Coral transplantation, an innovative measure in the frame of environmental impact mitigation

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Abstract
The paper commences by describing Yemen LNG’s approach to the control of impacts on marine biodiversity, which mirrors its general 3-tier approach to managing social and environmental impacts. The paper recognises that some minor physical damages to corals may occur during the construction of a new LNG terminal in a sensitive coastal environment, in which detailed surveys have found the coral and fish populations to be particularly sensitive and diverse. The paper then discusses a unique and innovative approach which Yemen LNG has adopted to mitigate impacts to corals. Yemen LNG is working with internationally recognised coral transplantation experts to transplant sensitive corals away from the areas of construction activities, to new areas nearby, to promote new populations and new growth on natural substrata. The scale of this exercise is larger than has ever been attempted and the corals which have been transplanted represent particularly sensitive and diverse species. The largest coral transplanted so far has been recorded at 4000kg, believed to be the largest coral ever transplanted successfully. It is believed that this is the largest and most successful exercise in coral transplantation ever attempted by an energy company. The paper describes the positive results from this innovative transplantation project in which transplanted coral colonies of differing sensitive genus are regularly monitored and found to be healthy and repopulating on natural substrate. The paper also records the positive effect on fish populations whereby demersal species are seen to relocate to the new coral areas thus creating new and sustainable biomass. The conclusion is reached that coral transplantation, on a larger scale than has ever before been attempted, can be a successful mitigation measure when dealing with potential construction impacts. This offers a positive way forward when constructing installations in sensitive coastal marine environments.

Introduction
Yemen LNG Company Ltd. (YLNG) is constructing a natural gas pipeline and a LNG plant in Yemen (Fig. 1). The project is known as the Yemen Liquefied Natural Gas (YLNG) Project. The YLNG project consists of a LNG plant at Balhaf fed by a pipeline, the main Line, from the Kamil Processing Unit (KPU) and a Transfer Line between the Central Processing Unit (CPU) and KPU. The existing gas processing plants in the Marib area, which have been in operation for about 12 years, extract pentanes and heavier fractions for export, LPG for domestic consumption, and return the residue gas for re-injection into the oil fields. The Balhaf LNG plant will comprise two processing trains of 3.45 Million Ton per annum (Mtpa) each, thus a design production capacity of 6.9 Mtpa and the finished product will be shipped out by sea in 135,000 to 205,000 m³ capacity LNG carriers. The LNG plant is located at Balhaf, in the South of Yemen along the Gulf of Aden. Environmental baseline studies conducted in 1997 and 2005 have pointed out the large natural biological marine abundance; about 400 species were recorded (Fig. 1). This abundance was observed in all the biological compartments including sediment fauna, coral reef fauna (GCRMN, 2002), fish species, reptiles and marine mammals. The area extending from Balhaf to Burum, qualified as an area of regional importance, was identified and proposed to become a Marine Protected Area (MPA) of Yemen (Kemp et al., 2002; Wilson and Klaus, 2000). This coastal area located in the eastern Gulf of Aden is characterized by extensive fringing coral reefs and rich fishing sites; it is an important site for nesting of seabirds and marine turtles. During, coastal surveys conducted in 1997 and 2005, the coral reefs in the eastern side of Balhaf Cape were extensively studied with the assistance of marine biologists and international coral experts. The marine ecosystem includes coral communities and associated marine life. The impacts of the construction and operational phases of the LNG plant on the overall environment including the coral populations were assessed in an Environmental and Social Impact Assessment (ESIA) study. This study has been prepared to provide the Yemeni Authorities, the Environmental Protection Authority (EPA) and the Lending Institutions with a full
discussion of the significant environmental and socio-economic impacts of the Project. In addition to these assessments, mitigation measures which have been implemented to reduce these impacts were addressed. This ESIA study addresses the key environmental and social issues of the YLNG project which are required by the Yemeni regulation (EPL no 26, 1995). It was prepared according to the guidelines of the World Bank operational policies on the Content of an Environmental Impact Assessment report (OP 4-01 – Annex B). The objective of this ESIA is also to provide the lending institutions information on how the project, which they will be part-financing, is developed in a manner that is environmentally responsible and reflects sound management practices, as required by the Equator Principles. In addition to this important work, YLNG is committed to comply with a number of specific Agency policies and guidelines and the current World Bank Standards were adopted for the YLNG project.

This paper presents the Yemen LNG Company’s approach to the control of impacts on marine biodiversity, then discusses a unique and innovative approach which Yemen LNG has adopted to mitigate impacts to corals communities using corals transplantation methodology and finally describes the results from this innovative transplantation project.

Study site

The south of Yemen along the Gulf of Aden has unique coastal and marine ecosystems, which include extensive coral reefs, and sea grass areas that are of economic importance for fisheries and tourism. The climate is quite hot along the coast and affected by seasonal monsoon which brings with it a significant upwelling. Rainfall is scarce, typically less than 50 mm per year. Sea temperatures are affected by the seasonal monsoon and the associated upwelling currents. From November to May, it is about 29°C in the first 20 meters of depth but can rapidly decrease to 18°C during the upwelling which comes with the seasonal monsoon period (Fig. 2). The South of Yemen hosts a variety of habitats, which range from some coastal mangroves, shrub lands, large dunes, sandy areas and rocky volcanoes. The Balhaf - Burum coastal and marine environment is both diverse and attractive from its rocky and sandy coasts to the saline mud flats, mangrove swamps, coral reefs and seagrass beds (Coles, 1996; GCRMN, 2002; Kemp et al., 2002; Sheppard and Sheppard, 1991; Wilson and Klaus, 2000). The Balhaf cape, where the LNG plant is being constructed, has a large natural biological marine abundance. This abundance was observed in all the biological areas (sediment fauna, coral reef, fauna, and commercially valuable fish species). This area is qualified as an area of regional importance, and it was identified and proposed to become a Marine Protected Area (MPA) of Yemen (Glastone et al., 2002; Kemp et al., 2002). This potential MPA is now part of the proposed Zoning Plan for the Coastal Zone Management (CZM) area Bir Ali - Burum, Sector 1, which comprises several zone categories of protected status along more than 50 km of coastline and a group of high aspect islands with extensive fringing coral reefs, rich fishing areas, seabird and, to the East of Bir Ali, marine turtle nesting sites and a salt water crater with fringing mangroves. Balhaf cape, including the LNG plant lies at the Western edge of the proposed area and it has been classified by EPA as a “General Use Zone”. Sea turtles were observed in the sea during the coastal diving surveys but no evidence of nesting on the shores of the area was demonstrated; most of the shores are rocky and thus inappropriate for nesting. During the coastal survey conducted in September 2005, the coral reefs in the eastern side of Balhaf cape were found affected by bleaching. The south of the cape was found densely colonized by Porites sp. with specific coral banks in shallow waters including rare species such as Millepora sp. The presence of reef constructions of Porites sp. was confirmed in the western part of the Cape and further north. The LNG plant area is located between the fishing areas of Al Ayn Bay to the West and Bir Ali to the East. These are large commercially valuable areas for local fishing industries in Yemen. During some seasons, this area is considered to be a prime fishing ground due to its high productivity and the high number of natural shelters. It should be noticed that in 2004, the fish production from Shabwah Governorate accounted for 3.9 % of the total Yemeni production, according to the Ministry of Fish Wealth. Most of the Shabwah fish production comes from Bir Ali located 15km east of Balhaf. According to Ministry of Fish Wealth, Bir Ali is 10 times larger than the three other main selling locations of Shabwah Governorate (Ein Bama’abad, Iqrah and Al Hawrah). The fishing activity in the Balhaf area is largely a summer activity (June to September) and the temporary shelters there are used by fishermen mostly during these months.

Country background: Yemen’s role in the conservation of biodiversity

International regulations and laws

Yemen is party to a number of international environmental agreements, the most important of which are:
- the Convention on Biodiversity (CBD),
- the Convention on the Conservation of Migratory Species (CMS; starting on the 1st of December, 2006; Yemen is party no 100),
- the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES),
- the United Nations Framework Convention on Climate Change (UNFCCC),
- Kyoto Protocol,
- the United Nations Convention on Combating Desertification (UNCCD),
- Environmental Modification,
- Hazardous Wastes,
- Law of the Sea,
- Ozone Layer Protection.
In 1993, the cabinet of the Yemeni government approved the draft Environment Protection Law (EPL) and, in 1995, the proposed legislation was ratified by Parliament as presidential decrees and laws. The EPL includes regulations for the protection of both the marine and terrestrial (land) environments and outlines the basic objectives and roles of concerned authorities in the protection of air, water, and soil. It establishes controls on pesticide use, environmentally damaging activities, transportation and disposal of hazardous materials and wastes, environmental monitoring, and marine pollution. It is very general in nature, and does not provide specific compliance standards for area such as air and water emissions or soil and groundwater contamination. The Executive Plan for the above law is under preparation.

The following is a chronological list of the legislation that addresses environmental issues in Yemen:
- Prime Ministerial Decree n°7 of 1987: establishing the Environmental Protection Council;
- Law n°42 of 1991: on the regulation and protection of sea life,
- Law n°11 of 1993: amended by Law n°16 of 2004: on the protection of marine life from pollution,
- Law n°12 of 1994: on crime and punishment,

A national legal framework for habitat and species protection was established by the EPL 1995. The Law provides for the establishment of natural protected areas, defined as land or water (both coastal and inland) that enjoys special protection to preserve its environment, archaeological features, or to protect fauna, flora, birds or marine species that are endangered or threatened with extinction (Article 2(20) & 11(1)). The law n°11 for the Protection of the Marine Environment, 1993 amended by Law n°16 of 2004 is aimed at protecting the Free Polluted Area from oil pollution. Except for Part 6 (the penalties) and part 7 (final rules), the articles of this law have been revised and included in the EPL Law n°26 of 1995 under part 4 (marine pollution).

Conservation issues
The conservation and sustainable use of Yemen’s natural resources requires translation of Yemen’s environmental problems and issues into conservation goals, objectives and a potential program of actions for achieving the targeted objectives. Therefore, the Environmental Protection Agency (EPA) developed a draft National Environmental Action Plan (NEAP) of 1995 to be the first environmental planning document outlining the government’s vision, objectives, strategy and priority actions for halting environmental degradation for the period from 1996-2000. The NEAP identifies 4 environmental problems as main areas of focus for halting biodiversity and natural resources degradation. These issues are water depletion, land degradation, habitat loss and waste disposal. Some key features of the program are:
- Establishment and development of comprehensive National Integrated Protected Areas System (NIPAS) in Yemen,
- Development & implementation of an Integrated Coastal Zone Management Plan (ICZMP),
- Developing and implementing specific policy, legislation and regulations on biodiversity
- National biodiversity education & awareness.

Coastal Zone Management in the Gulf of Aden can be traced back to the Jeddah Convention of 1982 when the Regional Organization for the Conservation of the Environment of the Red Sea and the Gulf of Aden (PERSGA) was founded. The national environmental action plan was launched in 1996 with two key objectives relating to the protection of the coastal marine environment: one was to prepare and develop an Integrated Coastal Zone Management Plan (CZMP), and the second one aimed at developing and establishing a system of marine protected areas (MPAs) with effective management plans.

The National Biodiversity Strategy and Action Plan was, then, published in draft in January, 2005 by the Ministry of Water and Environment, Environment Protection Authority (EPA).

Stakeholders in Yemen
Few national environmental NGOs operate in Yemen, including the Friends of the Environment and the Yemen Ornithological Society, while international NGOs like IUCN, Bird Life International, WWF and Wetlands International are more active and have active focal points in the Republic. The collective interests of the national NGOs are represented through a Yemen NGO Forum.

Conservation areas: Marine protected areas (MPAs)
Over the past few years, conservation efforts of the country biological resources have focused primarily on the establishment of protected areas. These efforts have led to the identification of 15 areas throughout the country including the Bahlafl – Burum area, which are of outstanding biodiversity/natural value and urgently need to be protected. These actions are implemented through a project designed with the support of and funding by the Global Environment Facility (GEF) of the United Nations Development Programme (UNDP). The pilot sections of the coastal zone identified by the GEF Project are located in the Governorates of Shabwa and Hadhramout: (1) Bir-Ali-Burum, 75 km in length, west of Mukalla: a site characterized by its coral reefs (Sector 1) and (2) Sharma-Jethmun, 50 km in length, east of Mukalla: a major sea turtle nesting site (Sector 2).
These areas were chosen because of their known biological diversity and because of the potential threats from uncontrolled commercial activities and artisanal fishing. Yemen LNG’s plant is located in Balhaf on the western edge of Sector 1, and forms part of the proposed Zoning Plan under the overall Coastal Zone Management Plan (CZMP). The zoning plan is a key outcome from the CZMP design project and will determine the permissible developments along the coastline. There are a number of zoning definitions under the CZMP, with Balhaf defined as a General Use Zone (GUZ), the least restrictive in terms of economic activity. The current zoning status is influenced by the two GEF funded marine surveys undertaken in 2002 and 2005, respectively. The 2002 survey concentrated on Pilot Area 1, the area that covers the Balhaf bay. The 2002 survey report did not recommend a zoning plan until a subsequent survey by consultants MacAlister Elliott and Partners was discussed and agreed with interested parties and stakeholders in a public meeting in June 2005. This zoning plan which defined Balhaf as part of a General Use Zone was communicated to Yemen LNG in July 2005. It is understood that the CZMP recommendations will be translated into Yemeni legislation in late 2007. Funding for the implementation of the CZMP has not yet been secured, thereby delaying the prospects of implementing coastal zone management in the pilot sections.

Participation to the national action plan
Yemen LNG has therefore decided to support this important initiative, which would otherwise be a lost opportunity for Yemen. In November 2005, Yemen LNG agreed with the Environment Protection Authority (EPA) to provide funding to implement the Coastal Zone Management Plan for Sector 1. The precise level of funding will be determined once the management plan has been confirmed by EPA and has been translated into legislation. The current plan is for Yemen LNG funding to be managed through an independent third party with relevant competence and experience to ensure appropriate and optimal use of the funds in improving the coastal management of Sector 1.

Yemen LNG environmental management strategy and environmental responsibility

Management Strategy
YLNG’s approach to the control of social and environmental impacts is designed to follow a 3-tier management strategy (Fig. 3):

1. Eliminate or mitigate impacts by redesign.
2. If elimination or mitigation is not completely effective, provide offset for impacts.
3. Provide investment to promote sustainable improvement in social or environmental conditions.

This strategy was put in place prior to marine construction works commencing (January 2006) and it still holds good some 22 months later (October 2007). Furthermore, the effectiveness of this policy is proven by a programme of regular monitoring missions as will be discussed later in this paper.

Project environmental action plan
Following the Environment and Social Impact Assessment (ESIA) study, environmental management plans and procedures have been developed within the boundary of a World Bank compliant Environment and Social Management Plan (ESMP). These measures are implemented to mitigate and thereby minimise the environmental impacts identified in the ESIA. During the construction phase, mandatory plans and procedures are being produced to ensure contractors adherence. Implementation of the relevant construction plans and procedures by the Engineering Procurement & Construction (EPC) contractors is being supervised and monitored by Yemen LNG. For the operational phase, the plans and procedures will be produced and implemented directly by Yemen LNG.

The relevant Environmental Management Plans comprise the following components:

- Operational control of environmental impacts through the adoption of various plans and procedures, examples include the Pollution Prevention Plan, the Coral Management Plan and the Waste Management Plan – including water disposal methods – as well as an Emergency Response Plan,
- Training through the production of a specific manual and supplemented by briefings conducted by HSSE staff,
- Preservation and restoration of the environment with a view to addressing the needs of every potentially disturbed area,
- A series of monitoring activities including, but not limited to, air quality monitoring, water quality monitoring, coral reef monitoring and emission and discharge monitoring,
- An audit procedure consisting of several levels ranging from an EPC Contractor audit to a Lenders/Agency audit of the entire project implementation,
- An overall Environmental Management Review to be conducted regularly to ensure that the system is adequate, appropriate and effective.

Yemen LNG report to the concerned local authorities, to the Minister of Water and Environment as well as to the Environmental Protection Authority which in turn, will carry out their own monitoring on a regular basis.
Marine ecosystem preservation and restoration key actions
The knowledge of coral communities along the Yemeni coast, and around the offshore islands of Shabwa, is very recent, and has been limited mostly by the difficult field work logistics (Kemp and Benzoni, 1999, 2000; Benzoni et al., 2003). The marine ecosystems include the coral reefs, the marine life and sea water quality in the eastern and western parts of the rock cape. Following the initial environmental baseline study in 1997, a second environmental assessment of the Balhaf area was performed in September 2005. This included a detailed description of the fish and coral communities. The conclusion of the study was that the fish and coral communities were particularly rich and diversified in the project area. An intensive marine diversity monitoring programme has been implemented which involves successive observations of the coral health throughout the construction phase and subsequently. This monitoring allows the detection of any changes that may occur within the coral community during construction and allows appropriate response measures to be executed. Yemen LNG has also commissioned a detailed study to document the effectiveness of Balhaf bay as a fish nursery – both to act as a baseline of diversity and to assess the importance of the bay to local fisheries. The main potential impacts on intertidal and marine ecosystems during construction activities include a small area of corals. During the coastline rock berm works, jetty, marine offloading facility (MOF) and water intake and outfall construction, mitigation measures are being taken to minimise the impacts. Other potential impacts include an increase of turbidity in sea water due to the dredging activities. Mitigation measures include construction methods that will minimize turbidity in the sea water and minimize direct impacts on the corals. Main measures include the use of silt curtains to avoid silt deposition on the corals and minimisation of dredging impacts caused by transported fine sediments. The dredged material will be disposed of offshore in a specific deep location in water depths of greater than 150 meters. The impact on sensitive coral populations on the western part of the Balhaf cape relative to the overall length of coast to Burum classifies the residual impact of construction on intertidal and marine ecosystems as between negligible and moderate. The main potential impacts on the intertidal and marine ecosystems during operation of the LNG plant and facilities include possible modifications in the water currents west of Balhaf due to the presence of the MOF and an increase in sea water temperature due to discharge of cooling water on the east side of the cape. The location, length, orientation and design of the water outfall for cooling water and other waste water discharges have been studied and physical modifications implemented, in order to ensure that there is a negligible impact on the coral reefs on the eastern part of the Balhaf cape due to the temperature of the discharge. Other mitigation measures include minimizing suspended solid content and chemicals in the water discharges and strict management of chemicals and fuel tanks in the MOF facilities. The residual impact of the LNG plant operation on the marine and intertidal ecosystems is then considered to be negligible in the ESIA study.

Coral reef protection during construction and coral transplantation
The marine ecosystems in the vicinity of the Balhaf Plant include coral reefs and a diversified fish population. The main potential impacts on intertidal and marine ecosystems during construction activities include a potential increase in sea turbidity due to the movement of earth during land preparation activities. Construction mitigation measures have been put into place to minimise the impacts of the coastline rock berm works, and the construction of the jetty, of the MOF and of the water intake and outfall. These measures include selecting construction methods to reduce turbidity in the seawater as well as minimising any direct impact (contact or siltation overlay) on the corals. Silt curtains manufactured from a durable geotextile material have been used to avoid silt deposition on the corals. However, the LNG plant requires an efficient and sustainable shoreline protection to maintain the integrity of the plant over 30 years and specifically, to avoid any damages during the monsoon period. The shoreline protection has been completely redesigned during the latest stage of the project in order to limit as much as possible the interference with some coral communities. Despite these preventive and mitigation actions, some impacts on the coral communities are unavoidable. These unavoidable impacts include the physical presence of some pilings of the jetty, some segments of the intake water cooling pipelines on the corals and plumes of fine sediments generated during the construction and dredging activities. These physical impacts are localized and qualified as minor in the ESIA document. But YLNG has committed to save these specific coral communities and rare species threaten by these impacts. Following an intensive study of potential solutions, coral transplantation has been selected as an innovative, useful and practical management tool to preserve the Marine Environment.

Coral transplantation and resettlement: an innovative solution for ecological savings
As natural and human pressures on coral resources have recently drastically increased, initiatives for coral preservation and coral reefs restoration are of great importance (Bryant et al., 1998; Knowlton, 2001; Yap, 2000, 2001; Riegl, 1994). Recognition of the value of reefs and coastal fringing ecosystems (UNEP-WCMC, 2006), the development of marine reserves, MPAs, parks in reef areas and increased efforts focused on reef management have resulted in a worldwide and widespread interest in reef rehabilitation, restoration and/or preservation using techniques such as coral transplantation as an aid to management (Edwards and Clark, 1998; Edwards and Gomez, 2007; Yap, 2003; Yap et al., 1998). Transplantations were restricted, initially, to experimentation in controlled conditions at the laboratory scale, then small scaled field experience were tested in the marine environment (Baird and Hughes, 2000; Dizon and Yap, 2006) and finally, some recent attempts at a larger extent were performed (Yap and Molina, 2003; Villanueva et al., 2005; Yap, 2004; Edwards and Gomez, 2007). Based on the scientific literature review, corals transplantation efficiency cannot be over evaluated and does not constitute the only way to
restore degraded reefs. Coral reefs and coral assemblages’ restoration is in its infancy (Edwards and Gomez, 2007). The method is intrinsically limited. Transplanting a few coral colonies does not mean that a reef ecosystem and its associated biodiversity and economic importance are transplanted. To preserve colonies threatened by construction works or indirect impacts is laudable but there will be no guarantee that a degraded reef will be compensated by a restricted number of transplanted corals because fully functional reefs cannot be recreated and transplantation method cannot be extended to the whole coral community (Edwards and Gomez, 2007; Yap, 2003). Corals are part of a complex ecosystem and transplantation usually focuses on this component and tends to ignore the others. Transplantation has then to be carefully evaluated in the framework of a global environmental description before trials and realizations. There are some evident direct benefits to do so, but potential drawbacks are also possible. In that context, and following a number of successful trials, Yemen LNG focused on saving specific areas of sensitive corals and decided to launch some semi-large scale transplantation works based on the success of the trials.

Results

Background

Coral communities in the vicinity of the LNG plant have been recently thoroughly investigated and identified by internationally experts (Fig. 4). It is evident from the brief history of the scientific explorations of the Balhaf coral communities from 1997 to date, that the study conducted in September 2005 represents the most detailed and complete baseline assessment of the coral and coral assemblages found around the rocky headland of Balhaf. The biodiversity of coral communities was also evaluated by surveys and scientific studies performed at a bi-monthly frequency. The use of permanent monitoring stations around the site allowed Yemen LNG to gather a precise view of the underwater environment. These studies facilitated a complete and definitive description of corals in the vicinity of the construction works. The results of these studies can be summarized as follows:

- Balhaf coral communities present a high scleractinian coral species diversity with as much as 79% of the coral species known to occur between Dhofar (Oman) and Bab el Mandeb found around the same headland (communities in the Gulf of Aden present a total Scleractinia diversity of 93 coral species whereas in Balhaf about a total of 73 hard coral species and 8 genera of reef cnidarians between soft corals and non-scleractinian reef builders were found).
- It should be noted that among the 73 scleractinian corals reported, some are particularly important within the frame of the regional and Indo-Pacific coral biogeography, these species are: Acropora downingi (Wallace, 1999), Montipora circumvallata (Ehrenberg, 1834), Porites harrisoni (Veron, 2000), and Parasimplastrea sheppardi (Sheppard, 1985).
- Balhaf presents a very rich variety of coral community types. All the known coral community types described along the Yemeni coast of the Gulf of Aden, plus a previously unreported one (the monospecific giant Millepora assemblage recorded in one area), were observed around the site of the LNG plant.
- Corals presence is restricted along the coast to the rocky substrate with a 100m maximum continuous width strip.
- While many of the most sensitive coral communities found along Bir Ali and offshore islands coasts had suffered heavy to total mortality after the 1998 bleaching, and despite evidence of past massive coral mortality, and reported presence of some coral bleaching in three of the seven areas, the Balhaf corals were found healthy and in generally good condition, or recovering well from only partial mortality.
- Balhaf coral communities present high levels of bio-construction, and form very complex and tridimensional benthic assemblages that host a very high diversity of invertebrate and vertebrate animal species. The living cover represents about 60% (up to 90% in some stations), non-living cover 25% and sediments 15% (Fig. 4).

The very complex and diverse coral structure at Balhaf can be explained by the combination of several positive factors such as the availability of hard substrate, a high degree of complexity of the coastline around the headland, and relatively undisturbed and unpolluted conditions for many centuries. Following the surveys, corals sensitivity and general sensitivity maps were proposed.

Candidates for transplantation were then selected based on the following criteria:

- abundance (number per square meters),
- sensitivity,
- capability to resist to disturbances,
- quality of the individual (presence-absence of necroses, ecto parasites, bleached parts, …),
- size and weight,
- integration into other corals,
- potential ability of transplantation based on literature data and experiences,
- capability to be removed and transported easily,
- safety and health related issues.

Methods and field works

In January, May, June and September 2007, four intensive phases of coral transplantation field works were performed on the Yemen LNG plant site. Before these works, feasibility assessment studies were conducted by scientists. The transplanted
corals were initially located in the vicinity of the future cooling water intake and outfall pipelines, pilings places of the LNG jetty and on some restricted berms of the shoreline protection area (Fig. 5). Scientists and experts, involved in the field works, were consultants from external organisations working with international experts in coral communities’ transplantation, professional underwater cameraman and professional underwater workers assisted by a logistic team from a local diving center (Fig 6). The purposes of the dives were to:

1. identify and delineate the coral communities’ areas that were expected to be impacted by the construction works. The initial assessments determined a total potential impacted area of 4771 m² for the four construction areas,
2. to select the corals that will be removed and transplanted,
3. to select the zones for the reinstatement of the corals,
4. to implement the corals transplantation program,
5. to make extensive underwater videos and monitoring on site.

The Stylophora colonies were the most predominant corals in the sites with some colonies of 30 to 40 cm in diameter. There were also large colonies of healthy Porites (1 to 2m large) and scattered colonies of Platgyra and other Favids, as well as Pavona were recorded, most of them with a small diameter (20 to 30 cm) but healthy and straightforward to move. About 1089 colonies were transplanted in the first 3 missions: 608 in January including 69 massive ones (Porites sp., weight > 2 tons), 400 in May and 81 in June (Table 1). More recently, following the fourth mission in September 2007, the total has increased to around 1500 transplanted corals. The corals were reinstated in four virgin areas near the MOF area (Fig. 5). It was not the objective of the works to remove the whole coral communities’ populations, but only the sensitive ones were removed. Very few large scale experiments of coral transplantation have been conducted all over the world. Most of the works already performed consisted in the transplantation of small corals that can be handled manually. Also many transplantation and corals developments in controlled conditions have been performed for the aquariophily market. However, large scale transplantation and reinstatement of diverse and massive colonies such as the works performed in Yemen have never been reported. This is therefore a unique project which has been performed in an area of outstanding natural biodiversity.

**Transplanted corals and reinstated areas**

The choice of the re-implantation sites was very important. Indeed, the corals have a greater potential to recover if the final site offers conditions similar to the original site (Fig. 5).

The criteria for choosing the transplanted areas were as follows:

- Different areas to increase the number and diversity of transplanted coral colonies,
- Low density of corals onto the chosen area substrate to allow regrowth and repopulation,
- Areas not directly potentially impacted by future maritime works (long term),
- Same oceanographic conditions compared to the area where corals were sampled (depth, water quality, and agitation / currents),
- Hard substrate (large slabs of basaltic rocks) to stick the coral colonies,
- Protected areas from fishing activities to avoid physical damage,
- Same habitats and exposure,
- Opportunities for coral larvae to colonize artificial structures (“Acropode” along the shoreline protection and the MOF).

Corals which were selected for transplantation were healthy colonies of sensitive corals (with slow growth rate, the reef builders, the rare or uncommon species and the species with low capacity for recruitment). Others colonies, the healthiest and largest (among the less sensitive species) were also considered for transplantation. The genera considered for the transplantation were: Porites, Platgyra, Echinopora, Acropora, Pocillopora, Pavona, Stylophora, other Favids and others corals (Psammocora, Leptastrea, Galaxea, Hydnophora …) (Table 1). The small coral colonies (less than 60 / 70 cm) were easier to detach compared to the branching colonies, which are more fragile. To remove the largest colonies (100 to 400 cm), specific equipments were designed to cut the base of the large Porites without damaging the coral tissue and then, special lifting and handling techniques were developed to transport the colonies in safe conditions to their new locations. The coral colonies were transported either underwater in cages and/or with airbag lifting equipments or in boats in the ambient air, protected from the sun and continuously moisturised. On the reinstated area, after cleaning the substrate with a wire brush, the coral colonies were re-attached to the hard substrate with special cement / adjuvant and/or resin. Cement became hard after less than one hour and was invisible after two weeks, colonized quickly by turf algae. In the first mission (January 2007) after ten days of collecting the corals, a total of 608 coral colonies were removed. In January and in May, respectively 69/34 big Porites from 500 kg to more than 1500 kg, 539/366 small and medium sized coral colonies out of 10 families and 17 genera were selected from the intake and jetty area. Only the healthy ones and the most sensitive ones were selected. Compared to the total number of corals on the site, per species collected, almost 100% of some species such as Acropora downingi, Goniopora cf djiboutensis, Leptoria frygia or Lobophyllia cf corymbosa were removed. These species were not very prevalent at each area.
and each colony was easy to remove and quite large. Finally, concerning the Porites, some of them were noted to be infested by a red sponge which grows on the coral tissue, or by worms, therefore only the healthy ones were chosen for transplantation. This massive species is a main reef builder and can be dominant between 4 and 10m depth. Its larvae have difficulties to settle on a reef (poor competitor). The large colonies form a heavily bioconstructed coral carpet, with corals situated close to each other (sometimes adjacent).

**Surviving corals and primary evaluation**

All the collected corals were transported and distributed among the transplanted areas. At the end of the transplantation field trips, the density of corals on all the four transplanted areas was about 1.37 ± 0.34 individual per m². This density will allow a reasonable coral growth increment. Each colony has the possibility to develop without competing with the adjacent ones, as on a natural coral reef. It is known that some species are aggressive against other corals or organisms (such as Galaxea sp. or Hydnophora sp.), other genus supports specimens of the same genus (e.g. Acropora sp.). During the cementing phase, the positioning of the colonies was chosen depending on the biology of corals. Indeed, some species vary considerably in their tolerance of their neighbors. Fields experiments demonstrated a significant decline in the growth rate of competing colonies of Stylophora compared to non-competing control colonies. The more locations the corals have, the better growth they demonstrate. When some corals are in competition for growth with other ones, their growth rate slowed or their shape can be modified. They can kill their subordinates with their repulsive tentacles (Galaxea or Hydnhophora for example). The number of female gonads per polyp was significantly reduced and the typical synchrony in reproduction among different branches of a given colony was changed and desynchronized. To conclude: intraspecific competition in reef corals involves great investment of energy.

After collecting, transporting and cementing all the colonies, a baseline monitoring was organized to monitor the capacity of the corals to adapt to their new environment (Fig. 7). Different methods of work were performed in the monitoring of the entire area by photoquadrates, growth measurements on some selected families and close up picture monitoring for a selection of corals on each area. The transplanted areas have been selected to be outside of potential impacts by maritime works. They have to be protected from other human activities as recreational activities (bathing, fishing). Monitoring after 10 months has shown that almost 100% of the coral colonies are still alive and growing. The monsoon period with high currents and waves regimes has not impaired the transplanted corals. Visual observations have pointed out that the newly “created” sites have been actively colonized by fishes and other marine organisms whereas they were totally virgin before. In terms of the success of the transplantation missions, the intake corals (January 2007) are showing strong signs of growth and a post-replantation survival rate of 96.4%. The Jetty corals (May) have a survival rate of 93% and the Shoreline area corals (June) 79%. This gives a current (at October 2007) overall survival rate of 95.3% which is much better than other (smaller) works performed around the World where a survival rate of only 50% to 70% is typical. Furthermore, many important lessons have been learned about transplantation protocols and this has moved the knowledge of this new technique forward considerably.

**Conclusions**

YLNG faced a significant challenge in building an LNG terminal in an area of outstanding natural biodiversity. The construction schedule demanded quick, firm and decisive action. The pressures from external stakeholders were intense but the decision to implement an innovative and daring programme of coral transplantation has proven to be the correct one. Yemen LNG has been working with internationally recognised coral transplantation experts to transplant sensitive corals away from the areas of construction activities, to new areas nearby, to promote new populations and new growth on natural substrata. The scale of this exercise is larger than has ever been attempted and the corals which have been transplanted represent particularly sensitive and diverse species. A high percentage of the healthy coral colonies have been successfully transported from several threatened areas to new protected areas. No critical damages due to coral handling were observed. Coral pictures, quadratpictures, coral measurements and geo-referenced cartographies of the new transplanted areas were realized for future monitoring. This project was the largest attempt ever made to transplant a large and diverse range of coral colonies and monitoring the results is important for future considerations. The monitoring is intended to last over several years to demonstrate the feasibility to transplant massive coral communities. In this way, a unique and innovative approach was adopted by Yemen LNG in order to mitigate impacts to corals. The largest coral transplanted so far has been recorded at 4000 kg among all the selected Porites, believed to be the largest coral ever transplanted successfully. It is believed that this is the largest and most successful exercise in coral transplantation ever attempted by an energy company and, to date, almost 1500 corals have been successfully replanted. Monitoring is demonstrating at the present time the success of this technique. Transplantation of corals could then become a model which from which other projects could usefully learn.
Acknowledgements

Many people have contributed to this important and innovative project and, whilst the following list is not exhaustive, it is representative of the diversity of these contributions. The authors would therefore wish to thank:

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References

Figure 1: Location of the LNG plant and environmental context
Figure 2: Oceano-meteoreogical conditions on the site

Balhaf
Figure 3: 3-tier management strategy for Yemen LNG environmental and social responsibility
Figure 4: Typical coral communities’ assemblage in two monitoring stations
Figure 5: Coral transplantation areas and sampling sites
Figure 6: Transplantation of coral colonies
Figure 7: Monitoring of transplanted colonies
<table>
<thead>
<tr>
<th>Family</th>
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