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Coral relocation for impact mitigation in Northern Qatar

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Abstract. A large-scale, long-distance coral relocation project was conducted as mitigation for impacts to hard coral habitat associated with marine construction activities offshore Ras Laffan Industrial City, Qatar. Working under the guidance of the Supreme Council for the Environment and Natural Reserves, Qatargas Operating Company Limited and its Venture partners engaged in a hard coral relocation project. The project salvaged and relocated over 4,500 hard corals from pipeline corridors to mitigate for pipeline installation impacts. Proven techniques for coral reattachment and newly developed methods to enhance coral survival were used for the mass recovery, transport, and reattachment of the corals. Corals were transported 46 km, a single day transit, from the north coast of Qatar to a coral habitat along the east coast and reattached with concrete. Initial monitoring of approximately 5% of the reattached corals and randomly selected reference corals indicates high survival rates. This project represents an option for off-site mitigation and is an example of proactive environmental regulation, corporate responsibility, and advanced field technology applied in concert to reduce impacts to a viable hard coral habitat.

Key words: Off-site mitigation, Coral relocation

Introduction

Qatargas Operating Company Limited (QG) and its Expansion Projects (i.e., Qatar Liquefied Gas Company Limited [II], Qatargas 3 and Qatargas 4 Joint Asset Development Team [QG3&4], and Common Condensate Single Point Mooring [SPM] Project) are installing five export pipelines within three corridors offshore the coast of Ras Laffan Industrial City (RLC), Qatar to expand their production capabilities in the Arabian Gulf.

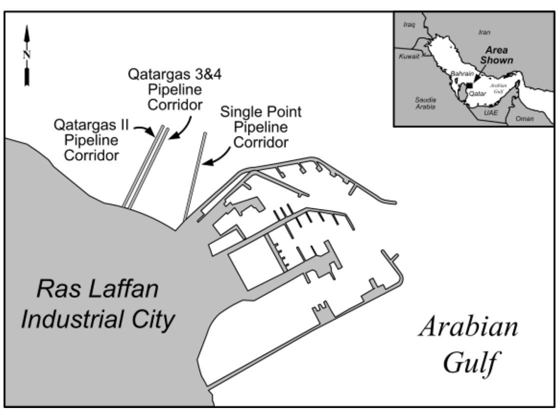

Figure 1: Location of nearshore portions of Qatargas II, Qatargas 3&4, and Common Condensate Single Point Mooring (SPM) pipeline corridors relative to Ras Laffan Port.

The pipelines will be installed on the seafloor from the offshore platforms to a point 2.5 km offshore RLC (Fig. 1). From 2.5 km offshore to the pipeline landing, the pipelines will be buried in three 7-m wide trenches. It was estimated that pipeline burial activities would affect a 50-m wide area along the 2.5-km distance for each pipeline corridor.

The Arabian Gulf, a semi-enclosed shallow sea, supports many complex and unique hard coral habitats. The Gulf is connected to the Indian Ocean by the Straits of Hormuz and experiences some of the widest seasonal fluctuations in water temperature and salinity recorded anywhere in the world. Gulf corals have adapted to fluctuations in temperature ranging from 10°C to 40°C and salinity changes from 28 to 60 ppt (Pilcher et al. 2000). Therefore, many endemic species are found in the Arabian Gulf but overall the coral habitats have low biological diversity. Recent bleaching events attributed to extreme high water temperatures occurred in 1996, 1998 and 2002 and reduced coral cover to less than 1% in many of the shallow water areas (Rezai et al. 2004).

The slow growing hard coral populations, which have only begun to recover from these bleaching events, are also threatened by anthropogenic impacts. Corals in sensitive coastal habitats are affected by turbidity and suspended sediments from land reclamation and dredging projects. Cooling water discharged from desalination and power plants exposes coral habitat to heated effluent water, generally 10°C above ambient temperatures, and toxins including anti-fouling and anti-scaling chemicals. Nearshore construction projects for the oil and gas industry also threaten sensitive coral reef habitats.

The proposed new pipeline routes for Qatargas Expansion Projects cross sensitive coral habitats offshore RLC. The proposed pipeline corridors were surveyed in 2004 and 2006 to characterize habitats that would be affected by pipeline installation activities. The nearshore portions (defined as approximately 1.2 to 2.5 km offshore) of each of the pipeline corridors were characterized by low-relief hard bottom substrate and a biological community that includes hard corals at an average density of 0.47 colonies m^{-2} (Continental Shelf Associates Inc. 2005a, b, 2006a).

Based on the habitat characterization surveys, a Coral Management Plan (CMP) was prepared, approved by the Supreme Council for the Environment and Natural Reserves (now the Ministry of Environment), and implemented to mitigate the unavoidable impacts of pipeline installation activities to this sensitive habitat. The CMP recommended the reduction of biological impacts by salvaging and transplanting hard corals affected by pipeline installation rather than the alternative of compensating for destroyed corals by creating artificial reef habitats. Based on the observed average live hard coral density and coral relocation experience from other areas, approximately 4,500 hard corals were relocated from the area to be dredged to a fasht (shallow, emergent rock marine outcrop) coral habitat along the east coast of Qatar (Continental Shelf Associates Inc. 2006b).

Materials and Methods

Reattachment area

Water depth measurements, temperature and salinity water column profiles, substrate classifications, general habitat observations, and video and still photographs were collected at eight sites along the east coast of Qatar to determine the most suitable site for coral reattachment activities. Site 7 (25°33' 02.00"N, 051°37'22.50"E), known locally as the Fasht al Hurabi, was selected as the most suitable site for reattachment activities. The Fasht al Hurabi area is a crescent-shaped, 1–5 m deep, gently-sloping rock outcrop with strong north-to-south running currents. The coral community was historically diverse and thriving, and suffered mass mortality in the last decade likely due to elevated seawater temperature anomalies that occurred in the region. Since that time, recovery of this community has been slow, as reflected by the lack of acroporid branching corals (*Acropora* spp.) and the dominance of available hard substrate by opportunistic massive coral species (*Cyphastrea microphthalma* and *Porites harrisoni*) and associated biota. Coral skeletal remains indicate a once flourishing *Acropora* dominated coral community in shallow water at depths of 2–3 m, transitioning to a more massive coral species dominated community comprising the genera *Porites* and *Platygyra* at depths of 3–5 m.

Coral removal

A total of 4,517 coral colonies was chosen for removal based on a general set of criteria, i.e., selected colonies must be 1) representative of the species and densities present within the pipeline corridors; 2) greater than or equal to 10 cm in diameter; 3) preferably mounding and boulder growth forms rather than encrusting forms; and 4) relatively healthy with no obvious disease, bleaching, or partial mortality. Selected colonies were removed by shearing the coral/substrate attachment point using a hammer and masonry cold chisel and lifting the colony off in one piece, to the extent possible. Each coral colony was carried by hand or in a bucket to a 2 m x 2 m metal transport tray, where it was cached *in situ* in a single layer until all corals were detached and ready for transport to the relocation site. Once all corals had been cached, the transport trays were prepared for recovery by attaching a buoyed lifting bridle and small meshed covering to each of the transport trays.

Coral transport

A 33.5-m landing craft was used to transport the corals a distance of 46 km from the removal area to the relocation area. Approximately 2,250 corals were transported per transit to the relocation area. To maintain corals in ambient temperature seawater and a dark environment during the day-long transport, a large (44-m^2) covered circulating seawater pool was constructed on the deck of the transport vessel (Fig. 2). A large crane was used to bring cached coral colonies to the surface in the transport trays and place them in the pool on board the transport vessel. The pool was covered during transit to the relocation area to prevent or reduce stress to the corals from overheating and excessive solar illumination. Once at the relocation area, the filled transport trays were removed from the pool and lowered to the seafloor with the large crane. Once the transport trays were stable on the seafloor, transport bridles and nets were removed by scientific divers. Global positioning system (GPS) coordinates were recorded for each on-bottom transport tray cache location.

Coral reattachment

Corals were reattached with specialized concrete at 22 sites within the reattachment area (Fig. 3). Prior to attaching corals, the attachment surfaces of both the coral and the selected receiver site were prepared by removing loose surficial debris and biota (i.e., algae and fouling organisms) to ensure proper bonding with the concrete. Manageable amounts of sand and cement were mixed in plastic buckets on the deck of support boats and then lowered to divers who placed sufficient amounts of concrete directly on the pre-cleaned substrate. The non-living base of the detached coral colony was then pressed firmly into the concrete mixture. Attached corals were checked periodically during reattachment operations to ensure their stability, address the aesthetic quality of the reattachment matrix, and dissipate cement residue that may have settled on adjacent living coral tissue and biota.

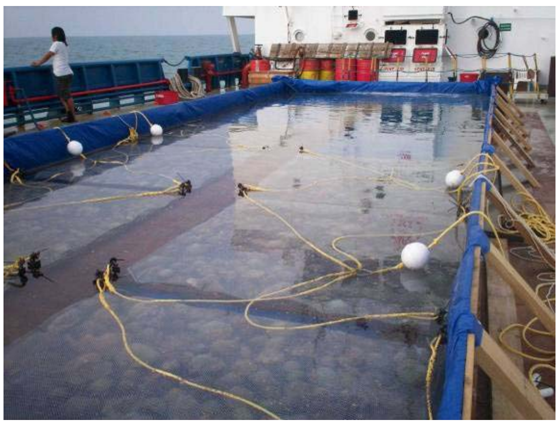

Figure 2: Loaded transport trays within the circulating seawater pool on the deck of the transport vessel.

Monitoring
Six of the 22 reattachment sites were randomly selected to bi-annually monitor the success of the coral relocation project and to assess and record detectable changes in the benthic community structure (Fig. 3). A subset of the relocated corals (approximately 5%) and natural (reference) corals were randomly selected, uniquely tagged, and mapped to monitor the relative coral health and success of the reattachment activities (Fig. 4). *In situ* observations of colony health and status of the cement bond as well as scaled digital photographs were collected for each monitored colony during all monitoring surveys. Four permanent 10-m transects were established at each of the monitoring sites to quantitatively document temporal changes in seafloor habitats and the associated benthic community. Temperature data loggers were installed to continually record seawater temperatures between monitoring surveys.

Results and Discussion
Hard coral colonies within the pipeline corridors generally were less than 30 cm in diameter with mounding or boulder morphologies that enabled the removal and reattachment of intact colonies. Relocated colonies ranged in diameter from 10 to 35 cm from seven species with mounding or boulder morphologies. Fragmentation of colonies was avoided because branching colonies were not encountered and the colonies were relatively small and manageable. Additionally, colonies were not fragmented as transplantation of large fragments or whole colonies has a greater likelihood of success compared to small fragments (<10 cm) (Plucer-Rosario and Randall 1987; Harriott and Fisk 1988; Edwards and Gomez 2007).

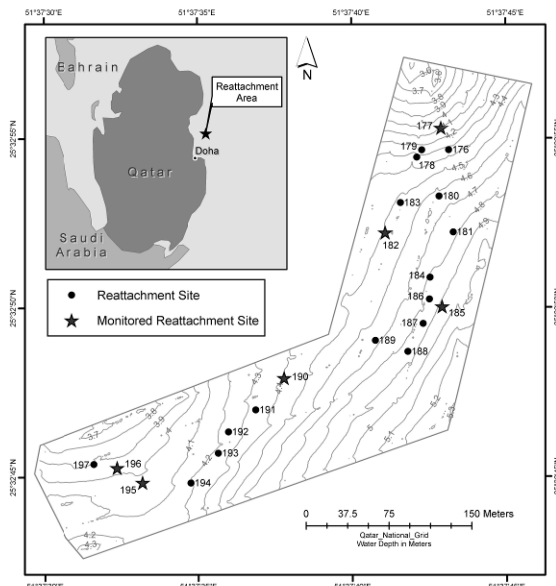

Figure 3: Coral reattachment and monitoring sites relative to the bathymetric contours at Fasht al Hurabi.

Figure 4: Monitored reattached colony of *Platygyra lamellina*.

Reattachment activities were completed in February 2007 with 4,548 colonies (4,517 transported colonies and 31 additional colonies found loose at the reattachment area) from seven species reattached at 22 sites at Fasht al Hurabi (Fig. 3).

The attachment status and relative health of 285 reattached colonies and 101 natural (reference) colonies was monitored bi-annually to assess the success of the relocation project (Table 1). After one year, 99% of the reattached monitored colonies survived compared to 79% survival of reference colonies, and a greater percentage of reattached colonies were healthy (58%) when compared to reference colonies (33%) (Fig. 4). The greater percentage of dead and unhealthy reference colonies compared to reattached colonies may be due to smothering from increased sedimentation observed during the 12-months post-reattachment survey since natural colonies are often located near the bases and sides of rocks. Coral colony health declined during the period between the 6-month and 12-month post-reattachment surveys. The decline was observed in both reattached and reference corals, which may be attributed to increased stress during the winter months due to extreme sustained low sea water temperatures documented by the on-site temperature data. Low temperature events and adverse effects on corals have previously been documented in the Arabian Gulf (Coles and Fadlallah 1991). Additional stressors experienced across the reattachment area during the month of February included increased sedimentation and a seasonal bloom of the brown alga *Colpomenia sinuosa* (Coles 1988).

Table 1: Summary of monitored coral colonies by species.

Scientific Name	Reattached	Reference
Anomastraea irregularis	10	1
Cyphastrea microphthalma	4	51
Favia sp.	123	8
Platygyra lamellina	46	12
Plesiastrea versipora	45	4
Porites harrisoni	55	18
Pseudosiderastrea tayami	2	7
Total	285	101

The benthic community was dominated by turf algae during the summer 2007 survey (6 months post-reattachment) and by *Colpomenia sinuosa* during the winter 2008 survey (12 months post-reattachment). Hard corals and other fauna (e.g., sponges and oysters) combined provided less than 12% cover during both surveys. Average hard coral density was low at all sites, ranging from 1.8 to 2.5 colonies/m^2, a slight decrease from 6 months post-reattachment (2.3 to 2.7 colonies/m^2).

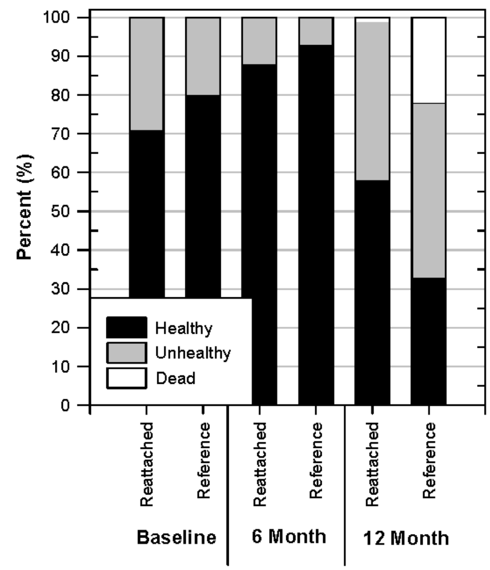

Figure 4: Comparison of the percent of healthy, unhealthy, and dead monitored colonies among monitoring surveys.

Seawater temperatures were similar at all of the monitoring sites, ranging from a high of 36.1°C in August 2007 to a low of 14.4°C in January and February 2008 (Fig. 5), representing a temperature range of 21.7°C. This range in water temperature is similar to the extreme temperature range previously documented on coral reefs in Qatar (Shinn, 1976) and is one of the greatest temperature ranges recorded on high latitude coral reefs. Minimum water temperatures fell below 18°C for 4 consecutive days in December (28 to 31 December 2007) and for 37 consecutive days beginning 7 January 2008 until 13 February 2008. During the latter extreme low water-temperature event, colonies were exposed to water temperatures below 16°C for 8 consecutive days in January (15 to 22) and again in February (1 to 8).

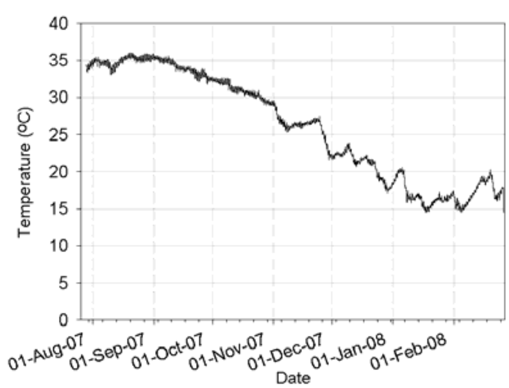

Figure 5: Continual seawater temperature data recorded from 27 July 2007 to 26 February 2008.

Conclusions

The results of this project indicate that hard coral relocation is a viable means of off-site mitigation for unavoidable impacts to sensitive coral habitats. After 1 year, 99% of monitored reattached colonies have survived. Although previous monitoring studies (Yap et al. 1992; Yap 2004) indicate that 1 year is an adequate period of time to evaluate the response of reattached corals to environmental conditions, biannual monitoring will be continued for at least two years following the transplantation to further assess the success of the relocation effort.

This successful project provides a benchmark for off-site mitigation that environmental regulators may utilize as a viable option for minimizing direct impacts to hard corals from offshore construction activities. Coral relocation in Qatar has been used as mitigation on another construction program based on the relative success of this project (CSA International Inc. 2008). Reattachment sites for future relocation activities should be carefully selected with similar environmental conditions (depth, temperature, salinity, turbidity, and benthic habitat type) to those at the removal site to increase the likelihood of coral survival. If possible, future relocation projects should consider conducting relocation activities during mean water temperatures to minimize stressful environmental conditions immediately after reattachment.

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