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Survivorship and growth rates for some transplanted coral reef building species and their potential for coral reef rehabilitation in the Red Sea

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ABSTRACT

The deterioration of coral reefs in Egypt is a serious environmental problem. As part of studying the reef habitats rehabilitation; about 180 specimens of 8 hard coral reef species belonging to 2 families (Pocilliporidae and Acroporidae) were transplanted using table-type galvanized steel frameworks. Survival and growth rates were measured ***in situ*** then monitored over 24 months. From the transplanted 180 specimens, 128 fragments representing 71% were still survived after 4 months decreased to 121 fragments with a percentage of 67.2% after 12 months increased to 123 fragments (after recovery of two specimens) with 68.3% of the transplanted specimens after 24 months. Significant differences (P<0.05) in growth rates were observed among the three periods of investigation (4, 12 and 24 months) in both families. The mean growth rates of investigated species of Pocilliporidae; *S. pistillata*, *P. damicornis* and *P. verrucosa* after 4, 12 and 24 months were; 1.27±0.06 cm yr^{-1}, 1.2±0.07 cm yr^{-1} and 1.03±0.07 cm yr^{-1} (F = 3.43, 3.16 and 4.95) respectively. The investigated species of Acroporidae; *Acropora tenuis*, *A. digitifera*, *A. horrid*, *A. samoensis* and *A. variabilis* recorded the annual mean growth rates of; 0.56±0.02 cm yr^{-1}, 0.45± 0.04 cm yr^{-1}, 1.04± 0.05cm yr^{-1}, 0.83± 0.04cm yr^{-1} and 0.98± 0.03cm yr^{-1} (F = 17.58, 0.59, 0.60, 1.50 and 2.83) respectively. New coral reef recruits were observed for *S. pistillata*, *P. verrucosa*, *P. damicornis* and *A. degitefera*, but the coral recovery was observed for *S. pistillata* only.

INTRODUCTION

Coral reefs of the world are being degraded at disturbing rates and calcification rate have been decreasing as a result of natural and human activities disturbances (Spalding and Brown, 2015; Lizcano-Sandoval *et al.* 2018), that requires the development of real restoration systems. Two of the methods frequently used today are (1) the direct transplantation of coral fragments/colonies to corrupted reefs; and (2) the "coral gardening" method, which supports coral transplantation only following an transitional nursery phase, where corals are cultivate until reaching appropriate sizes (dela Cruz *et al.* 2015).

Restoration projects have used totally coral colonies, planting of planula larvae, transplanting of petite “nubbins,” and transplanting of branches or fragments. Various methods of supporting corals to the substratum have been used, and experiments have been done to recognize the best substrates for attachment.

Although coral transplanting has aptitude and is commonly supported (Precht, 2006; Forrester *et al.* 2011). In the relatively short past decades of coral restoration, the direct transplantation of coral fragments or whole colonies has regularly been employed, because it is easy and directly compared to other methods (Rinkevich, 2014; Horoszowski-Fridman *et al.* 2015).

Transplantation of coral fragments is a typical methodology for the restoration of debased coral reefs because coral fragments can possibly reattach to the substrate and develop to become reproductively mature colonies, thus, fragmentation is an important method of asexual reproduction and may determine local colony abundance and distribution for some species (Shaish *et al.* 2010; Lizcano-Sandoval, *et al.* 2018). The coral transplantation experiments have been carried out in tropical countries. But, the experimental coral transplantation and a long term monitoring have hardly ever carried out for the extensive coral reef protection (Guest *et al.* 2011). Though a number of studies have successfully transplanted coral fragments, there is no agreement on the type of the used substratum. Artificial transplantation of corals is a common method used to restore damaged or unhealthy coral assemblages. (Hesley *et al.* 2017).

The main factor to building reef is coral growth with calcareous hard structures that provide indirect and direct habitats for marine organisms and therefore sustain the growth and construction of coral reef ecosystems (Tortolero-Langarica *et al.* 2017). Various techniques have been employed to study coral growth, including measurements of the linear extension of whole colonies or branches (Herler and Dirnwöber, 2011). The linear extension rate (cm yr^{-1}) have been supportive to evaluate coral growth rate over interval. This allows us to know how the animals are responding to local environmental factors, which thereby allows for the modeling of future growth of the coral reef on an ecosystem level (Glynn *et al,* 2015; Tortolero-Langarica *et al.* 2017).

In the Egyptian Red Sea, few studies have been done about coral transplantation in Hurghada e.g. (Ammar, 2000; Kotb, 2003, 2013; Ammar and Mahmoud, 2005; Mohammed *et al.* 2012) and in Ras Muhammad National Park (Abdo and Hegazy, 2015). The aim of this study is to evaluate coral growth rates, survivorship and new natural recruitments *in situ*, using transplantation technique on a galvanized steel water pipes artificial substrate, in order to rehabilitate and restore the destroyed coral communities and developing new reef habitats in different areas in the Red Sea.

MATERIALS AND METHODS

Study site

Several marine survey trips were done along the Red Sea between Hurghada and Shalateen to select the appropriate site and species for coral transplantations during 2016. One site was selected (Fig. 1) to execute the transplantation experiment that distinguished by unique local oceanographic conditions, protected from the natural predators and intensive wave actions that may pull out artificial frames, has the coral sources for the transplantation specimens and secure from stolen. The site was selected at the marine area in front of Wadi El Gemal National Park in Marsa Alam city 350 km Southern from Hurghada city at the coordinates: 24° 41' 09.17"N and 35° 05' 07.09"E

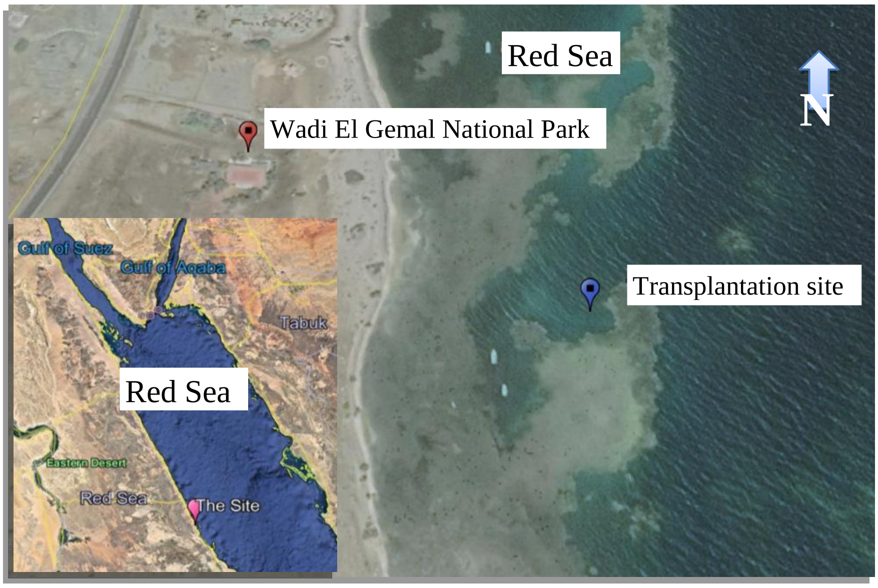

Fig. 1: The site of the transplantation study at Wadi El Gemal National Park, Marsa Alam city.

Design and construction of the table-type frameworks

Ten table-type frameworks (Fig. 2) were designed from 3/4 inch galvanized steel pipes with measuring 150 cm length by 100 cm width, each framework stands on four legs with a legth 100 cm from the same material fastened by a weld. The middle zone of each table framework was reinforced by two parallel pipes, from the same material, fastened from an equal distance of the widths. The surface area of the table frameworks was covered with coated and galvanized steel wire mesh (mesh size 3.0 cm). The all ten table type frameworks were arranged side-by-side in a longitudinal shape at a depth of 8 m (the frames were 1 m above the sea bottom) so the transplanted area equals 15 m^2.

Collecting specimens

One hundred and eighty healthy branched coral fragments (10-20 cm) were collected during October 2016 by SCOBA diving up to 8 m from Wadi El Gemal National Park marine area. The fragments collected from the only broken colonies in the area and not to be allowed to break any new colonies. Eight different branched coral species belonged to two families were considered here; five species belonged to family Acroporidae (*Acropora digitifera, A. horrida, A. samoensis, A. tenuis and A. variabilis*) and three species belonged to family Poclloporidae (*Pocillopora damicornis,P. verrucosa and Stylophora pistillata*). All species are hermatypic corals protecting the symbiotic algae zooxanthellae, which significantly accelerate the calcification process, thus empowering their host corals to quickly establish fragments in coral reefs (Veron, 2000).

Each coral fragment was tied well from the base together with the steel pipes and with the net in the frames using a big plastic strap and was tagged by about 1.0-2.0 cm from the tip of the branch. The linear extension was measured using vernier caliper (± 0.1 mm precision) to measure the length of the tagged branches from the plastic strap to the tip of the branch. Growth rates in terms of linear extension (cm yr^{-1}) were estimated. Linear extension rate was determined based on the change in tagged coral fragment length over 4, 12 and 24 months after transplantation. Survival rates were calculated as the percentage of coral fragments that were alive at 4,12 and 24 months. Coral recruit diversity, number, size and growth were monitored and recorded on the frameworks along 24 months. Recruit size was recorded as horizontal and vertical maximum diameters.

Seawater characteristics

Environmental conditions including total dissolved salts (TDS), salinity, pH, Dissolved oxygen (DO) and turbidity were measured *in situ* using YSI professional multiparameter and turbidity meter instruments. The nutrient salts (ammonia, nitrite, nitrates, silicate and phosphorous) were measured spectrophotometercally using GenWay Spectrophotometer; (Ammonia at 630 nm., Nitrite at 540 nm., Phosphates at 880 nm. and Silicates at 700 nm.).

Sediment characteristics

The samples of the seafloor sediments were collected for Grain Size analyses. The collected sediment samples were air dried, disaggregated then the grain size analyses were obtained, each one to delineate the main size characteristics. The sedimentation rates at the studied site were obtained by fixing four glass gars with specific diameters and depths below the transplantation frames for specified periods.

Data analysis

Statistical analysis was performed using SPSS *V.* 18.0 for Windows. Growth rates (mean ± S.E.) were analyzed with a one-way ANOVA. Survival rates were calculated considered only fragments that survived and still alive. The statistical significance level was set at 0.05.

RESULTS

Physico-chemical parameters of seawater

Physical parameters; water temperature (ºC), total dissolved salts (TDS), salinity (‰), dissolved oxygen (O_2), pH and turbidity (NTU) and chemical parameters (nutrient); ammonia, nitrites, nitrates, phosphate and silicate are listed in Table (1).

Table 1: Physico-chemical parameters of sea water at Wadi El Gemal Protectorate marine area.

Physico-chemical parameters		units	Min	Max
Physical parameters	Temperature	ºC	23	30
	TDS	ppm	38514	39741
	Salinity (‰)	ppt	40.12	41.32
	DO	mg l^{-1}	5.66	6.85
	pH		8.05	8.16
	Turbidity	(NTU)	32	44
Chemical parameters	Ammonia	µg l^{-1}	22	46
	Nitrites	µg l^{-1}	66	211
	Nitrates	µg l^{-1}	1230	2456
	Phosphate	µg l^{-1}	112	980
	Silicate	µg l^{-1}	1687	5741

Sediment characteristics

The recorded data illustrated that sand category was the dominant fraction with mean percentages of 93.27 ± 3.5 % meanwhile the gravel was 4.22 ± 4.21 % but the lowest percentage was 2.51 ± 1.85 % for mud. The sedimentation rate at Wadi El Gemal National Park marine area recorded considerably high sediments rates relative to the natural habitats in the Red Sea**;** it fluctuated between 12.8 mg cm^{-2} day^{-1} to 27.8 mg cm^{-2} day^{-1} with an average of 25.7 mg cm^{-2} day^{-1}**.**

Survivals and coral growth rates

Survival and growth rates were measured ***in situ*** then monitored over 24 months. From the transplanted 180 specimens that were tagged at the onset of the experiment, 128 fragments representing 71% were still survived after 4 months decreased to 121 fragments with a percentage of 67.2% after 12 months increased to 123 fragments (after recovery of two specimens) with 68.3% of the transplanted specimens after 24 months (Fig. 2). Totally, all causes of mortality, four months after transplantation, were either due to the growth of algae on coral fragments or due to bleaching, except few fragments were later died. Survival rates, of the coral fragments species, varies from one species to another, while, the highest survival rates (100%) were in *A. horrida* and *A. tenuis* family Acroporidae. The lowest survival rates (30%) were in *A. variabilis* in the same family. In family Pocilliporidae the highest survival rates (80 %) were in *P. damicornis* and the lowest survival rates (60%) were in *A. samoensis* and *S. pistillata*. The recorded survival rates of Acroporidae and Pocilloporidae at Wadi El Gemal National Park after 24 months were reached 67% and 71% respectively.

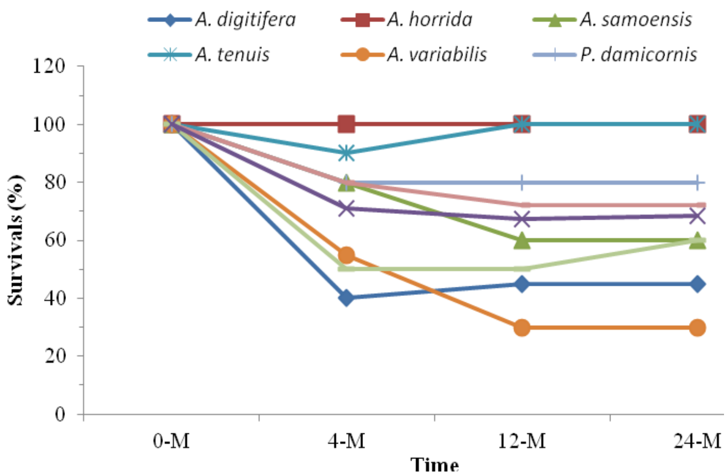

Fig. 2: Survival rates percentage (%) of the eight transplanted coral during the study period in Wadi El Gemal National Park.

The linear extension was measured as the change in length for tagged coral fragments on the eight species. Accordingly, lived coral fragments, only were considered to linear extension measuring. All fragments from each of the eight species investigated showed similar cumulative growth patterns after 24 months of transplantation. The related growth rates significantly ($p<0.05$) increased linearly over time (Fig. 3). The value of mean monthly growth rates varies between the two families; even it varies from one species to another in the same family (Fig. 4). In general, family Pocilliporidae showed highest growth rates compared with family Acroporidae. After 24 months of transplantation, the highest growth rates were in *S. pistillata* and the lowest growth rates were in *A. digitifera*

In family Pocilliporidae; There were significant differences (ANOVA, $P<0.05$) were recorded between growth rates after 4, 12 and 24 months (Fig. 4) in *S. pistillata*, *P. damicornis* and *P. verrucosa* and the mean growth rate was 1.27 ± 0.06 cm yr^{-1}, 1.2 ± 0.07 cm yr^{-1} and 1.03 ± 0.07 cm yr^{-1} (F=3.43, 3.16 and 4.95) () respectively.

In family Acroporidae; There were significant differences (ANOVA, $P<0.05$, F= 17.58) were recorded between growth rates of *A. tenuis* after 4, 12 and 24 months, the mean growth rate was 0.56±0.02 cm yr^{-1}. On the other hand there were no significant differences (ANOVA, $P>0.05$, F= 0.59, 0.60, 1.50 and 2.83) were recorded between growth rates of *A. digitifera, A. horrida, A. samoensis and A.*

variabilis after 4, 12 and 24 months and the mean growth rate was 0.45± 0.04 cm yr^{-1}, 1.04± 0.05 cm yr^{-1}, 0.83± 0.04 cm yr^{-1} and 0.98± 0.03 cm yr^{-1} respectively.

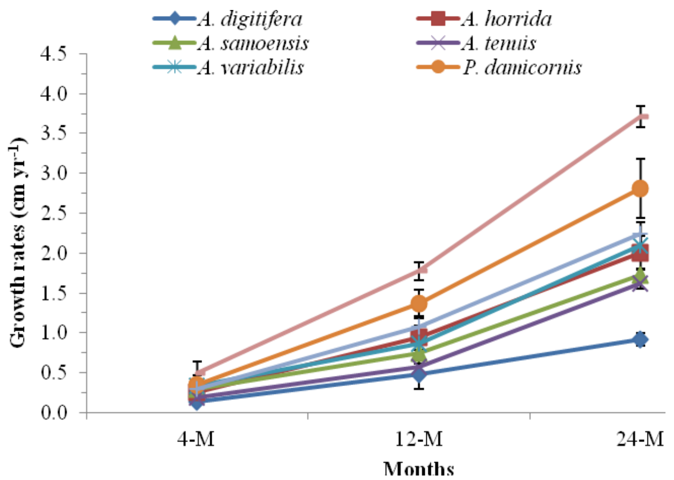

Fig. 3: Time course of cumulative fragments growth rates (cm yr^{-1}) of the eight different coral species. The error bars are the standard error (S.E.).

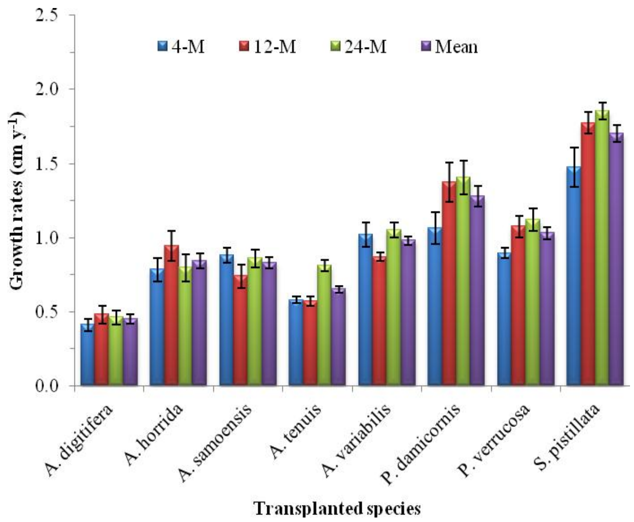

Fig. 4: Growth rates (cm yr^{-1}) of the eight different coral species after 24 months of transplantation. The error bars are the standard error (S.E.).

Natural coral recruitments

The results showed that, the first appearance of coral recruitments after 4 months of transplantation. The first species observed was *S. pistillata* then *P. verrucosa*, *P. damicornis* and finally *A. degitefera* over 24 months after transplantation. The most dominant coral recruit species were *P. verrucosa* (35%) (Fig. 5), then *S. pistillata* and *P. damicornis* (29% and 24% respectively), but the lowest recruit were *A. degitefera* (12%).

Recovery of coral branched

Some *S. pistillata* branches, (Fig. 5) which dead through transplantation due to handling or due to physical parameters as high sedimentation rates, recovered again and new growths have been shown on the same dead fragment. No species were recovered again from the other seven transplanted species.

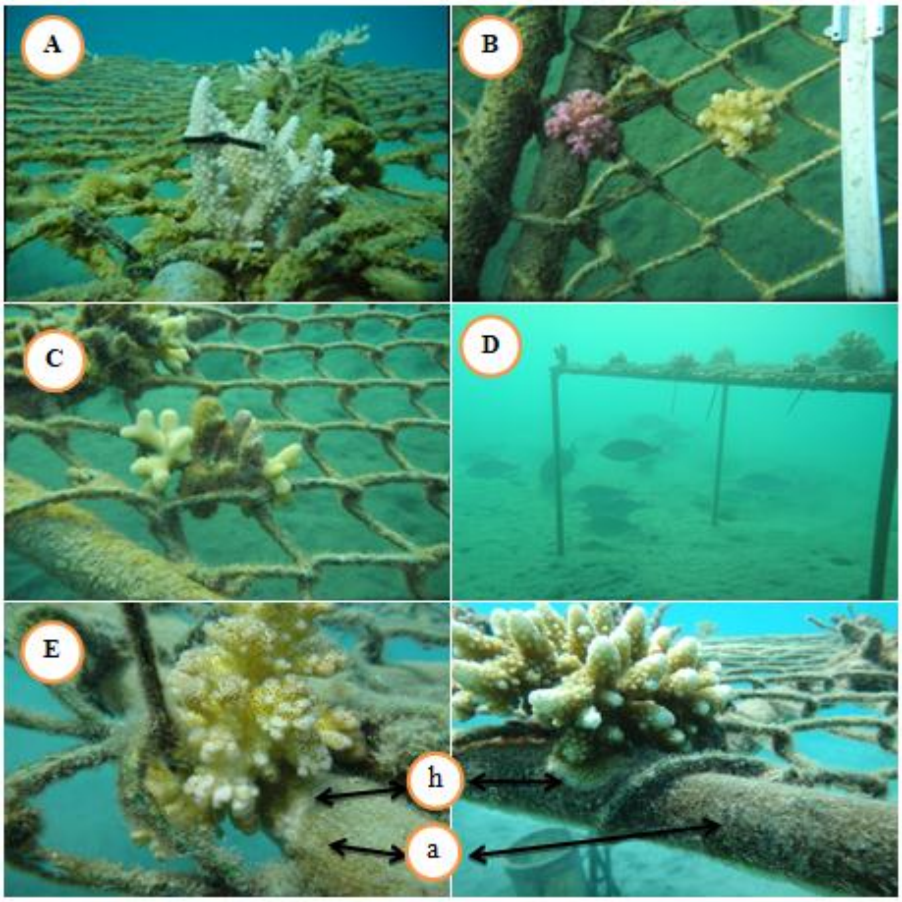

Fig. 5: Showed transplantation processes in Wadi El Gemal National Park; A) tagged coral, B) Coral natural recruitments, C) S. pistellata make recovery, D) Framworks attracted fishes, E) Developing of coral showed; h) A strong holdfast development and a) algae settling on the substrate in *P. verrucosa* (right) and *A. digitifera* (left).

DISCUSSION

In the last two decades, coral fragments have been transplanted onto various and unusual substrates such as; cement (Edwards and Clark 1999; Kotb 2003; Okubo *et al.* 2005; Schlacher *et al.* 2007; Herlan & Lirman 2008; Ferse 2010; Dubininkas 2017), consolidated rock (Bruckner and Bruckner 2001; Forrester *et al*. 2013; Dubininkas 2017), Galvanized steel Yap 2004; Dizon and Yap 2006; Romatzki 2014), Glass (Yap *et al.* 1998; Dubininkas 2017), Live and dead hard coral (Bruckner and Bruckner 2001; Yap 2004; Garrison and Ward 2008), Marble (Schlacher *et al.* 2007; Dubininkas 2017), Plastic (Yap and Molina 2003; Shafir *et al.* 2006), PVC pipes (Abdo and Hegazy, 2015), Sand (Bowden-Kerby 2001), Porecelain (Dubininkas 2017), Suspended wire (Ammar 2000; Bowden-Kerby 2001; Lindahl 2003; Soong and Chen 2003), Tridacna valves (Guest *et al.* 2011), steel slag (Mohammed *et al.* 2012). In the present study galvanized steel pipes table frameworks covered with coated and galvanized steel wire were used for coral transplantation. Conceivably, it is not the cheapest materials but it used for environmental sustainability and long term monitoring.

Generally, coral fragment transplantation is effective way from a biological point of view, with survival rates ranging between 50 % and 100 %, when coral fragment are transplanted into similar habitats to those from which they were gathered (Harriott and Fisk, 1988). The recorded survival rates of Acroporidae and

Pocilloporidae at Wadi El Gemal National Park after 24 months were reached 67% and 71% respectively which are higher than the recorded percentages for the same families at Ras Muhammad National Park after 14 months (Abdo and Hegazy, 2015) and Mohammed *et al.* (2012) in Hurghada after 12 months but lower than Kotb (2003) for Acroporidae after 16 months at Hurghada, Red.

The lowest percent of survival rate of *A. variabilis* (30%) and *A. digitifera* (45%) after 24 months (Fig. 2) indicates that, these species are highly sensitive to handling during transplantation on to one of the unsuitable parameters as sedimentation rate (25.2 mg cm^{-2} d^{-1}). On the other side, *A. horrida* and *A. tenuis* have the highest percent of survival rate (100%) were not affected by handling during transplantation or sedimentation rate. Rogers (1990) showed that heavy sedimentation might cause coral mortality, lower coral growth rates, reduced coral recruitment, decreased calcification and slower rates of reef accretion. He also clarified that sedimentation rate less than 10 mg cm^{-2} d^{-1} was safe to coral. The mean sedimentation rate in the present study was 25.2 mg cm^{-2} d^{-1} which more than that of Abdo and Hegazy 2015 (2 mg cm^{-2} d^{-1}) in Ras Muhammad National Park and lower than that of Mohammed et al. (2012) (50 mg cm^{-2} d^{-1}) in winter seasons in Hurghada. In some places in Hurghada, sedimentation rates may reach higher values (1123 mg cm^{-2} d^{-1}) that may cause coral recruit death or buried under the sediments (Kotb 2003)

Coral transplantation considered a successful process when the coral fragment begins to attachment to the substrate (Okubo *et al.* 2005; Abdo and Hegazy 2015). In the present study, most of the survival corals attached to the galvanized steel and even to the coated wire with big and strong holdfast (Fig. 6), this results agreed with previous studies of Abdo and Hegazy (2015), Kotb (2003) and Mohammed et al. (2012) in the Red Sea. The linear measurements units of the coral fragments were standardized to cm yr^{-1} to compare growth rates between coral species growth rates in this study and the previous studies. Growth rates are characteristically variable among different corals species that play an important role in the ecology and dynamics of coral reef ecosystems, affecting reef growth and productivity (Anderson *et al.* 2012; Mohammed and Dar, 2017). Growth rates of coral of the present study are considered high compared with the previous records in other areas in the Red Sea of the same species but low compared with other areas of the world like Pacific. Growth rate of *P. damicornis* (1.2 ± 0.07 cm yr^{-1}) in this study was approximate equal to that of Abdo and Hegazy (2015) (1.24 ± 0.1 cm yr^{-1}) in Ras Muhammad National Park and higher than that of many areas in the Red Sea, as in Hurghada (0.64 ± 0.11 cm yr^{-1}) (Mohammed and Dar, 2017) and in Na'ama Bay it was 0.74 cm yr^{-1} (Ghobashy and Kotb, 2001) but it was lower than that of many areas in the Pacific as in central Pacific of Mexico it was 2.7 cm yr^{-1} (Tortolero-Langarica et al. 2017) and 1.89 cm yr^{-1} in the tropical eastern Pacific of Colombia (Lizcano-Sandoval et al . 2018).

Growth rate of *P. verrucosa* (1.03 ± 0.07 cm yr^{-1}) in this study was higher than that of Abdo and Hegazy (2015) (0.65 ± 0.06 cm yr^{-1}) in Ras Muhammad National Park) but it was lower than that of many areas in the Pacific as in central Pacific of Mexico it was 2.3 cm yr^{-1} (Tortolero-Langarica et al. 2017). Growth rate of *S. pistillata* (1.27 ± 0.06 cm yr^{-1}) in this study was higher than that of many areas in the Red Sea, as in Hurghada and Hamrawin (0.63 ± 0.03 cm yr^{-1} and 0.65 ± 0.02 cm yr^{-1} respectively) (Mohammed and Dar, 2017), in Hurghada it was 0.55 cm yr^{-1} (Ammar and Mahmoud, 2005), in Na'ama Bay it was 0.92 cm yr^{-1} (Ghobashy and Kotb, 2001). Even in other sites as Lord Howe Island, Australia growth rates was 0.86 cm

yr^{-1} (Anderson *et al.* 2012). In Acroporidae, the highest recorded mean growth rates were in *A. variabilis* (0.98 +0.03 cm yr^{-1}) and the lower growth rates were in *A. digitifera* (0.45 +0.04 cm yr^{-1}). In Ras Muhammad National Park, Abdo and Hegazy (2015) showed that the highest recorded mean growth rates in Acroporidae were in *A. eurystoma* (2.1 +0.14 cm yr^{-1}) and the lower growth rates were in *A. squarrosa* (0.64 +0.04 cm yr^{-1}) but it were 0.7± 0.08 cm yr^{-1} in *A. digitifera*.

CONCLUSION

The results of this study concluded that high survival rates, acceptable growth rates, appearance of new recruitments and recovery of some dead coral branched showed that the use of coral fragments that naturally obtained for transplantation on galvanized steel pipes seems practically and relatively simple alternative for reaching successful coral reef restoration in reefs of the Red Sea.

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