

Large coral transplantation in Bal Haf (Yemen): an opportunity to save corals during the construction of a Liquefied Natural Gas plant using innovative techniques

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Abstract. As part of a mitigation measure associated with the construction of a Liquefied Natural Gas plant, four large coral transplantations were carried out in Yemen between January and October 2007. Around 1,500 selected coral colonies were removed from areas to be impacted, transported and cemented in new sites. Transplanted colonies belong to 36 species and 25 genera. Among these, 140 large *Porites* spp. weighing from 200 kg up to 4 tonnes, were moved using new transplantation techniques. Growth, *in situ* mortality and health of the transplants were monitored over one year using photo quadrats, close-up pictures and linear growth measurements. Overall, survival of corals one year after transplantation was 91%. Most losses of transplants were apparently due to sedimentation of fine particles in the transplanted areas, fish predation, fisher activity and swell effects. Evidence of coral growth after transplantation was observed, especially in *Acropora* and *Porites* species, and on some faviids. The transplantation results demonstrate the capacity of corals to adapt to a new environment, in favorable conditions. They show that carefully designed coral reef rehabilitation strategies can be part of industrial development processes, whenever necessary.

Key words: coral transplantation, reef restoration, mitigation measures.

Introduction

The Yemen Liquefied Natural Gas (YLNG) project is a \$5 billion project to build a pipeline and a liquefaction plant to process and ship natural gas from Yemen to the world markets. In the plant the gas is compressed and liquefied at minus 160°C and transported via sea tankers. YLNG's environmental approach is: first to eliminate or mitigate impacts by redesign when this is possible. If elimination or mitigation is not effective or possible, YLNG policy is to compensate for impacts, and to provide investment to promote sustainable improvement in marine environmental conditions, and monitoring of the marine environment to ensure that these measures are effective. Creoccean carried out an Environmental Baseline Study (EBS) in 1997 and 2005. Up to that time, knowledge of corals in the region was limited to a few published references (Sheppard et al. 1992; Kemp and Benzoni 1999; Kemp and Benzoni 2000; Benzoni et al. 2003). The EBS showed that Bal Haf cape where the LNG plant is being constructed was characterized by a high coverage of diverse corals, abundant and diversified fish, and highly three-dimensional coral communities. As part of the

mitigation measures, a coral transplantation was proposed to save coral colonies from destruction on sites where the marine works would take place.

Three localised areas with dense coral communities will be impacted by the construction works (Fig. 1). On the North side: 1) the Intake area where an intake water cooling pipeline will be placed to pump deep water, 2) the Jetty area where a loading jetty will be built to receive tankers, and 3) the Golf area, where a shoreline protection with concrete blocks is required. On the South side, one area will be impacted: the Outfall site where a pipeline is to be placed to discharge warm seawater after it has been used for cooling during the gas liquefaction process.

Different sites were chosen to receive the transplanted corals (Fig.1). Selected sites met the following criteria: they were close to the original sites but out of the impacts of the plant construction (the selected sites were from 100 to 1100 m away from the donor sites), and were characterized by similar depth, hydrodynamic and water quality conditions.

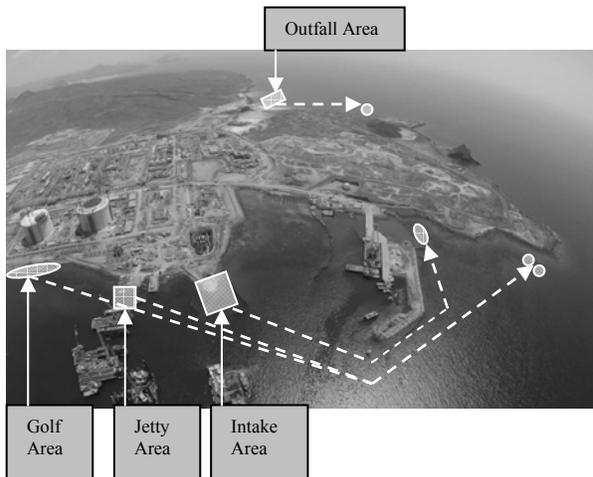


Figure 1: Aerial view showing the donor and the receiving sites.

A study of the coral communities on the donor sites revealed domination by the branching *Stylophora* with presence of large massive *Porites lutea* and *P. lobata*, and different faviids, especially *Platygyra daedalea* and *Favites* spp. A few tabular *Acropora* were also found. Because these areas were too large to be integrally transplanted and to increase the chances of coral survival, it was decided *a priori* to transplant selectively the largest colonies, the rare or uncommon species, the slow growing species, and only the colonies in good health. Edwards and Clark (1998) argued that there has been too much focus on transplanting fast-growing branching corals instead of slowly recruiting massive species, which generally survive transplantation well but often recruit slowly.

Material and Methods

The variety of colony shape and size among the transplanted corals required different methodologies of collection, transport and attachment. The small to medium-sized colonies (40–60 cm diameter) were removed using hammer and chisel and placed in pierced plastic baskets underwater. The baskets were loaded on a boat and directly transported to their final location (Fig. 2). They were protected from the sun and wind by a plastic cover and regularly splashed with fresh seawater. The medium to large-sized colonies (0.6–4 m diameter) were removed using a crowbar. Those colonies ≤ 1 m diameter were placed in a large steel basket (2 m² [base] x 100 cm [high]) directly underwater, which could be raised to the surface with lifting balloons and towed under the surface by boat. The large *Porites* colonies (1–4 m diameter and up to 4 tonnes) were drilled to a 20 cm depth in order to fix with epoxy resin one or two (12 or 18 mm) stainless steel screws into the skeleton, which could be attached to a lifting balloon (Fig.2).

Each of these colonies were then lifted to the surface and slowly towed by boat to the transplantation site.

All the corals colonies were cemented at their final location to avoid damage by swell or fish predation. Epoxy was chosen for the fragile colonies such as branching *Acropora* species. It took around half an hour for the cement bond to become strong and a few hours to be totally hard.



Figure 2: Moving of a large *Porites lutea* using lifting balloons (left), transport of small colonies in baskets out of water (right).

A monitoring program was set up to survey the different transplantation sites and to measure the adaptation of corals to their new environments. Every four to six months (2007: January, May, October; 2008: February, June) a digital image mosaic was taken of each entire site, after installing a grid. Survival and health (occurrences of diseases or damage) were recorded for each colony.

Close-up pictures and measurements using large calipers were used to survey the health of a dozen selected colonies per site, with quadrats being used to follow the growth of 10 tabular *Acropora*, 15 branched *Acropora*, 17 massive *Favites* and 24 *Porites lutea*. Plastic collars fixed to the colonies at the beginning of the monitoring were used as references for diameter, radial, or branch extension measures. Stainless steel cables were also installed on the surface of massive *Porites* to monitor their growth by coral tissue extension on the cable.

Results

1,495 coral colonies belonging to 11 families (Table 1), 25 genera and 36 species were removed from sites to be impacted and transported to new areas safe from the effects of the construction works. The taxonomic composition of the transplants (Table 1) was dominated by faviids with a large number of *Platygyra daedalea* and different species of *Favites*. A lot of Poritidae were translocated as well, with a special care taken in the case of 140 particularly large colonies (1–4m in diameter), weighing from 200 kg up to 4 tonnes .

Table 1: Number of transplanted colonies per scleractinian family and relative percentage

FAMILIES	NUMBER	%
Acroporidae	113	8.0
Agariciidae	71	5.0
Dendrophylliidae	7	0.5
Faviidae	750	50.0
Fungiidae	10	0.5
Mussidae	17	1.0
Oculinidae	12	0.5
Pocilloporidae	102	7.0
Poritidae	376	25.0
Psammocoridae	7	0.5
Siderastreaeidae	30	2.0
TOTAL	1,495	100.0

Fourteen months after the first transplantation operation in January 2007, 91% of the transplants were alive and healthy. The survivorship for each operation is shown in Table 2.

Table 2: Survivorship rate (%) of the transplantations depending on the duration of survival.

Area	Total (n)	Duration of survival (month)			
		3 (%)	5 (%)	10 (%)	14 (%)
Intake	608	99	-	96	94
Jetty	400	-	89	82	
Golf	79	-	78	74	
Outfall	408	-	100		

From the first monitoring after transplantation, there was some evidence of growth of the corals. Growth was observed at the base of the colonies where the living tissue overgrew the cement, the epoxy or the substrate directly. Colonies of the genus *Acropora* showed the most rapid growth, especially for the tabular colonies, with an average diameter extension of 1 cm mo⁻¹ (\pm 0.4 cm).

Growth was also visible on the large *Porites lutea* on which stainless steel cables were placed. These were quickly covered by living tissue. A few samples were collected and analysed by tomography to determine the rate of growth of these corals.

Various types of damage occurred to corals after transplantation. An invasive red sponge (*Clathria* sp.) attacked corals at all sites, especially massive *Porites*. Its fast expansion induced considerable localised damage at transplanted sites, killing the coral by its growth over the living coral tissue. This phenomenon has also been recorded in other areas of the Gulf of Aden by Benzoni et al. (2008). Infestation by pyrgomatid barnacles was also recorded especially on *Porites* colonies and seemed to be seasonal and may possibly have been linked to the sedimentation at the sites. It was observed as well on non-transplanted corals. Fishermen caused additional damage. Swell and current induced coral damage occurred in July and August during the monsoon season. The use of cement with an adjuvant to keep it compact

underwater was successful for most of the corals. Only three small colonies became detached after one year, but 17 out of the 140 large *Porites* were moved by the strong swell at the most exposed site (Fig.1, close to the cape). Rubble, sand and gravel transported by swell waves covered some of the branching colonies.

Fish were responsible for some coral damage, during the attachment phase. The large wrasse *Coris formosa* turned over the corals to eat boring shellfish living inside the coral skeleton and revealed by the collection process. Damage of *Porites* by the giant hogfish *Bodianus macrognathos* was also observed. Most of the loss transplants, especially on one of the areas where a large part of the transplanted corals belong to the Acroporidae (*Montipora* sp.) and the Agariciidae (*Pavona cactus*) were due to fish predation. Parrotfish and triggerfish scraped and broke parts of the coral colonies during feeding or nest-building respectively. This damage occurred to both natural colonies as well as the transplants, but the fish appeared more attracted by stressed corals than by healthy ones.

Finally, sediment deposits, which formed on the coral colonies, induced necrosis on top of massive corals such as *Platygyra daedalea* and *Favites* spp. in the transplant area closest to the plant construction works.

Discussion

The use of a screws drilled directly into the coral skeleton to fix to lifting balloons was an innovative technique to transport large corals. It allowed corals to be protected from damage during the collection and the transport phases (for example, abrasion of the living tissue by lifting belts usually used to move large corals). Moreover, it allowed the corals to remain underwater during translocation and allowed them to be positioned precisely on the receiving reef. No published references were available to compare the success of this technique because it is the first time such large corals have been successfully moved. Only references on the transplantation of small colonies (10–20cm) were found (Clark and Edwards 1995; Alcalá et al. 1982; Plucer-Rosario et al. 1987; Yap et al. 1992) and these workers all used plastic baskets for underwater transports. All reported the same problem: considerable loss of transplants from higher energy sites, whatever methods of attachment. Following these results, we decided to cement all the transplants, even the heavy colonies (up to 1 tonne) and we only had loss due to swell at the most exposed site. This points out that the location of a relocation site is one of the most important variables in a transplantation operation.

The differences in survivorship between our different operations (from 74% to 94% over one year) are most likely due to effects of the monsoon. During the summer monsoon, extreme oceanographic conditions occur, with strong swell, current and wind, and an upwelling carrying cold water at around 17°C (Sheppard et al. 1992). We conclude that corals which were removed and transplanted just before the monsoon season did not have enough time to recover and adapt to their new environment before they faced adverse sea conditions. Indeed, the transplantation process, even if it is done well, is likely to be stressful for corals (Clark and Edwards 1995). The transplants need time to recover to be able to resist new stress. This may be why they seemed to be susceptible to predators and diverse attacks such as fish, red sponge or pyrgomatids. Survival in this study appeared relatively high compared to previous studies. For example, Alcalá et al. (1982) obtained 40% survival of transplants after one year, Auberson (1982) 70%, but 20 to 50% on high-energy shallow sites, and Clark and Edwards (1995) 75% survival. This was probably partly due to the focus on larger, massive and sub-massive species in this project.

To contend with fish predation, we adapted our methodology, for example attaching the corals directly after their removal. Fish may be more attracted by stressed corals, perhaps due to the increase in the mucus production. The selection of corals in good health before transplantation is very important to limit these attacks.

To conclude, the 91% survival after more than one year is encouraging but other surveys are needed to complete these data. We can determine the best period of the year to move corals, depending on the season and the weather conditions: for Yemen waters it seems to be during the months following the monsoon. According to other authors, the species that better support the transplantation seem to be the massive ones such as the Poritidae and the Faviidae. The best way to move corals depends on the species, the size and the distance they need to be translocated. Large colonies can be towed underwater by boat and

small ones transported out of water in pierced plastic baskets.

These operations show that it is possible to do something to save part of the reef when a construction work is necessary. It is also possible to use these transplantation techniques during the building of industrial plants, hotels, harbor extension, or any construction that will damage part of the reef for coastal development. The cost of mitigation appears relatively modest. As an example, the cost of this operation represents less than 1% of the total amount of the plant construction.

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