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Rehabilitation of Dead Coral Rocks in the Gulf of Aqaba, Red Sea; Coral Engineering Protocol

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Abstract

Coral deterioration is often linked with coastal pollution and other anthropogenic impacts. In many cases, the impacts can be severe and may lead to death of corals and eventual loss of coral reef ecosystems. The Gulf of Aqaba is seen by many scientists as a coral refuge for the rest of the world, and therefore it is important to conserve its coral reef habitats. Because of this, each individual coral can be very important for the survival of the whole ecosystem. This study aims to develop an effective, easy to apply and relatively cheap method to rehabilitate dead coral rocks to bring them back into function within the ecosystem. To do this, small and medium sized coral fragments were cultured on ceramic tiles in a raceway before being transplanted to the sea. The survival rates, growth rates and coral fusion were observed over a period of two years. The results obtained have shown high survival and growth rates, where all cultured fragments were able to fuse and form bigger colonies. The tiles with the fused corals were then fixed to the dead skeletons of corals in the sea. Preliminary results from the field over a short period of observation showed a hundred percent survival rates of the transplanted corals, which suggests high success rates. The method used seems to be effective in rehabilitating the dead coral rocks, although long term observations are required to determine the length of time needed for the surfaces of the coral rocks to be fully covered with living tissue. The method is simple and cost effective and is recommended to be applied in any impacted coral ecosystem in the world. Though, in areas where extreme environmental conditions are prevailing, a careful field evaluation might be needed to assess the applicability of this method.

Keywords: Coral; Rehabilitation; Coral rocks; Conservation; Gulf of Aqaba; Red Sea; Coral engineering

Introduction

Coral reefs are one of the planet's most important marine ecosystems due to their productivity, complexity and species richness [1]. These ecosystems represent important sources of food and drugs, nursery habitats for commercial fish species and tourism assets in coastal areas [2-5].

The Red Sea has globally significant and highly diverse coral reefs [6]. The Gulf of Aqaba (GoA), which extend to the north east from the Red Sea represents the only marine access to Jordan, while all sea-related activities are concentrated in the relatively short coastline [7,8]. Fringing coral reefs are dominating the bottom habitat along the coastal region, which makes them particularly vulnerable to impacts from overlapping human activities [9]. Current pressures that have already been observed in the region include industrial wastes, solid waste and ship-based discharges, impacts resulting from corallivores and coral diseases as well as marine dredging and sedimentation from port constructions in adjacent coastal habitats [10,11]. This continuous and uncontrolled anthropogenic coastal development and possible influence may threaten the existence of coral reefs in the GoA [9]. Specifically, the increased presence of marine pollutants constitutes a major threat to marine ecosystems through accumulation of pollutants inside marine organism tissues [12].

Natural recovery of the deteriorated coral reefs is a very long process that can be complicated by many environmental factors. It takes many years for some of the impacted coral reef constituents to get back to its original status, while the main framework constituents, stony corals, may need several decades for complete

recovery [2]. This is because corals grow at very slow rates, which may not exceed 1 cm per year such as the case in massive corals (Figure 1). Furthermore, natural recovery process might be impeded by factors like invertebrate herbivores, overgrowth by algae and pollution [13-16]. When algae are established in the site, it will prevent coral recruitment, which makes it difficult to revert back to a coral dominated community [17,18]. In such cases, restoration activities are needed. Restoration is the process of assisting the recovery of an ecosystem that has been degraded and is critical for habitats where natural recovery is hindered [19]. Activities like establishing coral nurseries (the gardening concept) and artificial reefs were adopted in the Gulf of Aqaba [8,20-22]. Ecological engineering was also adopted in some cases [23,24].

This study aims at applying the coral engineering concept on dead and aged individual coral colonies to restore the living tissue layer within a relatively short period of time.

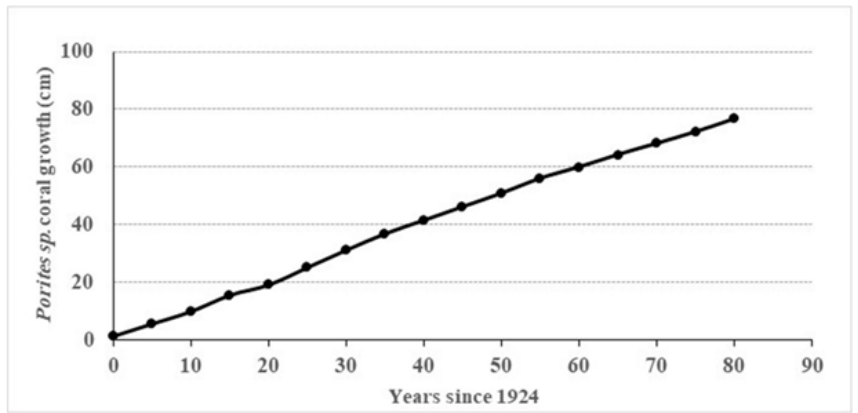

Figure 1: Growth rate measured over a period of 80 years in Porites sp. collected from the Gulf of Aqaba. Data redrawn from Al-Rousan et al. [42].

Methods

Coral Samples

Coral samples representing *Pachyseris sp., Porites sp., Coscinaraea monile, Pavona sp., Acropora sp., Galaxea fascicularis, Blastomussa sp.*, and two species from the genus Favia were collected from areas destined for possible sea reclamation process and/or from shallow reef slopes (<10 m) at the Marine Science Station (MSS) Aqaba. The Mother colonies were kept at the coral wet laboratory in a flow-through seawater raceway fed with seawater directly from the sea with ambient sea conditions. Natural light was used in the wet laboratory raceway. There were no special treatments or feeding for the coral samples in the raceway. The only difference made between the raceway conditions and the field was the cleanup of grazers and any intruding species that may harm the corals in the raceway.

After acclimation to raceway conditions, the mother colonies were fragmented into small pieces (1-5 cm in diameter) using a chisel and hammer for the branching species, while a rock saw (Type; Marmo Macchine Mark, Company; Italian Stone Technology, Italy) was used to fragment the massive coral species. Mini-fragments (less than 1 cm in diameter) and single polyps were made using wire cutter to cut small pieces from the mother colonies. The fragments were left in plastic trays for a week time to recover and get rid of the mucus. Any fragment that showed weakness or signs of tissue necrosis were excluded. The study was comprised of two phases, the first phase was conducted in the wet laboratory unit of the coral laboratory, while the second phase was conducted in the sea as a continuation of the work done in the lab. In the first phase (i.e. ex situ experiments), the coral fragments produced were glued on ceramic tiles and/or dead coral colonies using underwater epoxy as described by Al-Horani [8]. Pictures were taken for the cultured corals with time and the image analysis was done by using AmScope software to measure growth rates.

The dead coral colonies (rocks) were collected from damaged coral reef areas and were kept in the lab until use. In the sea, coral rocks that were found in sea were used as a target coral head for phase two of the project. Corals grown in the lab were prepared for field plantation by making holes in their ceramic tiles using a drill and were then affixed to dead coral colonies (coral rocks) using screws. Then, routine observation for the planted corals was done by SCUBA divers.

Results

Growth rates of the corals were expressed as changes in surface area per unit time. The rates varied from one species to another (Table 1). Depending on the coral shape and fragment

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size, the results obtained have shown that branching and leafy corals achieved higher growth rates per unit time, while massive corals grew at slower rates. Smaller coral fragments grew faster than larger fragments for all species. For example, a direct comparison between relatively small and big fragments obtained from the same mother colony for the coral *Porites sp.* (average sizes of 0.4 and 0.71 cm^2, respectively) revealed that smaller coral fragments achieved an average monthly growth rate of 0.51 cm^2 compared with 0.38 cm^2 for the bigger coral fragments. The percent increase relative to the original size was about 130% per month for the small fragments compared with about 53% per month for the bigger fragments (Table 1). The survival rates were close to 100% for all cultured corals for all coral genera that were cultured (Figures 2 & 3). The coral fragments could fuse with each other within a period of 14-28 months after fragmentation depending on the type of coral. For example, a distance of about 2.5 cm between fragments was covered with coral tissue within 19 months for the coral *Porites sp.* (Figures 2E & 2F), while *Acropora sp.* needed only 5 months to cover a distance of about 1.5 cm between fragments (Figures 3C & 3D).

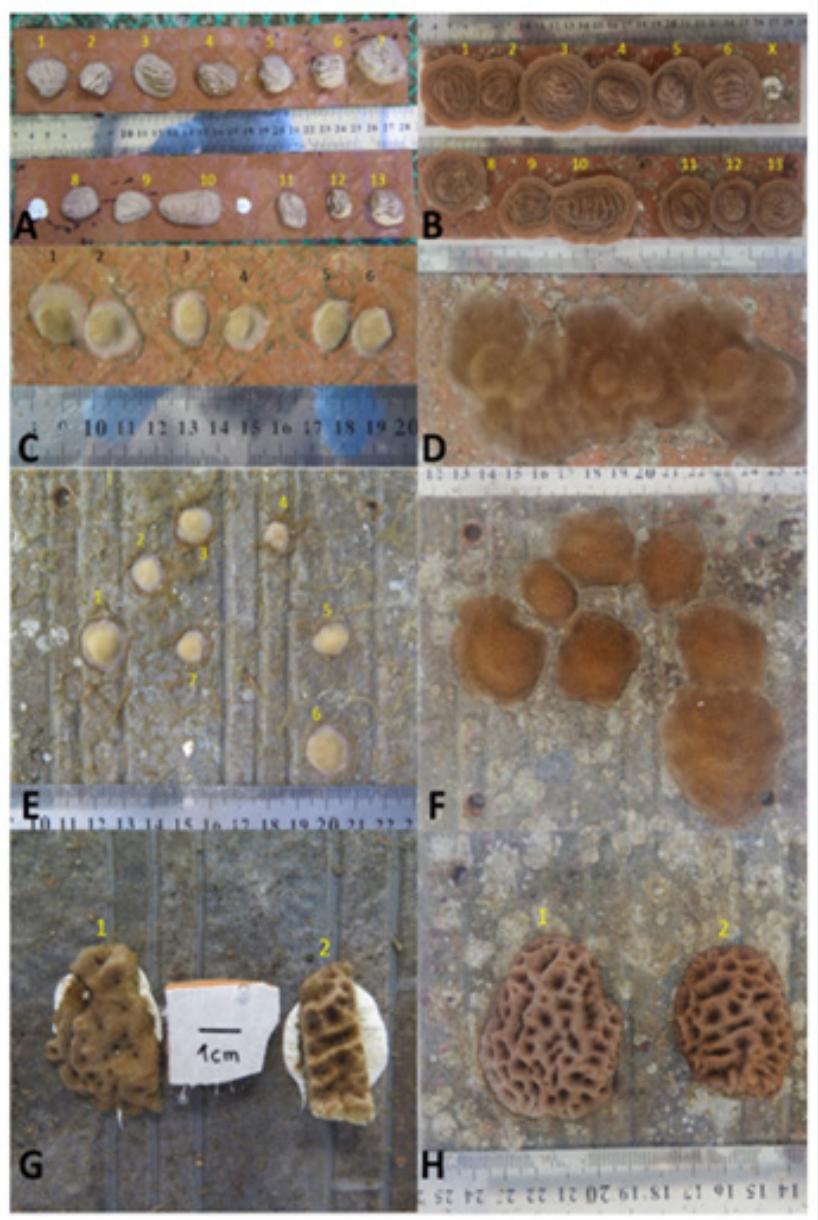

Figure 2: Ex situ coral culture in the raceway using ceramic tiles. The age in months after fragmentation is indicated in brackets. A: Pachyseris sp. (9), B: Pachyseris sp. (22), C: Porites sp. (7), D: Porites sp. (26), E: Porites sp. (9), F: Porites sp. (28), G: Coscinaraea sp. (1), H: Coscinaraea sp. (25).

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In phase two of the study, the corals that were cultured in the lab were transplanted to coral rocks, where they were affixed to the surface of dead coral colonies (Figure 4). The coral rocks were selected randomly, which means that any dead coral colony was targeted without respect to the type of the dead coral. This part of the study is still at its early stages and therefore no measurements were conducted. At this stage of the study, the survival rate is the most important as it represents the transfer from the laboratory conditions to the field conditions. All planted corals showed 100% survival, though it is hard to notice any growth within the relatively short period that has passed since their transplantation.

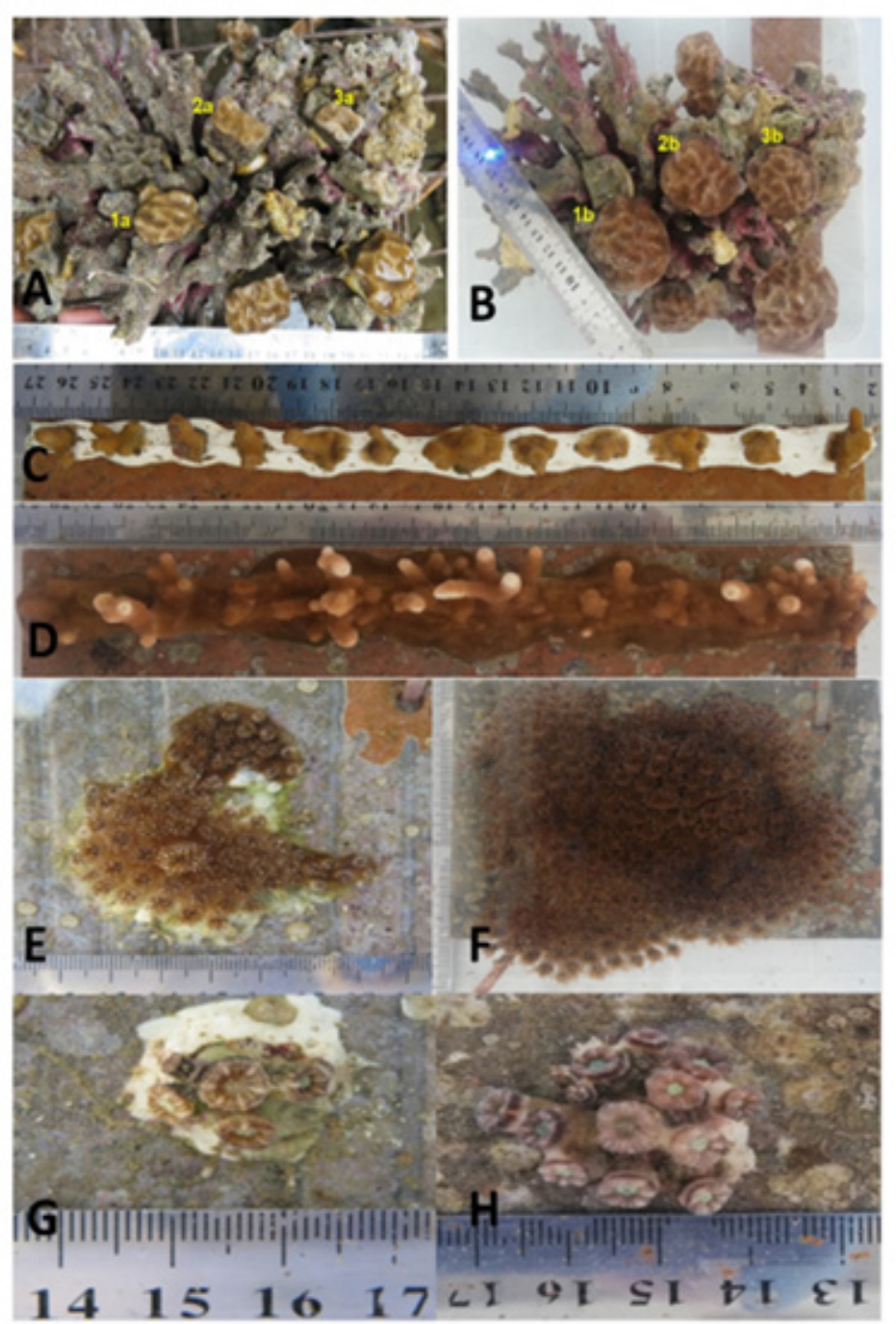

Figure 3: Ex situ coral culture in the raceway using ceramic tiles and/or dead coral skeleton. The age in months after fragmentation is indicated in brackets. A: Pavona sp. (1), B: Pavona sp. (13), C: Acropora sp. (9), D: Acropora sp. (39), E: Galaxea sp. (16), F: Galaxea sp. (35), G: Blastomussa sp. (10), H: Blastomussa sp. (35).

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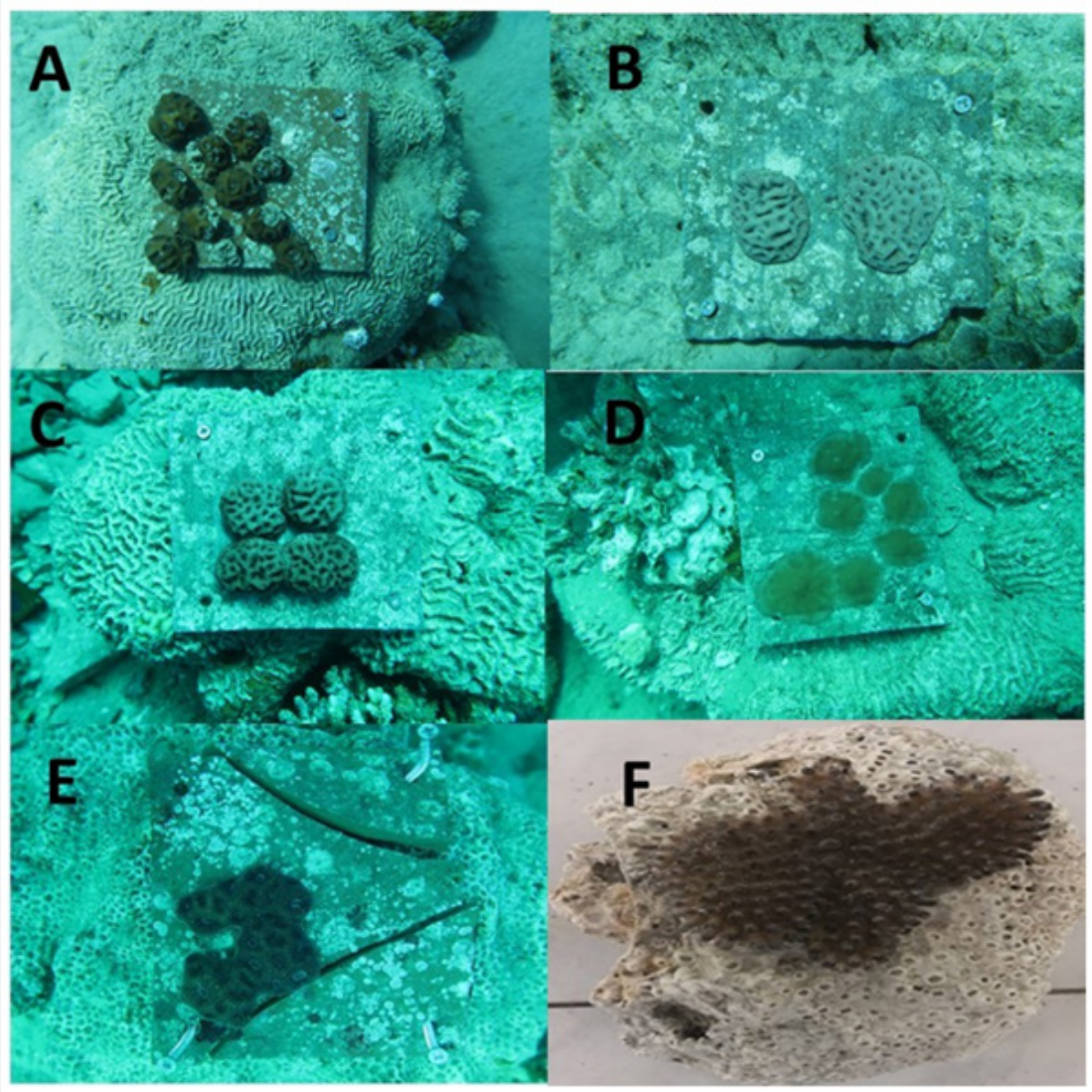

Figure 4: Cultured corals after being fixed on dead coral rocks in the sea. A: Favia sp., B and C: Coscinaraea sp., D: Porites sp., E: Favia sp., F: Galaxea sp.

Discussion

When the interactions of the coral with ecosystem components is weakened or lost, the coral may become unable to cope with the requirements of the ecosystem and will die after sometime of resistance. The weakness of the coral can be caused by either physical-chemical stresses or by biological factors, such as diseases and coralivorous organisms. After death, the remaining of the coral skeleton will be used by boring organisms and may be occupied by other opportunistic reef organisms, which might lead to community shifting. In some cases, the coral skeleton may be tens or hundreds of years old, which represents huge loss for the ecosystem as this represents the framework of the reef structure. When corals are lost from the ecosystem, the food chains will be affected. The loss of the reef ecosystem can be much more, when the death of corals become massive as they can lose their roles as food and oxygen suppliers to the reef community. There might be a community shifting towards becoming algae dominated communities instead of coral dominated ones. The main goal of this study was focused on developing cost-effective techniques that can bring those coral rocks back into function in the coral reef ecosystem after they lose their living tissues.

The rates observed for the coral deterioration and bleaching episodes have accelerated dramatically over the past few decades [25]. Some factors were directly linked to climate change and

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natural disasters, while others were linked to anthropogenic reasons. In many cases, direct interventions were described to conserve the natural habitats and maintain the functions of the coral reef ecosystems [25,26]. This is because the traditional management activities and natural recovery processes are not sufficient to confront the accelerated reef damages events [21,27,28]. Therefore, the development and use of active restoration techniques for the rehabilitation of the damaged reefs became very popular in past few decades [24,27]. This study has made use of the accumulated knowledge in restoration techniques to establish a method for the recovery of the dead coral colonies. The method described here is cost effective and relatively fast and easy to apply. In this method, the corals were cultured in raceways in a wet lab before being used for rehabilitation of the dead coral colonies in the sea. Several coral types with a variety of colony sizes were cultured on ceramic tiles for up to two years in the lab.

Table 1: Coral growth rates for seven coral genera cultured in the raceway (Ex situ).

Genus	n	Average start area (cm^2)	Average end area (cm^2)	Observation Period (months)	Growth Rate (cm^2/month)	% increase/ month	% Survival
Pachyseris sp. (13 fragments fused into 4)	13	7.76	12.17	19	0.23	2.99	85%
Porites sp. (6 fragments fused)	6	0.71	10.09	25	0.38	52.70	100%
Porites sp. (7 fused into 3)	7	0.40	9.61	18	0.51	129.23	100%
Coscinaraea sp.	2	5.64	15.77	24	0.42	7.48	100%
Pavona sp.	3	4.92	12.23	13	0.56	11.42	100%
Acropora sp. (12 fragments all fused)	12	1.34	2.66	5	0.26	19.66	100%
Galaxea fascicularis (Started as 1 polyp)	1	22.00	142.28	25	4.81	21.87	100%
Blastomussa sp. (Started as 1 polyp)	1	0.99	5.93	25	0.20	19.96	100%

The results obtained have shown a 100% survival rates for most of the species used even after two years of culturing (Table 1). This is compared with survival rates of about 60% in the field [29]. It was suggested that a coral survival rate of more than 40% at 3–4 years post-transplantation would be a reasonable performance target for active coral restoration [30]. In the field, the survival rates of transplanted corals are affected by biological as well as environmental factors. It was suggested that fragment size is an important factor for determining the rates of survival, where smaller fragments showed a lowered survival rate [31]. For example, in a study carried out by Raymundo & Maypa [32], it was shown that fragment size of less than 0.5 cm had 0-2.5% survival rates, this rate has increased to 15% for medium sized fragments, while it reached about 45% for fragment sizes of 1-3cm. The biomass also affects coral survival, where lower biomass is linked with increased death of the coral [33]. Other factors include temperature and salinity fluctuations, Predators and grazers, overgrowth by algae, pollution and sedimentation [11,18,34-38]. Furthermore, the culture conditions provide an opportunity to enhance survival of a transplanted corals [32], though it was also claimed that growth and survival are better in the field than in the land-based tanks, which was suggested to be due to unrestricted water circulation in the field [34]. The 100% survival rates obtained in this study might indicate that the raceways provide perfect conditions for culturing corals.

Growth rates (expressed per unit area) varied among the different coral species and ranged between 0.2-4.81 cm^2/month (Table 1). The percent growth rates ranged between 3%-129%. When the culturing conditions are fixed for all species, then growth rates might vary among the different species due to inherent reasons, the colony form, or the fragment size [34,39]. Although this is not an objective for this study, when different fragment sizes of the same coral (e.g. *Porites sp.*) was compared, it was found that small fragments (area = 0.4 cm^2) achieved more than double growth rates (expressed as percent growth rate) in comparison with the bigger fragments (area = 0.7 cm^2), with a monthly percent growth of 129% and 52% for the small and bigger fragments, respectively. Those results agree with previous findings by Page et al. [40] who found that smaller fragments had faster growth rates compared with the bigger fragments, while it contradicts with findings by Forsman et al. [41] who found the contrary. The contradictions among the different studies in the literature could be due to inherent factors of the corals used or to environmental conditions prevailing during the experiments. In

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either case, fragmentation of corals leads to growth enhancement [39]. It was also reported that coral transplantation lead to increased growth metrics [29]. Those reports together with the results obtained in this study indicate that this kind of technique allows for faster restoration process in the damaged reefs.

Almost all coral fragments, which were glued to the ceramic tiles were able to fuse with each other forming larger coral colonies (Figures 2 & 3). Such colony fusion is an important strategy for clonal organisms to increase access to shared resources, to compete for space, and to recover from disturbance [41]. Furthermore, fusion of the colonies may result in lowering the rates of mortality, which give better chances for the cultured corals to survive [32]. The colony fragmentation and fusion of the cultured fragments are key components of resilience to disturbance [41].

The last step in this study was to transplant the cultured corals from the raceways to the target dead coral rocks in the sea, where dead colonies were selected to fix the cultured corals on their dead skeleton (Figure 4). In this part, the tile with the grown corals on them were fixed using screws, which aid in reducing disturbance and is expected to enhance survival in the field. No further data were collected from the field, other than the survival rates, which were 100% for all transplanted corals. This is because the time passed so far (2 months) is not enough to collect data about their growth rates. Though, they will be subjected to continuous monitoring in future. This kind of strategy, which include culturing and fusion of coral fragments was suggested to enhance survival of transplanted populations since fusion will help them better resist field disturbances [32]. The cost effectiveness of the restoration processes is judged against the economic benefits of coral reefs [30]. Since the cost of the method described in this study is very low, in comparison with the normally used methods, it will likely be cost effective to conduct even in low-income countries [42-44].

From the above discussion, it was concluded that the culture technique used in raceways as a first step before transplanting to the field would be an important step for successful coral reefs restoration process, especially with the high survival rates and the successful fusion of the coral fragments, which aids in better survival rates in the field. The relatively low cost and the relative ease by which it can be applied, may suggest that this restoration method can be adopted in many areas around the world, especially in low-income countries. Finally, the field study needs more time to be evaluated, though a second study will be conducted to focus more on the restoration of dead coral colonies is being planned.

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References

1. Loya Y, Rinkevich B (1980) Effects of oil pollution on coral reef communities. Mar Ecol Prog Ser 3: 167-180.
2. Jaap WC (2000) Coral reef restoration. Ecol Eng 15(3-4): 345-364.
3. Rocha J, Peixe L, Gomes N, Calado R (2011) Cnidarians as a source of new marine bioactive compounds- An overview of the last decade and future steps for bioprospecting. Mar Drugs 9(10): 1860-1886.
4. Burke L, Reytar K, Spalding M, Perry A (2012) Reefs at risk revisited in the Coral Triangle. World Resources Institute, Washington DC.
5. Leal MC, Calado R, Sheridan C, Alimonti A, Osinga R (2013) Coral aquaculture to support drug discovery. Trends Biotechnol 31(10): 555-561.
6. Gladstone W, Tawfiq N, Nasr D, Andersen I, Cheung C, et al. (1999) Sustainable use of renewable resources and conservation in the Red Sea and Gulf of Aden: issues, needs and strategic actions. Ocean Coast Manag 42(8): 671-697.
7. Manasrah RS, Al-Horani FA, Rasheed MY, Al-Rousan SA, Khalaf MA (2006) Patterns of summer vertical and horizontal currents in coastal waters of the northern Gulf of Aqaba, Red Sea. Estuar Coast Mar Sci 69(3-4): 567-579.
8. Al-Horani FA (2013) Sustainable resources of corals for the restoration of damaged coral reefs in the Gulf of Aqaba, Red Sea. Life Sci J 10: 352-360.
9. Al-Horani FA, Al-Rousan SA, Al-Zibdeh M, Khalaf MA (2006) The status of coral reefs on the Jordanian coast of the Gulf of Aqaba, Red Sea. Zool Middle East 38(1): 99-110.
10. Al-Moghrabi SM (2001) Unusual black band disease (BBD) outbreak in the northern tip of the Gulf of Aqaba (Jordan). Coral reefs 19: 330-331.
11. Al-Horani FA, Hamdi M, Al-Rousan S (2011) Study of Drupella cornus prey selection and grazing on corals from the Jordanian coast of the Gulf of Aqaba-Red Sea. Jordan J Biol Sci 4: 191-198.
12. Binelli A, Provini A (2003) POPs in edible clams from different Italian and European markets and possible human health risk. Mar Pollut Bull 46(7): 879-886.
13. McCook L, Jompa J, Diaz PG (2001) Competition between corals and algae on coral reefs: a review of evidence and mechanisms. Coral reefs 19: 400-417.
14. Guzman H M, Cipriani R, Jackson JB (2008) Historical decline in coral reef growth after the Panama Canal. AMBIO 37(5): 342-346.
15. Al-Rousan S (2012) Skeletal extension rate of the reef building coral Porites species from Aqaba and their environmental variables. Nat Sci 4(9): 231-239.
16. Davies SW, Matz MV, Vize PD (2013) Ecological complexity of coral recruitment processes: effects of invertebrate herbivores on coral recruitment and growth depends upon substratum properties and coral species. PloS One 8(9): e72830.
17. Hughes TP, Tanner JE (2000) Recruitment failure, life histories, and long-term decline of Caribbean corals. Ecology 81(8): 2250-2263.

How to cite this article: Fuad A Al-H, Chris L. Rehabilitation of Dead Coral Rocks in the Gulf of Aqaba, Red Sea; Coral Engineering Protocol. Oceanogr Fish Open Access J. 2024; 17(4): 555967. DOI:10.19080/OFOAJ.2024.17.555967

18. Kuffner IB, Walters LJ, Becerro MA, Paul VJ, Ritson WR, et al. (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Mar Ecol Prog Ser 323: 107-117.

19. Bayraktarov E, Saunders MI, Abdullah S, Mills M, Beher J, et al. (2016) The cost and feasibility of marine coastal restoration. Ecol Appl 26(4): 1055-1074.

20. Epstein NRPM, Bak RPM, Rinkevich B (2003) Applying forest restoration principles to coral reef rehabilitation. Aquat Conserv: Mar Freshw Ecosyst 13(5): 387-395.

21. Rinkevich B (2005) Conservation of coral reefs through active restoration measures: recent approaches and last decade progress. Environ Sci Technol 39(12): 4333-4342.

22. Al-Horani FA, Khalaf MA (2013) Developing artificial reefs for the mitigation of man-made coral reef damages in the Gulf of Aqaba, Red Sea: coral recruitment after 3.5 years of deployment. Mar Biol Res 9(8): 749-757.

23. Horoszowski FYB, Izhaki I, Rinkevich B (2011) Engineering of coral reef larval supply through transplantation of nursery-farmed gravid colonies. J Exp Mar Biol Ecol 399(2): 162-166.

24. Rinkevich B (2020) Ecological engineering approaches in coral reef restoration. ICES J Mar Sci 78: 410-420.

25. Anthony K, Bay LK, Costanza R, Firn J, Gunn J, et al. (2017) New interventions are needed to save coral reefs. Nat Ecol Evol 1(10): 1420-1422.

26. Rinkevich B (2019) The active reef restoration toolbox is a vehicle for coral resilience and adaptation in a changing world. J Mar Sci Eng 7: 201.

27. Young CN, Schopmeyer SA, Lirman D (2012) A review of reef restoration and coral propagation using the threatened genus Acropora in the Caribbean and Western Atlantic. Bull Mar Sci 88: 1075-1098.

28. Kleypas J, Allemand D, Anthony K, Baker AC, Beck MW, et al. (2021) Designing a blueprint for coral reef survival. Biol Conserv 257: 109107.

29. Tortolero LJJ, Rodríguez TAP, Cupul MAL, Rinkevich B (2020) Micro-Fragmentation as an Effective and Applied Tool to Restore Remote Reefs in the Eastern Tropical Pacific. Int J Environ Res Public Health 17(18): 6574.

30. Omori M (2019) Coral restoration research and technical developments: what we have learned so far. Mar Biol Res 15(7): 377-409.

31. Okubo N, Motokawa T, Omori M (2007) When fragmented coral spawn? Effect of size and timing on survivorship and fecundity of fragmentation in Acropora formosa. Mar Biol 151: 353-363.

32. Raymundo LJ, Maypa AP (2004) Getting bigger faster: Mediation of size-specific mortality via fusion in juvenile coral transplants. Ecol Appl 14(1): 281-295.

33. Thornhill DJ, Rotjan RD, Todd BD, Chilcoat GC, Iglesias PR, et al. (2011) A connection between colony biomass and death in Caribbean reef-building corals. PLoS One 6(12): e29535.

34. Yap HT, Molina RA (2003) Comparison of coral growth and survival under enclosed, semi-natural conditions and in the field. Mar Poll Bull 46: 858-864.

35. Lesser MP (2006) Oxidative stress in marine environments: biochemistry and physiological ecology. Annu Rev Physiol 68: 253-278.

36. Al-Rousan S, Al-Shloul R, Al-Horani F, Abu-Hilal A (2012) Heavy metals signature of human activities recorded in coral skeletons along the Jordanian coast of the Gulf of Aqaba, Red Sea. Environ Earth Sci 67: 2003-2013.

37. Kuanui P, Chavanich S, Viyakarn V, Omori M, Lin C (2015) Effects of temperature and salinity on survival rate of cultured corals and photosynthetic efficiency of zooxanthellae in coral tissues. Ocean Sci J 50: 263-268.

38. Kteifan M, Wahsha M, Al-Horani FA (2017) Assessing stress response of *Stylophora pistillata* towards oil and phosphate pollution in the Gulf of Aqaba, using molecular and biochemical markers. Chem Ecol 33(4): 281-294.

39. Lirman D, Thyberg T, Herlan J, Hill C, Young LC, et al. (2010) Propagation of the threatened staghorn coral Acropora cervicornis: methods to minimize the impacts of fragment collection and maximize production. Coral Reefs 29: 729-735.

40. Page CA, Mulle EM, Vaughan DE (2018) Microfragmenting for the successful restoration of slow growing massive corals. Ecol Eng 123: 86-94.

41. Forsman ZH, Page CA, Toonen RJ, Vaughan D (2015) Growing coral larger and faster: micro-colony-fusion as a strategy for accelerating coral cover. Peer J 3: e1313.

42. Al-Rousan SA, Al-Shloul RN, Al-Horani FA, Abu-Hilal AH (2007) Heavy metal contents in growth bands of Porites corals: record of anthropogenic and human developments from the Jordanian Gulf of Aqaba. Mar Pollut Bull 54(12): 1912-1922.

43. Horoszowski FYB, Brêthes JC, Rahmani N, Rinkevich B (2015) Marine silviculture: Incorporating ecosystem engineering properties into reef restoration acts. Ecol Eng 82: 201-213.

44. Spurgeon JP (2001) Improving the economic effectiveness of coral reef restoration. Bull Mar Sci 69: 1031-1045.

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