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RESEARCH ARTICLE

Coral diversity and similarity along Sudanese Red Sea Fringing reef.

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Abstract

This study investigated and assessed the coral diversity and similarity along the Sudanese Red Sea fringing reefs, aiming to establish baseline data for future studies and document coral diversity and similarity between different sites. This study was carried out during the period between 2008 and 2011 in seven different areas extended from north to south for 300 km; Osef, Dungonab, Arkiyai, Arous, Abuhashish, Bashair and Suakin. The methods used comprised of three 50 m transects (point intercept transect and belt transect) surveyed at each of three depths; 1-3m, 5-7m and 10-12m. For all transect data, a hierarchical cluster analysis, ANOVA test and t-test were performed. The results showed some variation and differences between depths, and sites. 136 species of hermatypic corals belonging to 42 genera were identified, species richness ranged from 38 species in Dungonab to 12.33 species in Bashair. The highest value for the index of similarity was 68 % registered between Arkiyai and Suakin, whereas, the lowest value was 32 % registered between Suakin and Bashair. Coral reef biodiversity of the Sudanese Red Sea fringing reef is probably not seriously threatened as long as the legislated conservation measures are maintained.

Introduction:-

The Sudanese Red Sea supports an extensive near continuous fringing reef, a complex offshore barrier reef system, and numerous uninhabited islands. While some of the more accessible reefs, such as those in the vicinity of Port Sudan and Sanganeb Atoll, have previously been the subject of research (Head 1980, Merger and Schumacher 1985, Edwards and Head 1987, Reinicke *et al*., 2003), and others are renowned tourism dive sites (e.g. Sha'ab Rumi), many of the reefs have never previously been surveyed.

The reefs of Sudan have, in the past, been referred to as being among the most diverse in the Red Sea (Ormond, 1976). However, the reality is more complex due to the interplay of many physical and environmental factors (Vine and Vine, 1980). Species lists for Sanganeb (Schroeder, 1981) and Wingate are available, and the reefs in the vicinity of Port Sudan have been extensively described (Schroeder and Nasr, 1981; Head, 1980). The Towartit reef complex has been studied extensively by Vine and Vine (1980) who report poor hard coral growth and high algal covering on the fringing reef south of Port Sudan. Hard corals comprise significantly more of the substrate offshore in the Towartit complex (Head, 1980), and the offshore reefs of Suakin have also been described as being of high diversity offshore with decreasing diversity as one proceeds towards the coastal fringing reef (Ormond, 1976).

Along the Red Sea, almost 50 % of sites had more than 40 coral species and 12 % of sites had over 50 species, similar to counts at reefs in the central and northern Red Sea. The richness of hermatypic corals in the Red Sea has been estimated to be 180- 200 species (Sheppard and Sheppard, 1991). Elmak has (1988) investigated the coral communities in Suakin area of Sudanese Red Sea coast. A total of 138 Scleractinian species of 46 genera was found, of these 20 species have not been previously recorded in Sudan, two of these are new records for the Red Sea as a whole. A total of 209 hard coral species (Veron 2000) and approximately 120-125 soft coral species (Fouda, 1995) have been recorded in the Egyptian Red Sea. However the central Red Sea boasts the greatest number of hard corals with 143 different species. In Djibouti, a total of 166 to 167 species of corals were recorded (Obura, 1998). In Somalia, a total of 74 species of scleractinian coral, 11 species of alcyonacean (soft) coral and two species of fire coral were found (PERSGA, 1998b). In Yemen, a total of 176 species of stony corals have been recorded. The Socotra archipelago supports a diverse fauna of 240 stony coral species, placing it among the richest sites in the western Indian Ocean (Sheppard and Sheppard, 1991). In Saudi Arabia, the coral communities were composed of at least 260 species (Veron, 2000).

Material and Methods:-

The study was undertaken within the Sudanese Red Sea coast from 2008 to 2011. The study area spanned approximately 300km of coast from north to south (Fig. 1). Seven sites were selected to represent the Sudanese reefs which are accessible and showing different levels of pressures and richness. Selection was done after a preliminary surveys to a wider range of sites. These sites are O’Seif, Dungonab bay, Arkiyai, Arous, Abuhashish, Bashair and Suakin.

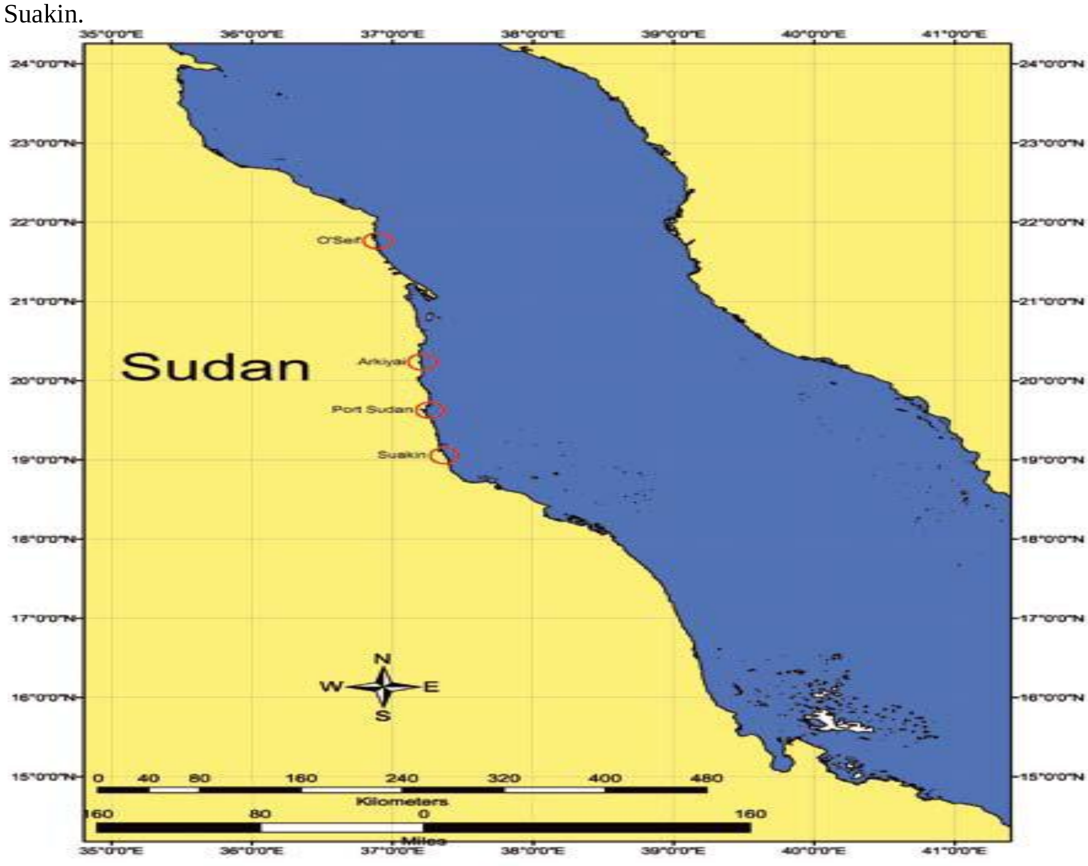


Fig. 1 The locations of the study sites indicated by red circles

The method used in this study comprised of three 50 m transects surveyed at each of three depths, shallow (1-3m), (5-7 m) and mid-reef (10-12 m. Diversity of hermatypic corals was assessed qualitatively for the 50m transects by using the visual survey method of Kenchington (1978). All hermatypic coral species were identified and recorded per 50 point transect. The duration for the inspection of each transect was 50-60 minutes. Within the substrate survey hermatypic corals were identified to genus and species level to assess the coral diversity.

From all data, species richness (S); Shannon-Wiener diversity index (H'); species diversity under conditions of maximum equitability (Hmax); evenness or equitability (E); Simpson’s diversity index (D) and index of similarity (IS) were calculated to compare coral diversity and community assemblage among sites and depths as suggested by Muller (1984).

Species richness (S):-
species richness (S) = number of species present in the community

Shannon-Wiener -Index H':

Shannon-Wiener -Index H': $$H' = -\sum_{1=i}^{S} (Pi)(\log_2 Pi)$$

H' = index of species diversity, S = number of species (species richness), Pi = proportion of total sample belonging to *i*th species. The diversity index (H') converges to zero if all colonies belong to one species and reaches its peak H'max if all species have a similar amount of colonies (Muller, 1984).

Species diversity under conditions of maximum equitability (Hmax):
Hmax = $\log_2 S$
S = number of species in the community.

Evenness or equitability (E):
Evenness or equitability: E = H'/ Hmax
Where: H' = Shannon-Wiener – Index (observed species diversity), Hmax = maximum species diversity = log2 S. This index is typically on a scale ranging from near 0, which indicates low evenness or high single-species dominance, to 1, which indicates equal abundance of all species or maximum evenness.

Simpson's diversity index (D):

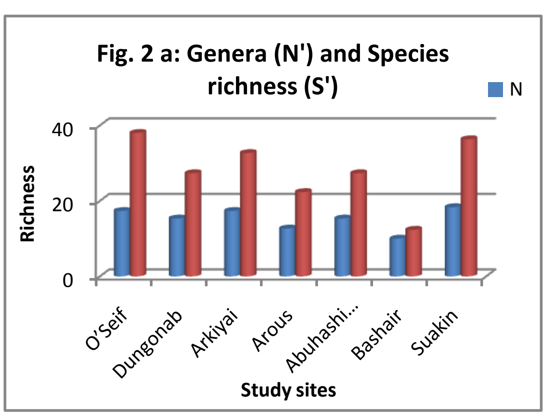
Simpson's diversity index (D): $$D = -\sum_{1=i}^{S} (Pi)^2$$

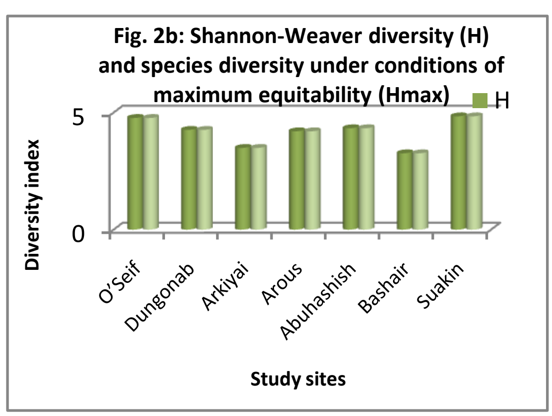
D = Simpson's index of diversity (ranging from 0 to 1), *Pi* = proportion of individuals of species in the community.

Index of similarity (IS):
Index of similarity (SI) = 2C/ a+b
a = number of species in the community a, b = number of species in the community b, c = species occurring in both communities. This index ranged from 0 to 1 to quantify the range from no similarity to complete similarity.

Results and discussions:
During the study period 136 species of hermatypic corals belonging to 42 genera were identified; 31 species are endemic to the Red Sea. 136 species of hermatypic corals are growing along the fringing reef of Sudanese coast, 134 of which are stony corals. Data on species numbers for stony corals species varies between 128 (Abou Zaid, 2000) and 220 (Sheppard and Sheppard, 1991) for the northern Red Sea. The results of the current study are consistent with the results of Abou Zaid (2000), although in these studies only a defined area of the reef was surveyed. It is likely that not all species were recorded, since some species are restricted to certain depths or sites which were not examined here. A comparable study (Heiss *et al*. 2005) found 144 species of stony corals for El-Quadim-Bay near El Quseir, Egypt. A fraction of these species was found within the bay's protected areas. Furthermore, all reef areas down to a depth of 40 m were surveyed. The species growing in these zones are most likely present in this study as well, yet these areas were not surveyed. A comparison to other studies, which were also restricted to certain sites and depths, resulted in a different image. Riegl and Velimirov (1991) found 96 hard coral species (92 stony corals) for the region around Hurghada, Elmak (1988) found 138 hard coral species for the area around Suakin, and Loya and Slobodkin (1971) found 97 species (95 stony corals) for Eilat in the Gulf of Aqaba. These studies were based on the line-intercept-transect method and are not directly comparable. The point intercept method, which was used for the present study, is not capable of determining species richness. It was rather used for an assessment of dominant species. It can be stated with certainty that the majority of hermatypic corals of the northern Red Sea can also be found in the study area.

Diversity indices varied from site to site and within different depths. Genera richness (N') reached the maximum value of 18.33 at Suakin site and the minimum value of 10 at Bashair site. Species richness (S') reached the maximum value of 38 at Osef site and the minimum value of 12.33 at Bashair site (Fig. 2 a- c).





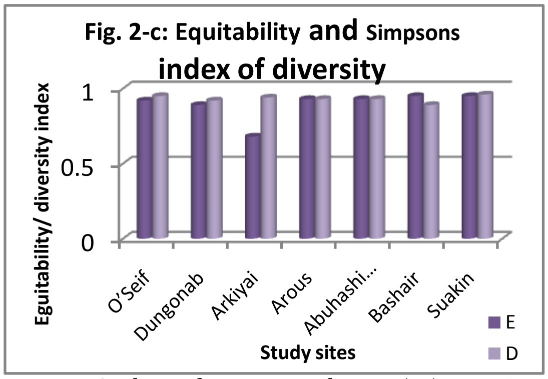


Fig. 2-c: Equitability and Simpsons index of diversity

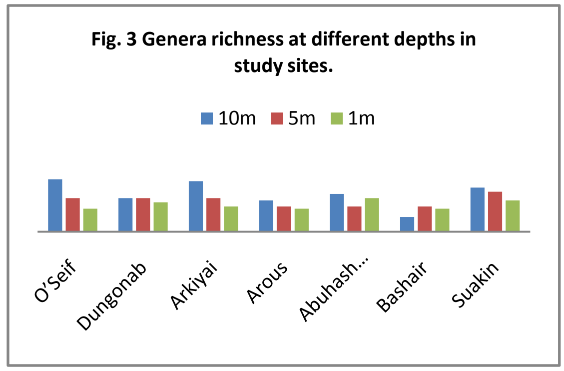


Fig. 3 Genera richness at different depths in study sites.

Figs. 4 to 8 showed genera richness (N'), species richness (S'), Shannon-Weaver function of species diversity (H'),species diversity under conditions of maximum equitability (Hmax), Simpson's index of diversity (D) and equitability (E) at different depths (10m, 5m and 1m) along 50m length transects at all sites.

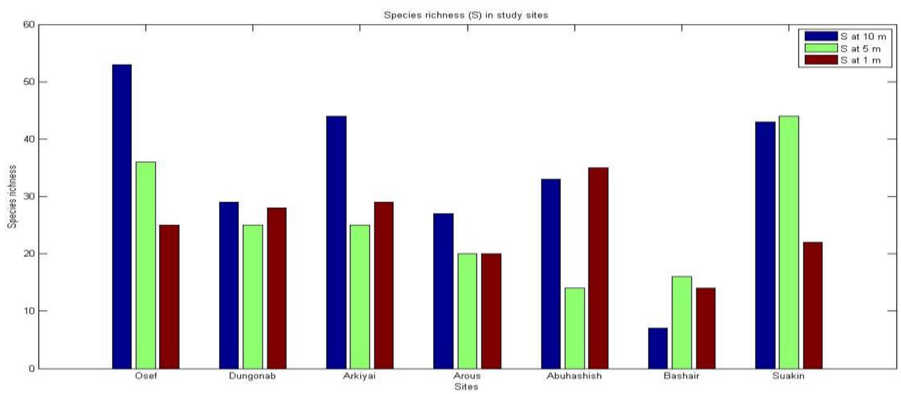


Fig. 4 Species diversity (s) in different sites at different depths

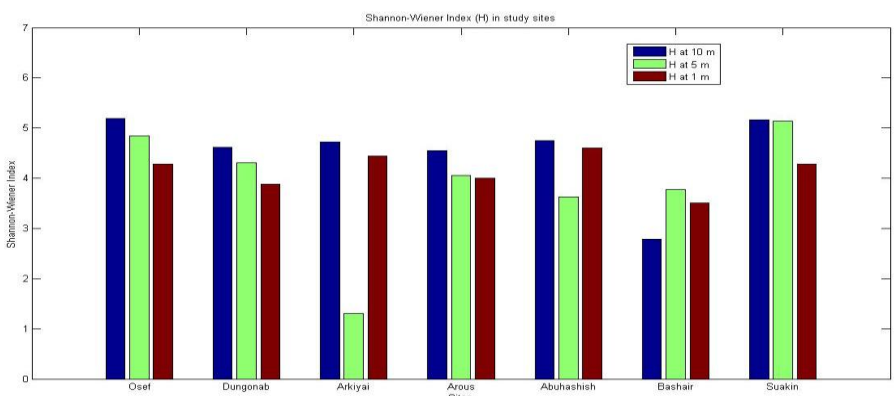


Fig. 5 Shannon-Weaver function of species diversity (H') in different sites at different depths.

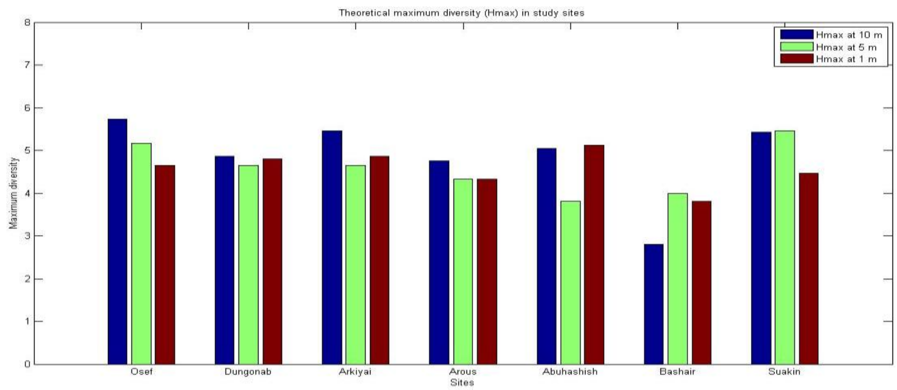


Fig. 6 Species diversity under conditions of maximum equitability (Hmax) in different sites at different depths.

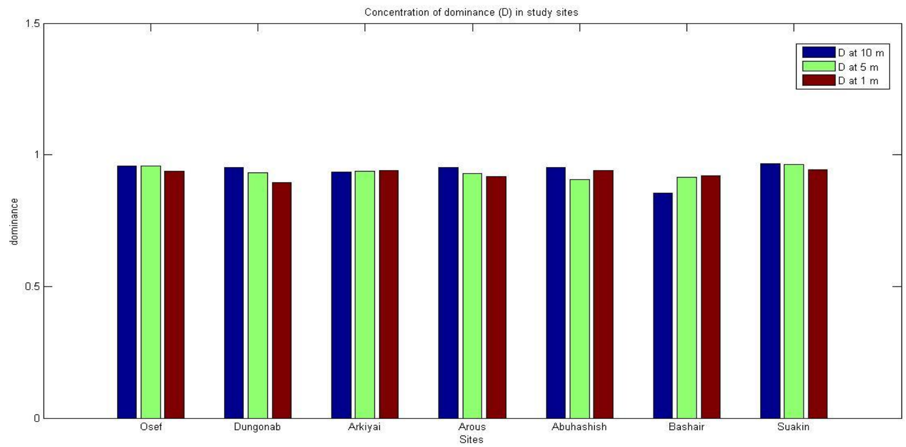


Fig. 7 Simpson's index of diversity (D) in different sites at different depths.

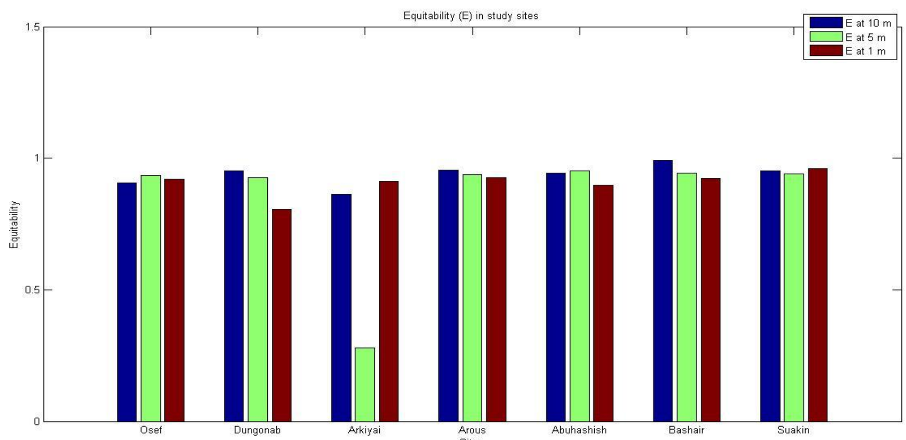


Fig. 8 Equitability (E) in different sites ay different depths.

ANOVA test showed that there was significant difference ($P<0.05$) between Hmax ($P=0.022$) and different depths and sites and insignificant difference ($P>0.05$) between S ($P=0.66$), between H ($P=0.274$) and different depths and sites.

The total coral genera found throughout this study comprised more than 70% of the genera known to occur in the Red Sea region (Veron, 2000), with all of the common genera found, but few of the rarer genera recorded. Coral diversity indices (Shannon-Weaver function of species diversity (H), Species diversity under conditions of maximum equitability (Hmax) and Simpson's index of diversity (D)) and live coral cover are positively correlated; however both are decreased in Bashair and increased in Suakin, Osef and Dungonab respectively, this agreed with Smith and Mellor (2006).

Index of similarity varied between different depths and sites. Table 1 showed index of similarity (IS) between three depths (10mand5m, 10mand1m, 5mand1m) for each study sites, IS reached the maximum value of 0.58 between 10mand5m at Osef site where as the minimum value of 0.17 recorded between 10mand5m at Bashair site.

Table 1: Index of similarity (IS) between different depths.

Sites	Index of Similarity			
	10mand5m	10mand1m	5mand1m	Average
Osef	0.58	0.36	0.36	0.43
Dungonab	0.22	0.56	0.34	0.37
Arkiyai	0.29	0.22	0.37	0.29
Arous	0.38	0.34	0.4	0.37
Abuhashish	0.38	0.41	0.24	0.34
Bashair	0.17	0.19	0.27	0.21
Suakin	0.57	0.28	0.33	0.39

Similarity index (SI) showed high variations between depths in every single area (Table 2) with low SI (<0.50) in 19 comparisons from 21 comparisons (three comparison for each study site) and low variations between study sites with slightly high SI (>0.50) compared to SI between depths in 16 comparisons from 21 comparisons. Index of similarity increased between adjacent reefs and decreased between depths in a single area (Veron, 2000).

Table 2: Index of similarity between sites, number of coral species in community 1 (a), number of coral species in community 2 (b) and number of coral species occurring in community 1 and 2 (c).

Between sites	**a**	**b**	**c**	**IS**	Between sites	**a**	**b**	**c**	**IS**
OSandDU	71	62	42	0.63	AKandAR	68	46	35	0.61
OSandAK	71	68	41	0.59	AKandAB	68	58	37	0.59
OSandAR	71	46	28	0.48	AKandBA	68	30	18	0.53
OSandAB	71	58	40	0.62	AKandSU	68	71	47	**0.68**
OSandBA	71	30	19	0.38	ARandAB	46	58	32	0.62
OSandSU	71	71	41	0.58	ARandBA	46	30	16	0.42
DUandAK	62	68	34	0.52	ARandSU	46	71	30	0.51
DUandAR	62	46	30	0.56	ABandBA	58	30	16	0.36
DUandAB	62	58	31	0.52	ABandSU	58	71	35	0.54
DUandBA	62	30	15	0.33	BAandSU	30	71	16	**0.32**
DUandSU	62	71	38	0.57					

Conclusions:-

From the results of the analysis of the coral diversity and similarity of fringing reef along the Sudanese Red Sea coast; we can concluded that a successive increase in species diversity of hermatypic corals were recorded in Suakin, Osef and Dungonab respectively; decrease in species diversity were recorded in Arkiyai, Arous, Abuhashish and Bashair respectively from the reef flat (1m) to a depth of 10 m; this decrease may be due to the lower abundance, smaller colony size and lower living coral coverage on these sites as compared to others; Species diversity of corals was significantly greater in steeper zones as compared to flatter zones of the reef and there is a similarity in species composition between areas with varying degrees and different depths. These observed variations would be useful when addressing issues of climate change adaptation and resilience of these species.

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Appendix (1): Coral species recorded in study sites.

Acropora	***Pavona***	***Leptastrea***
Acropora austera	*Pavona clavus*	*Leptastrea bottae*
Acropora clathrata	*Pavona decussata*	*Leptastrea purpurea*
Acropora digitifera	*Pavona maldivensis*	*Leptastrea transversa*
Acropora forskali	***Caulastrea***	***Leptoria***
Acropora formosa	*Caulastrea tumida*	*Leptoria pharygia*
Acropora grandis	***Cyphastrea***	***Montastrea***
Acropora humilis	*Cyphastrea chalcidicum*	*Montastrea curta*
Acropora haimei	*Cyphastrea hexasepta*	***Oulophyllia***
Acropora maryae	*Cyphastrea microphthalma*	*Oulophyllia crispa*
Acropora massawensis	***Diploastrea***	***Platygyra***
Acropora nobilis	*Diploastrea heliopora*	*Platygyra daedalea*
Acropora parapharaonis	***Echinopora***	*Platygyra lamellina*
Acropora rufus	*Echinopora forskaliana*	*Platygyra sinensis*
Acropora squarrosa	*Echinopora fruticulosa*	***Plesiastrea***
Acropora tenuis	*Echinopora gemmacea*	*Plesiastrea versipora*

Acropora valida	*Echinopora irregularis*	***Ctenactis***
Acropora variabilis	*Echinopora lamellosa*	*Ctenactis echinata*
Acropora variolosa	***Erythrastrea***	***Cycloseris***
Acropora yongi	*Erythrastrea flabellata*	*Cycloseris erosa*
Anacropora	***Favia***	*Cycloseris costulata*
Anacropora spumosa	*Favia albidus*	***Fungia***
Montipora	*Favia favus*	*Fungia danai*
Montipora circumvallata	*Favia helianthoides*	*Fungia concinna*
Montipora cryptus	*Favia lacuna*	*Fungia scruposa*
Montipora effusa	*Favia matthaii*	***Herpolitha***
Montipora foliosa	*Favia pallida*	*Herpolitha limax*
Montipora floweri	*Favia rotundata*	***Podabacia***
Montipora meandrina	*Favia rotumana*	*Podabacia crustacea*
Montipora monasteriata	*Favia speciosa*	*Podabacia sinai*
Montipora spongiosa	*Favia stelligera*	***Merulina***
Montipora spumosa	***Favites***	*Merulina ampliata*
Montipora stellata	*Favites abdita*	***Acanthastrea***
Montipora stilosa	*Favites complanata*	*Acanthastrea echinata*
Montipora tuberculosa	*Favites flexuosa*	***Blastomussa***
Montipora venosa	*Favites halicora*	*Blastomussa merleti*
Montipora verrilli	*Favites pentagona*	*Blastomussa wellsi*
Gardineroseris	*Favites vasta*	***Cynarina***
Gardineroseris planulata	***Goniastrea***	*Cynarina lacrymalis*
Leptoseris	*Goniastrea aspera*	***Lobophyllia***
Leptoseris explanata	*Goniastrea edwardsi*	*Lopophyllia corymbosa*
Leptoseris gardineri	*Goniastrea peresi*	*Lopophyllia hemprichii*
Leptoseris mycetoseoides	*Goniastrea retiformis*	***Galaxea***
Leptoseris scabra	*Goniastrea thecata*	*Galaxea astreata*
Mycedium	***Alveopora***	*Galaxea fasciculris*
Mycedium elephantotus	*Alveopora daedalea*	***Porites***
Mycedium umbra	*Alveopora verrilliana*	*Porites columnaris*
Oxypora	*Alveopora viridis*	*Porites lichen*
Oxypora convoluta	***Goniopora***	*Porites lopata*
Oxypora egyptensis	*Goniopora ciliatus*	*Porites lutea*
Seriatopora	*Goniopora minor*	*Porites mayeri*
Seriatopora hystrix	*Goniopora planulata*	*Porites nodifera*
Stylophora	*Goniopora somaliensis*	*Porites rus*
Stylophora danae	*Goniopora stokesi*	*Porites solida*
Stylophora kuehlmanni	*Goniopora sultani*	***Coscinaraea***
Stylophora mamillata	*Goniopora tenella*	*Coscinaraea monile*
Stylophora pistillata	*Goniopora tenuidens*	***Millepora***
Stylophora subseriata	***Siderastrea***	*Millepora dichotoma*
Stylophora wellsi	*Siderastrea savignyana*	*Millepora platyphyll*