DUBAI PILOT PROJECT:

TEST REPORT FOR '*REEF SYSTEMS*' AT THE PALM JUMEIRAH

by

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1. INTRODUCTION

1.1 Background

Following the *Workshop on Challenges in the Oceans: The Runde Reef System*, held on 29-30 May 2004 in Dubai/UAE, the Zayed International Prize for the Environment together with Kyodo International and Reef Systems agreed to establish a pilot project to test the performance of the Runde reef, produced by Reef Systems. With the support of Nakheel, it was mutually agreed that the test project would be conducted in the proximity of the Palm Jumeirah artificial island that was being constructed by Nakheel.

The Palm Jumeirah, situated off the coast of Dubai, at the commencement of its construction was the world's largest man-made island. Concerns were expressed by environmentalists that the extensive seabed and waterfront construction activities would threaten the marine life of the Gulf's delicate ecosystem. Accordingly, Nakheel and the local authorities at the time were actively considering actions and measures for conserving and enhancing the biodiversity status in the vicinity of the marine constructions.

1.2 Aim of the test project, and terms of reference and constraints for production of the report

The aim of the test project was to examine the ability of the Runde reef system to:

- Form suitable habitat for colonization by indigenous fauna and flora, thereby contributing to conservation and enhancement of marine biodiversity, even though the prevalent environmental conditions (*e.g.* human and naturally caused) of the locality selected for the test in the vicinity of the Palm Jumeirah artificial island may not be optimal;
- Provide a range of important 'ecological goods and services' of potential benefit to the marine environment and human society, through the biological colonization of the new reef habitat and resulting cultivation of selected parts of the seabed, which may help compensate for human impacts from marine constructions and waterfront development.
- Be deployed in and endure the prevalent marine environmental conditions (*e.g.* high water temperature and salinity, sea state changes forced by the seasonal Shamal winds and storms) characteristic of the Arabian Gulf.

Christopher C.E. Hopkins was engaged to write the current report, taking into account the available information and data from monitoring the reefs since their deployment in January 2005 until March 2007. Representatives from the initiators of this pilot project (Zayed International Prize for the Environment, Kyodo International, Reefs Systems and Nakheel) met in March 2007 to discuss the draft report. Feedback concerning the draft report was transmitted to the author by the respective parties. The author has carefully considered this feedback in producing this revised report.

As pointed out clearly in section 3 of this report, the project has been severely limited by resources and the monitoring schedule and its design were not intended, under the prevalent circumstances, to be in accord with the standards of a quantitative scientific study. Within these constraints, the author emphasizes that he has not been involved with the design of the deployment situation for the reefs or with the system for their monitoring. He has made all reasonable endeavour to ensure that the content of this report, the data compiled, and the methods of presentation of the results and conclusions are objective and independent of the influence of any parties and that they are consistent with normally accepted standards and practices. However, neither is any warranty given to that effect nor any liability accepted by the author for any loss or damage arising from the use of this report by any party.

2. REEF DESIGN AND DEPLOYMENT, AND ENVIRONMENTAL CONDITIONS

2.1 Design and deployment of the reefs

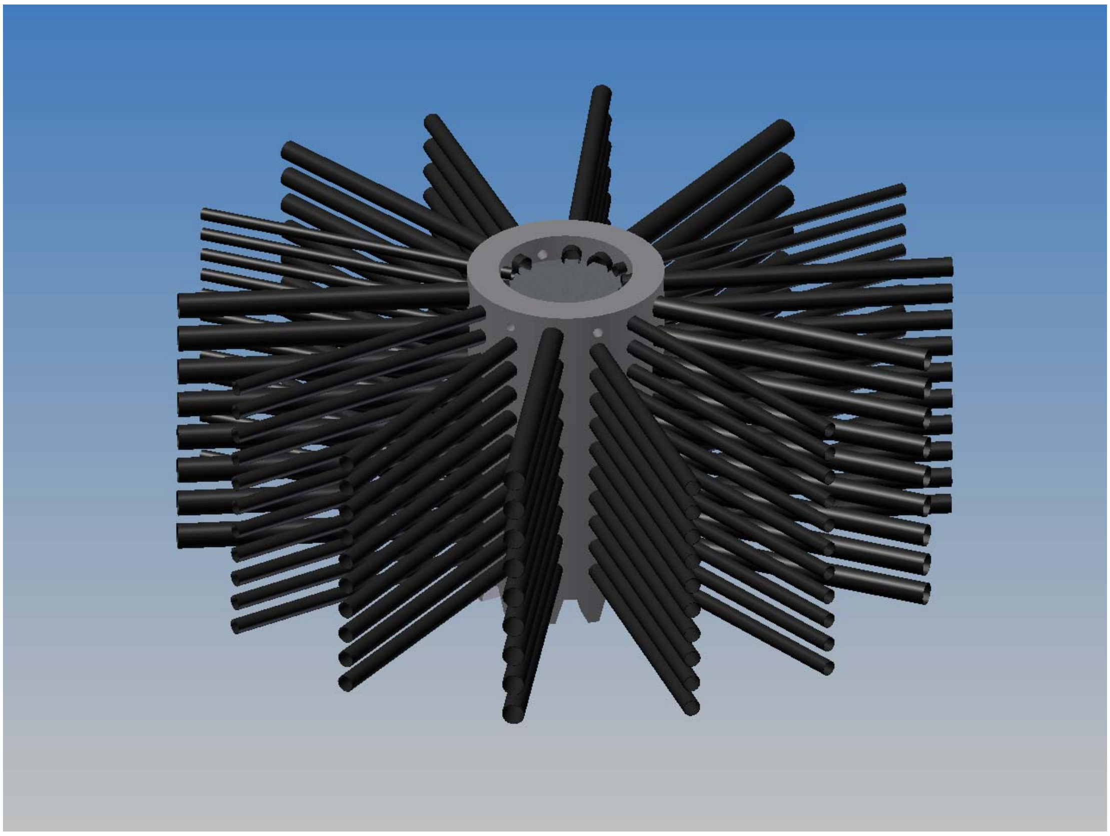
Three Runde reefs and one modified Svenner reef were put in place on 8 January 2005 on the seabed at the selected test site (GPS location 25º 7' 57.00" N - 55º 6' 59.7" E) in about 10 m depth of water, close to the crescent-shaped outer wall of the breakwater of the Palm Jumeirah (**Fig. 1**). The reefs were supplied by Norwegian company Reef Systems and are design and patent protected.

The specific test units were two of the deployed Runde reefs, while the Svenner reef was used for comparative reference purposes.

Each Runde reef element consists of a central cylinder made of concrete that is 2.5 m in height and 1.4 m in diameter. The cylinder is filled with stones and sand from the seabed, to increase its weight and stability, after it has been set down on the bottom. From the concrete cylinder 14 vertical rows of 1.5 to 2.4 m long plastic pipes, of varying diameter (9-18 cm) radiate outwards (**Fig. 2**). Each pipe is open at both ends, and in total they provide about 300 m of pipe length. The plastic pipes are made of recycled, toxically inert polyethylene (also known as polythene or polyethene) which is light in weight, tough and is bendy. Together, the cylinder and plastic pipes provide an internal and external surface area of about 300 m^2. The arrangement (*e.g.* length and diameter) of the pipes, including boring of holes along the length of the pipes, can be developed according to requirements, *e.g.* to better withstand forces from water currents at the deployment locality, and to provide habitat in the form of specific living and refuge space for various types of fauna and flora. The total weight of each Runde reef is about 9 metric tonnes.

Fig. 1. ***The Palm Jumeirah showing the location of the reefs deployed in the test project.***

Fig. 2. ***Schematic view of a Runde reef unit showing the vertical central concrete cylinder and horizontally radiating polythene pipes.***



The Svenner reef comprised a horizontally lying concrete half-pipe, originally designed for protect underwater pipes and cables with a surface and holes for habitat cultivation. The deployed Svenner reef was modified by having shorter polythene pipes inserted at regular intervals along the length of the concrete half-pipe (**Annex 8.6**). The half-pipe used in the test is 3.0 m long and 0.6 m in height and weighs about 0.8 metric tonnes. The attached pipes are 1.2 m in length and 11 cm in diameter.

2.2 Marine environmental conditions of the Dubai area and test locality

The Gulf and Dubai environments

The Arabian Gulf, also known as the Persian Gulf, is a shallow sea whose depth is about 35 meters. Evaporation exceeds runoff and precipitation gives rise to dense, saline waters, particularly in the shallow areas (less than 10 meters) of the southern and southwestern coasts (Hunter 1986; Elshorbagy, Azam & Taguchi 2006). The Arabian Gulf is increasingly seen as a complete biogeographic province of global importance in its own right (Sheppard *et al.* 1992; Chiffings 1995). A summary review of the Gulf's environment and biodiversity is provided Chiffings (1995).

The marine environment of the Gulf, including the Dubai/UAE area, is characterized by high water temperature and salinity (Hunter 1986; Elshorbagy, Azam & Taguchi 2006), which poses a harsh environment for coral communities whereby some species have experienced periodically *(e.g.* 10-20 years) recurrent environmentally instigated mortality events (Riegl 1999) . The thermal regime is influenced to a great degree by solar radiation and wind. Sea temperature generally ranges from about 18 to 34° C in the Dubai/UAE area (Coles & Fadlallah 1991). The average salinity can rise above 40 ppt due to the high rates of evaporation being in excess of inputs from rain and run-off (*e.g.* rivers and estuaries) from land discharges. The balance is made up by inflow of seawater into the Gulf from the Indian Ocean through the Straight of Hormuz (Fadlallah *et al.* 1995).

In late November and December each year, a transition from the warm to cold season is marked by a marked drop in seawater temperature of about 10° C. This coincides with the onset of the winter Shamal, a strong north-westerly cold-air wind blowing from November through April, with the strongest winds occurring from January to March. Winds offshore can reach 45 to 65 kph producing very rough seas, but along the coast 30 to 50 kph is more common. The early stages of the Shamal may result in storms that can cause sea state surges in tidal amplitude of several metres, while the later Shamal stages produce long period tidal oscillations resulting in extreme low, meteorologically induced tides (Perrone 1979; CEA 1986; Lardner 1993). The Shamal weather system is intermittent, normally lasting from 24-72 hours (CEA 1986; Hunter 1986; Lardner 1993; Reynolds 1993). The summer Shamal is much weaker and lasts from early June through to July.

Test locality environment

The seabed at the selected test locality, close to the breakwater of the Palm Jumeirah island, currently consists of a shallow layer of sand overlying hard sedimentary rock (*e.g.* barren shale). Boulders and stones are rare.

In the early stages of the Palm Jumeirah island construction, prior to the deployment of the reefs, trailing suction hopper dredger (TSHD) vessels had taken up sand extensively from wide-reaching areas of the seabed in order to provide the central mass of the island. According to Van Oord, the dredging company responsible, about 110 million m^3 of sand was needed for the reclamation works. Thus, the construction of the Palm Jumeirah had already disturbed—by removal of sand and reduction of the thickness of the soft-bottom sediment overlying the shale bedrock—the naturally occurring seabed environment of the locality selected for testing the artificial reefs. Such environmental impacts change the naturally occurring pelagic and benthic habitats and their biological communities compared with the pre-existing baseline state (MIRO 2005). The impacts are generically well-known and include a) extraction and removal, injury and mortality of sessile and less mobile epibenthic and infaunal organisms by the TSHD activities, and b) release, loss and suspension of sediment (mainly sand), creating sediment plumes and turbidity from the TSHD technique due to extensive overflowing and possible screening (if a particular sediment fraction is required) (John *et al.* 2000). Mobilized sediment eventually gets re-deposited on the seabed, but local hydrodynamic conditions such as strong waves and tidal current velocity, exacerbated by seasonal forcing by the Shamal, increase the extent of suspension in the water column. Sediment suspension and re-deposition has the potential to create a range of impacts on seabed composition and topography and biological communities within affected areas.

At the time of the deployment of the reefs, which commenced on 8 January 2005, ongoing physical/mechanical construction activities at the Palm Jumeirah island, and associated ship (*e.g.* barge) passage still affected the test locality with copious underwater noise and water-borne sediments (sand and silt) that substantially reduced underwater visibility. Very limited and patchy macrobenthic and fish fauna, either sessile or mobile, and flora were visible on the seabed selected to be the test locality.

On 11 January 2005, an extremely strong winter Shamal storm pounded the Dubai area including the Palm Jumeirah. Peak wave height[2] reached during the Shamal was in excess of 2.5 m whilst water levels reached about 1.3 m above mean sea level[3]. This particular Shamal storm was one of the strongest registered in recent years[4].

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[2] Wave height is defined as the vertical distance between the crest and trough of the wave.

[3] Mean sea level is measured by satellite altimeter data where synoptic mapping of the geocentric height of the ocean surface is routinely achieved with a point-to-point accuracy of better than 5 cm.

3. MONITORING TIMETABLE AND APPROACH

The monitoring of the reefs and their immediately surrounding water column and seabed started in January 2005 and continued periodically to February 2007 (**Table 1**). Monitoring was conducted by Scuba divers—mainly provided by Nakheel and the Emirates Diving Association—using visual inspection combined with still camera and video photography recording. The degree of colonization and coverage by various fauna (mobile and sessile) and flora was registered and followed over the monitoring period of about 25 months.

It is emphasized that the resources for the monitoring scheme were substantially constrained by limited availability of personnel and funding. Accordingly, the monitoring has been carried out in an essentially qualitative manner. There has been a lack of use of standard stratified, random sampling methodology involving use of replicate quadrats, *etc*., in which ideally the various taxonomic entities of biota should have been expertly identified and the abundance of the various faunal and floral entities determined by counting techniques. Furthermore, the monitoring schedule (**Table 1**) has been much less frequent than the monthly periodicity that otherwise would have been desirable. ***So, the current study does not purport in any way to be a quantitative scientific investigation. The results and their interpretation should be viewed as indicative rather than definitive.***

Identification and life history information on fish was obtained from FishBase[5] (Froese & Pauly 2000).

Table 1. ***Monitoring timetable for reefs deployed at the Palm Jumeirah locality***

2005 monitoring
January
March
May
June
July
August
September
December

2006 monitoring
February
June
September

2007 monitoring
March

4. TEST RESULTS AND DISCUSSION

The Annex (*i.e.* **Section 8**) provides photographic documentation in support of the report.

Since 1992, satellite altimeters have been measuring sea level with unprecedented accuracy and provide a database for different sea areas including the Gulf.

[4] http://www.khaleejtimes.com/DisplayArticle.asp?xfile=data/theuae/2005/January/theuae_January325.xml&section=theuae

[5] http://www.fishbase.org/home.htm

Although the first strong Shamal storm—occurring on 11 January 2005 only three days after the deployment of the reefs—toppled all of the Runde reefs, these reefs settled in a semi-horizontal position and remained securely in place thereafter. As noted in section 2.2, this particular Shamal storm was one of the strongest registered in recent years. The Svenner reef remained sturdy and undisturbed. Despite this, their polythene pipes, owing to their resistant nature and flexibility, remained intact without significant damage in almost all cases.

Already in March 2005, clearly visible colonization and growth of benthic fauna (chiefly barnacles but also some seaquirts) had started and smaller fish had become attracted to the reefs.

By May 2005, only five months after deployment of the reefs, substantial external and internal colonization of the polythene tubes and central concrete cylinder had occurred by sessile benthic fauna, and several species of fish were seen at the reefs. The fish appeared to be attracted by the habitat formed by the pipes both for foraging on the colonized benthic fauna and for the security and refuges provided in and among the pipes.

After 6 months (July 2005) in the sea, the reefs had increasingly become fully covered with a variety of corals, anemones, gastropods and bivalve molluscs, sea squirts, barnacles and other invertebrate animals characteristic of natural hard-bottom (*e.g.* rock and coral reefs) areas. Additionally, various young greenish-coloured macrophytes strands (*e.g.* seagrass) were also registered. The polythene pipes as well as the concrete cylinder attracted settlement, colonization and growth of corals, eventually resulting over several months in the growth of clearly visible plates and branches. The Dubai coral fauna is entirely made up by scleractinia (Riegl 1999): the scleractinian corals currently registered on the Runde reef units include the families Dendropphyllidae *(e.g. Turbinaria mesenterina)*, Acroporidae and Faviidae. Colonization by sessile and motile benthic fauna, including corals and pectinid bivalves, also occurred on all the artificial reef units within the openings of the polythene pipes, indicating good water flow within these for sustaining filter-feeding and respiration. Gulf coral communities are recognized as living in a harsh environment with respect to high seawater salinity and temperature stress as well as stress from turbidity and sedimentation, which restrict the number of species in the area and periodically result in recurrent mortality among the dominant species (Fadlallah *et al.* 1995; Riegl 1999; Al Cibahy & Al Abdelsalaam 2006).

At first the average size of the fish noted on the deployed reefs was quite small but later the size increased. This was probably due to growth of the stationary individuals and immigration of larger individuals into the reef area. In particular, the variety and abundance of the fish increased markedly from March to December 2005. Many species of fish (**Table 2**) were attracted to both the Runde and Svenner types of reef. These include several species (*e.g.* goldsaddle goatfish, angelfishes) that are almost exclusively found in the vicinity of natural coral reefs. Some of these fish (*e.g.* groupers, snappers, terapons, sardinella, sweetlip and rubberlip) are prized by artisanal fishers for food and income.

In March 2007—26 months after the original deployment of the reefs—the final monitoring covered by this report showed substantial numbers of large and small fish (*e.g.* Arabian angelfish) swimming among the polythene pipes. The polythene pipes were heavily encrusted by the dominant fauna of barnacles. However, substantial numbers of pectinid bivalves (particularly in the end openings of the pipes but also externally near their bases on the concrete foundation), gastropod snails, ascidians, and cnidarians were noted. Increased colonization of juvenile brown and red algae, as well as some filamentous green algae, was notable since the summer and autumn of 2006. Although some corals were evident from the DVD pictures taken by the divers, there was some uncertainty as to whether the earlier noted coral community had temporarily peaked and receded. Future follow-up monitoring should clarify this aspect.

Table 2. ***Fish frequently registered among the Runde and Svenner reef habitats***

Scientific name	***Common English name***
Epinephelus spp.	Groupers (*e.g.* Orange-spotted grouper *E. coioides* locally called 'Hamoor')
Lutjanus fulviflamma	Dory/Blackspot snapper
Chromis sp.	Damselfish
Sardinella spp.	Sardinella (*e.g.* White Sardinella *S. alba*)
Labridae family	Wrasse
Parupeneus cyclostomus	Goldsaddle goatfish
Terapon jarbua	Jarbua terapon
Plectorhincus schotaf	Minstrel sweetlip
Plectorhincus sordidus	Sordid rubberlip
Pomacanthus maculosus	Yellowbar angelfish
Pomacanthus asfur	Arabian angelfish
Pomacanthus imperator	Emperor angelfish
Sphaeramia orbicularis	Orbiculate cardinalfish

5. PILOT PROJECT CONCLUSIONS

The main conclusions from the artificial reef test project are:

- The reefs within six months of their initial deployment had already demonstrated their ability to form an impressively good habitat for colonization of a wide range of species of sessile benthic organisms, including corals, molluscs (*e.g.* shellfish crustaceans such as crabs, pectinid bivalves, and nudibranch gastropods), sea squirts, barnacles and anemones. Additionally, many species of fish—several of which are otherwise almost exclusively associated with natural biogenic (*e.g.* coral) reefs—were clearly attracted by the reefs for foraging and refuge. Up to the present time (*i.e.* 26 months since the project start), this positive impression has been further strengthened.
- Encrusting fauna (*e.g.* barnacles, bivalves, polychaete worms, and some corals) have almost covered all the outer surfaces of the reef units as well as the openings of the pipe. Currently, the dominant fauna in terms of covering area and biomass is still barnacles, indicative of a relatively early phase in the colonization process. It is much too early to compare developments with the biodiversity of a natural, climax succession. However, the reefs are already almost completely enclosed by naturally occurring biogenic material (*e.g.* barnacles, bivalves), and within a few more years it is highly probable that these reefs will increasingly resemble naturally occurring reefs. Thus, given time, it will be difficult to see that the reefs had an 'artificial' origin.
- The colonized habitat of the reefs provides indigenous biodiversity that forms the basis for a range of *ecological goods and services*[6]. On the deployed reefs, such goods and services are provided by organisms (*e.g.* barnacles, corals and mussels) that are able to: a) improve water quality by filtering organic and inorganic particles, b) scavenge and remove dead and decaying organic detritus (*e.g.* crabs and polychaete worms), c) act as target species (*e.g.* several of the fish and shellfish species) for artisanal fishers thereby providing food security and income to local human communities, d) flora (*e.g.* seagrass) that photosynthesize and produce oxygen that aerates the water, and e) contribute to potentially important food webs for biological and human communities. Furthermore, in due course, as they become more encrusted and covered by biogenic material, the reefs may provide f) protection

[6] **Ecological goods and services** are the benefits arising from the ecological functions of healthy ecosystems.

against climate change effects (*e.g.* wave action and erosion) and g) attractive habits for scientific study (*e.g.* research) and h) recreation (*e.g.* diving and tourism) purposes. For an appropriately large or important area, a dedicated management plan can be developed that determines the sustainable use and conservation of the specific reef habitat and the associated biodiversity.

- Colonization of these reefs by the indigenous biodiversity has occurred under challenging conditions where the prevalent natural and human induced environment exerts extreme pressures on the reefs themselves and on their biodiversity. These conditions include high water temperature and salinity, the effects of the physical forcing from the Shamal as well as from the Palm Jumeirah construction activities (*e.g.* substantial levels of turbidity and particulate sedimentation, abnormal noise from shipping and mechanical activities, and winter storm events). Thus, it is probable that colonization of the reefs would have occurred even more rapidly under environmental conditions where human disturbances are less prevalent. The colonizing fauna and flora are mainly those characteristically from hard-bottom communities and habitats (*e.g.* rocky bottoms and reefs), which have for the most part been transported to the artificial reefs, via water currents, as planktonic/pelagic early life history stages from the surrounding hard-bottom and water column habitats. In the case of the hard-bottom habitats, these organisms are likely to be transported from quite some distance away beyond the immediately surrounding soft, sandy bottom. Exceptions are primarily the medium and larger fish that have actively migrated to what is clearly an attractive habitat. Once on the reefs, good growth rates of many of the colonizing biota have occurred as evidenced by substantial increases in body size over time. The question has been raised as to whether the nearby crescent breakwater of the Palm Jumeirah could have acted as a substantial donor of the biota colonizing the Runde and Svenner reefs. However, the crescent as a new structure would have needed more time to first become 'seeded' and then evolve towards a climax community before becoming a significant donor for the Runde and Svenner reefs. Given the necessary time frame, this possibility is unlikely in the author's considered opinion. However, no background monitoring evidence over time as been made available from the crescent to help support or reject such a 'donor' contention.
- The test confirms that the polythene and concrete materials from which the reefs are formed are inert and non-harmful as evidenced by their being easily and widely encrusted and colonized by a diverse range of fauna and flora.
- Although the Runde reef units toppled under the force of one of the most severe Shamal storms of recent years, they have remained intact for more than two years. They show little if any visible signs of degradation of their constituent concrete and polythene. The deployment of the Runde reefs on a thin layer of loose, sandy sediment lying on top of flat bed-rock must be considered to be a most unusual and highly undesirable substrate for their deployment, particularly under conditions where extreme horizontal forces are applied by the Shamal. In the future, the stability of the Runde reefs in this highly uncharacteristic seabed environment can be improved by a number of adaptive measures. Such measures include a) reducing the aspect ratio of the concrete core (*i.e.* reducing its height/increasing its width), and b) reducing and/or varying the length of the various polythene pipes, so that the reef better withstands being toppled by horizontally applied forces during poor weather conditions. Notably, the horizontally lying Svenner reef unit, with a low center of gravity, remained robustly stable throughout the test period. However, the main advantage of the Runde reef must be maintained, *viz.* 1) its 3-D 'tree-like' profile that attracts colonization by hard-bottom fauna above the soft-bottom seabed, and 2) its ability to produce a very large growing area in a relatively small space, *i.e.* an area covering 5 m^2 produces a growing area of 250 m^2.
- *The Next-Steps*, either in the current or other localities, may potentially involve linking several reef units together to create larger-scale habitats that will attract even

larger and more diverse biological communities and also be more solid and stable to counteract extreme physical forcing. As each reef unit is able to be easily lifted and transported, 'virgin' reefs can be seeded and colonized in biologically diverse and productive areas and later moved into degraded areas as 'seedling' habitats for compensatory and restoration/rehabilitation purposes.

- As emphasized in this report, the pilot project was prepared for and implemented under conditions of substantial resource constraints. It was not designed or conducted according to desirable scientific standards. However, the indications arising from the current simple pilot project are very promising with respect to actions to enhance/rehabilitate habitats and biodiversity. It is recommended that follow-up is planned and occurs as a properly planned scientific project involving a range of parties contributing diverse skills and expertise.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Al Cibahy A. & T. Al Abdesalaam 2006. The status and management of coral reefs in the United Arab Emirates. Environment Agency – Abu Dhabi (EAD), UAE. EWS-WWF Marine Conservation Forum Abu Dhabi, United Arab Emirates, September 11-14, 2006.

CEA 1986. Investigation of meteorological forcing of tides, Arabian Gulf, Eastern Province of Saudi Arabia. Final Report-Data Analysis and Summary of Findings, Contract No. 704135/00 and 704135/01. Coastal Environmental Associates, Report to Saudi Aramco, Dhahran Saudi Arabia (available from KWA).

Chiffings A.W. 1995. Marine Region 11: Arabian Seas. Pp 39-71, In: Kelleher G., C. Bleakley & S. Wells (Editors) A Global Representative System of Marine Protected Areas. Vol III. The Great Barrier Reef Marine Park Authority, World Bank and IUCN, Washington, D.C.

Coles S.L. & Y.H. Fadlallah 1991. Reef coral survival and mortality at low temperatures in the Arabian Gulf: new species-specific lower temperature limits. Coral Reefs 9:231-237.

Elshorbagy W., M.H. Azam & K. Taguchi 2006. Hydrodynamic characterization and modeling of the Arabian Gulf. J. Wtrwy Port, Coast., and Oc. Engrg. 132(1): 47-56.

Fadlallah Y.H., K.W. Allen & R.A. Estudillo 1995. Damage to shallow reef corals in the Gulf caused by periodic exposures to air during extreme low tides and low water temperatures (Tarut Bay, eastern Saudi Arabia). In: Ginsburg R.N. (Editor) Proc. Colloq. Global Aspects of Coral Reefs, Health, Hazards, and History. RSMAS University of Miami, 1993: 371-377.

Froese R. & D. Pauly (Editors) 2000. FishBase 2000: Concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines. 344 pp.

Hunter J.R. 1986. The physical oceanography of the Arabian Gulf: a review and theoretical interpretation of previous observations. In: Halwagy R., D. Clayton & M. Behbahani (Editors) Marine Environment and Pollution, Proc First Arabian Gulf Conf Environ Poll the Advancement of Science, and Environmental Protection-Council of Kuwait.

John S.A., S.L. Challinor, M. Simpson, T.N. Burt & J. Spearman 2000. Scoping the assessment of sediment plumes form dredging. CIRIA Report C547.

Lardner R.W. 1993. Computer models of the hydrodynamics of the Arabian Gulf. Arabian J. Sci. Eng. 18(2):191-215.

MIRO 2005. Marine aggregate extraction: Approaching good practice in environmental impact assessment. Royal Haskoning Report.

Perrone T.J. 1979. Winter shamal in the Persian Gulf, Naval Env. Prediction Res. Facility, Tech. Rept. 79-06, Monterey, 180 pp.

Reynolds R.M. 1993. Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman – Results from the Mt Mitchell expedition. Mar. Pollution Bull. 27: 35–59.

Riegl B. 1999. Corals in a non-reef setting in the southern Arabian Gulf (Dubai, UAE): fauna and community structure in response to recurring mass mortality. Coral Reefs 18: 63-73.

Sheppard C.R.C., A.R.G. Price & C.M. Roberts 1992. Marine ecology of the Arabian area. Patterns and processes in extreme tropical environments. Academic Press, London. 380 pp.

8. ANNEX

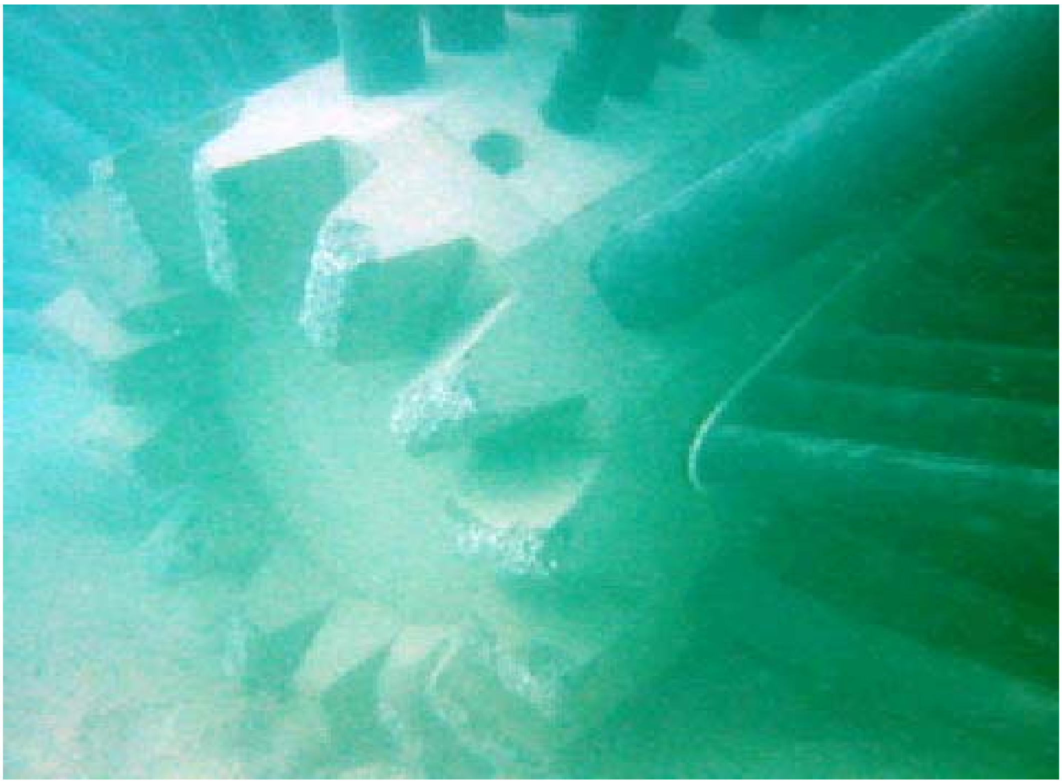
All photos marked by '*' in this section are Source: Emirates Diving Association – EDA©.

8.3 A Runde reef being lifted from a barge on 8 January 2005 for seabed placement.

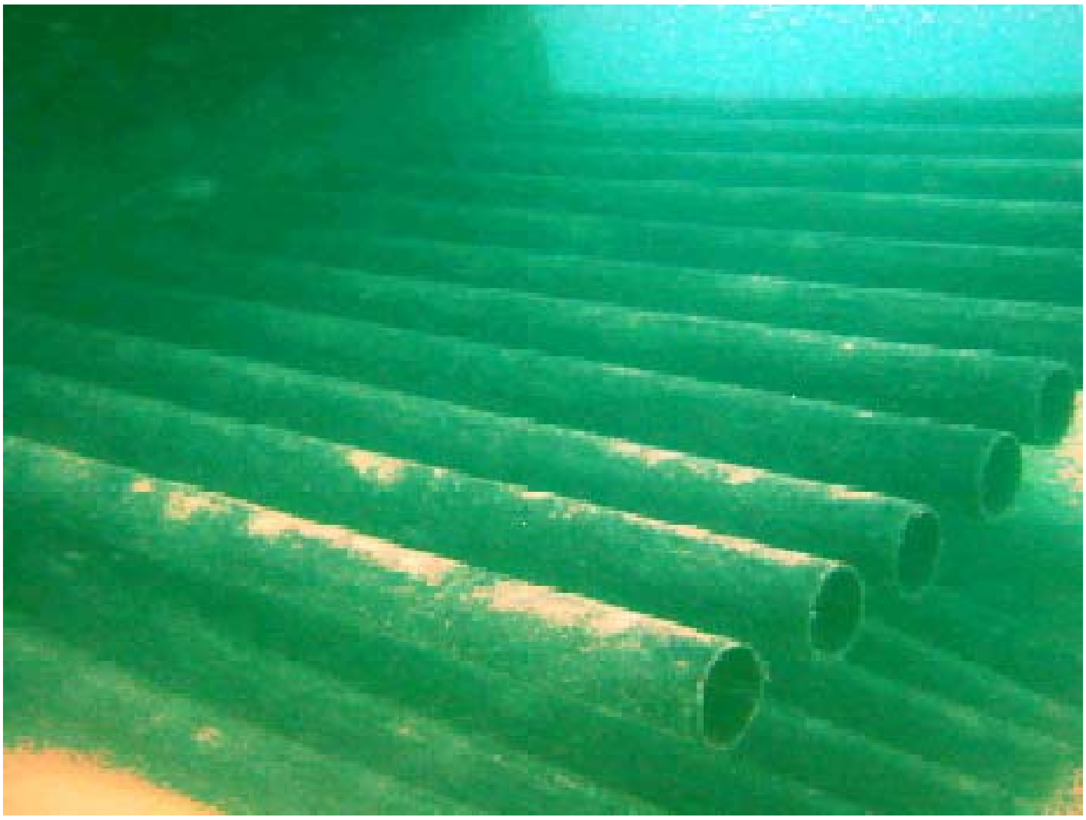
Note the Palm Jumeirah breakwater in the background

8.4 Toppled Runde reef unit on the seabed after the 11 January 2005 storm.

A) View of the base of the horizontally lying concrete cylinder.

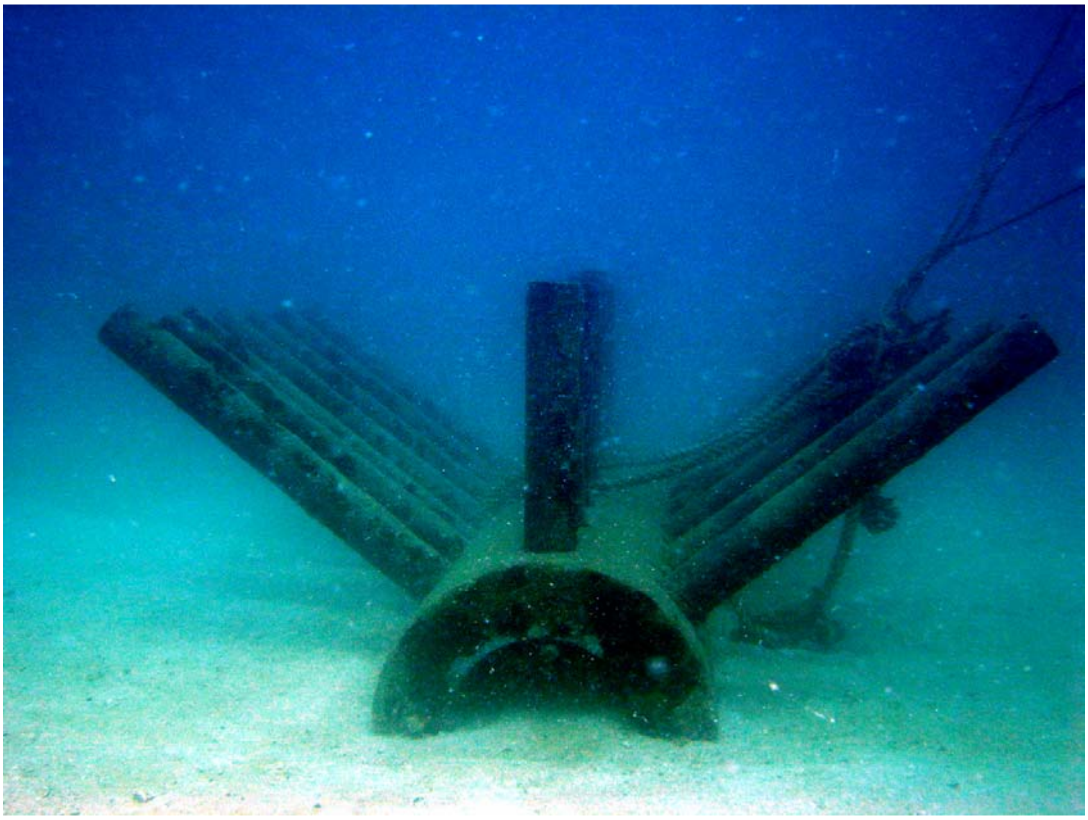


B) View of polythene pipes from a toppled reef on and near the seabed.



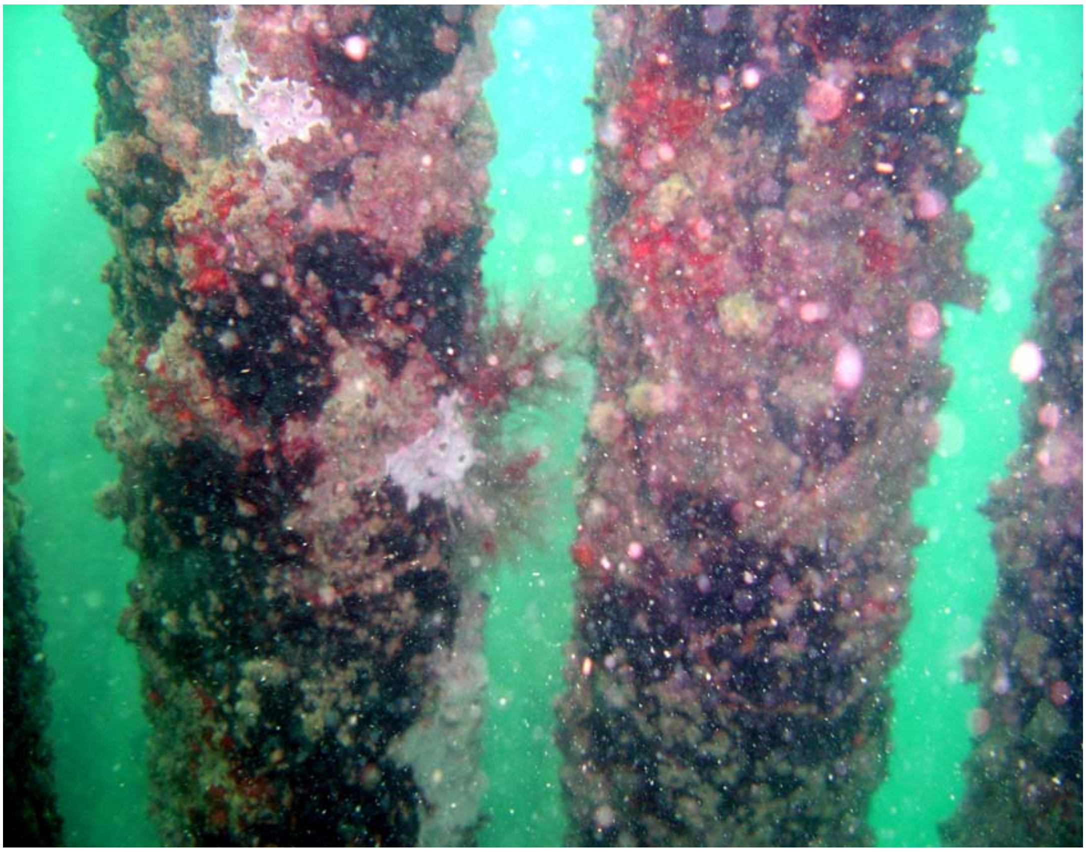
8.5 Polythene pipes of a large Runde reef with Scuba diver for scale*.

8.6 The Svenner reef on the bottom at an early stage of its deployment*.



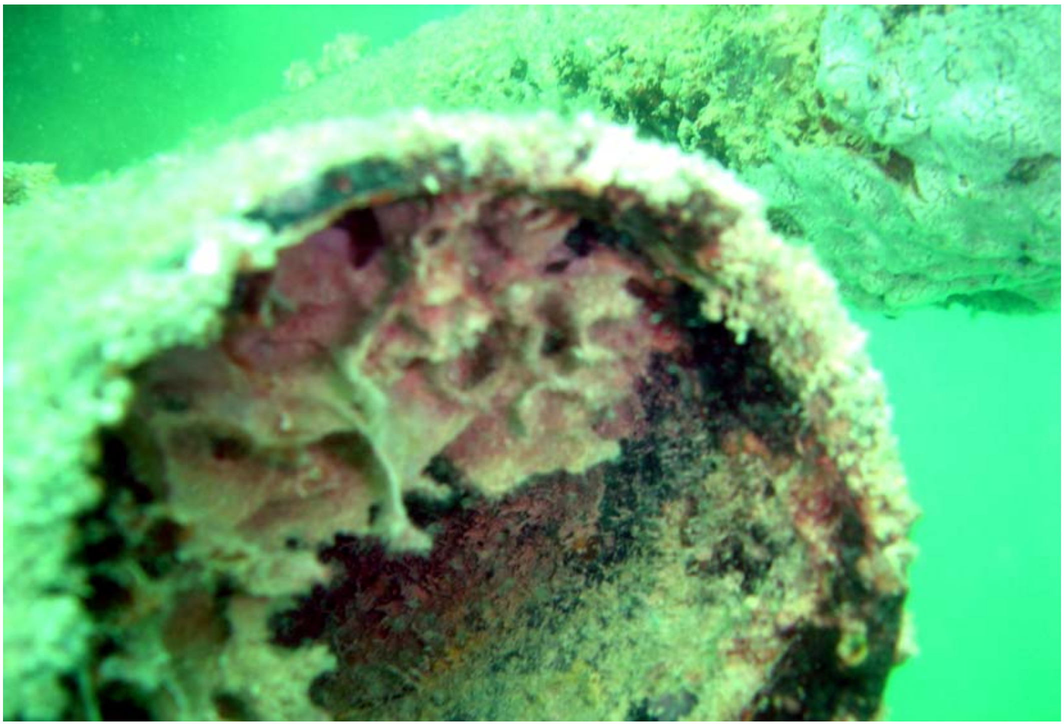
8.7 By March 2005, fish were evident and benthic organisms covered the reefs*.

8.8 After six months (July 2005), corals, molluscs, barnacles and anemones, covered the reefs*.



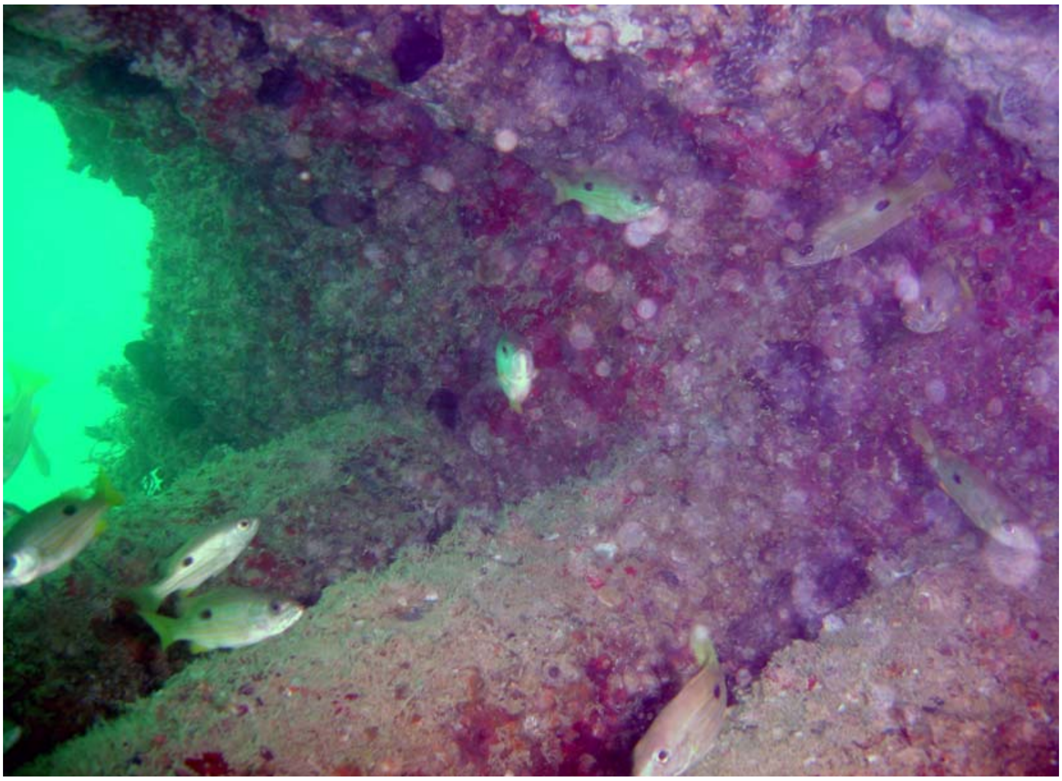
8.9 Well-developed coral growth occurred on the test reefs.

A) In the opening at the end of a polythene pipe and on its outer surface*.



B) Coral growth (*Turbinaria mesenterina*) on the outside of a concrete cylinder*.

8.10 By December 2005, several parts of the Runde reefs resembled natural coral reefs*.



8.11 Pectinid bivalves occupying the opening of a polythene pipe and filter feeding*.

8.12 Some of the diverse fish community attracted to the Runde reefs.

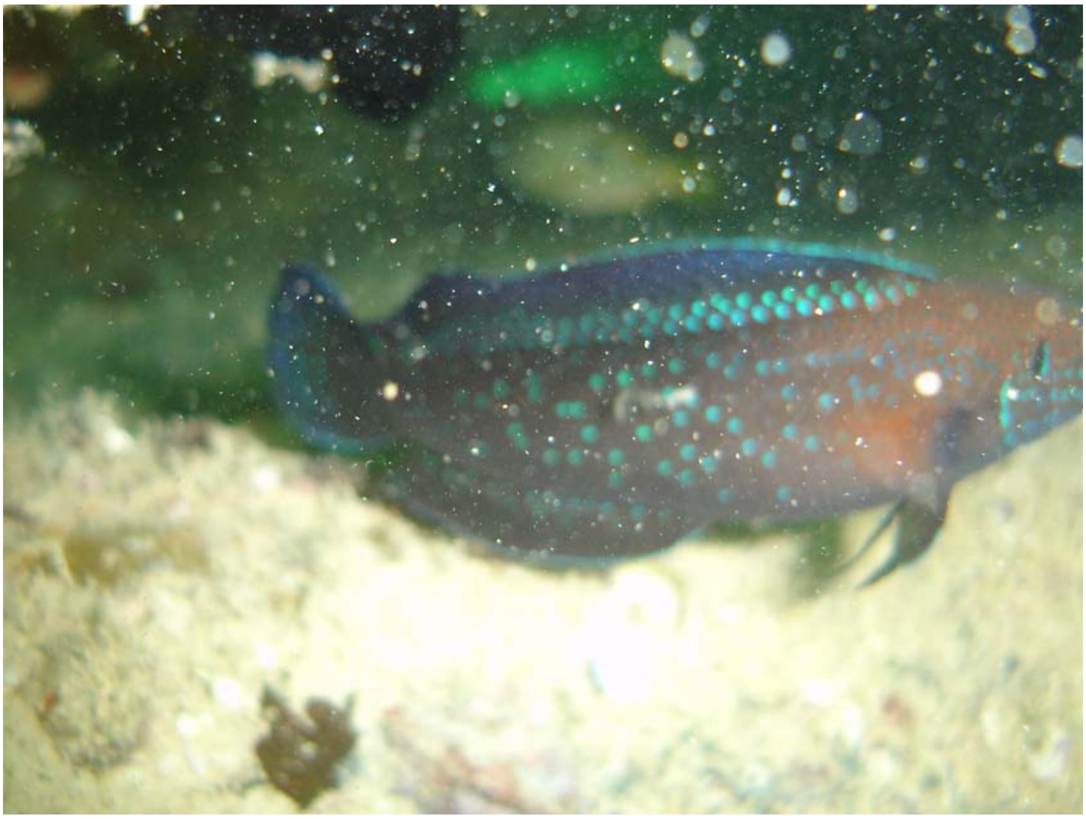
A) Arabian angelfish, Dory snapper and other fish in May 2005*.

B) Juvenile yellowbar angelfish foraging on a reef*.

C) Orbiculate cardinalfish living and foraging among the diverse benthic community*.

D) Jarbua terapon among polythene pipes*.

E) A wrasse in the new reef habitat*.



F) A young grouper sheltering in an opening*.

G) A large grouper, and smaller fish, seen from between polythene pipes*.