010 season (5m and 10m depths). They are shown in the Figures 6–9. The photosynthesis characteristics of these curves are summarized in the Table 4.

(a) Species Variations

S. hystrix had a maximum gross photosynthesis (pg_{max}) in the winter season ranging from 4.145 ± 2.402 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹at 10m depth to 8.712 ± 4.2114 (11) µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 5m depth. In the Summer season it was ranging from 6.4339 ± 2.892 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹) at 10m depth to 8.1965 ± 5.144 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹at 5m depth. In the case of *L. corymbosa*, the maximum gross photosynthesis of the winter season was in the range of (0.9515 ± 0.222 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹at 5m depth, to 2.379 ± 1.1915 (14), µl O₂ mg⁻¹ d. t. wt. h⁻¹ at 10m depth. In summer season, it was ranging from 2.067 ± 0.4127 (10) µl O₂ mg⁻¹ d. t. wt. h⁻¹) at 10m depth to 2.594 ±

013

Table 3: Comparison of dark respiration, maximum gross photosynthesis (Pgmax) rate of nubbins (μlO_2 mg^{-1}.d.t h^{-1}) and respiration rate of freshly isolated zooxanthellae (μlO_2 10^{-6} h^{-1}) of *S. hystrix* and *L. corymbosa*

Nubbins	*S. hystrix*	*L. corymbosa*	t - test	P - value
Respiration				
Summer 2009				
5 m v 5 m	4.563	1.035	4.758*	0.0001
10 m v 10 m	2.476	0.618	5.184*	0.0001
Winter 2010				
5 m v 5 m	3.164	0.846	6.896*	0.0001
10 m v 10 m	1.432	0.471	2.339*	0.029
Photosynthesis				
Summer 2009				
5 m v 5 m	8.197	2.5941	3.388*	0.003
10 m v 10 m	6.4339	2.067	4.727*	0.0001
Winter 2010				
5 m v 5 m	8.713	0.952	6.104*	0.0001
10 m v 10 m	4.145	2.379	2.384	0.226
Zooxanthellae				
Summer 2009				
5 m v 5 m	4.15	17.84	11.58*	0.0001
10 m v 10 m	2.69	5.11	2.98	0.08
Winter 2010				
5 m v 5 m	2.43	7.59	8.53*	0.0001
10 m v 10 m	1.73	2.97	4.23*	0.0001

*significance ($p \leq 0.05$)

Table 4: The maximum mean gross photosynthesis (P$_{gmax}$) of whole nubbins and the freshly isolated zooxanthellae of *S. hystrix* and *L. corymbosa* recorded from different depths (5 m, 10 m) and seasons (summer and winter).

		S. hystrix				*L. corymbosa*			
Photosynthesis	Depth (m)	Summer 2009	Winter 2010	t - test	P - value	Summer 2009	Winter 2010	t - test	P - value
Colony									
μlO_2mg^{-1}.d.t h^{-1}	5	8.1965	8.7129			2.5941	0.9515		
S.D±		5.1444(10)	4.2114(11)	0.253	0.803	0.0.9422(10)	0.2222(11)	5.626*	0.0001
μlO_2cm^{-2} h^{-1}		30.4888	60.4565			20.259	8.164		
S.D±		19.138(10)	29.230(11)	2.747*	0.013	7.358(10)	1.755(11)	5.301*	0.0001
μlO_2 10^{-6} h^{-1}		536.758	20.80			634.416	28.608		
S.D±		433.552(11)	16.16 (10)			443.37	23.672		
μlO_2mg^{-1}.d.t h^{-1}	10	6.4339	4.145			2.067	2.379		
S.D±		2.8923(10)	2.4025(10)	1.925	0.07	0.4127(10)	1.1915(14)	0.792	0.437
μlO_2cm^{-2} h^{-1}		21.0271	28.8231			19.288	20.079		
S.D±		9.4552(10)	16.7038(10)	1.284	0.215	3.853(10)	13.861(10)	0.174	0.864
μlO_2 10^{-6} h^{-1}		303.06	7.078			421.515	53.911		
S.D±		178.548	6.231			158.207	29.067		

*significance ($p \leq 0.05$)

0.094 (10) µl O_2 mg^{-1} d. t. wt. h^{-1}) at 5m depth. The difference was significant between both species at each depth during the summer (t – test p ≤ 0.005), but not significant during winter (t – test p < 0.001).

(b) Seasonal variation

Seriatopora hystrix: The mean maximum gross photosynthesis (pg$_{max}$), rates during summer were slightly lower 8.1965 ± 5.144 (10) µl O_2 mg^{-1} d. t. wt. h^{-1} than the gross photosynthesis 8.7129 ± 4.211 (11) µl O_2 mg^{-1} d. t. wt. h^{-1} of the winter season at 5m depth. They were not significantly different. In the case of 10m depth, the values were higher in summer 6.4339 ± 2.89 (10) µl

O_2 mg^{-1} d. t. wt. h^{-1} than in winter 4.145 ± 2.40 (10) µl O_2 d. t. wt. h^{-1} but they were not significantly different.

Lobophyllia corymbosa: The mean maximum gross photosynthesis (pg$_{max}$) was higher 2.594 ± 0.094 (10) µl O_2 mg^{-1} d. t. wt. h^{-1} during summer while compared with the winter season (0.9515 ± 0.222 (11) µl O_2 mg^{-1} d. t. wt. h^{-1}) at 5m depth. It was significantly higher during winter than the summer.

At 10m depth, the average maximum gross photosynthesis rate in summer, 2.067 ± 0.4127 (10) µl O_2 mg^{-1} d. t. wt. h^{-1} was not significantly different from the winter value 2.379 ± 1.1915 (10) µl O_2 mg^{-1} d. t. wt. h^{-1}.

b) Depth variations

Seriatopora hystrix: The mean maximum gross photosynthesis (pg$_{max}$) was significantly higher in summer at 5m depth, 8.1965 ± 5.1444 (10) when compared with 10m depth 6.4339 ± 2.892 (10) µl O_2 mg^{-1} d. t. wt. h^{-1}. Whilst the gross photosynthesis (pg$_{max}$) at 5m depth during winter was maximum (8.7129 ± 4.2114 (11) µl O_2 mg^{-1} d. t. wt. h^{-1}), and was not significantly different from 4.145 ± 2.402 (10) µl O_2 mg^{-1} d. t. wt. h^{-1} at 10m depth.

Lobophyllia corymbosa: The gross photosynthesis was maximum (2.594 ± 0.094 (10) µl O_2 mg^{-1} d. t. wt. h^{-1}) 5 m depth in summer and minimum (2.067 ± 0.4127 (10) µl O_2 mg^{-1} d. t. wt. h^{-1}) during summer at 10m depth respectively. They were not significantly different in summer. Whilst in winter season, the minimum gross photosynthesis (0.9515 ± 0.222 (11) µl O_2 mg^{-1} d. t. wt. h^{-1}) was observed in the 5m depth and was significantly different than the maximum (2.379 ± 1.1915 (14) µl O_2 mg^{-1} d. t. wt. h^{-1}) observed at 10 m depth.

- **Characteristics of the (P v I) curve**

The mean parameters of the P v I curve for two species were shown in (Tables 5,6) and (Figures 6–9).

- **The initial slope (α)**

Seriatopora hystrix: The mean values for α indicated that the zooxanthellae of *S. hystrix* could slightly utilize the light

during the winter 0.0724 ± 0.0614 (11) at 5m depth and also at 10m depth 0.0231 ± 0.0133 (10). But in summer it utilized more light 0.0455 ± 0.0294 (10) at 5 m depth and also more (0.042 ± 0.0163 (10) µl O_2 mg^{-1}.d.t h^{-1} / µE s^{-1} m^{-2}) at 10m depth.

The differences were not significantly different in seasons. During the summer and winter season, the α curve was also slightly higher at 5m depth than the 10m depth. The α values were not significantly different according to the depths.

Lobophyllia corymbosa: During summer, the mean values of α were significantly lower at 5m depth, 0.0099 ± 0.0045 (10) µl O_2 mg^{-1}.d.t h^{-1} / µE s^{-1} m^{-2} and higher 0.0111 ± 0.0041 (10) µl O_2 mg^{-1}.d.t h^{-1} / µE s^{-1} m^{-2} at 10 m depth. Where as in winter, it was lower 0.0053 ± 0.0023 (10) at 5 m and higher 0.0135 ± 0.0059 (10) at 10 m depth. The value was increased with depth both in summer and winter hence no significant difference.

- I_K

Seriatopora hystrix: During summer, the values of I_K, was higher 198.5 ± 78.728 (10) µE s^{-1} m^{-2} at 5m and lower 154.3 ± 25.829 (10) µE s^{-1} m^{-2} at 10m depth without significant difference. Whereas in winter, they were lower 158.273 ± 74.096 (11) µE s^{-1} m^{-2} at 5 m and higher 180.7 ± 30.423 (10) µE s^{-1} m^{-2} at 10m. These values were not significantly varied.

Lobophyllia corymbsa: During the summer season the light intensity was higher which was sufficient to saturate photosynthesis (291.1 ± 113.588 (10) µE s^{-1} m^{-2} at 5m depth and 250.4 ± 106.39 (10) µE s^{-1} m^{-2}) at 10m water depth. In winter it was lower (202.727 ± 75.39 (10) and 180.357 ± 58.5 (14) µE s^{-1} m^{-2} at 5m and 10 m depths respectively. In summer, these values were similar in the depths whereas in winter they were significantly different.

- I_C

Seriatopora hystrix: During summer, I_C were higher with the range of 114.6 ± 31.63 (10) µE s^{-1} m^{-2} at 5m depth whereas lower with the range of 65.8 ± 14.868 (10) µE s^{-1} m^{-2} at 10m depth. Similarly, higher in winter season (66.364 ± 40.418 (10) µE s^{-1} m^{-2}) at 5m depth and lower in winter season (77.5 ± 29.83 (10) µE s^{-1} m^{-2}) at 10m depth. During summer, the I_C values

Table 5: The mean values of the photosynthetic parameters of *S. hystrix* and *L. corymbosa* according to depths (5 m,10 m) and seasons (summer and winter).

Photosynthesis parameter	Depth (m)	S. hystrix				L. corymbosa			
		Summer 2009	Winter 2010	*t* - test	*P* - value	Summer 2009	Winter 2010	*t* - test	*P* - value
α									
µlO$_2$mg^{-1}.d.t h^{-1} / µE s^{-1} m^{-2}	5	0.0455	0.0724			0.0099	0.0053		
S.D±		0.0294 (10)	0.0614 (11)	1.26	0.223	0.0045 (10)	0.0023 (11)	2.95*	0.008
µlO$_2$cm^{-2}h^{-1} / µE s^{-1} m^{-2}		0.169	0.503			0.0769	0.0.045		
S.D±		0.109 (10)	0.426 (11)	2.39*	0.027	0.035(10)	0.0187(11)	2.88*	0.01
µlO$_2$mg^{-1}.d.t h^{-1} / µE s^{-1} m^{-2}	10	0.042	0.0231			0.0111	0.0135		
S.D±		0.0163 (10)	0.0133(10)	2.84*	0.011	0.0041 (10)	0.0059 (10)	1.08	0.291
µlO$_2$cm^{-2}h^{-1} / µE s^{-1} m^{-2}		0.137	0.16			0.104	0.113		
S.D±		0.0534 (10)	0.0925 (10)	0.69	0.502	0.038 (10)	0.0.070 (10)	0.44	0.665

*significance ($p \leq 0.05$)

015

Table 6: The mean values of photosynthetic parameters (I_K, I_C and I0.95) calculated from the net Photosynthesis Vs Irradiance of *S. hystrix* and *L. corymbosa* according to depths (5 m,10 m) and seasons (summer and winter).

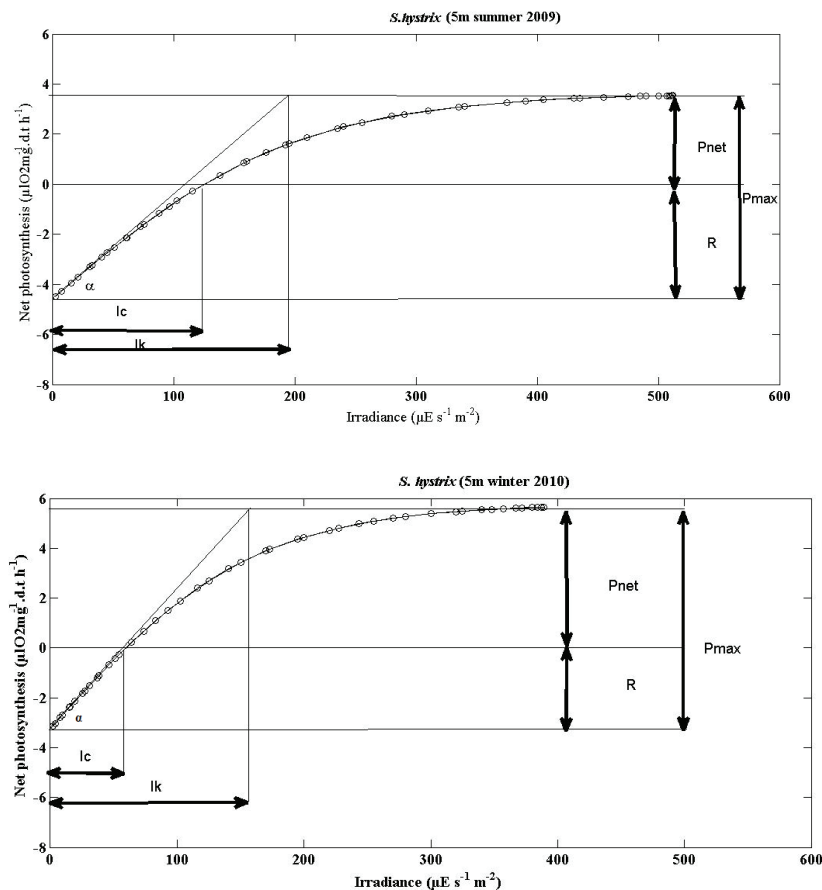| Photosynthesis parameter	Depth (m)	*S. hystrix*				*L.corymboa*			
		Summer 2009	Winter 2010	*t* - test	*P* - value	Summer 2009	Winter 2010	*t* - test	*P* - value
I_K									
µE s⁻¹ m⁻²	**5**	198.5	158.273			291.1	202.727		
S.D±		78.728 (10)	74.096 (11)	1.206	0.243	113.588 (10)	75.392 (10)	2.12*	0.047
µE s⁻¹ m⁻²	10	154.3	180.7			250.4	180.357		
S.D±		25.829 (10)	30.423 (10)	2.092*	0.51	106.391 (10)	58.501 (14)	0.89	0.383
I_c									
µE s⁻¹ m⁻²	5	114.6	66.364			110	83		
S.D±		31.631(10)	40.418 (11)	3.023*	0.007	19.488 (10)	17.321 (11)	0.498	0.624
µE s⁻¹ m⁻²	10	65.8	77.5			50.7	70.857		
S.D±		14.868 (10)	29.83 (10)	1.11	0.282	12.641(10)	17.399 (14)	3.115*	0.005
$I_{0.95}$									
µE s⁻¹ m⁻²	5	363.652	289.955			533.296	371.396		
S.D±		114.229 (10)	135.744 (11)	1.206	0.243	208.095 (10)	138.119 (11)	2.12*	0.047
µE s⁻¹ m⁻²	10	282.678	331.042			385.453	330.414		
S.D±		47.318 (10)	55.735 (10)	2.092*	0.051	194.907(14)	107.174 (10)	0.297	0.89
*significance ($p \leq 0$)									

Figure 6: Relationship between light intensity (I) and photosynthesis (P) for *S. hystrix* at 5m depth and season. The curves were derived from the mean values of photosynthesis parameters using the following equations:
S. hystrix
Pnet = Pg max. tanh (I/IK)-R Chalker [35]
Pnet = 8.1965 tanh (I/198.5) − 4.5635 m summer 2009
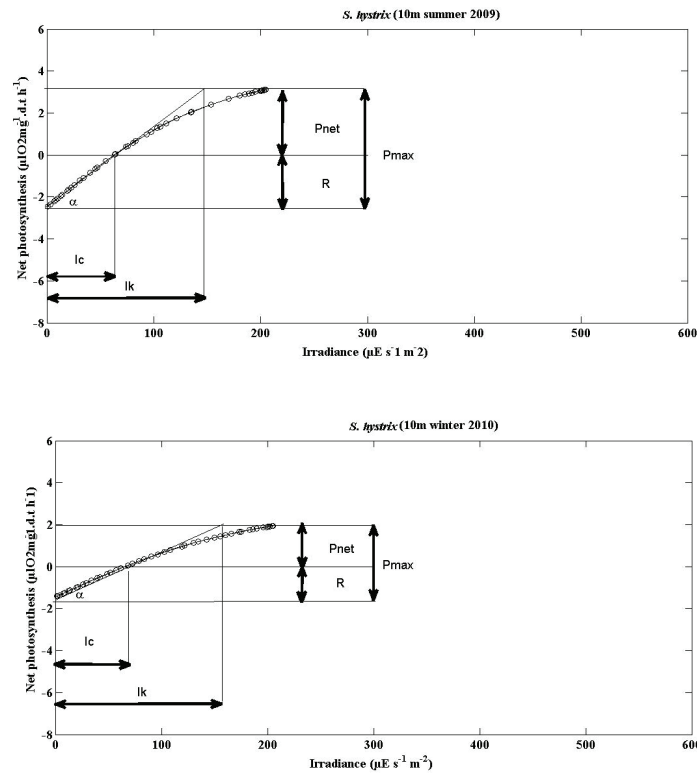Pnet = 8.7129 tanh (I/74.096) − 3.1645 m winter 2010.

016

Figure 7: Relationship between light intensity (I) and photosynthesis (P) for *S. hystrix* at 10m depth and season. The curves were derived from the mean values of photosynthesis parameters using the following equations:

S. hystrix

$Pnet = Pg\ max.\ tanh\ (I/IK)-R$ Chalker [35]

$Pnet= 6.4339\ tanh\ (I/154.3) - 2.477$ 10 m summer 2009

$Pnet= 4.145\ tanh\ (I/180.7) - 1.432$ 10 m winter 2010

Figure 8: Relationship between light intensity (I) and photosynthesis (P) for *L. corymbosa* at 5m depth and season. The curves were derived from the mean values of photosynthesis parameters using the following equations:

 L. corymbosa

$Pnet = Pg\ max.\ tanh\ (I/IK)-R$ Chalker [35]

$Pnet = 2.594\ tanh\ (I/291.1) - 1.03$ 5m summer 2009

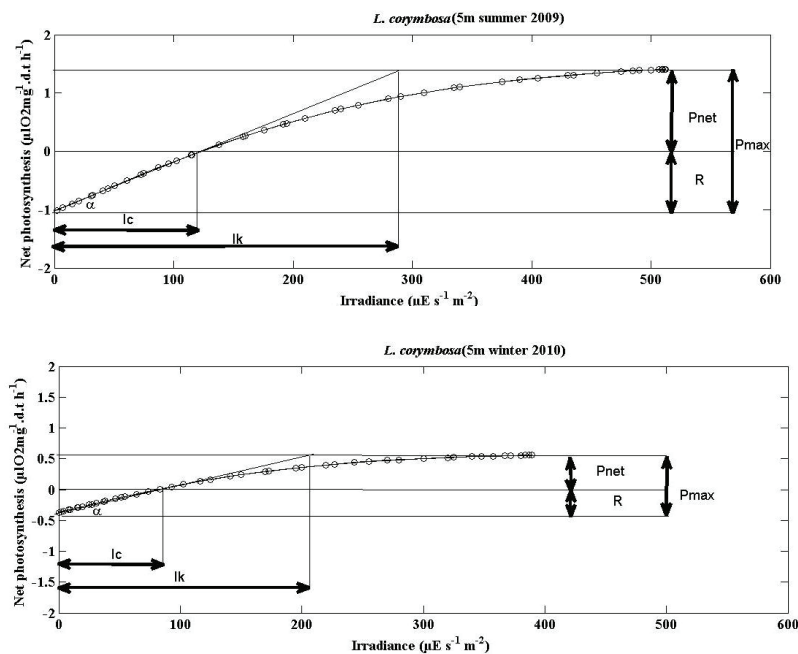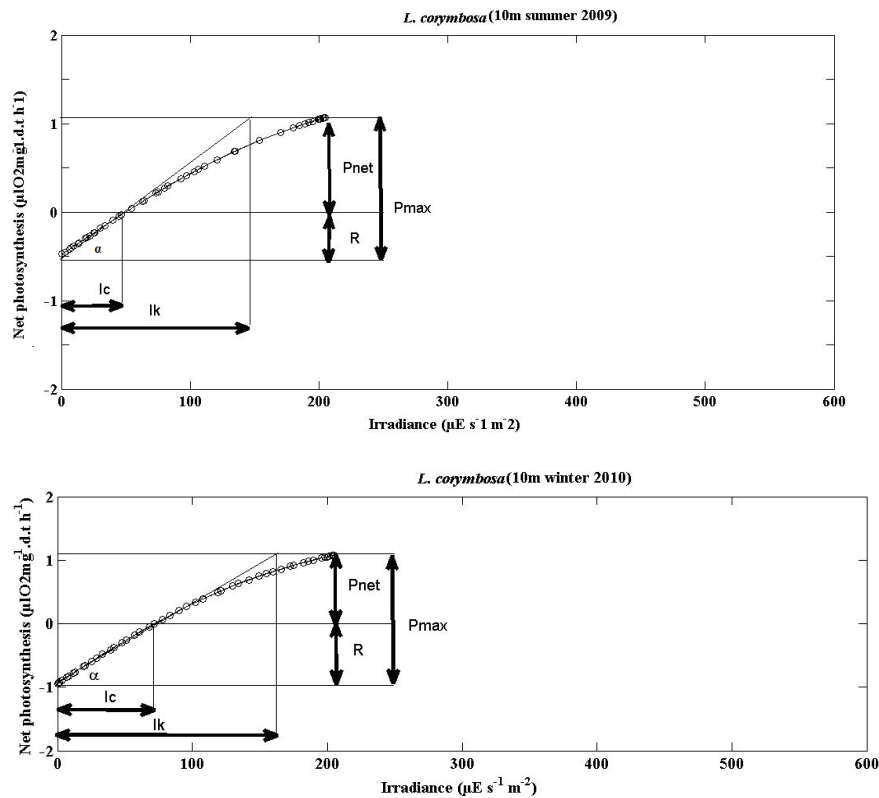 $Pnet = 0.951\ tanh\ (I/202.727) - 0.845$ 5m winter 2010

Figure 9: Relationship between light intensity (I) and photosynthesis (P) for *L. corymbosa* at 10m depth and season. The curves were derived from the mean values of photosynthesis parameters using the following equations:
L. corymbosa
Pnet = Pg max. tanh (I/IK)-R   Chalker [35]
Pnet= 2.067 tanh (I/250.4) − 0.618 10 m summer 2009
Pnet = 2.379 tanh (I/180.357) − 0.471   10 m winter 2010

increased according to the depth, however in winter, it was decreased with increasing depth. The S. hystrix I_c values were significantly different acording to the depth.

Lobophyllia corymbosa: In the case of L. corymbosa, the I_c values were higher in summer (110.00 ± 19.488 (10) µE s⁻¹ m⁻²) at 5m depth and lower in 10m depth (50.7 ± 12.641 (10) µE s⁻¹ m⁻²) but the values were not significantly different. During winter, higher (83.00 ± 17.312 (10) µE s⁻¹ m⁻²) at 5m depth and lower in 10 m depth (70.857 ± 17.399 (10) µE s⁻¹ m⁻²).

The values were shown the similar pattern of *S. hystrix* like increased with increasing depth during the summer, and decreased with increasing depth in winter.

• **Seasonal variation in daily growth rate**

Seriatopora hystrix: The growth rate was linear during each period of measurement (Figures 10,11). During summer 2009, the highest mean daily skeletal growth rate of S. hystrix was 2.3 ± 1.3 (20) mg .skel.d⁻¹ in 10m depth and it was 1.6 ± 0.5 (21) mg .skel.d⁻¹ at 5m depth. Whilst during winter 2010, the lowest was 1.9 ± 0.96 (20) mg .skel. d⁻¹ at 10m and also lowest (1.5 ± 0.7 (20) mg .skel. d⁻¹) at 5m depth. The statistical comparison of the mean daily growth rate of skeleton indicated that, there were not significantly different seasonally (Table 7).

Lobophyllia corymbosa: The mean growth rate of this species was also observed linear during the period of the study (Figures 12,13). L. corymbosa also showed higher seasonal variation in mean daily growth rate (7.27 ± 3.068 (17) mg .skel. d⁻¹) at 5m depth (Tables 3) in summer. Whereas in winter, the growth rate was 5.637 ± 2.56 (27) mg. skel. d⁻¹ at 5m with no significant difference. In the case of 10m depth, the mean growth rate was higher in summer 6.179 ± 2.95 (15) mg .skel. d⁻¹ than the winter 4.78 ± 1.869 (21) mg .skel. d⁻¹. The statistical comparison of mean growth rate revealed that there were not significant varied at difference depths (5m and 10m) and different seasons like summer 2009 and winter 2010 (Table 7).

• **Species variation in daily growth rate**

In general, the *L. corymbosa* had higher mean daily skeleton growth rate than S. hystrix compared at 5m and 10m depths at both summer 2009 and winter 2010 seasons (Figures 14,15). But there was no significant difference in growth rate between the two species (Table 7).

Discussion

Environmental measurements

Temperature: The annual mean seawater temperature variations at Sharm Ubhur were lowest in March 2010 at 5 m and 10 m depths 27.42 °C and 27.17 °C respectively. However, the maximum mean seawater temperature were observed

in August (2009) at 5 m and 10 m depths 32.67 °C and 31.17 °C respectively. Floos [37] observed the lowest seawater temperatures from February to March 2005 24.5 –24.75 °C at Sharm Ubhur at 3 m depth and the highest seawater temperature from July to August 2005 (30.25 to 33.00 °C). Similarly Al– Sofyani [34] recorded lowest temperatures in the months of February and March 1990 (25.5 °C (and the highest temperatures in the months of July to October 1990 (30 °C to 31 °C (respectively. In addition Fadlallah [38] recorded similar temperatures at Sharm Ubhur and adjacent Yanbu. He further described that the coldest season begins in February and the warmest season starts at September. The highest seawater temperature of Jeddah was recorded as 35 °C in July 1985 and the lowest as 22.5 °C during December 1985 [39] as well as lowest in February and March (1986) [39] . Similarly, the minimum temperature of 25.8 °C was observed in January 1981 and maximum of 34.8 °C in August 1981 were reported by

Behiry, et al. [40] from the coastal waters of Jeddah. Edwards and Head [41] recorded the lowest temperatures in January and February 21 °C) and the highest temperatures in August and September 27 °C in the North of the Gulf of Aqaba. Bleaching event caused by increased seawater temperatures [42].

The main feature of the seawater temperature along the coast of Saudi Arabian Red Sea generally decreases from South to North. The ranges between maximum and minimum, seawater temperature in Jeddah is lower than those found in Gazan [18,39,43–45]. The Red Sea is characterized by strong and opposing salinity–temperature–nutrient gradients [46,47].

Light: In summer, the longest duration of sunlight was 12.75 hours with integrated daily irradiation of 11.26 µE. m^{-2}.d^{-1} at 5m depth, whereas in winter the day length had shortened to 11.75 hours and the integrated daily irradiation was 7.32 µE. m^{-2}.d^{-1}. Al– Sofyani [34], recorded the longest duration of sunlight in summer as 13.75 hours with integrated daily irradiation of 30.12 µE. m^{-2}.d^{-1} at 3m depth while in winter the day length had shortened to 10.5 hours and the integrated daily irradiation was 14.99 µE. m^{-2}.d^{-1}. In Hawaii, and in the turbid water of the fringing reef of Coconut Island, Oahu, Davies [48] recorded an integrated daily irradiance value of 14.39 µE. m^{-2}.d^{-1} at 3m depth.

In general, P.A.R. decreases with increasing depths. The daily integrated P.A.R. in August 2011 at 10 m depth was only 39% whereas it was only 61% at 5 m in July. Al– Sofyani [34] recorded similar results in January 1990 as 39% at 10 m depth and 33% in July at 1 m depth. Head [49] recorded average light levels of about 45% of surface irradiance at the depth of 10 m in other areas of the Red Sea. Oliver, et al. [50] recorded transmission of 65% and 28% of surface light to depth of 3 m and 10 m depths respectively at Davies Reefs, Australia. Edmunds [51] recorded 26.9 and 19.4 % transmission of surface light to 10 m in clear water and turbid water respectively in Discovery Bay, Jamaica.

Skeletal densities for both *S. hystrix* and *L. corymbosa* **are 2.5 g.cm^{-3} and 2.75 g.cm^{-3}** respectively which are compared with 2.78 g.cm^{-3} and 2.77 recorded for both *Pocillopora damicornis* and *Pocillopora Verrucosa,* [37,52]. In addition, skeletal variation of 2.78 g.cm^{-3} was recorded for *Stylophora pistillata* **and** *Echinopora gemmacea* [34] , 2.783 g.cm^{-3} for *Pocillopora eydouxi* [32,34], 2.822 g.cm^{-3} for *Porites porites* [33] and lowest of 2.95 g.cm^{-3} for *Fungia fungites* [53], 2.78 g.cm^{-3} for *Sariatopora hystrix* [54] , 2.4 **g.cm^{-3} for** *Lobophyllia corymbosa* **[55].**
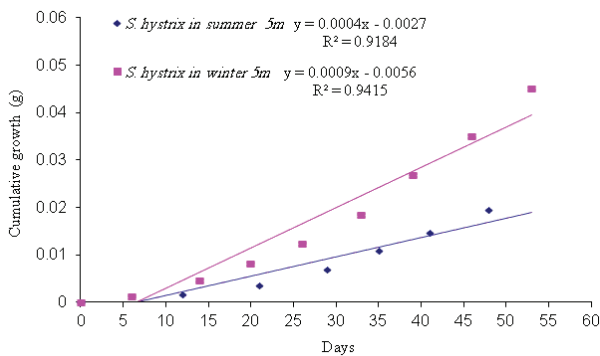

Figure 10: Cumulative skeleton growth rate of *S. hystrix* at 5 m depth during summer 2009 and winter 2010.
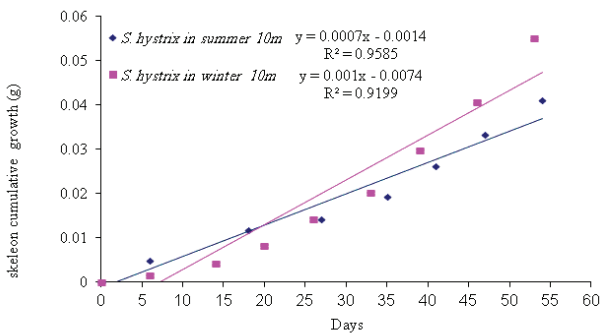

Figure 11: Cumulative skeleton growth rate of *S. hystrix* at 10 m depth during summer 2009 and winter 2010.

Table 7: The daily mean skeleton growth rate of *S. hystrix* and *L. corymbosa* for each season (summer and winter) and two depths (5 m and 10 m).

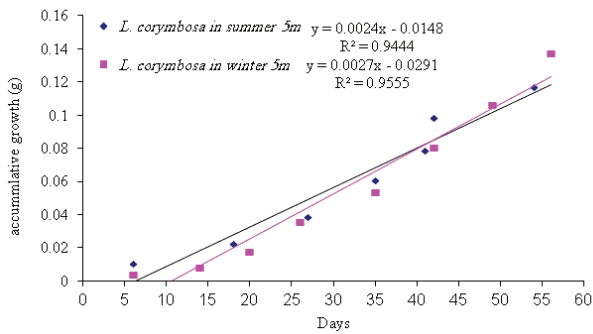| Growth rate	Depth (m)	S. hystrix				L. Corymbosa			
		Summer 2009	Winter 2010	t - test	P - value	Summer 2009	Winter 2010	t - test	P - value
Skeleton									
mg skeleton. d^{-1}	5	1.6	1.5			7.3	5.7		
S.D±		0.5 (21)	0.7 (20)	0.23	0.82	3.0 (17)	2.6(27)	1.9	0.06
mg skeleton. d^{-1}	10	2.3	1.9			6.18	4.8		
S.D±		1.3 (20)	0.96 (20)	1.16	0.25	2.95 (15)	2 (21)	1.7	0.09

*significance ($p ≤ 0.05$)

Figure 12: Cumulative skeleton growth rate of *L. corymbosa* at 5m depth during summer 2009 and winter 2010.
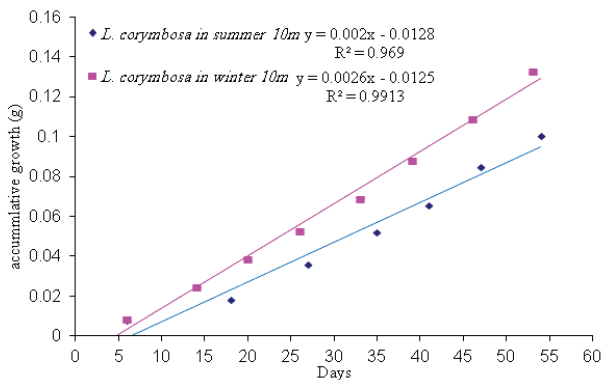

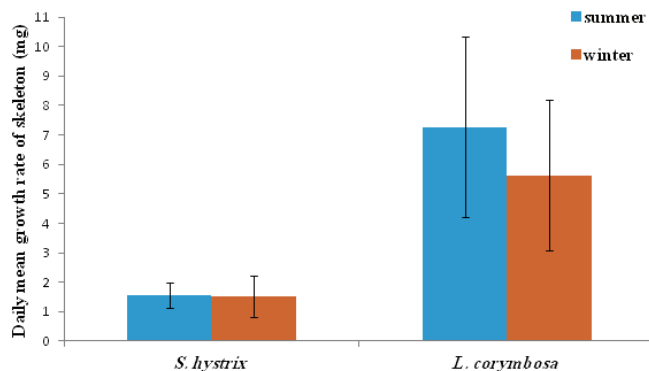**Figure 13:** Cumulative skeleton growth rate of *L. corymbosa* at 10 m depth during summer 2009 and winter 2010.

Figure 14: Comparison of the daily mean skeleton growth rate of the two species at 5 m depth during summer 2009 and winter 2010.
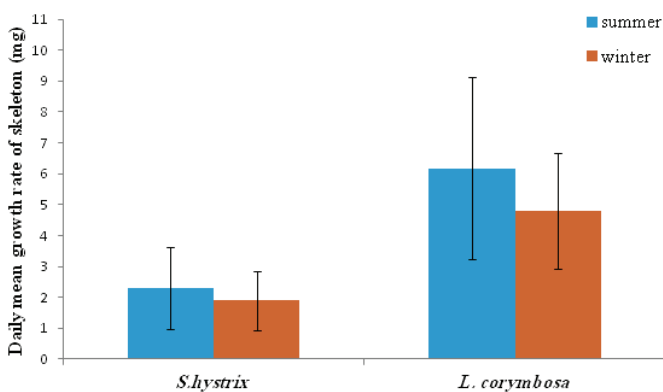

Figure 15: Comparison of daily mean skeleton growth rate of the two species at 10 m depth during summer 2009 and winter 2010.

The variations in the skeletal density among the species may be due to the difference in amount of organic matrix in the skeleton [32,34]. The difference of the skeletal density of both species in the present study may reflect a difference in percentage of the organic matrix in their skeleton.

S. hystrix has the lower tissue biomass of 37.12% per mg in the case of dry tissue weight 5m depth and 45.26% per mg dry tissue weight 10m depth in summer than the *L. corymbosa* while in winter, it was 63.96% at 5m depth and 73.47% 10m depth and was lower than the *L. corymbosa* at 5 m and 10 m depths.

Had the lowest tissue biomass than *L. corymbosa* in the case of surface area like 14.83% and 30.13% at depths 5 m and 10 m respectively in summer. Similarly, in winter, the biomass of tissue per surface area of *S. hystrix* was lower than L. corymbosa 5 m and 10 m depths 49.26% and 71.31% respectively. This may due to the differences in the growth form of the two species or from the tissue location within the skeleton [37,39,48].

The tissue biomass values of both depths were 24.9 mg.d.t.g⁻¹skel for *S. hystrix* and 39.6 and 45.49 mg.d.t.g⁻¹skel for *L. corymbosa* at depths in summer respectively. In winter they were 13.3 and 11.7 mg.d.t.g⁻¹skel for *S. hystrix* and 36.9 and 44.1 mg.d.t.g⁻¹skel for L. corymbosa at the 5m and 10m depths. Floos [37] reported that 28.1 mg.d.t.g⁻¹skel and 24.92 mg.d.t.g⁻¹skel for *Pocillopora damic*ornis and *Pocillopora verrucosa* from the Red Sea at 3m depth and Al-Sofyani [39] reported 10.30 mg.d.t.g⁻¹skel and 12.86 mg.d.t.g⁻¹skel for *Stylophora pistillata* and *Echinopora gemmace*a from the Red Sea at of 3m depth. Al-Sofyani and Nias [54] recorded 12.50 mg.d.t.g⁻¹skel for *Sariatopora hystrix* from the Red Sea at 3m depth. Al-Lihaibi, et al. [55] recorded 39.6 mg.d.t.g⁻¹skel for *Lobophyllia corymbosa* from the Red Sea at 2 m depth. Other studies on *Montipora verrucosa* and *Porites lobata* revealed that 44.29 and 45.02 mg.d.t.g⁻¹skel for at 3m depth respectively [32,48]. In addition to that another study which showed 2.2 mg.d.t.g⁻¹skel for *Fungia fungites* at 2m depth [53].

On the basis of unit area (mg.d.t.cm⁻²), the values were 7.81 and 7.7 mg.d.t cm⁻² in summer at 5m and 10m depths respectively for *S. hystrix.* In *L. corymbosa* they were 9.17 and 11.02 mg.d.t cm⁻² in summer at the same depths respectively. While in winter, at 5m and 10m depths they were 4.14 and 3.32 mg.d.t cm⁻² for *S. hystrix* as well as 8.16 and 11,57 mg.d.t cm⁻² for *L. corymbosa* close to the range of 5.56 mg.d.t cm⁻² to 9.65 mg.d.t cm⁻² for *Montastrea annularis* at 2m and 10m depths respectively [56]. Similarly the surface area range of 2.8 to 12.5 mg.d.t cm⁻² was observed for six species at 2.5m depth from Barbados, West Indies [57].

Al-Sofyani [34] reported lower values, 3.52 mg.d.t cm⁻² for *Stylophora pistillata* and 4.91 mg.d.t cm⁻² for *Echinopora gemmacea* at of 1m and 3m depths respectively. Floos [37] recorded lower values, 5.33 mg.d.t cm⁻² for *Pocillopora damic*ornis and 6.92 mg.d.t cm⁻² for *Pocillopora verrucosa*, while Edmunds and Davies [33] showed much higher value of 18.59 mg.d.t cm⁻² for *Porites porites* at 10m depth. These differences in this present study may due to the growth form or the methods used for measuring surface area [33,34] .

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The density of zooxanthellae by means of dry tissue weight for *S. hystrix* was approximately 73.7% and 77.8% at of 5 m and 10 m depths in summer respectively. While in winter it was lower 91.6% and 95.3% at 5m and 10m depths when compared with the number of zooxanthellae on the basis of biomass unit in winter and summer respectively. On the other hand, the surface area of *S. hystrix* was 58.3% and 63.8% at 5m and 10m depths in summer respectively, while in winter it was lower when compared *L. corymbosa* 81.6% and 82.8% at 5m and 10m depths in winter and summer respectively.

Floos [37] recorded the zooxanthellae density in winter was approximately lower as 13.3% in summer and 2.63% at 3 m depth in *P. verrucosa*. On the other hand, *P. damicornis* was also lower 39.36% and 42.9% when compared with *P. verrucosa* on the basis of surface area in winter and summer respectively. In addition, the other published data showed that in summer the density of zooxanthellae at 5m and 10m depths for both *S. hystrix* and *L. corymbosa* were $(1.2 \times 10^6 \pm 0.6, 0.50 \times 10^6 \pm 0.27)$ and $(0.58 \times 10^6 \pm 0.26, 1.6 \times 10^6 \pm 0.67)$ g^{-1}skel respectively. However in winter, it was $(19 \times 10^6 \pm 8.9, 3.51 \times 10^6 \pm 1.86)$ for *S. hystrix* and $(25.7 \times 10^6 \pm 12.9, 4.42 \times 10^6 \pm 1.53)$ g^{-1}skel for *L. corymbosa*. at 5m and 10m depths respectively.

Floos [37] stated that the density of zooxanthellae at 3m depth of both *Pocillopora damicornis* and *Pocillopora verrucosa* was $2.40 \times 10^6 \pm 0.57$ and $2.7 \times 10^6 \pm 1.07$ g^{-1}skel respectively, where as other values were similar to *Stylophora pistillata* $(2.87 \times 10^6$ g^{-1}skel) but lower in *Echinopora gemmacea* $(1.63 \times 10^6$ g^{-1}skel) than *Fungia fungite* $(1.5 \times 10^6$ g$^-$[34,53].

On the basis of dry tissue weight, the density of zooxanthellae of *S. hystrix* was $0.19 \times 10^5 \pm 0.23$ .mg^{-1} d.t at 5m depth and was $0.27 \times 10^5 \pm 0.14$.mg^{-1}d.t at 10m depth and for *L. corymbosa*, it was $0.05 \times 10^5 \pm 0.02$.mg^{-1} d.t at 5m depth and $0.43 \times 10^5 \pm 0.18$.mg^{-1}d.t at 10m depth. This was lower than *Stylophora pistillata*, 2.78×10^5 mg^{-1}d.t and *Echinopora gemmacea* 1.27.mg^{-1} d.t studied earlier [34]. It was much lower when compared to *Fungia fungites* 6.91×10^5 mg^{-1} d.t [53]. The number of zooxanthellae per unit area of *S. hystrix*, 1.2×10^5 cm^{-2} 1.6×10^5 cm^{-2} and *L. corymbosa* 0.5×10^5 cm^{-2}, 0.58×10^5 were lower than of *P. damicornis* 4.76×10^5 .cm^{-2} and of *P. verrucosa* 7.85×10^5.cm^{-2} [37]. And also it was lower than *Stylophora pistillata* 9.82×10^5 cm^{-2} [34].

When compared Stylophora species it was lower that the light-adapted shallow water *Stylophora pistillata* 10.0×10^5 cm^{-2} [58], for light-adapted *Stylophora pistillata* 16×10^5 cm^{-2} [59], *Stylophora pistillata* 15.6×10^5 cm^{-2} [60]. And it was also much lower than *Stylophora mordax* 48.8×10^5 cm^{-2} even at 1m depth [25]. These differences may be due to using of different methods for measuring the surface area. Stimson [61] reported high variability in the algal densities within coral species. Drew [60] and Porter, et al. [58] reported that the density of zooxanthellae per area unit were same at different depths and among coral genera. Dustan [62,63] described that the number of zooxanthellae in *Montastrea annular* was increased with increasing depth and the zooxanthellae appeared to be photo adapted to lower light intensity by increasing the size of the photosynthetic units.

Both species showed annual density cycle of zooxanthellae, lower in summer than the winter. The *S. hystrix* had lower density of zooxanthellae (6.5% and 6.2%) in summer than the winter at 5m and 10m depths respectively. Similarly, *L. corymbosa* also possessed lower density (13.6% and 12.23%) in summer than the winter at 5m and 10m depths respectively. Many studies reported that the number of annual cycle of zooxanthellae was changing due to the environmental parameters, such as irradiance, UV radiation, nutrients and temperature. There was a negative correlation between the number of zooxanthellae with increasing irradiance and temperature and a positive correlation with increasing nutrients. The density of zooxanthellae decreased in response to increasing irradiance [59,64,65]. In the present study, the seawater temperature increased during months of summer and photosynthetically active radiation (P.A.R. μE.m^{-2}.s^{-1}) at depth of 5m was at a maximum in August 2011 with a value of 512 μE.m^{-2}.s^{-1} and at a minimum at the end of February 2011 when the value was 389μE.m^{-2}.s^{-1} while at depth of 10m was at a maximum in August 2011 with a value of 204.8 μE.m^{-2}.s^{-1}and at a minimum at the end of February 2011 when the value was 204.8 μE.m^{-2}.s^{-1}.

In addition Al-Sofyani [34] reported that the photosynthetically active radiation (P.A.R. μE m^{-2} s^{-1}) at depth of 3m was at a maximum in June 1990 with a value of 1212 μE m^{-2} s^{-1} and at a minimum at the end of November when the value was 727 μE m^{-2} s^{-1}. Furthermore, at depth of 10m was at a maximum in July 1990 with a value of 455 μE m^{-2}s^{-1} and at a minimum at the end of January 1990 when the value was 430 μE m^{-2} s^{-1}.

Dark respiration

The mean percentage of dark respiration rates may vary between two species on the basis of milligram dry tissue weight (mg.d.t.wt. h^{-1}). In this study, the percentage of dark respiration rate of *S. hystrix* (77.3%) was higher than the *L. corymbosa* in summer (32 °C) and similarly the rate of *S. hystrix* was as higher as 73.3% than the *L. corymbosa* in winter 30 °C at 5m depth respectively. Similarly, in 10m depth also the mean percentage respiration rate was higher in *S. hystrix* (75.1%) in summer 31 °C and higher (67.1%) in winter 29 °C than the *L. corymbosa* respectively.

In this present study, the Summer respiration rate of *S. hystrix* was 4.563 μlO$_2$ mg.d.t.wt. h^{-1} at 5m depth whereas was 2.477 μlO$_2$ mg.d.t.wt. h^{-1} at 10m depth. Similarly in *L. corymbosa*, the rate was about 1.035 μlO$_2$ mg.d.t.wt. h^{-1} at 5m depth and 0.618 μlO$_2$ mg.d.t.wt. h^{-1} at 10m depth respectively. The mean respiration rates of this study was compared (mg.d.t.wt. h^{-1}) with other published values of this region. In summer, *Pocillopora damicornis* rate was lower than the present study (1.190 μlO$_2$ mg.d.t.wt. h^{-1}) and also respiration rate of the *Pocillopora verrucosa* was also lower (1.37 μl O$_2$ mg.d.t.wt. h^{-1}) at 3m depth of the same study site [37]. In *Echinopora gemmacea* also the respiration rate was lower (1.37 μl O$_2$ mg.d.t.wt. h^{-1}) than the present study on *S. hystrix* at the same study area [34]. Studies on the other regions like Hawaii also showed minimum respiration rates in *Mintipora annularis* (1.65 μlO$_2$ mg.d.t.wt.

h^{-1}) and *Porites lobata* (1.19 μlO_2 mg.d.t.wt. h^{-1}) than the present study [48].

In winter, the mean respiration rate of *S. hystrix* was 3.164 μlO_2 mg.d.t.wt. h^{-1} and 1.432 μlO_2 mg.d.t.wt. h^{-1}. The *L. corymbosa* respiration rate was lower than the *S. hystrix* 0.846 μlO_2 mg.d.t.wt. h^{-1} and 0.471 μlO_2 mg.d.t.wt. h^{-1} of the present study at 5m and 10m depths. It was (*L. corymbosa*) even lower in respiration rates when compared to the other studies on *Echinopora gemmacea* (1.21 μlO_2 mg.d.t.wt. h^{-1}) and *Stylophora pistillata* (1.77 μlO_2 mg.d.t.wt. h^{-1}) at the same study site [34]. This lower respiration rate of *L. corymbosa* of the present study may due to the higher tissue biomass than the *S. hystrix*.

Davies [56] stated that, the corals with lower surface area consumed less oxygen than the corals with higher surface area. Furthermore, Kawaguti [66] reported that the corals with large polyps contracted during daytime resulted in the lower respiration rate than the corals with small and expanded polyp of the day time. Hence the mean dark respiration rates of this study on the both species were higher in summer (32 °C and 31 °C) than the winter (30 °C and 29 °C) at 5m and 10m depths respectively. But, Nakamura Eriko, et al. [20] reported that the dark respiration rate of coral *Acropora pruinosa* was higher in winter at 20 °C than the summer at 30 °C.

In overall depth, the respiration percentage rate of *S. hystrix* was higher in summer (54.3%) than the winter (45.3%), similarly in *L. corymbosa*, the overall respiration rate was higher (59.7%) in summer and lower (55.7%) in winter.

In general, the worldwide studies revealed that the respiration rates of corals were decreased with increasing depths [34,56,67-69]. Furthermore, studies described that the corals in shaded area respire less oxygen than the open area corals [58,70].

Al-Sofyani [34] reported that the respiration rate percentage of *Stylophora pistillata* at 10m depth was 81% of the 1m depth both in summer and winter seasons. Whilst in *Echinopora gemmacea*, the respiration rate percentage was 93% at 10m depth and 79% 3m depth during both summer and winter. Similar to this, in *Montastrea annularis* off Discovery Bay, Jamaica, the dark respiration rate at 10m depth was 46% of that of 3m depth [56]. In shade-adapted *Stylophora pistillata*, the oxygen consumption was 54% of that of the light-adapted one [71].

The reduction in coral respiration rates with depth or shade may be related to the reduction in translocation of organic material from the algae which in turn was a function of decreased irradiance [51,56].

On the basis of surface area, the mean dark respiration rate of *S. hystrix* was higher 16.974 μlO_2cm^{-2} h^{-1} in 5m depth and also higher in 10 m depth (8.09 μlO_2cm^{-2} h^{-1}) than the *L. corymbosa* (8.082 μlO_2 cm^{-2} h^{-1}, 5.7610 μlO_2 cm^{-2} h^{-1}) respectively at during summer season.

In winter also, the mean dark respiration rate of *S. hystrix* was higher (22.01 μlO_2cm^{-2} h^{-1} and 9.958 μlO_2cm^{-2} h^{-1}) than the

L. corymbosa (5.871 μlO_2 cm^{-2} h^{-1}and 3.167 μlO_2 cm^{-2} h^{-1}) at 5m and 10 m depths respectively. In the case of *Pocillopora eydouxi* it was 8.1 μlO_2 cm^{-2} h^{-1} at Guam [32]. and in *Stylophora pistillata* it was 9.84 μlO_2 cm^{-2} h^{-1}[34] and 9.7 μlO_2cm^{-2} h^{-1} [58] at Red Sea. In Barbados, West Indies the respiration was within the range of 3.5-8.76 μlO_2cm^{-2} h^{-1} for six species of coral [72]. The present values were lower than that of *Porites lobata* (11.38 μlO_2 cm^{-2} h^{-1}) observed at 7 m depth [73] and of *Porites porites* (11.91 μlO_2 cm^{-2} h^{-1}) of at 10 m depth [33]. This comparison study revealed that the respiration rates of corals were decrease with increasing depths [56,67-69]. There is a difference in the mean dark respiration rate of two species on the basis of zooxanthellae count per hour. In *S. hystrix* it was 4.15 (5 m depth) and 2.69 (10 m depth) μlO_2 10^{-6}zoox^{-1}. h^{-1} and in *L. corymbosa* it was 17.84 (5m depth) 5.11 (10m depth) μlO_2 10^{-6}zoox^{-1}. h^{-1} during summer respectively. But in winter, the mean dark respiration rates of *S. hystrix* was (2.43 μlO_2 10^{-6}zoox^{-1}. h^{-1} and 1.73) μlO_2 10^{-6}zoox^{-1}. h^{-1} but in *L. corymbosa* it was (7.59 μlO_2 10^{-6}zoox^{-1}. h^{-1} and 2.97) μlO_2 10^{-6}zoox^{-1}. h^{-1} at 5m and 10m depths respectively,

Other studies reported that the *Pocillopora damicornis* respiration rate was 2.39 μlO_2 10^{-6}zoox^{-1}. h^{-1} (25 °C) to 3.03 μlO_2 10^{-6}zoox^{-1}. h^{-1} ((30 °C) during winter. In *Pocillopora* verrucosa it was 2.84 μlO_2 10^{-6}zoox^{-1}. h^{-1} at 25 °C and it was 2.48 μlO_2 10^{-6}zoox^{-1}. h^{-1} at 30 °C during winter, while in summer (35 °C) the values recorded, ranging from 7.46 μlO_2 10^{-6}zoox^{-1}. h^{-1}and 5.78 μlO_2 10^{-6}zoox^{-1}. h^{-1} for *Pocillopora damicornis* and *Pocillopora* verrucosa respectively in the Red Sea [37]. In the case of *Stylophora pistillata* it was 2.51 μlO_2 10^{-6}zoox^{-1}. h^{-1} at 1m depth and was 2.15 μlO_2 10^{-6}zoox^{-1}. h^{-1} at 10m depth in the summer (30 °C) similarly at 3m depth it was 3.1 μlO_2 10^{-6}zoox^{-1}. h^{-1} and at 10 m depth it was 2.63 μlO_2 10^{-6}zoox^{-1}. h^{-1} in the Red Sea [34]. Other studies on *Montastrea cavernosa* showed 2.61 μlO_2 10^{-6}zoox^{-1}. h^{-1}at 5m depth [32] and the studies on *Porites porites* showed 1.84 μlO_2 10^{-6}zoox^{-1}. h^{-1} at 10m depth [33].

During summer, the overall depth percentage of respiration rate by means of zooxanthellae in *S. hystrix* was 15.7% whereas in *L. corymbosa* it was higher 64.7%. Whereas in winter the overall depth respiration rate of *S. hystrix* was more in percentage 75.4% than the *L. corymbosa* 50.18% in the summer. The mean dark respiration rate was decreased with the increasing depths in the both species. Other studies reported that the respiration rate of the *Pocillopora damicornis* at 25 °C was about 7.69 % and was maximum 48.94 % at 30 °C. Similarly, in *Pocillopora verrucosa* the respiration rate was lower 3.7 % in 30 °C and higher in 23.53 % 35 °C respectively [37].

The work of Baker, et al. [14] suggested that members of clades D may have greater thermal tolerances than clades C in their zooxanthellae samples of *Palythoa caribaeorum*. Clade A and B inhabited shallow water colonies, while clade C zooxanthellae are found in deeper water colonies, or in shaded areas of the same individual coral colony[15,16] .

There was major bleaching in the Red Sea corals in the year 1998. In that period some coral species like *Pocillopora verrucosa* had found resistant to the bleaching event than the *Pocillopora damicornis* [16,18]. Moreover, Coles and Jokiel [21] reported very high response in metabolic rate due to temperature changes

(19-31 °C) in *Pocillopora damicornis*, *Montipora verrucosa*, *Porites compressa* and *Fungia scutaria* in Hawaii and Enewetak. This difference in the metabolic rates may be the indication of compensatory acclimation of the species to the temperature [74]. Acclimation has the effect of increasing metabolic rate during long-term exposure to reduced temperature. If acclimation is completed, the measured metabolic rates at the temperature at which the animals are living are identical.

Photosynthesis

The mean maximum gross photosynthesis (Pg_{max}) on the basis of both biomass and surface area were higher in *S. hystrix* than the *L. corymbosa*. This may be due to the higher number of zooxanthellae when expressed on both biomass and surface area basis. When the values were expressed on the basis of zooxanthellae density, *L. corymbosa* showed higher values than *S. hystrix* suggesting that self-shading of zooxanthellae may occur in the latter species [75].

During summer, the value of Pg_{max} on the basis of surface area, was higher in *S. hystrix* (30.4888 μlO_2 cm^{-2} h^{-1} at 5m depth) than the light-adapted *Stylophora pistillata* (22.9 μlO_2 cm^{-2} h^{-1}) at 2m depth [34,54] but at 10m depth the value of *S. hystrix* of the present study was 21.027 μlO_2 cm^{-2} h^{-1} when compared to the *Stylophora pistillata* of the different regions 18.67, 20.2 and 21.34 μlO_2 cm^{-2} h^{-1} [34,54,76] respectively. The Pg_{max} for *S. hystrix* during summer was similar to the *Pocillopora eydouxi* (36.1 μlO_2 cm^{-2} h^{-1}) at 5m depths [32].

The maximum gross photosynthesis values on the basis of mg.d.t.wt. h^{-1} for *S. hystrix* was 8.1965 mg.d.t.wt. h^{-1} at 5 m depth and 6.4339 μlO_2 mg.d.t.wt. h^{-1} at 10 m depth and in the case of *L. corymbosa* it was 2.594 μlO_2 mg.d.t.wt. h^{-1} at 5m depth and 2.067 μlO_2 mg.d.t.wt. h^{-1} at 10m depth in summer. These values were lower than the *Stylophora pistillata* (8.81-5.23 μlO_2 mg.d.t.wt. h^{-1} and higher than the *Echinopora gemmacea* (3.83-3.39) μlO_2 mg.d.t.wt. h^{-1} [34]. When compared to *Porites porites* it was 4.76 μlO_2 mg.d.t.wt. h^{-1} at 10m and in *Porites lobata* it was 4.26 μlO_2 mg.d.t.wt. h^{-1} at 3m respectively, both these species had large tissue biomass [33,48].

The Pg_{max} for *L. corymbosa* was lower in the winter than the summer and this could be probably due to the lower water temperature in the winter. However, at 5m depth, the rate of photosynthesis of *S. hystrix* was higher in winter than the summer.

The values of Pg_{max} in the present study for *L. corymbosa* decreased with increasing depths in winter, but in summer increased with increasing depth. Hence in *L. corymbosa* the value of α increased with increasing depths, however, in *S. hystrix* it declined with increasing depth and hence in *S. hystrix* the value of α decreases with increasing depths. These results have been shown to be associated with the processes of photoadaptation in corals [35,58,69,70,77,78], although Chalker and Dunlap [79], Falkowski and Dubinsky [80], reported the increase in Pg_{max} with increase in depth.

The I_k values of the PvI curve were the indication of the relative efficiency of photosynthesis at low light-levels. Similarly the lower value of I_k was indicating the higher efficiency. The I_k values of *S. hystrix* declined from 198.5 μE. m^{-2}. s^{-1} (5m depth) to 154.3 μE. m^{-2}. s^{-1} (10m depth) in summer while in winter was increased from 158.273 μE. m^{-2}. s^{-1} (5m depth) to 180.7 μE. m^{-2}. s^{-1} (10m depth) this might due to the photoadaptation ability of the zooxanthellae. Gattuso [77] worked on *Stylophora pistillata* and reported that at 1m it was 318 μE. m^{-2}. s^{-1} and 10 m it was 158.3 μE. m^{-2}. s^{-1}. Whilst Porter, et al. [58], found values of 273 μE. m^{-2}. s^{-1} at light adapted and 60 μE. m^{-2}. s^{-1} at dark adapted *Stylophora pistillata* respectively. The I_k values for *L. corymbosa* declined from 291.1 μE. m^{-2}. s^{-1} at 5m to 250.4 μE. m^{-2}. s^{-1} at 10m in summer similarly in winter it decreased from 202.72 μE. m^{-2}. s^{-1} at 5m to 180.4 μE. m^{-2}. s^{-1} at 10m. According to Davies [48], *Montipora verrucosa* was 176 and *Porites lobata* was 177 μE. m^{-2}. s^{-1} at 3 m depth.

Both *L. corymbosa* and *S. hystrix* displayed lower values of I_k in the winter than the summer at both depths indicating the photoadaption to the lower light levels prevailing during these months. This appears to be the first report of a seasonal photoadaption response in corals of the Red Sea. The deep-living corals exhibited difference in photosynthetic characteristics, which could be explained by photoadaptation to reduced light by the zooxanthellae. Changes were observed in the shape of the P v I curves. Notably the deep corals had lower values of I_k although values for α were similar.

Growth

Linear growth rates studies in this two species can be interpreted that, it may rapidly increase at the tips of the nubbin rather than lateral [32,34,37,81-83]. The growth rate of hermatypic corals is influenced generally by the external factors like light intensity, sedimentation [5,34,37,83-85]. The temperature is also another important parameter that can affect coral growth. In tropical corals, several studies showed that a 1 °C increment in mean annual temperature may resulted into the increase in the coral calcification rate by 3.1% especially when temperatures increased above the upper threshold limit of corals [86,87].

In *L. corymbosa* also, the growth rate was reduced by the internal factors such as reproduction, genetics, growth form of colony, number or type of zooxanthellae and production of mucus tunics by species. The light quality and intensity and seawater temperature during summer also affected the growth rate of *S. hystrix* and *L. corymbosa*. Hence, the mean respiration rate of zooxanthellae increased dramatically with an increasing temperature. The reduction in coral respiration rates with an increasing temperature was associated with a reduction in number of zooxanthellae. It may be possibly due to the translocation of organic material from the algae due to decrease in photosynthesis, in addition to decrease the growth rate of skeleton during winter.

The respiration of the corals was consumed the most important portion of the energy input [34,51]. However, both species, especially the *S. hystrix* seemed to be more sensitive to exogenous and endogenous factors. This was evidenced by the

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mean growth rates which recorded in the summer for *S. hystrix* and *L. corymbosa*. They were about 93.8% and 78.1% at 5m, and at 10m were about 82.6% and 77.7% in winter respectively.

In compared the mean growth with other studies, showed that the mean growth rate was 1.6 mg. skel. d^{-1} to 2.3 mg. skel. d^{-1} for *S. hystrix* and 7.3 mg. skel. d^{-1} to 6.18 mg. skel. d^{-1} for *L. corymbosa* at 5m and 10m in summer respectively. It was more or less similar to the growth rates of *P. damicorni* (3.90 mg. skel. d^{-1}) and also of *Pocillopora verrucosa* (5.40 mg. skel. d^{-1}) at 3m. But it was lower than the *Echinopora gemmacea* (13.46 mg. skel. d^{-1}) and *Stylophora pistillata* (56.03 mg. skel. d^{-1}) of even at 1m from the Red Sea [34]. In winter, the mean growth rates of *S. hystrix* was (1.5 mg. skel. d^{-1} to 1.9 mg. skel. d^{-1}) and for *L. corymbosa* it was 5.7 mg. skel. d^{-1}to 4.8 mg. skel. d^{-1} at 5m and 10m respectively.

Hence, the growth rate of the corals in the present study were higher in summer than the winter at 5m and 10m depths. But it was still lesser than the other studies which fallen within the range of 12.5 mg. skel. d^{-1} to 51.6 mg. skel. d^{-1} for several other coral species from 2 to 10m depths [32–34,36,48,88]. Another study by Floos [37] showed that the values in winter were 6.08 mg. skel. d^{-1} and 7.44 mg. skel. d^{-1} for *Pocillopora damicorni*s and *Pocillopora verrucosa* respectively.

Conclusion

The lower respiration rate of *L. corymbosa* of the present study may be due to the higher tissue biomass which is not active than the *S. hystrix.*

The mean maximum gross photosynthesis (Pgmax) on the basis of both biomass and surface area were higher in *S. hystrix* than the *L. corymbosa.* This may be due to the higher number of zooxanthellae when expressed on both biomass and surface area basis

The reduction in coral respiration rates with an increasing temperature was associated with a reduction in number of zooxanthellae . It may be possibly due to the translocation of organic material from the algae due to decrease in photosynthesis, in addition to decrease the growth rate of skeleton.

All these findings indicate that *S. hystrix* is predominantly dependant on autotrophic feeding while *L. corymbosa* relies mainly on heterotrophic feeding.

Recommendations

1. Avoiding coastal settlement (construction of building) will reduce the sediment input on the corals.

2. Reef fishing and boat anchoring on reefs should be banned. Separate boat jetty should be arranged (if necessary) in reef areas to avoid reef damage.

3. Dumping of wastes and drainage or ballast water discharge in the reef environment should be completely avoided.

4. Awareness campaign for both public and students will be essential to know the important of coral reefs will provide positive result

5. Assess the environmental impact of socio-economic development and identify hotspots of environmental stress along the shores of the Red Sea.

6. You must establish the Red Sea coral ecosystem and biodiversity.

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