Restoration of oysters and associated habitats in the United Arab Emirates: Literature review & feasibility study

On behalf of the Blue Marine Foundation and DP World

Report Title	Restoration of oysters and associated habitats in the United Arab Emirates: Literature review & feasibility study
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With support from DP World and other partners, the model of oyster restoration developed in the Solent in the south coast of the United Kingdom has delivered impressive levels of regeneration of oysters. This restoration model has attracted attention from an international audience and has allowed BLUE to develop the following feasibility report for the Dubai region.

Our initial findings suggest that the potential for oyster restoration in the UAE is huge and the co-benefits in terms of water filtration, biodiversity regeneration, re-oxygenation of dangerously anoxic waters, increased fish populations, revival of cultural heritage, job creation and education are highly alluring.

The global pandemic forced us to put any in-person research on hold. However, we hope that with restrictions lifting, we can move onto the next stage of this project. Below, meanwhile, are the complete findings of our desk-based work.

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EXECUTIVE SUMMARY

The study, conducted by Blue Marine Foundation (BLUE), aimed to determine if restoration of any native pearl or true oyster species was feasible, and if a whole ecosystem approach, adding other associated and ecologically important habitats, would maximise the impact of oyster restoration and thus deliver a better ecological return on the investment.

Several oyster species of interest were identified. The most promising and culturally significant was the Gulf Pearl Oyster, a species that provided the initial economic boom that enabled the UAE to develop and prosper prior to the discovery of oil in the region.

There is a huge amount of potential for habitat restoration in the area, with oyster reefs, mangrove forests and seagrass beds all requiring some level of intervention to improve their status. Throughout the duration of this study a diverse range of stakeholders and organisations have expressed an interest and willingness to be involved in such a scheme. The opportunity to establish a restoration project with ecological and socio-economic benefits to the region should be taken, to revitalise not only the natural environment, but also the cultural heritage around oyster pearls and the history.

The models and mechanisms to allow this to happen are established for similar species in other areas around the world. Adopting and adapting them would capitalise on clear engagement and desire for this kind of activity in the UAE.

Longevity of restoration projects should be planned from the outset. This should involve the outreach and engagement with as many demographics as possible, with particular attention paid to younger generations who will ultimately determine the future of long-term projects.

BLUE is well positioned to take on such a project, be that direct management and operations, or advice and guidance. BLUE is experienced in and recognised for habitat restoration expertise, establishing marine protected areas, combating overfishing, conducting scientific monitoring, and for its work in education and outreach. This experience would be very relevant to the suggested course of action outlined in this report.

SUMMARY OF POTENTIAL CAUSES OF THE LOSS OF SPECIES, HABITAT AND INDUSTRY

The pearling industry provided the foundation upon which the UAE, in particular the cities of Dubai and Abu Dhabi, was built; and it once supported 95 per cent of the economy in the region, employing 4,500 boats and 74,000 workers. The success rate, for oysters that produced pearls, was extremely low within wild populations (< 1 in 10,000) and over-extraction ultimately put strain on the species harvested.

With much of the population relying on the marine environment for their income, many families moved to the coast, which inevitably led to development of coastal infrastructure to support the workers and other industries that began to thrive. As with almost all examples of large coastal expansions of human populations, construction removed vast areas of marine habitat, including that in which oysters would have been found. This dependence on vast expanses of coastal developments has caused dramatic reductions in the quantity and quality of coastal habitats that many species rely on.

Arguably one of the main drivers of the decline in the pearl industry, not necessarily the wild populations, was the discovery of oil in the 1930s. This valuable resource was a more reliable and consistent supply of income and fuelled the rapid development and expansion of the UAE.

The practice of diving for pearls also suffered due to the development of cultivation techniques, primarily in Japan, that resulted in vast improvements in yield for a dramatically reduced amount of time and effort.

1. INTRODUCTION

Blue Marine Foundation (BLUE) has been commissioned by DP World to conduct a study into the feasibility of restoring native habitats and species along the coast of the United Arab Emirates (UAE), with a focus on pearl and true oysters, using lessons learned from the Solent Oyster Restoration Project and other projects around the world. The area being investigated incorporates the Arabian (Persian) Gulf and the Gulf of Oman, but with a focus on the potential of restoration in Dubai, where DP World operates.

As we are in the United Nations decade on ecosystem restoration, there is a duty from all nations to increase efforts to prevent, halt and reverse the degradation of ecosystems worldwide. All life on Earth is dependent on a delicate balance between all systems, and the trend towards unbalance is going to have devastating effects for all inhabitants. Restoration, along with protection, is now, more than ever, a crucial activity that can help to restore the natural balance and connect people with nature to empower a sense of ownership to ensure the longevity of the environment.

Restoration work aligns directly with the UAE Government objectives and addresses a wide range of issues to present numerous benefits to people and nature: *"Environmental protection is considered the main objective of the UAE's developmental policies aimed at increasing green areas, developing water resources, improving marine environment and protecting it from pollution, preserving fisheries and livestock, and developing strategies to protect biodiversity."*

Oyster restoration alone provides numerous measurable benefits that are directly relatable to goals and objectives that can be easily reported and are understood by a range of audiences (Figure 1).

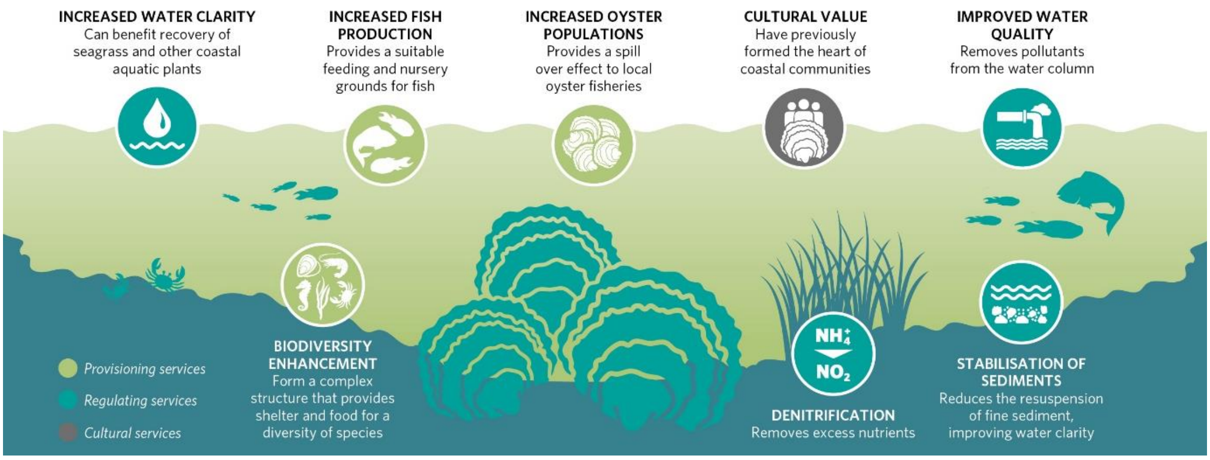


Figure 1. The ecosystem services that are provided by oysters. Source: adapted from Preston *et al. (*2021*)*.

1.1. THE ARABIAN (PERSIAN) GULF

The Arabian Gulf (also known as the Persian Gulf) is a semi-enclosed body of water in the western part of Asia that is surrounded by the UAE, Qatar, Bahrain, Saudi Arabia, Kuwait, Iraq, Iran and Oman, that joins the Gulf of Oman and Indian Ocean through the Strait of Hormuz (Figure 2). The intense heat, high salinity and low pH nature of this subtropical, hyper-arid area make it one of the harshest marine environments environmentally (Uddin *et al.* 2012), with conditions harsher in the northern and western parts compared to the eastern parts (Reynolds 1993). This is in part due to the influx of water occurring from the Indian Ocean in a counter-clockwise direction and the fact the average depth along the Arabia and Persian coastlines is only 35 and 60 m (Figure 3), respectively, with much of the coastline gradually sloping to that depth (Sheppard *et al.* 2010; Amante & Eakins 2009), with the Iranian coast being the only shoreline that slopes steeply in some areas (Sheppard *et al.* 2010). The combination of dry winds, extreme temperatures and slow flushing rates results in large quantities of evaporation (1-2m/year), thus high salinities (>39 psu in most areas, >70 psu in some cases). The only relief from the sedimentary flat seabed is provided by limestone domes or reefs, and the area supports a variety of habitats including mudflats, saltmarshes, seagrass meadows, coral reefs, mangrove forests, macro algae meadows and oyster reefs (Sheppard *et al.* 2010) that are vital to the survival of numerous marine species (John & George 2006; Medio 2006).

In addition to the abiotic factors that make the Gulf a harsh environment, the area is also one of the most developed coastlines globally, with an estimated 40 per cent having been impacted by anthropogenic influences even a decade ago (Halpern *et al.* 2008; Hamza & Munawar 2009).

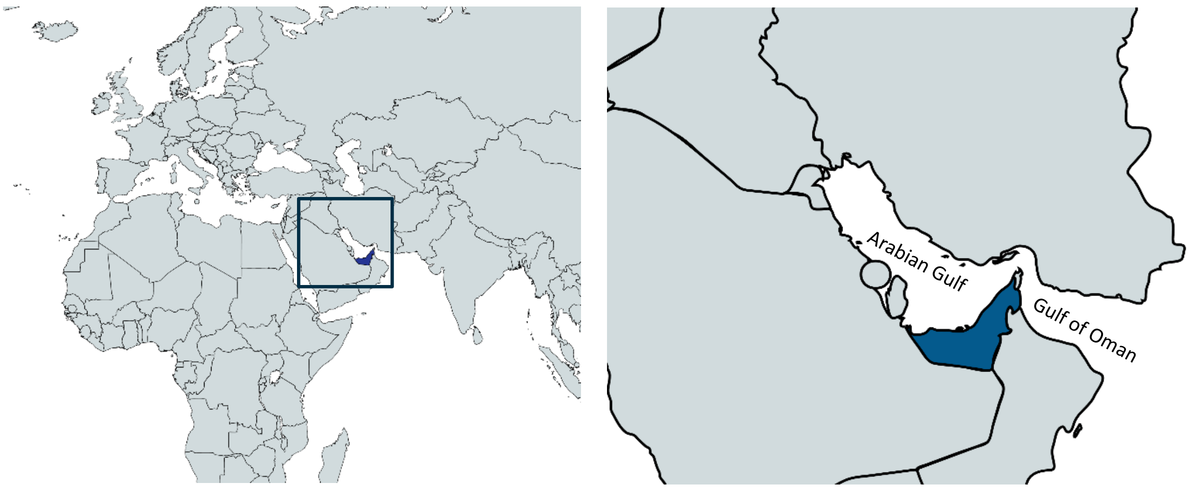


Figure 2. Location of the United Arab Emirates (Blue), the Arabian Gulf and the Gulf of Oman.

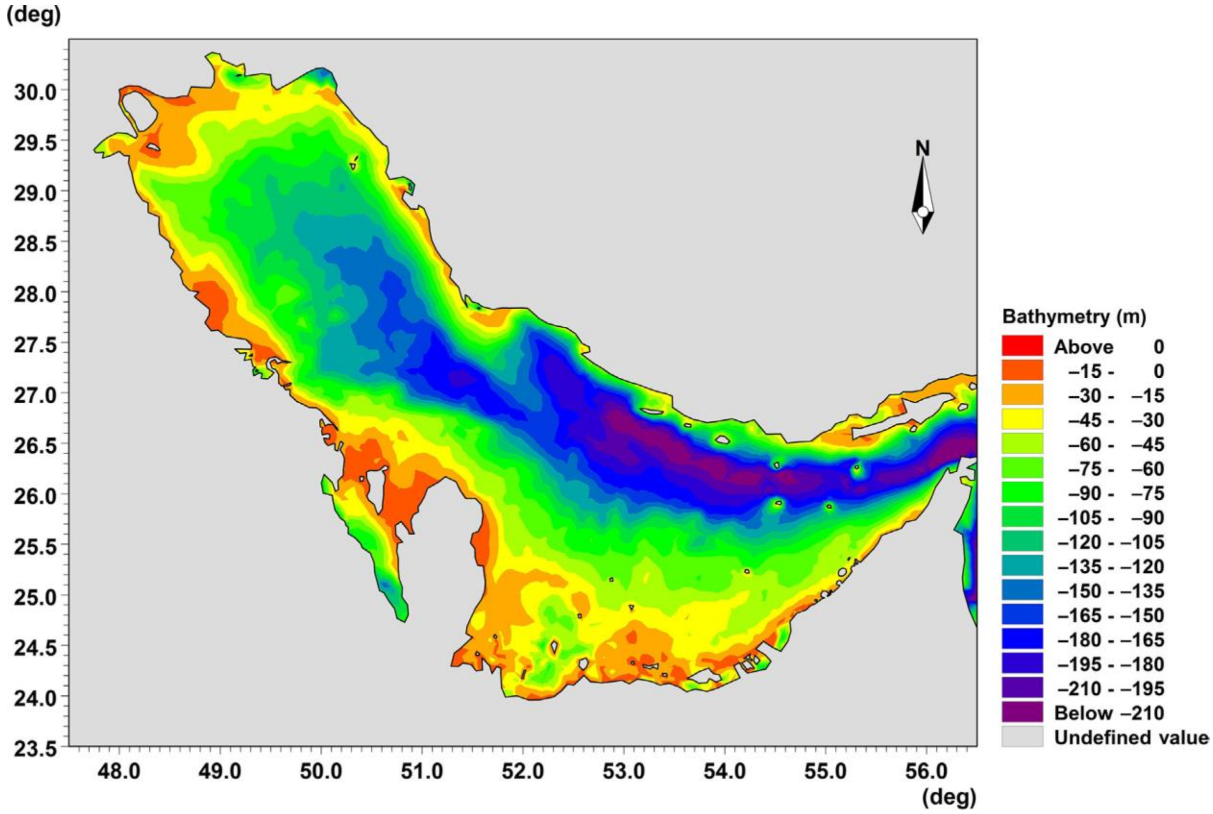


Figure 3. Bathymetric map of the Arabian Gulf. Source: Vaughan *et al.* (2019) modified from Amante & Eakins (2009).

The potential provided by restoration of the habitats present within the Gulf, and species within them, offers the opportunity to revitalise the association with the sea that many of the original inhabitants of the area would have relied upon so heavily.

The aim of this study was to provide a literature and stakeholder-based assessment of the decline of oysters and their associated habitats in the UAE and the potential for restorative work, with provision of recommendations for future activities and investment. As a result of this it was decided that three objectives be identified:

- To review the reasons for the decline in native oysters (true or pearl) in the UAE;
- To review potential options for restorative work to enhance the recovery of such populations and their associated habitats;
- To provide recommendations, based on the findings, for restorative work and investment.

As part of the stakeholder consultation the following individuals and/or groups were contacted during the study:

Person(s) Consulted, Affiliation	Discussion Type	Date of Discussion
Dr David Smyth, University of Bangor	In person and via email	19/02/2020
Mr Rashid Mohammed Said AlShihi, Ministry of Climate Change & Environment (MOCCAE)	Online video call	13/04/2020
Mr Ramie Murry, Dibba Bay Oysters	Online video call	15/04/2020
Prof. John Burt, New York University - Abu Dhabi	Online video call	15/04/2020
Mrs Sara Mohammed, Suwaidi Pearls	Online video call	23/04/2020
Mr Mohammed Mustafa Eltateb Mr Nestor Cordero Deatras Mr Jeruel Cabadonga Aguhob (All Dubai Municipality)	Online video call	11/05/2020
Mr. Hamad Ahmed Almansoori Mrs. Ayesha Hassan Alhammadi (Both Environment Agency - Abu Dhabi)	Online video call	22/06/2020
Dr Ian Hendy, University of Portsmouth	In person and via email	24/08/2020

This report has been produced as part of DP World's Sustainability and Ocean Enhancement initiative. Blue Marine Foundation's Restoration Science Officer and researcher Dr Luke Helmer was commissioned to conduct this feasibility report. This involved a desk-based study, an initial round of stakeholder engagement (for which he was joined by DP World Representative Mrs Anita Mehra), and field surveys.

On behalf of the Blue Marine Foundation and DP World, Dr Luke Helmer and Mrs Anita Mehra would like to take this opportunity to thank all those who kindly offered their support and expertise throughout the process.

2. NATIVE OYSTER SPECIES IN THE UAE

It is important to initially distinguish between oysters that are commonly known as true oysters and those commonly known as pearl oysters.

Pearl oysters are medium to large sized marine clams that are members of the Pteriidae family, which are not closely related to true oysters, of the family Ostreidae (Table 1). Despite some morphological similarities, there are distinct differences that set them apart. One of the most notable is the ability of Pteriidae to attach to various substrates using byssus threads, whereas members of the Ostreidae secrete a biological cement that permanently attaches to the substrate. If broken away they cannot re-secrete this cement.

Table 1. Scientific classification of pearl oysters and true oysters and their distinction.

Scientific classification	Pearl oysters	True oysters
Kingdom	Animalia	Animalia
Phylum	Mollusca	Mollusca
Class	Bivalvia	Bivalvia
Order	Pteriida	Ostreida
Family	Pteriidae	Ostreidae
Genus(') of interest	*Pinctada, Pteria*	*Saccostrea*, *Crassostrea*, *Ostrea*

Regardless of any differences between the two families of bivalve mollusc species present and of interest, they are both considered for restoration potential within this report. Recently mapping of marine molluscs within the UAE, conducted by Grizzel *et al.* (2018), has indicated areas where both pearl and true oyster populations are present (Figure 4). To the author's knowledge this is the most up to date, publicly available, documentation of oyster species in the region, and highlights the fact that conditions still allow for their survival. However, limited quantitative information is available with simple presence/absence and common/sparse data providing a foundation, upon which further evidence could be gathered to determine suitable locations for either the collection of adults or larvae to be used as broodstock, or restorative work in general.

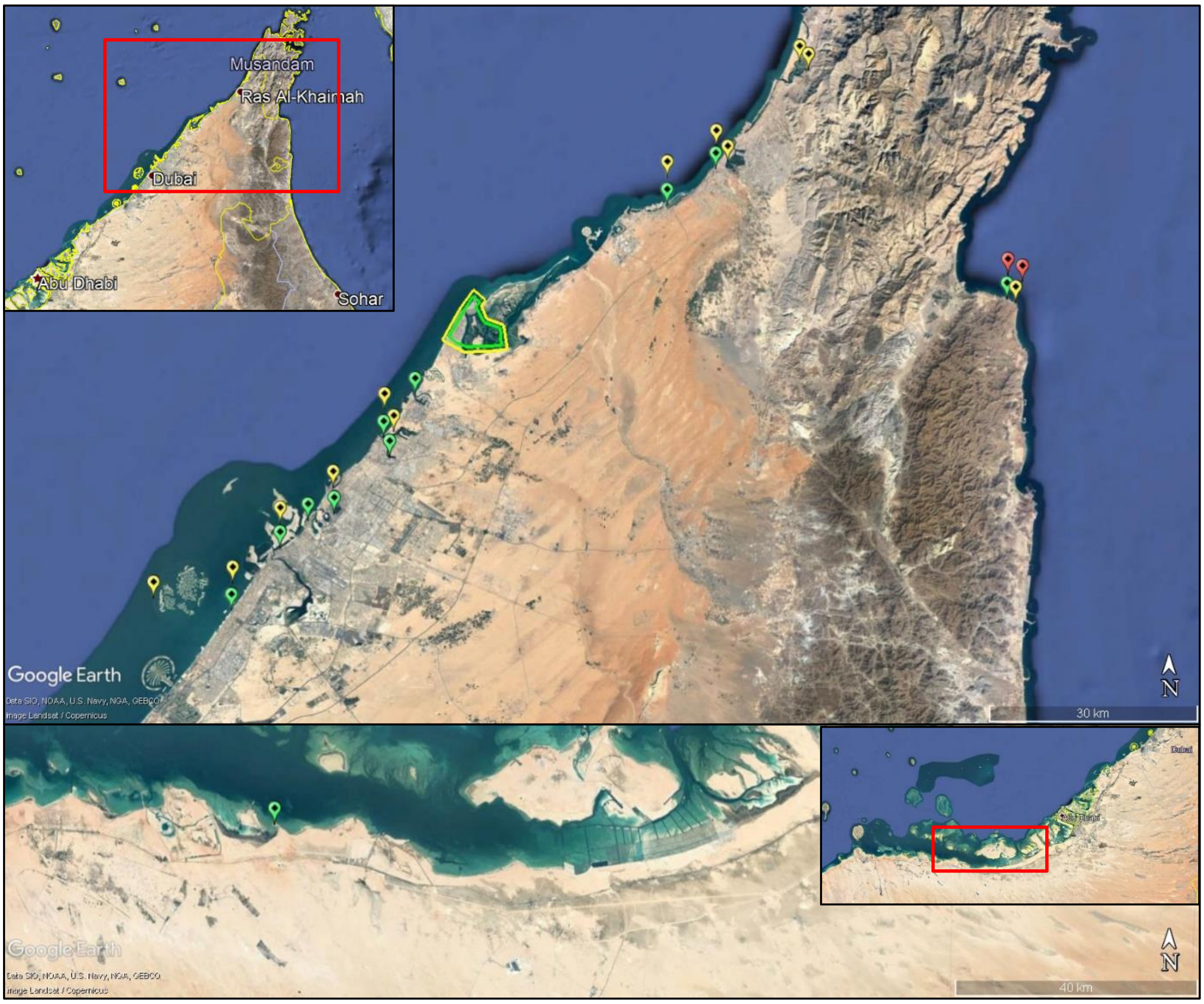


Figure 4. Current distribution of *Saccostrea cucullata* (yellow), *Pinctada radiata* (green) and *Pinctada margaritifera* (red) in the United Arab Emirates. Modified from Grizzle *et al.* (2018). Image created using Google Earth Pro.

2.1. PEARL OYSTERS IN THE UAE

Pearl oysters fall within the genera *Pinctada* (Roding 1798) and *Pteria* (Scopoli 1777) and are characterised by a compressed and ovate shell that has a straight hinge line, as well as their recognisable inner shell layer that is iridescent and known as “mother of pearl”. This thick layer is formed from nacre, a continuous parallel lamina composed by a hexagonal arrangement of aragonite platelets that are 0.5 µm thick (Nudelman *et al.* 2006). The nacre is deposited throughout the life of the oyster, acting as a barrier to parasites and debris that may otherwise be detrimental to the individual. The process that leads to pearl formation is known as encystation, occurring when a foreign object becomes entombed after entering the individual. Consecutive layering then takes place and results in the formation of either a blister, which remains part of the inner shell, or, more recognisably, a free pearl within the soft mantle tissue (Figure 5). The process of pearl formation incurs surprisingly low energetic costs, < 1 per cent of total energy expenditure (Le Moullac *et al.* 2018). It is a common misconception that all oyster species produce pearls, but it is an extremely rare occurrence within true oysters.

Figure 5. The process of encystation, entombing a fish within a pearl oyster (left), natural formation of a blister pearl in *Pinctada margaritifera* (centre) and anatomy of *P. margaritifera* where natural formation of a free pearl would take place in the pearl sac (PS) (right). Source: (left) Kita Williams, taken at the Natural History Museum, London, (centre) Wikipedia - shell on display at the Muséum de Toulouse & (right) Le Moullac *et al.* (2018).

Two species of *Pinctada* pearl oyster occur naturally within the Arabian Gulf, the Gulf or Rayed pearl oyster *Pinctada imbricata radiata* and the Black-lip pearl oyster *Pinctada margaritifera* (Figure 6). One species of *Pteria* pearl oyster, the penguin’s wing pearl oyster *Pteria penguin* (formerly *P. macroptera*) is also present in the region (Figure 7) and can be distinguished by its elongated hinge-line that extends posteriorly from the dorsal end of the shell (Lamprell & Healy 1998) (Figure 8). For the purposes of restoration, this report will focus on *Pinctada* species.

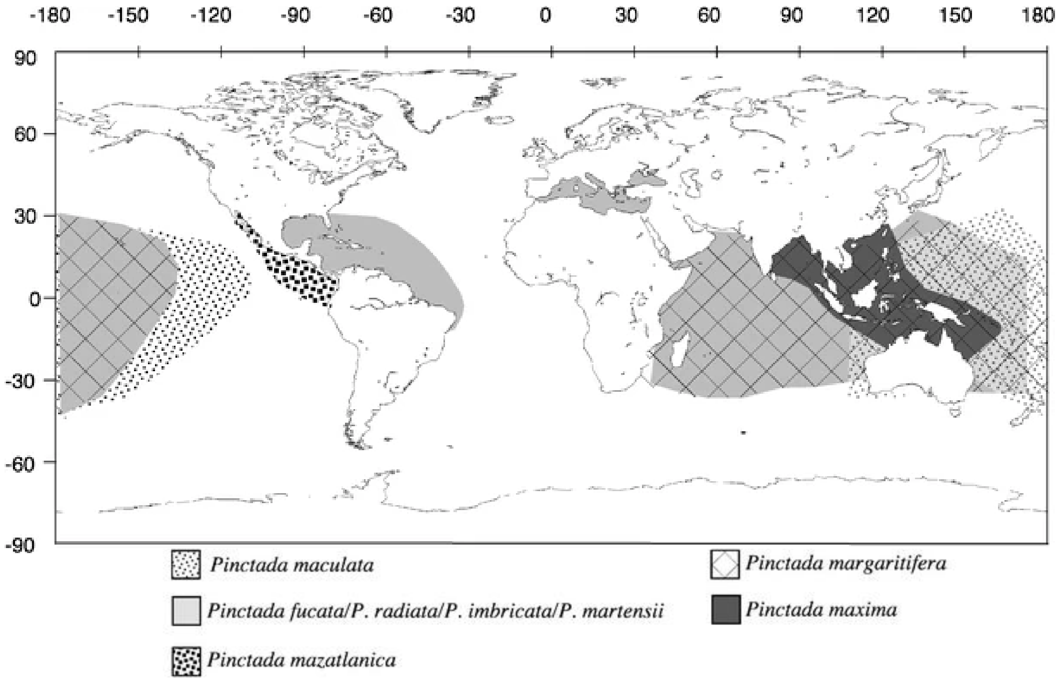


Figure 6. Approximate global distribution of some of the 19 species within the genus *Pinctada*. Source: Cunha *et al.* (2011).

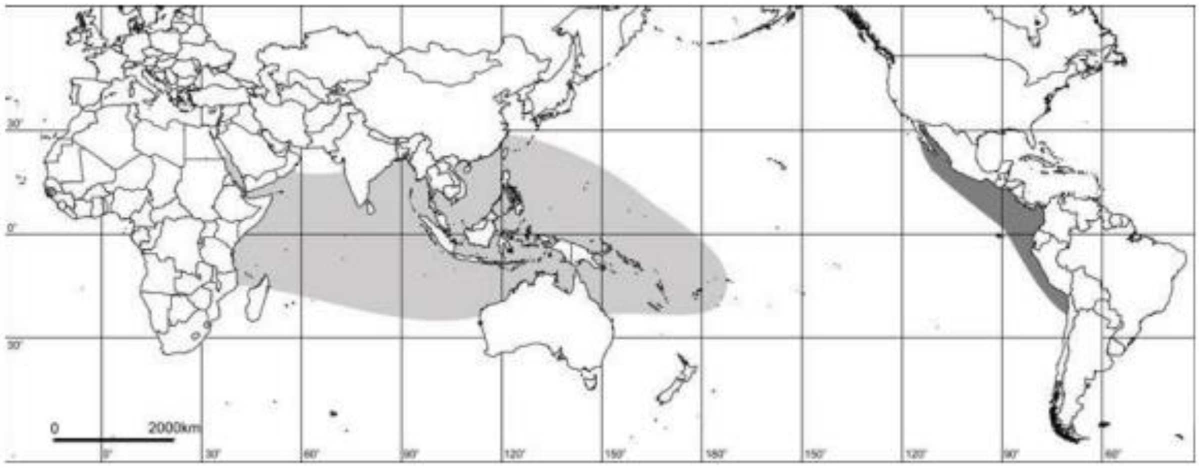


Figure 7. Approximate global distribution of *Pteria penguin* (light-grey) and *Pteria sterna* (dark grey). Source: Wada & Temkin (2008).

Figure 8. The penguin wing pearl oyster *Pteria penguin* on a coral reef in Aqaba, Jordan (left) and Fujairah, United Arab Emirates (right). Source: Roger Blum.

2.1.1. GULF PEARL OYSTER *Pinctada imbricata radiata*

The smaller of the two *Pinctada* species present in the region, mature *Pinctada imbricata radiata* reach an average size of 50 - 65 mm in length with occasional occurrences of growth to over 100 mm. Smaller (35 - 40 mm) individuals have been observed inhabiting coastal waters where hypersaline conditions of 50-60 ppt prevail (Al Sayed *et al.* 1997). Typically, this species is found lying loosely on the sand or attached to rocks, debris and dead coral at a depth of 5 - 25 m. In soft sandy seabed environments, and under the right conditions, the gregarious settlement behaviour of *P. i. radiata* whereby they aggregate together, can lead to high-density reef formations. Individuals attach themselves to suitable substrate by secreting byssus treads from their byssal glands (Figure 9) and unlike many species this can continue throughout the lifetime of *P. i. radiata* (Wada & Temkin 2008) and along with detachment and re-secretion, can be used for short movements (Giraldes *et al.* 2019).

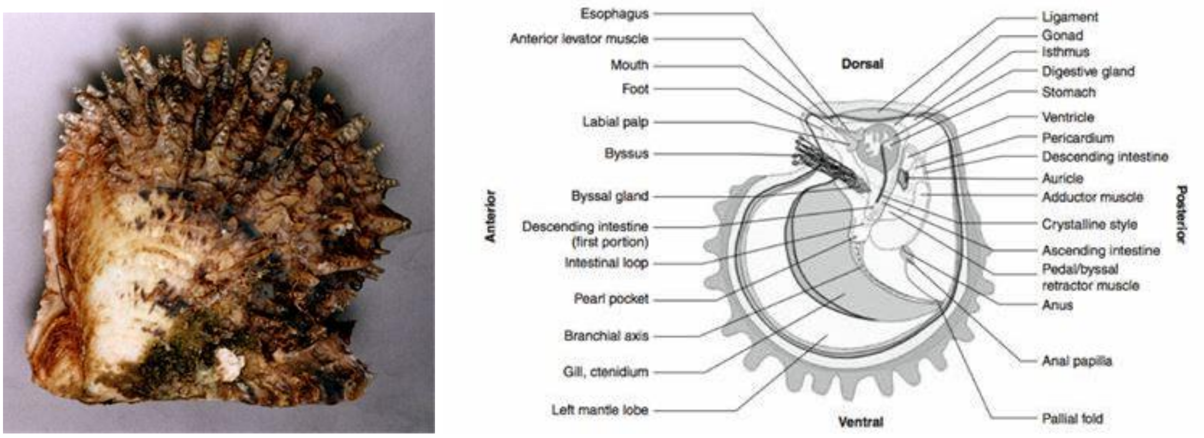


Figure 9. *Pinctada imbricata radiata* external shell morphology (left). General internal anatomy of species within the genus *Pinctada* (right). Source: ©Stratos Xentidis (left), Anatomy Note 2019 (right).

The species is native to waters stretching from the Arabian Gulf to the Indian Ocean and Red Sea (Figure 6 (Cunha *et al.* 2011)) and is believed to be the first lessepsian bivalve species to have been reported in the Mediterranean Sea, including coastal areas of Tunisia (Tlig-Zouari *et al.* 2009), Croatia (Doğan & Nerlović 2008) and Montenegro (Petovic & Macic 2017), having travelled through the Suez Canal. Intentional importations for mariculture purposes also took place in many areas of Greece and Italy during the last century (Katsanevakis *et al.* 2008). This success across such an extensive non-native range has led to its inclusion within the top 100 list of worst invasive species (Streftaris & Zenetos, 2006). Of the pearl oyster species present in the Gulf, *P. radiata* is the most abundant, for example, in Qatari waters *P. i. radiata* makes up 95 per cent of the population and the other 5 per cent is a combination of *P. margaritifera* and *Pteria marmorata* (Al-Khayat & Al-Ansi 2008).

2.1.2. BLACK-LIP PEARL OYSTER *Pinctada margaritifera*

The external shell of *P. margaritifera*, the larger of the two species in the region, is often dark in colour with brown, grey or green tints and the species is distinguished by its lack of teeth on the hinge (umbo) (Figure 10). Whilst filter feeding, the distinctive black colouration which runs along the mantle and which species its common name, can be seen. Reaching a size of 200 - 250 mm in its natural environment, *P. margaritifera* is typically found on or near the seabed, attached to rocks or coral debris and in seagrass meadows at depths of 0 - 40 m. Often associated with less turbid environments where coral reefs and reef lagoons are prominent, *P. margaritifera* has a wide range of salinity tolerance but spat growth is optimal between 19 - 37 psu (Libini *et al.* 2018). Although the species is present in the Gulf of Oman (Grizzle *et al.* 2018), populations are more prominent in Indo-Pacific regions (Le Pennec *et al.* 2010; Southgate & Lucas 2011) (Figure 6). Exploitation of *P. margaritifera* occurs across this natural range, with the French Polynesian industry generating €90 million in annual turnover from natural stocks (Chávez-Villalba *et al.* 2011).

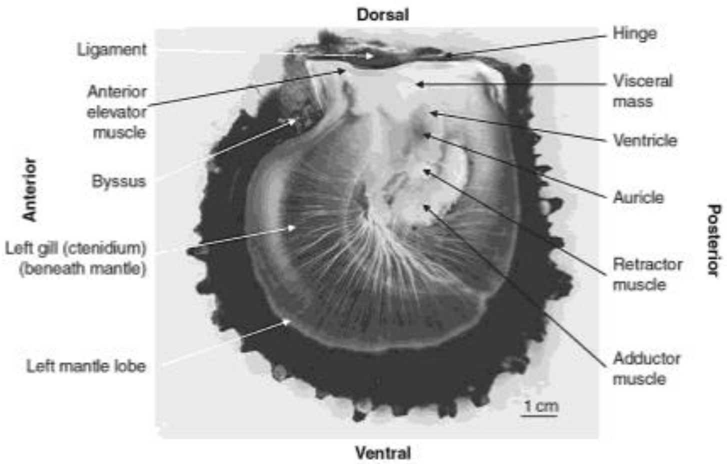


Figure 10. Anatomy of *Pinctada margaritifera*. Source: Southgate & Lucas (2011).

As protandrous hermaphrodites, individuals develop as males until they reach two years of age and gradually change to females. The sex ratio evens out to approximately 1:1 in populations over eight years of age (Tranter 1958; Chávez-Villalba *et al.* 2011). During the initial two years sex does not appear to change, but after this period genetic and environmental (including water temperature, food availability, population density and pollution) factors can influence gender (Adzigbli *et al.* 2019).

2.1.3. HISTORY AND CULTURAL HERITAGE OF THE PEARL INDUSTRY

Prior to the discovery of rich oil supplies, the whole region around the Arabian Gulf relied almost entirely upon income from the pearl diving industry (Bowen 1951). Pearl banks once stretched along the coast from Ras Al-Mishab in Saudi Arabia to Ras Al- Khaimah in the UAE (Figure 11). One of the earliest records of pearls in the Gulf dates to 2000 B.C. and a cuneiform tablet found at Ur of the Chaldees contains an inscription translated to "*a parcel of fish-eyes*" believed to be a reference to pearls from Bahrein (Bowen 1951). Records of harvesting, for both food and pearls, has been dated to 1050 CE (Carter 2005) with the most intense harvesting occurring between the late 1700s and early 1900s (Bowen 1951).

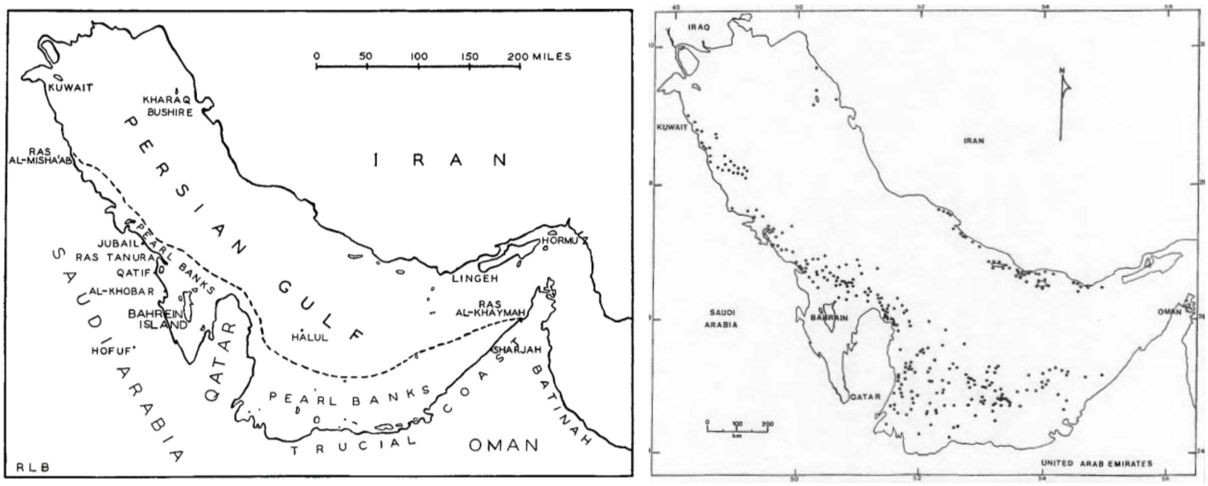


Figure 11. Historic pearl fishery locations in the Arabian (Persian) Gulf from Bowen (1951) (left) and Lorimer (1915) (right)

In relatively recent times, it is estimated that 80 per cent of the world's natural pearls were sourced from the Arabian Gulf (Almatar *et al.* 1993a) and that pearl fishing in the area supported in the region of 4,500 boats and 74,000 workers. The economic valuation of the industry is not easily estimated with such vast numbers of ports, vessels and workers, but some of the earliest figures available are summarised in Table 2. There are numerous factors that govern the value of pearls, and these are often influenced by environmental factors such as depth, temperature and light (Ikenoue & Kafuku 1983). It is argued that lustre is the most important trait, but in general, first grade pearls require a perfect exterior lacking specks or defects, with a cream or translucent pink colouration and iridescent lustre. Spherical pearls that are symmetrical are desired over those that are oval or flat, and the size of the pearl is important but only when combined with the other desirable factors.

Table 2. The estimate value of the pearl industry in the Arabian Gulf. Valuation for GBP in 2019 was calculated using the Bank of England online Inflation calculator with inflation increase of 2.6 per cent per year. Valuation for USD in 2019 was calculated using the Bureau of Labor Statistics website. *Cox (1946) states that these values calculated are likely to be ten times greater but does not clarify the reasoning.

Year	Value in year	Value in 2019	Reference(s)
1833	£300,000	£35,977,894	Wilson (1833) Lorimer (1915)
1835	£400,000	£51,204,494	Wellsted (1838)
1866	£400,000	£47,970,526	Lorimer (1915)
1896 (Bahrein only)	£303,941	£40,738,821	Zwemer (1900)
1903/04 (mother of pearl only)	£30,439	£3,728,941	Lorimer (1915)
1905/06	£1,434,399	£175,721,589	Lorimer (1915)
1925 (Bahrain only)	£220,000	£13,475,591	Cox (1946)*
1925 (Lingeh, Iran only)	£9,000	£551,274	Cox (1946)*
1926 (Bahrain only)	£192,000	£11,824,086	Cox (1946)*
1926 (Kuwait only)	£11,000	£677,422	Cox (1946)*
1926 (Lingeh, Iran only)	£5,200	£320,236	Cox (1946)*
1949 (Bahrain only)	$200,000	$2,148,382	Kruegar (1949)

The industry, also known as the Ghaus (literally translating to “diving”), was structured with two main classes, the Musaqqams and Ghawawis or Financiers and Operatives (Lorimer 1915). Typically, the operatives consisted of a total crew of about 10 to 40 men, with 16 being the typical crew size across the whole Gulf, the ranks and roles of which are detailed in Table 3.

Table 3. The pearl industry structure with traditional names, English translations and their roles.

Class	Translation	Role
Musaqqams (Plural Musaqqamin)	Financier	Generally, a person of substance or wealth who was involved with financing the operations and crew of pearl vessels.
Ghawãwïs (Singular Ghawwãs)	Operatives	Any class involved with active operation.
Nãkhuda (Plural Nawãkhidah)	Captain	Often the owner of the vessel, this person was in full authority and all responsibilities were vested in him.
Ghäsah (Singular Ghais)	Divers	Diving for pearls, often poor Arabs, free or slaves.
Siyűb (Singular Saib)	Haulers	Manage the boat, lower and raise the divers. Often landsmen or ex-divers who were too old to dive.
Extra Siyub: Jalalis (Singular Jallas)	Sitters	Not to be confused with the Radhafah, these extra persons were cheaper to employ to replace a Ghasah that was unavailable.
Radhafah (Singular Radhïf)	Extra hands	Assist the haulers.
Walaid (Plural Aulãd)	Apprentice	Catch fish, cook, prepare coffee, maintain pipes and other small tasks.

There were two seasons during which diving operations were conducted, a colder season or Ghaus-al-Bard and a warmer principal season or Ghaus-al-Kabir which translates to “Great Diving”. The former took place in the shallower waters during mid-April for 40 days and divers would work shifts that lasted only half an hour due to the low temperature of the water. The latter took place between June and September. The start of the season was known as Rakbah and the season end as Quffal. Due to events such as Ramadhan, the timings of the season were not fixed and often varied slightly.

Vast areas of the Gulf provided suitable habitat for oysters (Figure 11). Many of the fishers operated without the use of compasses or charts and were extremely skilled at finding their desired location with the use of the sun, stars, land bearings, the colour or depth of the sea and the nature of the seabed. Divers would work every day during favourable conditions, beginning an hour after sunrise and finishing an hour before sunset. The previous day's catch was opened, using a knife called a Mufaliq (singular Mufliqah), in the period between early morning prayer and the first dive of the day. The Nakhuda would oversee the operation and record the weight and description of the pearls. The majority of the shell material, along with juveniles, was returned to the seabed.

The process of diving was relentless, with only a small meal, some dates and a few cups of coffee being all that a Ghais would consume before entering the water. In preparation, the Ghais would remove his clothes, place a Fatam (horn pincers) on his nose, place cottonwool or beeswax in his ears, put on Khabat (leather finger protectors) and attach a Diyin (small bag) to his waist or around his neck (Figure 12). To descend, the Ghais would place a foot into a noose that was attached to a weighted rope or Zaibal (plural Ziyabil) that was lowered to the seabed. A second rope or Ida (plural Ayadi) was fixed to the girdle and used to pull him to the surface when he tugged or jerked it. Each dive or Tabbah (plural Tabbat) would last between 40 and 75 seconds and could often yield between three and 20 oysters, with up to 50 Tabbat a day.

Work would not cease until Dhuhr at about 13:30 - 14:00, when they would stop for an hour's break to pray and have a few cups of coffee before returning to work until the evening. After evening prayers or Maghrib the Ghais would have a larger meal of meat or fish, rice and dates along with some coffee before resting for the night.

Figure 12. Traditional pearl diver in Qatar. Source: www.qatarmarine.net

In addition to the operations at sea there was also a foreshore season that occurred in winter called the Mujannah. Those involved would wade out into the shallows during low tides to collect the oysters, whose pearls were often small and discoloured compared to those collected by diving.

2.2. TRUE OYSTERS IN THE UAE

2.2.1. ROCK OR HOODED OYSTER *Saccostrea cucullata*

The rock or hooded oyster *Saccostrea cucullata* (Born, 1778) is the only native species of 'true oyster' within the family Ostreidae that is of interest in the UAE region. Inhabiting coastal environments predominantly between 0 and 15 metres on hard structures, such as rocky habitats, harbour walls and the rhizomes (root structures) of mangroves (Tack *et al.* 1992) (Figure 13) *S. cucullata* has a high temperature tolerance (up to 43˚C) (Davenport & Wong 1992) and is found across a wide range of temperature and salinity regimes. Harvesting, by artisanal fisheries, occurs across this geographic range (Davenport & Wong 1992), as does cultivation in aquaculture facilities (Nell 2001).

The natural distribution of *S. cucullata* extends from Indo-Pacific regions to the Eastern Atlantic, including areas within the Arabian Gulf and Gulf of Oman. The species has also been introduced into the Mediterranean. Grizzel *et al.* (2018) documented numerous locations around the UAE including Dubai, where *S. cucullata* was present and common (4.2 ± 0.97 oysters / m^2 in Dubai and 29.4 ±2.77 oysters / m^2 in Umm Al Quwain) with numbers declining further south west along the coast. Densities of 500 oysters / m^2 with 100 per cent coverage were recorded on rock jetties at Umm Al Quwain. In Oman, *S. cucullata* is the most abundant bivalve and is present along the entire coastline of the country (Yesudhason *et al.* 2013).

Generally, the exterior shell is purple and brown, but these oysters are variable in their morphology (shape and size). For example, in the Mediterranean they are often 40 - 60 mm in shell height, whereas in the Pacific they are found growing up to 130 mm in shell height. The lifespan of this species is dependent on environmental conditions, predominantly water quality, with individuals living between 14 and16 years on Ascension Island and up to 26 years of age in South Africa and Ascension Island (Dye 1990; Arkhipkin *et al.* 2017). In comparison, populations in Southern Asia that experience poor water quality, pollution and eutrophication live only between 2 and 4 years (Morton 1990; Chiu 1997).

Reproductive activities in the Northern Hemisphere occur from June to October and the larvae display gregarious behaviours, whereby they show preference for settlement in areas occupied by adult members of the same species, or actually on those adults present. A recent study indicated that *S. cucullata* was one of the dominant species found on floating marine debris along the Iranian coast, and this may be one mechanism for transporint populations around the Gulf (Shabani *et al.* 2019).

Figure 13. *Saccostrea cucullata* - *Images to be updated for the final report with those collected on site.

As a filter feeding organism *S. cucullata* predominantly feed on phytoplankton and suspended organic material, often accumulating heavy metals in polluted areas. This provides an indication of pollution levels, known as bioindicator (Amoozadeh *et al.* 2013). Existing research in the Arabian Gulf indicates that the oysters selectively remove these metals and can therefore act as biofilters as a pollution control measure (Azarbad *et al.* 2009).

Most of the published literature for the region has focused on *S. cucullata* populations in the northern areas of the Gulf, along the coast of Iran, with few studies focusing on populations in the UAE (Akkah Beach and Abu Dhabi (de Mora *et al.* 2004). There has been a strong focus on heavy metal contamination within *S. cucullata* research and its implications for human health and potential exposure through consumption (Chaharlang *et al.* 2012; Mirza *et al.* 2012; Shirneshan *et al.* 2013).

2.3. SOCIAL, ECOLOGICAL AND ENVIRONMENTAL IMPORTANCE OF OYSTERS IN THE UAE

As with many locations around the world, evidence of oyster consumption by early human populations can be seen in the Gulf region in the form of shell middens. A shell midden occurs as a result of historic anthropogenic activity such as hunting, gathering and food processing and is defined as a mound of debris, primarily mollusc shells. Parker & Goudie (2007) discovered evidence of *S. cucullata* middens in the Rub' al-Khali desert dating back to the Holocene era (4,555 ±70 years old), indicating that consumption of oysters occurred during the Bronze Age.

Due to the geological nature of the Gulf and the combination of high sea-surface temperatures, low wind speeds, intense light and increased levels of nutrient input, harmful algal blooms (HABs) pose a substantial threat to marine life and human populations (Al-Arajay 2001). Several neurotoxical algae have been reported in the Arabian Gulf, including *Gymnodinium catenatum*, *Pyrodinium bahamense var. compressum*, and known producers of paralytic shellfish toxins (PSTs), *Karenia mikimotoi* and *Dinophysis caudata* (reviewed by Anderson, Grizzle and Bricelj 2011; Grizzle *et al.* 2018).

As suspension feeders, with a diet that consists of phytoplankton and suspended organic material, oysters have the potential to reduce the frequency and intensity of these algal blooms when present in significant numbers. *Saccostrea cucullata* has been shown to be highly efficient at removing nutrients and chlorophyll-a in coastal waters that become eutrophic due to shrimp (*Litopenaeus vannamei*) farming practices. In addition, *S. cucullata* was more efficient than when it was also present in combination with the striped barnacle *Amphibalanus amphitrite*, another filter feeding species present in the Gulf (Kohan *et al.* 2019; Shabani *et al.* 2019). In addition, both pearl and true oysters play an important role in sediment processing and nutrient cycling through their water filtration capacity. Culture of pearl oysters in French Polynesia highlighted that particulate sedimentation rates beneath oysters were in the region of five times greater than control locations (Gaertner-Mazouni *et al.* 2012). But pearl oyster culture also has the potential to stimulate phytoplankton growth (primary productivity) through rapid recycling of inorganic nutrients (Lacoste & Gaertner-Mazouni 2016). This can be a problem in some areas of the Gulf, highlighted by Sheppard *et al.* (2010) (Figure 14).

The three-dimensional structures that bivalves can form provide refuge and a food source to a diverse array of other species. This is the case for *Pinctada* species with Al-Khayat & Al-Maslamani (2001) and Al-Khayat & Al-Ansi (2008) describing between 111 and 189 benthic faunal species at 18 locations in Qatar. The assemblages of species has been shown to be influenced by proximity to anthropogenic activities in natural systems (Smyth *et al.* 2016).

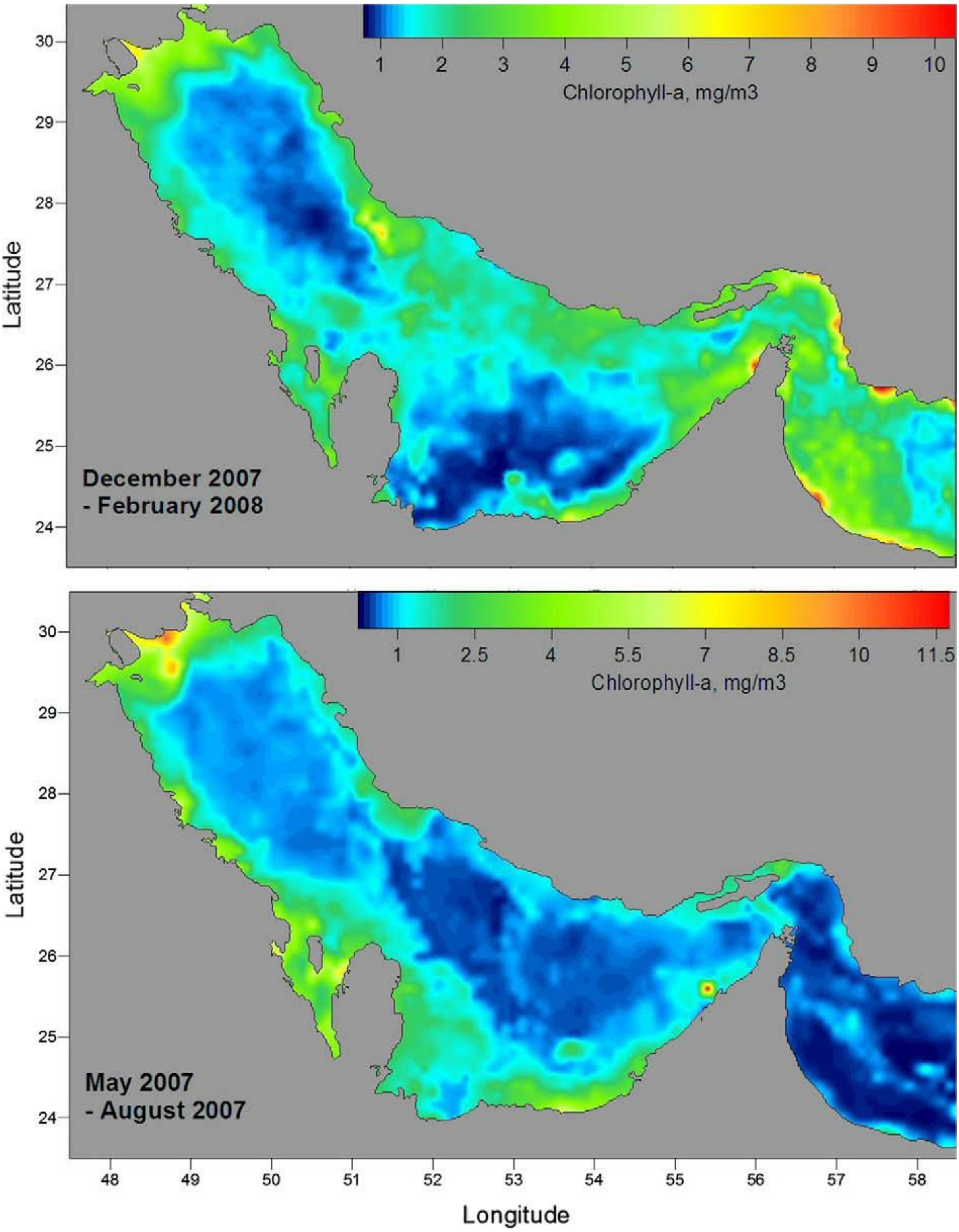


Figure 14. Seasonal surface chlorophyll concentrations in the Arabian Gulf. Source: Sheppard *et al.* (2010).

3. MANGROVE HABITAT IN THE UAE

Mangrove habitat offers numerous ecosystem services by acting as fish nurseries, improving coastal water quality, enhancing fisheries, sequestering carbon and providing shoreline protection, shellfish habitat, timber, and cultural and recreational activities (Brander *et al.* 2012; Vo *et al.* 2012; Himes-Cornell *et al.* 2018). In the UAE, mangrove trees are known as "Qurm" and they were once an integral part of the cultural heritage of the area, particularly due to their rot- and termite-resistant properties that made them ideal for boat building.

Occurring across a wide geographic range (Figure 15), the Grey or White mangrove *Avicennia marina* (Figure 16) is the dominant vegetative species that is native to coastal areas around the Arabian Gulf and grows as a shrub or tree that is typically three to five metres tall (Moore *et al.* 2015). Thriving in high-salinity environments, optimal growth occurs between 0 and 30 ppt (parts per thousand), resulting in distribution in intertidal areas along coastal areas (Robertson & Alongi 1992). The species is fast growing and hardy but, as highlighted by International Union for Conservation of Nature (IUCN), is threatened by coastal development and its associated extraction (Duke *et al.* 2010). Although the IUCN status requires updating, the species has been reported to have suffered a 21 per cent decline in total area between 1980 and 2008 and 74 per cent along the UAE coastline (Howari *et al.* 2009). Mapping work of the entire UAE area by Moore *et al.* (2013) provides an in-depth and recent overview of the current state of *A. marina*, estimated to cover approximately 13,615 ha (three times the area previously reported, due to inaccuracies with patchy low-density populations) (Figure 17). A second species is also present in the Gulf, *Rhizophora mucronata* which is found within the Strait of Hormuz (Danehkar & Jalali 2005) but as this species is not present in the UAE it will not be covered in this report.

The mangroves of the UAE support a vast array of species including populations of Greater Flamingo (*Phoenicopterus roseus*), Western Reef Heron (*Egretta gularis*), Kalba Collared Kingfisher (*Todiramphus chloris kalbaensis*), Mottled Crab (*Metopograpsus messor*), Greater Spotted Eagle (*Clanga clanga*), White Spotted Grouper (*Epinephelus coeruleopunctatus*), Hooded Oyster (*Saccostrea cucullata*) and Green Turtles (*Chelonia mydas*) (Saenger *et al.* 2002; Boere *et al.* 2006 in Shah *et al.* 2018).

Figure 15. Distribution (orange) of the Grey Mangrove *Avicennia marina* in 2008. Source: ICUN (Duke *et al.* 2010).

Figure 16. Grey mangrove *Avicennia marina* regeneration after ten months on restored floodplains in Sóc Trăng Province (Mekong Delta, Vietnam). Source: Schmitt & Duke (2015).

Figure 17. Total mangrove area estimates for the United Arab Emirates (13, 616 ha) during the period of 2011-13, spread across (a) Abu Dhabi (10,834 ha), (b) Ajman (158 ha), (c) Dubai (63 ha), (d) Ras Al Khaimah (480 ha), (e) Sharjah (204 ha) including (f) Sharjah (Khor Kalba) and (g) Umm Al Quwain (1,877 ha). Source: Moore *et al.* (2013).

4. SEAGRASS HABITAT IN THE UAE

Seagrass meadows are an extremely important ecosystem globally, providing food, habitat and nursery functions for numerous marine species, as well as providing cultural, wellbeing and socio-economic benefits for local human populations.

Seagrasses in the Arabian Gulf are also an invaluable resource for one of the last remaining strongholds for the venerable Dugong (*Dugong dugon*) and support the world’s second largest population (Sheppard *et al.* 2010). They also provide vital habitat for endangered green turtles (*Chelonia mydas*) and support in the region of 530 to 835 species in total (Basson *et al.* 1977; Coles & McCain 1990), including *P. i. radiata* (especially juveniles), with approximately nine per cent of the Gulf’s species believed to be endemic to these meadows, (Basson *et al.* 1977; Sheppard *et al.* 2010).

Due to the extreme environmental conditions in the Gulf, only three of the fifty-plus seagrass species occur naturally in the region (*Halodule uninervis*, *Halophila ovalis* and *Halophila stipulacea*) (Sheppard *et al.* 2010; Winters *et al.* 2020). *Halodule uninervis*, or narrowleaf or needle seagrass in English and a’shab bahriya in Arabic, is the dominant species, accounting for > 90 per cent of meadows across the total extent in the Gulf (around 7,000 km^2) (Erftemeijer & Shuail 2012). Less common but also capable of forming dense meadows is *H. stipulacea* with *H. ovalis*, commonly known as paddle weed, spoon grass or Dugong grass, identifiable by its broad ovate leaves. The later species rarely forms dense monospecific meadows but along with the other two species is a preferred food of *D. dugon* (Erftemeijer *et al.* 1993).

These three species are small-bodied pioneering hardy species that are adapted to a broad range of temperature and salinity, with the ability to recover quickly (Den Hartog 1970). Typically confined to waters shallower than ten metres the most extensive area of seagrass is found in the coastal areas of Abu Dhabi (Philips *et al.* 2002; Howari *et al.* 2009), with areas of interest to this report also occurring in Jebel Ali (2 km^2 (Riegl & Purkis 2005)), Jumeirah (< 0.1 km^2 (Martin Mid-East 2000)) and Al Taweelah (20-30 km^2 (Delft Hydraulics 2001)) (Figure 18 & Table 4). All three seagrass species and mangrove (*Avicennia marina*) habitats characteristic of this region are highly productive and support a rich diversity of avian life (Saenger et al. 2002; Boere et al. 2006).

Seagrasses have also colonised shallow areas within Palm Jebel Ali, which is now further enhanced through transplantation (Katakura *et al.* 2008). Several anthropogenic activities are impacting seagrasses in the region (Table 5).

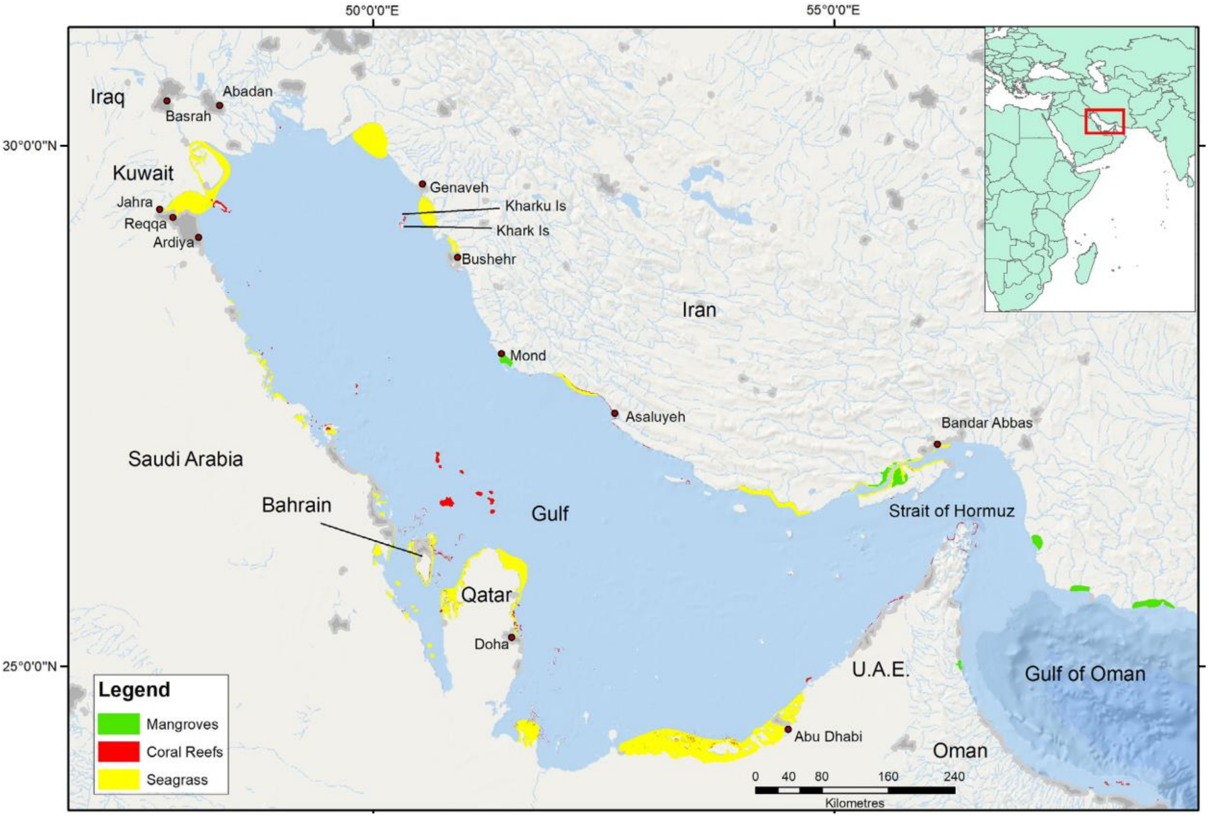


Figure 18. Major seagrass, mangrove and coral habitat within the Arabian Gulf. Source: Vaughan *et al.* (2019).

Table 4. Mapped seagrass meadows in the Arabian Gulf. Source: Erftemeijer & Shuail (2012)

Location	Area (km^2)	*Halophila ovalis*	*Halophila stipu-lacea*	*Halodule uninervis*	Source
KUWAIT					
total Kuwait	50	x		x	Jones et al. (2002)
Az Zour	1			x	Delft Hydraulics (2004)
Doha, Dbaiyah & Nuwaiseeb	2–3	x		x	Shuail (2008a, b)
SAUDI ARABIA					
total Saudi Arabia (Gulf coast)	370	x	x	x	Phillips (2003a)
Tarut Bay	175				Basson et al. (1977)
Al Qair coastal lagoon	20		x	x	Delft Hydraulics (2007a)
BAHRAIN					
southeast (up to Qatar)	500–1000	x	x	x	BCSR (2001)
QATAR					
Mesaieed	6–10	x	x	x	Delft Hydraulics (2005a)
Lusail	15–20				COWI (2004)
UNITED ARAB EMIRATES					
Abu Dhabi waters (total)	5500	x	x	x	Phillips (2003a)
Shuwayhat (Ruwais)	30	x		x	Emu (1999a)
Das Island	0.5	x		x	Fugro (2005)
Mubarraz Island	70–80	x	x	x	Delft Hydraulics (2007b)
Al Dhabayah	30	x		x	Emu (1999b)
Al Taweelah	20–30	x	x	x	Delft Hydraulics (2001)
Jebel Ali	2	x	x	x	Riegl & Purkis (2005)
Jumeirah	<0.1	x		x	Martin Mid-East (2000)
TOTAL GULF (mapped):	6,790 –7,320				

Table 5. Human activities that have caused major environmental disturbances in the United Arab Emirates. Source: Price (1993).

Coastal and marine use	Actual or potential environmental pressures
Shipping & transport shipping ports	Oil spills; anchor damage; coastal ‘reclamation’ and habitat loss; dredging, sedimentation; oil and other pollution
Residential & commercial	Coastal ‘reclamation’ and habitat loss; dredging, sedimentation; sewage, fertilizer and other effluents; eutrophication; solid waste disposal
Industrial development oil & petrochemical industry	Oil, refinery and other effluents containing heavy metals; drilling muds and tailings; air pollution
Desalination & seawater treatment plants	Effluents with elevated temperatures, salinities and sometimes heavy metals and other chemicals
Power plants	Various effluents; air pollution, increasing greenhouse gases and global warming; acid deposition
Fishing & collecting	Population declines of target and non-target species and changed species composition of fish, shrimp and other biota; habitat degradation (including anchor damage)
Recreation	Some reef degradation from anchor damage and collecting
Agriculture	Local eutrophication (e.g. from fertilizers), only low levels of insecticides such as DDT, aldrin, dieldrin & lindane recorded in marine sediments and biota, saline intrusion and possible effects on coastal ecosystems

5. EXISTING RESTORATION PROJECTS

To be confirmed during site visits

6. RESTORATION CONSIDERATIONS AND RECOMMENDATIONS

It is recommended that the primary focus of oyster restoration in the UAE be with regards to the ecological enhancement of the natural environment, and that activities such as pearl cultivation or human consumption be secondary considerations. The timeline produced by Preston *et al.* (2020) (Figure 19) details the appropriate order of activities to ensure that restoration efforts are conducted in a manner that optimises chances of success. Should it be decided that restoration efforts are to take place following the completion of this feasibility study, a working group of relevant interested parties should be formally established to enable goals and objectives to be set. Before any restoration work is conducted, extensive baseline surveys should be conducted to provide evidence of site suitability and the existing status of the various species to be restored and other associated metrics. The baseline surveys should be conducted in a manner to align them with the goals and objectives of the project.

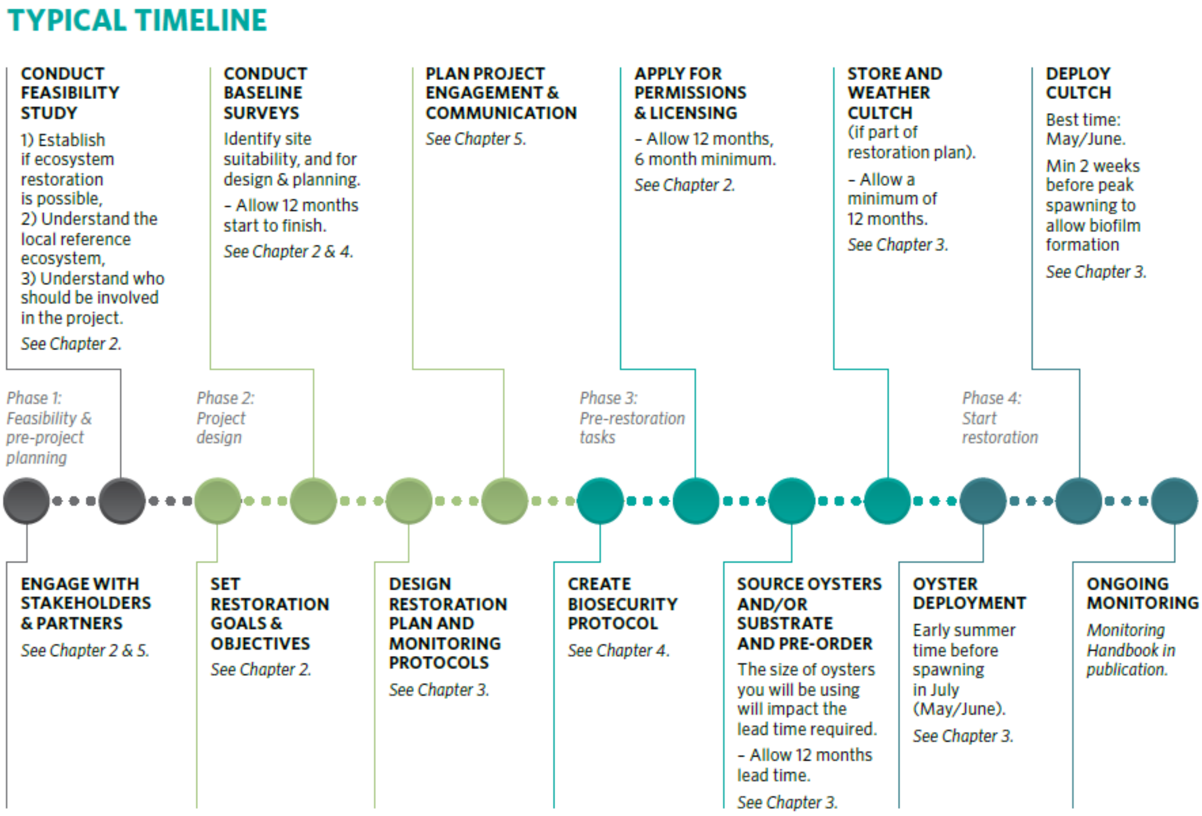


Figure 19. Anticipated project timeline and associated activities. Source: Preston *et al.* (2020)

6.1. ESTABLISHING A WORKING GROUP AND RESTORATION NETWORK

With the habitat-restoration momentum growing on a global scale there are numerous lessons to be learned, both from successes and failures or attempts that could be done differently. An example of this momentum can be seen within Europe, the formation of the Native Oyster Restoration Alliance (NORA) and the Native Oyster Network - UK & Ireland (NON). These networks bring together government, restoration practitioners, scientists, the fishing industry, and others in a collaborative approach to share knowledge and best practice to facilitate effective, collaborative and ecologically coherent restoration.

NORA Mission Statement:

"The Native Oyster Restoration Alliance (NORA) supports the protection and ecological restoration of the native European oyster, Ostrea edulis, and its habitat in areas of its current or historical distribution. NORA works to overcome existing barriers to the conservation, restoration and recovery of the European oyster by providing a platform for the NORA community to collaborate and participate in knowledge exchange. NORA seeks to support responsible restoration practice, in compliance with biosecurity and sustainability."

Stakeholders having been consulted, with expressions of interest from all parties, it seems highly desirable to establish a working group as part of the proposed DP World restoration project. Appropriate stakeholders can be selected dependent on the decision-making process following this feasibility report. Potential stakeholders are highlighted in Figure 20.

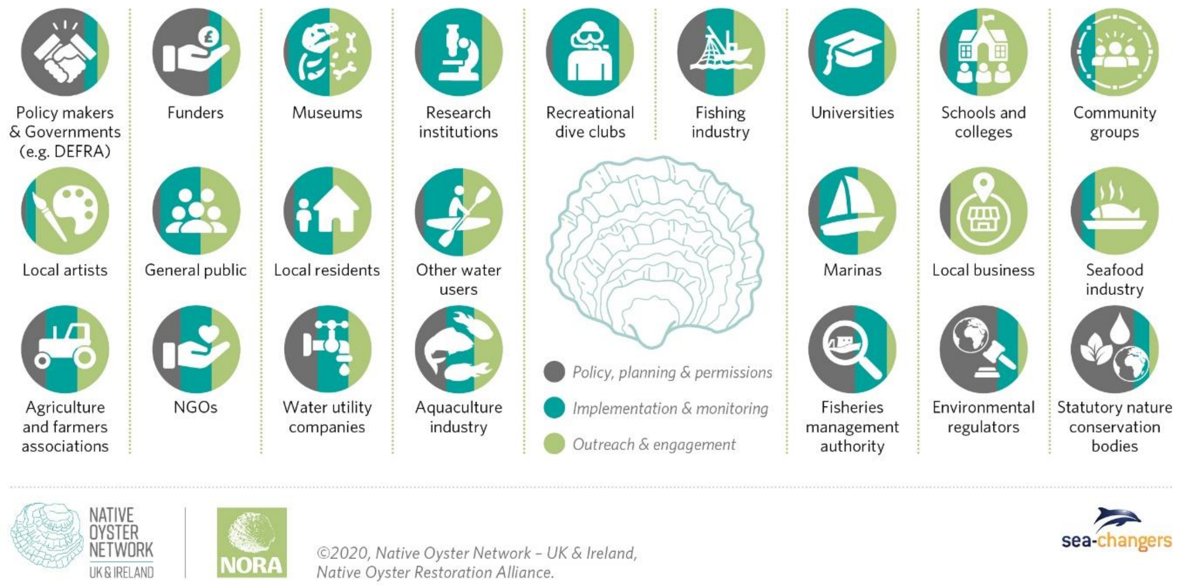


Figure 20. Potential stakeholders to consider involving in design and delivery of oyster restoration projects. Source: Preston *et al.* (2021).

The success observed within the restoration networks of Europe over a relatively short period should also be replicated, so it is recommended that a similar type of network be established for the Gulf region. For the restoration of any of the species or habitats mentioned in this report to occur at an ecologically meaningful scale, significant resourcing and collaboration will be required over a large area that will inevitably span political and geographical borders. Having the network and associated relationships in place will be invaluable and could allow for systemic change to occur.

6.2. AN INTEGRATED AND HOLISTIC APPROACH

To date, most marine restoration projects have focussed on the recovery of one habitat or species. However, some countries have recognised the interconnected nature of marine ecosystems with initiatives adopting an integrated approach. Marine ecosystem restoration has been pioneered in the United States for over 20 years. These projects have revealed the co-benefits that can be realised for not only the target habitat or species but also the expansion of other critical habitats. In the Rachel Carson Reserve, North Carolina, half of the restored oyster reefs facilitated the seaward expansion of saltmarsh through the stabilisation of sediment and wave attenuation. This has been done with success in several other locations, including in sub-tropical climates in Bangladesh. In Australia, artificial reefs installed to restore native Kelp forests also revealed unintended benefits. The reefs installed quickly became colonised by the critically depleted oyster native to those waters. When investigated further, it was shown that as the density and patch size of Kelp increased, so did the density of oysters. Indeed, after 24 months oysters were approximately three times more numerous in areas where kelp was present compared to those without.

In order to lead the way and pioneer habitat restoration in the Arabian Gulf, an integrated approach to restoration, that looks at the Gulf in a holistic manner, should be strongly considered. Incorporating all the habitats present (oyster reefs, mangroves, seagrass meadows and coral reefs) into restoration plans from the outset will result in a multiplier of long-term benefits. The Gulf’s intertidal habitats, including saltmarshes, mudflats, sabkhas (salt flats) and mangrove forests, as well as algal beds, seagrass meadows, and coral reefs in subtidal areas support substantially higher biodiversity and productivity than the surrounding arid lands, and also generate nearly half a billion dollars in commercial fisheries, the second highest value resource after oil (Burt, 2014; Van Lavieren et al., 2011).

6.3. STRATEGIC APPROACH

The key focus areas surrounding the benefits of oyster restoration varies across the globe, with improvements to commercial fisheries in the US, recreational fishing in Australia and biodiversity and water quality in the UK and Europe being at the forefront of interest. These are some of the main incentives for academic, charitable, private and governmental/federal financial investment.

Emphasis should be placed on local, regional, national and international assessments. Oyster restoration has the capacity to address numerous issues highlighted by the United Nations Sustainable Development Goals. The goal that is immediately apparent is Goal 14 (Life Below Water), however goals 3, 4, 5, 8, 9, 10, 12, 13 and 17 all highlight issues that, to some extent, can be addressed by enabling ecological restoration.

6.3.1. WATER QUALITY

The United Arab Emirates Ministry of Climate Change & Environment (MOCCAE) produced the 'Guiding Standards for Marine Water Properties in the United Arab Emirates 2020' document. It states that: *'Maintaining marine water quality is one of the important objectives of the MOCCAE strategic plans. This objective is associated with an important set of indicators defined in the National Agenda of the UAE Vision 2021, the UAE Centennial and the Ministry's strategic goals'*

Therefore, focusing project messaging on the impact oysters can have on the surrounding water quality would be extremely prudent given the emphasis on this topic at international level. However, care should be taken not to overstate the capability if this has not been fully quantified for the species in question. Estimates can be obtained from similar species for which values are available.

6.3.2. CULTURAL HERITAGE

The current perception of Dubai is that of a world of luxury, tall buildings, and fast cars. This modern lifestyle was built on a foundation of the pearl industry, but the rich cultural heritage of the region can often be forgotten in the bright lights of the big city. Oyster restoration, both for ecological enhancement and industry rejuvenation, can be used as an extremely visual mechanism to engage with a wide range of people to reignite their appreciation of the cultural heritage and values that helped to establish the UAE's position in the global community.

By collaborating, awareness of the plans to enhance oyster populations and habitats can be maximised. Developing the existing education material developed by Suwaidi Pearls and Abdulla Al

Suwaidi in combination with the education and outreach expertise offered by Blue Marine Foundation would be an effective way to achieve this.

6.3.3. BIODIVERSITY

Fouling organisms on the surfaces of pearl oysters have previously been perceived negatively with regard to growth and mortality (Mohammed 1976, 1998). However, when considering the habitat provided by *P. i. radiata* the associated flora and fauna should be viewed as a positive, with increased species abundance and diversity in an area. Some problematic species that bore into the shells of oysters (worms such as *Polydora* spp. and boring sponges) may be present but by restoring substantial numbers of oysters their impact should be absorbed. It is a naturally occurring event that cannot be completely prevented.

The biodiversity along the western coast of the Gulf has been shown to decrease from north to south (Samimi-Namin & Van Ofwegen 2009; Bauman *et al.* 2013). Therefore, providing opportunities to enhance the diversity and abundance species present is of utmost importance in the area around Dubai. Improving the ecology of the marine environment in such a manner allows for resilience within the communities to be establish, thus the overall health and balance of the system can be restored (Grabowski & Peterson 2007).

6.3.4. FISHERIES ENHANCEMENT

Associated with improvements to the primary productivity and the whole ecological community of an area, enhancement of commercial and recreational fisheries - not involving the extraction of oysters themselves - is an important consideration for any restoration project. There are numerous examples of the benefits that oysters, and oyster reefs, can provide for recreational and commercial fish stocks, many of which are demonstrated in the United States (Coen *et al.* 1999; Harding & Mann 1999; Lenihan *et al.* 2001; Peterson *et al.* 2003; Grabowski *et al.* 2005; Gilby *et al.* 2018).

6.3.5. SOCIO-ECONOMIC BENEFITS

As previously discussed, oysters provide much more than ecological benefits. Coastal communities in the UAE have been built with a foundation of oysters at their heart, and a positive feeling towards this cultural heritage remains. But it could be enhanced if awareness of the importance of restoration efforts was increased. This community bond with the marine environment provides an opportunity to generate support for a project, especially if using grass roots elements that require hands-on voluntary work.

With the current global situation, job creation and economic prosperity are at the forefront of many individuals, organisations and governments. Coastal habitat restoration offers the opportunity to both enhance the local environment and provide opportunities for local communities. The Nature Conservancy (TNC) has in Australia calculated that for every $1 million Australian Dollars (AUS) invested in oyster restoration, a total of 8.5 full-time jobs are created within the industry. This is greater than the construction (5.9 jobs / $1 million), leisure (4.9 jobs / $1 million), mining (2.5 jobs / $1 million) and travel (1.4 jobs / $1 million) industries (Simon Reeves, Pers. Comm.). By restoring oyster reef habitat in Texas, TNC has been able to quantify the socio-economic and environmental benefits (see case study).

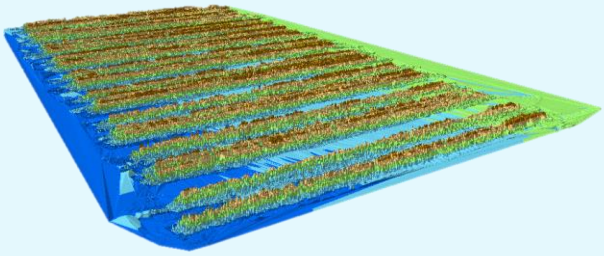
The importance of recreation and ecotourism cannot be understated. The habitats present in the UAE offer the opportunity for visitors to engage in a wide range of activities, from kayaking around the mangroves to diving on the coral reefs and wrecks. Utilising the positive message behind habitat restoration at a time when habitats around the world are under such pressure can only encourage more visitors and increase the associated economic input to the area.

The full suite of ecosystem services associated with natural oyster reefs across North America were estimated to have an economic value as high as $106,000 (USD) per ha per year (all values converted to 2017 $USD values by inflating in line with the annual average consumer price index; Grabowski *et al.* 2012). This is higher than estimates for other habitats such as mangroves ($82,000(USD) per ha per year; Balmford *et al.* 2002), seagrass ($31,000(USD) per ha per year; Grabowski *et al.* 2012), and permanent wetlands ($21,000(USD) per ha per year; Sutton and Costanza, 2002).

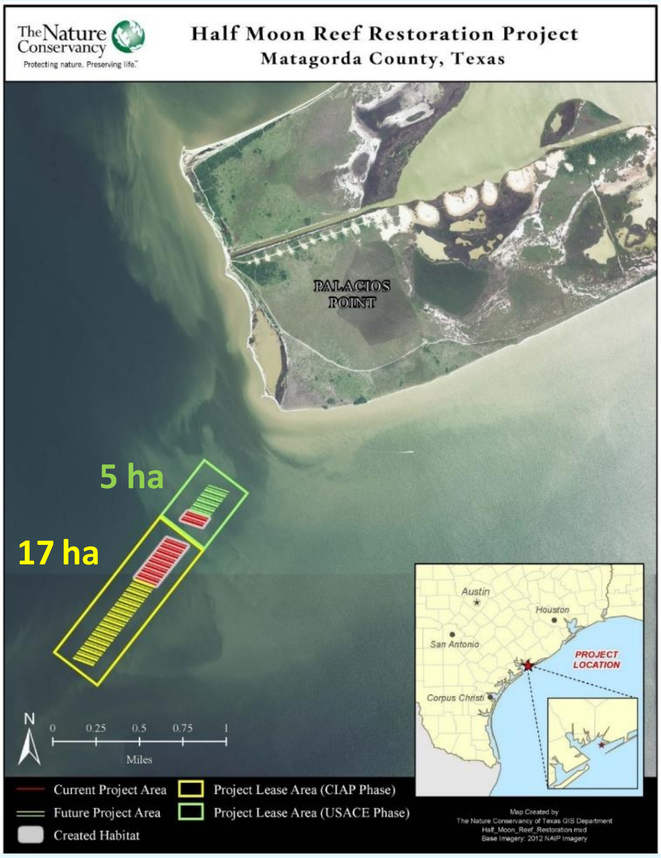
Aside from oysters there are numerous socio-economic opportunities associated with habitat restoration. For example, seagrass meadows represent another of the most valuable ecosystems on Earth, with an estimated value of $ 2.8 106 yr−1 km−2 (Costanza et al., 2014). Seagrass meadows in the Gulf are estimated to support 4,800 kg of fisheries production per square kilometre, in the 410 km^2 area of Tarut Bay (Saudi Arabia) approximately 4 million kg of fish and shrimp, equating to $22 million (USD), are supported by the seagrass meadows (Price *et al.* 1993). If this were to be increased in strategically selected locations, then the opportunities for commercial and recreational fishing activities could be enhanced.

Case Study: Half-Moon Reef, Texas

An example of the influence a restoration project can have on the local area can be seen in Texas and The Nature Conservancy's 'Half Moon Reef', where a total of 57 acres of oyster reef have been restored in the Gulf of Mexico. The reef generated 12 new jobs and $465,000 in annual labour income. After construction, biodiversity on the reef has found to be 40 per cent higher than on the surrounding seabed, and the biomass of organisms found as over one thousand per cent greater than surrounding areas. This has attracted recreational fishers as the area has gained a reputation as a 'hot spot', with 94 per cent of anglers saying the area offers a more satisfying experience than other locations. In turn, the reef has added $691,000 (USD) to the GDP of Texas and generates $1.27 million (USD) in annual economic activity.



Multi-Beam side-scan sonar survey of the reef.



PHASE I

FWS/GLO/TNC PARTNERSHIP

$3,800,000 (USD)

42 acres (~ 17 ha)

Limestone Rock

PHASE II

USACE/TNC PARTNERSHIP

$1,600,000 (USD)

12 acres (~ 5 ha)

Recycled Concrete

Images and information courtesy of Mark Dumesnil: presentation at the SRRN conference in Adelaide 2018.

6.3.6. CARBON CAPTURE

The global climate crisis is undoubtedly at the forefront of many people's mind, any activity that can help to mitigate against its impact is perceived positively. Limited information is available regarding the carbon sequestration and storage potential of oyster reefs; however, recent studies indicate that shallow subtidal and saltmarsh fringing reefs do indeed act as carbon sinks (Fodrie *et al.* 2017). Given the locations of existing populations in the UAE, this is promising.

Mangroves, seagrasses, and other vegetated coastal habitats are recognised 'blue carbon habitats', with mangroves among the most carbon-rich forests in the tropics (Duarte *et al.* 2005; Donato *et al.* 2011; Fourqurean *et al.* 2012). The soil between 0.5 and 3 metres depth, which is rich in organic material, accounts for around 49 to 98 per cent of carbon stored in these habitats.

Globally, mangroves have been estimated to store 1,023 Mg C ha^{-1} (Donato *et al.* 2011). It has been estimated that the remaining global extent of mangroves provides $2.7 trillion(sic) (USD) in services per year ($194,000 per hectare per year), and new evidence suggests that this sum may be even greater. Sanderman *et al.* (2018) found that 6.4 billion metric tons of carbon was stored in mangrove soil, 2.21 billion tons greater than previous estimates for both soil and plant biomass. Currently the UAE and the Arabian Gulf are among the areas of lowest aboveground biomass within the biogeographic range of mangroves (Figure 21). With substantial restoration efforts this value could be increased along with the carbon sequestration and storage capacity of the region.

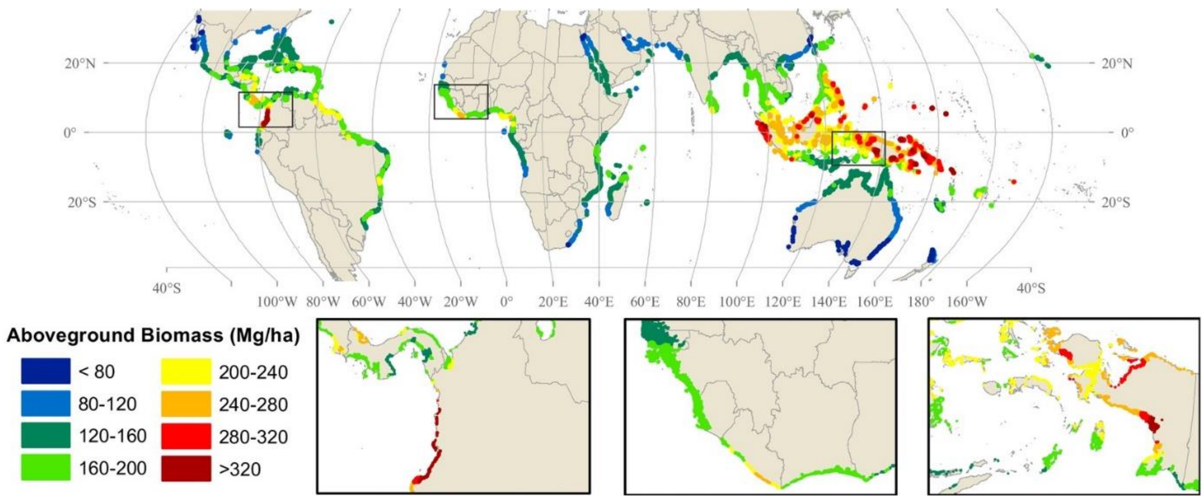


Figure 21. Global mangrove map showing modelled patterns of above-ground biomass per unit area. Source: Hutchinson *et al.* (2014).

Seagrass meadows also offer huge potential for carbon storage with the total global area covered estimated to be 300,000 - 600,000 km^2 (Charpy-Roubaud & Sournia 1990; Duarte *et al.* 2005). This equates to less than 0.2 per cent of the world's oceans but it is estimated that they bury ten per cent of annual organic carbon (27.4 Tg C yr^{-1}) (Fourqurean *et al.* 2012). When incorporating the top metre of seagrass soil, it is estimated that global storage of carbon in seagrass habitat is 9.8 to 19.8 Pg (Petagram - 10^{15} g), roughly equivalent to that in tidal marshes and mangroves combined (~10 Pg C (Chmura *et al.* 2003).

Areas of seagrass habitat within the UAE, incorporating all three species present, have been assessed for their carbon storage capacity. The coast of Abu Dhabi was surveyed by Campbell *et al.* (2015) in 2013. Despite relatively modest organic carbon storage in living seagrass and associated soil (as observed from the air), the total expanse of all seagrass meadows across the region was shown to contribute to large 'blue carbon' stores (400 Gg C in living seagrass and 49.1 Tg C in the associated soil). This study demonstrates that even small-bodied species contribute to carbon storage in coastal environments, and this should be an important consideration in restoration efforts.

6.4. POTENTIAL RISKS AND CHALLENGES

With any restoration activity that involves a natural system there are always going to be risks involved. As with terrestrial crops and livestock, that have been cultivated for millennia, success cannot be guaranteed. Numerous factors, many of which are beyond the control of practitioners, influence the biological, chemical, physical and socio-economic status of an area to be restored. However, should a certain activity or action fail, it should not be considered a failure of the whole restoration project. An adaptive and iterative approach is required to achieve success and to assess that success. Each project will encounter multiple site-specific factors that might influence the measures to be implemented, therefore thorough and detailed baseline surveys should be conducted prior to any activities taking place. Without such information, a project would risk undertaking activities leading to issues or failures, as well as losing the opportunity to measure the impact. It is suggested that a Before-After-Control-Impact (BACI) study design be adopted in order to effectively monitor the project as it develops, so that any improvements in populations or habitat can be attributed to the restoration work.

6.5. OYSTERS

It is suggested that the advice provided by the Restoration Guidelines for Shellfish Reefs (Fitzsimons *et al.* 2019) be followed in all cases. This handbook sets out the entire process required to successfully restore bivalve species and their habitat. By using the wealth of knowledge in the handbook, the entire process - from getting started to implementing, monitoring and communicating - can be dramatically streamlined, saving both time and resources.

Following detailed stakeholder engagement and desk-based studies, it became immediately apparent that one of the species to initially focus on in the UAE, particularly Dubai, was the Gulf Pearl Oyster *Pinctada imbricata radiata*. The existing operations in the area focus on the harvest and production of this species, and larval abundances appear to be sufficient to allow for wild spat collection. However, these operations focus on production of pearls and not on restoration efforts, nevertheless many of the techniques are transferable and can be adapted to facilitate the establishment of natural populations.

It is important to determine if the system is recruitment limited (with regards to larval supply) or substrate limited (with regards to suitable habitat). In the case of the UAE - more specifically Dubai - one has the general impression that the system is not recruitment limited for the Gulf Pearl Oyster. Rather it is substrate limited, with insufficient quantity of suitable habitat for the larvae of remnant populations of breeding adults to settle upon. This is likely to be, in part, due to the vast extent of costal development that has taken place in recent years. Of the two scenarios, this is less problematic as there is no need to establish breeding populations, which can often be time consuming and costly. Instead, the process requires the introduction of suitable substrata at the correct time of year, in the correct locations and with the appropriate level of protection (physical and legislative).

Habitat suitability index (HSI) models have been created for this species along the coast of Bangladesh, providing an extremely useful insight into the restoration potential during the site selection stages of project planning (Chowdhury *et al.* 2019).

6.5.1. RESTORATION TECHNIQUES/TECHNICAL FEASIBILITY

With larval supply of both the Gulf Pearl Oyster and Rock Oyster not currently believed to be a limiting factor, restoration techniques should focus on providing the suitable settlement substrate in the right places and at the correct time of year to maximise settlement and recruitment. A circular economy of restoration can be achieved by using existing mature broodstock populations that will reproduce naturally. The larvae can then be collected and used to boost the wild populations (Figure 22).

1. Wild populations of adult oysters naturally reproduce and release larvae into the water column.
   1.1. Larvae will spend a period in the water column before settling.
2. Re-used shells, rope or other suitable substrate is placed into areas of high larval settlement during the peak in the spawning season. Existing ‘hot spots’ known to local stakeholders can be used. Alternatively, if the location of broodstock populations is known, then hydrodynamic models can be used to predict the area where larvae will travel within the timeframe of their planktonic phase. Larvae that settle onto shell are then referred to as ‘spat-on-shell’.
3. Spat on shell can be held in lantern nets (or similar) or oyster nurseries at the surface of the water column where food availability is likely to be greater, allowing for improved growth. Oyster larvae that have been settled onto rope require no additional movement and can be left on the ropes to grow. It is at this point in the restoration project that public engagement can take place easily if collaborations with marina companies and other organisations are established. 3.1. If a degree of cultural heritage is to be associated with the project, then assigning a proportion of the pearl oysters from the ongrowing systems could enable the production of pearls.
4. Once the oysters have reached a desired size they can then be transplanted onto existing or prepared reef structures. 4.1. To maintain genetic diversity and build resilience within a population of an area, the locations used to collect individuals should be varied on an annual basis. Populations should be within the same body of water, and appropriate biosecurity measures put in place for the oysters, shells and equipment used.

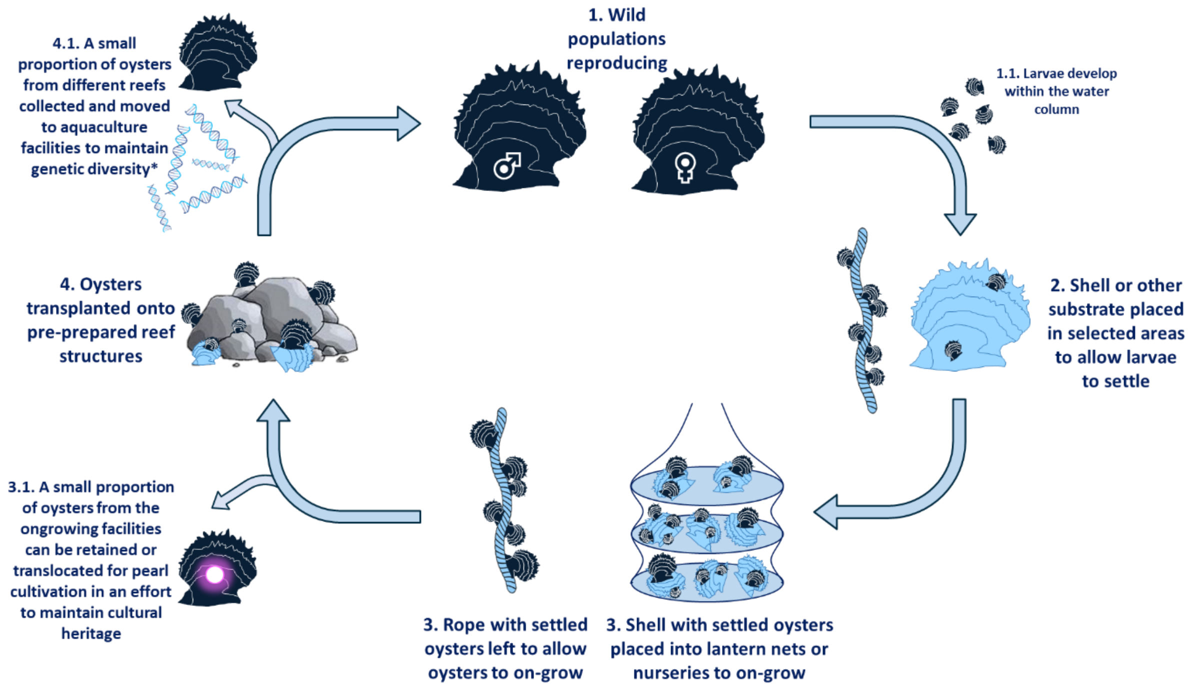


Figure 22. Restoration circular economy, the Gulf Pearl Oyster *Pinctada imbricata radiata* being used as an example. Similar techniques can be applied to other species such as *Saccostrea cucullata*. Dark blue represents live oysters, light blue represents oyster shells. *If proportions of populations are to be selected from a variety of reefs for aquaculture purposes or to vary the genetic diversity of an area, then the populations should be within the same body of water or geographic region, with biosecurity protocols adhered to at all times. ***Note:** it is essential to ensure any shell collection and deployment is conducted in a biosecure manner to minimise the spread of diseases and invasive non-native species.

Following discussions with the operators of a pearl farm in the Al Rams area it is clear that the collection of wild pearl oyster spat would be possible in known areas. This would likely prove the most appropriate option financially and logistically, as well as being a biosecure option that maintains genetic integrity of the stock - if they are used within the same body of water or moved over a short distance.

Wild pearl oyster spat can be collected in a variety of ways that involve suspending devices at the surface of the water column or near the seabed. The devices can differ in complexity ranging from simple ropes to old oyster shells that have been cleaned, cured, dried and then placed back into the water either on strings, in lantern nets or loose on the seabed. Examples of community led projects that operate in this manner can be seen in India and other areas around the world. See the YouTube video for one example: https://www.youtube.com/watch?v=4RAU5rPMe80&ab_channel=Scroll.in

The ability of *Pinctada* species, such as *P. i. radiata*, to attach and re-attach with byssus threads means that collection can take place in areas of high recruitment, and the resulting spat can then be transported to alternative restoration locations or placed into ongrowing systems beneath marina pontoons, for example (Figure 23). Southgate & Beer (2000) found that 24-pocket juvenile panel nets were the most effective with regards to overall culture, considering cost, construction, fouling, growth and survival of the similar species *P. margaritifera*. Kishore & Southgate (2016) also found that panel nets resulted in higher proportions of high-grade pearls produced by *P. margaritifera*, compared with those held on chaplets.

For community engagement projects that will require an increased level of accessibility, methods and construction developed as part of oyster gardening and broodstock nursery systems can be incorporated. An example of oyster gardening, relating to the eastern oyster *Crassostrea virginica*, can be seen in 'Oyster Gardening for Restoration and Education' (Goldsborough & Meritt 2001).

https://www.mdsg.umd.edu/sites/default/files/files/Oyster-Gardening-Guide-1.pdf

A guide to working in marina environments can also be seen from the work in the Solent, UK (Helmer *et al.* 2021). The combination of knowledge and information provided within the guide, along with the Preston *et al.* (2020) handbook, should enable the entire process of oyster restoration to be carried out successfully. It would be likely that the permitting and logistical considerations highlighted in these guides would be similar for the Dubai region.

Figure 23. Broodstock nursery systems used to suspend oyster populations beneath pontoons in the Solent.

Techniques for *Saccostrea* species, such as *S. cucullata*, vary due to the inability to reattach once a substrate has been attached to. Therefore, efforts should focus on preparing areas of the seabed or intertidal zones to receive larvae produced by existing adult populations, as well as boosting recruitment to areas already inhabited. With the species distribution occurring predominantly in the intertidal zone, determining areas of remaining broodstock should be a relatively straightforward process. Once broodstock 'hotspots' have been identified, hydrodynamic models can be implemented to determine where the larvae will be transported, allowing for suitable sites to be selected. This species would also be a suitable candidate for community-led projects (see previous YouTube link) that could focus on breeding for restoration, as well as for consumption.

Marina pontoons systems, or other measures that increase the densities of breeding adults, could also be incorporated into efforts to increase the reproductive success of the population, in turn creating a 'hotspot' that further improves larval supply to the system. Again, hydrodynamic models can then be used to predict where the larvae will be transported, allowing for the correct environmental enhancement to maximise recruitment and allow for optimal placement of these measures.

For larger scale restoration, locally sourced aggregates would be required to provide a foundation, upon which suitable settlement material and live oysters could be placed. Additional structures that have complex three-dimensional structures, such as reef balls, could be deployed to give vertical elevation. When moving to larger scale reefs, the timing of deployment should be coordinated around peaks in natural reproductive cycles to maximise the recruitment from spawning events. When deploying material with oysters settled onto them, emphasis should be placed on using younger oysters to minimise any husbandry required with ongrowing in aquaculture systems.

The proximity to shore should also be taken into consideration, for both logistical and ecological reasons. Working closer to shore minimises costs associated with vessel time, size and fuel consumption. Oyster populations closer to shore have also been shown to support greater epibiont assemblages than those offshore (Mohammed 1998) and would therefore be more suitable if the goal of a project was to enhance biodiversity. The lower current speeds experienced within onshore waters (0.1 - 0.3 knots (Hunter 1986; Hassan & Hassan 1987)) compared with those in offshore waters (> 2 knots (Parket *et al.* 1993) of the Gulf would also encourage larval settlement.

6.6. MANGROVES

From initial conversations with the Mangrove Action Project (MAP) it has been suggested that activities such as replanting are rarely successful, the importance of restoring the natural hydrology of disturbed areas through hydrological restoration techniques was emphasised. This way, labour-intensive hand-planting can be avoided. See relevant YouTube video explaining the rationale behind the promotion of this technique:

https://www.youtube.com/watch?v=Vh7CoPBLQa8&feature=emb_title&ab_channel=MangroveActionProject

With their knowledge and previous experience, it is suggested that MAP be included within the working group if the integrated restoration option is selected.

6.7. SEAGRASS

Seagrass restoration is essentially underwater gardening and there are two main techniques for it: replanting adult shoots and reseeding. The Seagrass Restoration Handbook UK & Ireland (Gamble *et al.* 2021*)* provides an in-depth overview of all considerations required for successful seagrass restoration. In general, reseeding involves the transplanting of seed in targeted areas and is employed when there is no readily available source of nursery-grown plants or seeds. Replanting involves the transplantation of adult shoots from existing beds. Where large-scale restoration is required, the establishment of a nursery may be required to facilitate this.

7.7. IDENTIFYING SUITABLE AREAS

Following the brief outlined by DP World, suitable areas have been assessed primarily for restoration potential of oyster species within, or near to, Dubai. Information is available on other suitable areas of the UAE, including Dibba, Fujairah and Kalba on the east coast in the Gulf of Oman, but these were not initially considered to be within the scope of this feasibility study. Areas around Dubai that contain other important habitats have also been considered and included here where appropriate.

Information obtained from available literature, stakeholder engagement and field site visits have all been carefully considered and the following section highlights the most suitable locations for restoration activities to take place (Table 6).

Table 6. Priority areas identified from Grizzle *et al.* (2018) in or near Dubai (**bold**) or on the west coast of the UAE (not bold) with populations of *Saccostrea cucullata* and/or *Pinctada imbricata radiata*, and *S. cucullata* & *Avicennia marina* mangrove. *Areas where integrated restoration would be possible.

Species	Site	General location	Habitat type	Species abundance
S. cucullata	**7**	**Umm Al Quwain**	Exposed rock or jetty	Common
	35	**Dubai**	Exposed rock or jetty	Common
	36	**Dubai**	Exposed rock or jetty	Common
	40	Ras Al Khaimah	Exposed rock or jetty	Common
P. i. radiata	**9**	**Umm Al Quwain**	Coral reef, sheltered lagoon	Molluscs abundant
	33	**Al Hamriya, Sharjah**	Exposed rock or jetty	*S. cucullata* BVO
S. cucullata & *P. i. radiata*	15	Ras Al Khaimah	Exposed rock or jetty	Sparse
	16	**Dubai**	Exposed rock or jetty	*S. cucullata* common BVO & *P. i. radiata* abundant
	17	**Dubai**	Exposed rock or jetty	*S. cucullata* common
	18	**Jumeirah, Dubai**	Exposed rock or jetty	*S. cucullata* common
	26	**Ajman**	Exposed rock or jetty	*S. cucullata* sparse
	31	**Sharjah**	Exposed rock or jetty	*S. cucullata* & *P. i. radiata* juv sparse
	34	**Umm Al Quwain**	Exposed rock or jetty	*P. i. radiata* juv common
	37	**Ajman**	Exposed rock or jetty	*S. cucullata* sparse, *P. i. radiata* juv common
	41	**Ras Al Khaimah**	Mangroves and adjacent soft sediments including seagrass	*S. cucullata* sparse
S. cucullata & *Avicennia marina*	**10***	**Umm Al Quwain**	Mangroves and adjacent soft sediments including seagrass	*S. cucullata* sparse clumps in seagrass
	14	Ras Al Khaimah	Mangroves and adjacent soft sediments including seagrass	*S. cucullata* clumps near mangrove on tide flat
	39	Ras Al Khaimah	Mangroves and adjacent soft sediments including seagrass	*S. cucullata* sparse
	43*	**Umm Al Quwain**	Mangroves and adjacent soft sediments including seagrass	*S. cucullata* sparse, extensive mangrove with adjacent seagrass

7.7.1. JABAL ALI

Jabal Ali Marine Sanctuary (JAMS) (Figure 24), incorporating the 2,002-hectare Jabal Ali Wetland Sanctuary, is situated in the southwest region of Dubai, between the Abu Dhabi-Dubai border and The Palm Jabal Ali. The area was recognised as a Ramsar Site in 2018 and has been recognised by the Convention on Biological Diversity as an Ecologically or Biologically Significant Marine Area (EBSA). The area is host to all of the habitat types of interest for this feasibility report including oyster reefs, coral reefs, mangroves and seagrass meadows. They are known to support over 500 marine species (124 species of bird, 34 species of coral and 147 fish and shark species) (Ramsar, 2018). The full taxonomic list of species present in the area can be found at https://rsis.ramsar.org/ris/2364.

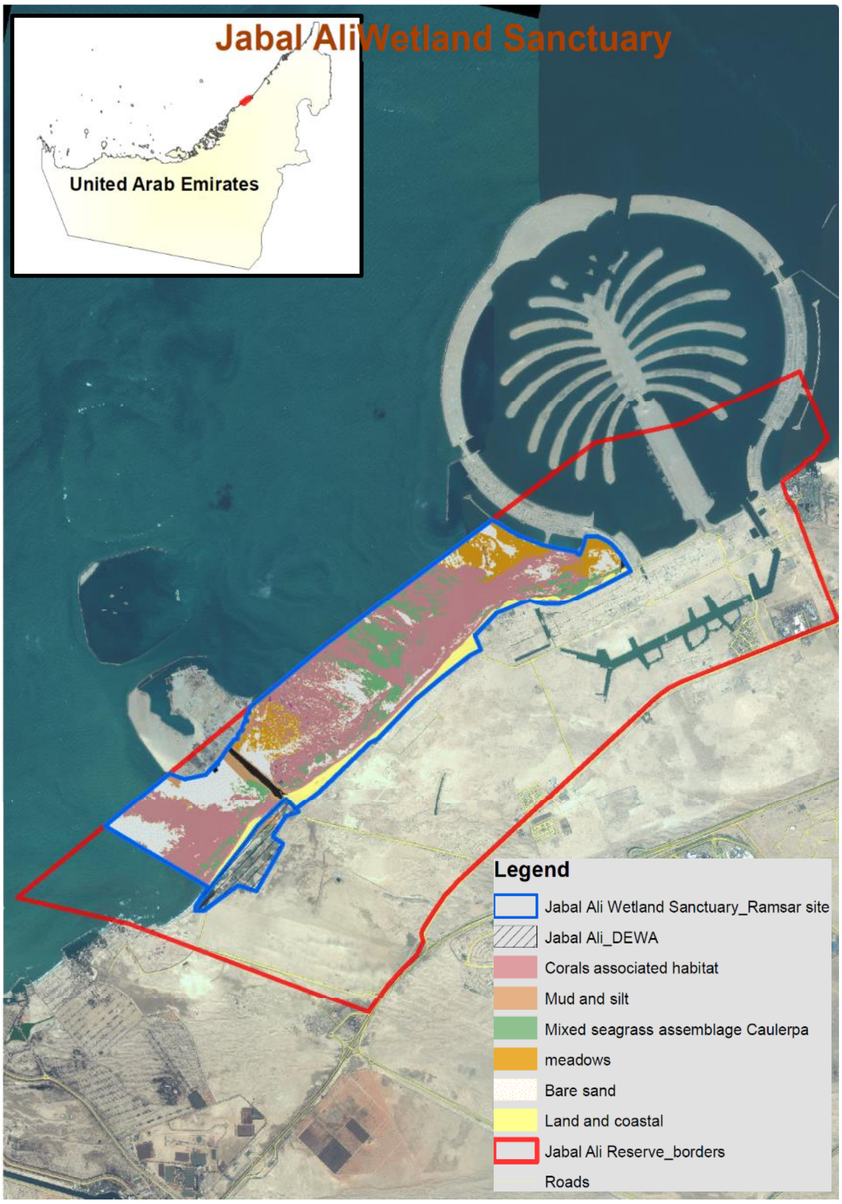


Figure 24. Jabel Ali Wetland Sanctuary area (Blue line). Modified from Ramsar (2018).

More information to be added after site visits

7.7.2. AL ZORAH

More information to be added after site visits

7.8. PROJECT COMMUNICATION

Informing others about restoration work is an essential element of developing networks, awareness and the impact of any project. It may even be included within the project's funding requirements. If outreach and education is conducted effectively, it can help projects engage with and receive help from volunteers, inform and persuade policy or decision makers, share knowledge, streamline processes, secure funding, and improve ocean literacy of the local community. Used efficiently, a combination of outreach and education can be a powerful way of scaling up the impact of a project to get more feet on the ground, and ultimately more oysters in the water. By reaching out to the local community, including school children, a sense of stewardship can be established, in turn increasing the number of people involved in spreading the word, saving time and money. BLUE has successfully engaged hundreds of schoolchildren in the Solent Oyster Restoration Project, where whole classes are able to learn about marine species and have practical exposure to marine restoration in action. This model could be applied in the UAE where a younger generation would benefit from this symbol of hope and regeneration.

7. RESTORATION AQUACULTURE IN THE UAE

Restorative aquaculture is an option that could provide continued supply of oyster species (as well as seagrass seeds and plants if needed) and enable a relatively reliable source of individuals to be used for a variety of restoration techniques. It does require a level of expertise and knowledge, but aquaculture is common practice around the globe.

There is a vast amount of knowledge surrounding the cultivation of bivalve molluscs, including pearl oysters. For example, Libini *et al.* (2018) also showed that sudden exposure to a higher salinity (above 40 psu) will be helpful for detachment of Black-lip pearl oyster spat from settlement tanks in the hatchery to facilitate stress-free spat transfer to sea farming systems. This can prevent stress to the spat due to physical removal from its attachment in the hatchery tank, which ultimately leads to high mortality in grow-out systems. This would be useful in adopting the Japanese technique of post-operative culture for producing high quality pearls from the Black-lip pearl oyster.

In addition, better growth performance and 100 per cent survival of Black-lip pearl oyster spat was observed in lower salinity levels (22-28 psu) than in ambient ones (31 psu). In the case of larval development of these oysters, Doroudi *et al.* (1999) reported high survival rate in a salinity range between 25 and 32 psu.

When considering sites for production of pearls it should also be noted that the Akoya pearl industries in Japan have shown that those in areas subject to freshwater input produce a higher quality nacre (Gervis & Sims 1992; Atsumi *et al.* 2011).

8. MONITORING AND COLLABORATION WITH UNIVERSITIES IN THE UAE AND UK

As with any restoration efforts, monitoring the various metrics that enable practitioners to assess the success of a project and adapt any management decisions to accommodate lessons learned along the way (see Chapter 7 of Fitzsimons *et al.* 2019) requires resources and person power. Many projects maximise their outputs by forming collaborations with universities, using community support and engagement with voluntary programmes, and with local dive clubs through citizen science.

Through the stakeholder engagement process the facilities and services of the New York University - Abu Dhabi were offered to anyone involved with an oyster restoration project in the area (Burt Pers. Comm.). In addition to this, a project could benefit from existing relationships that BLUE has established with UK-based universities which are experienced in oyster restoration efforts, as well as having access to mangrove and seagrass ecologists (University of Portsmouth and University of Southampton). Initial discussions indicate that exchange programmes, honours or masters project placements and residential field courses are all feasible and could be developed if needed (Preston Pers. Comm.).

9. ESTIMATED FINANCIAL INVESTMENT

Restoration projects typically operate following five-year management plans that are reviewed and updated according to the progress and success made throughout the duration. Funding requirements will vary throughout the duration of a project and the initial forecasts give an overview of initial set-up costs along with recurring costs that will be required on an annual basis. As the primary focus of the report is on the feasibility of restoration activities, a full market analysis has not been conducted to obtain the figures used in the estimates provided and they are based on experiences of ongoing restoration work elsewhere. In addition, the costings do not incorporate general operational costs such as insurances, staff training and sundry expenses. A full and detailed cost estimate would be needed before proceeding with the next stages of restoration.

Examples of expenditure from other countries are available, with one of the largest taking place in Harris Creek, Maryland, USA, having received over 30 million US dollars (USD) (Westby, S. pers. Comm.). Li *et al.* (2019) studied coastal restoration projects in the USA and China between 1992 and 2014 and determined that between the 1,620 projects in the USA, over 665 million USD had been spent on restoration efforts. Less information was available for the 914 projects in China but over 15 million USD had been spent in the Yellow River Delta, 500 million USD spent restoring mangroves in Futian (Guangdong province) and, among other projects, 7 million USD was budgeted to restore coral, mangrove and seagrass habitat in Hainan province

The following options have been based on work conducted around the world, and incorporates methodologies that are can now be considered among the standard practices in the field of oyster cultivation and restoration. It should be noted that although the general principle is similar to case studies from around the world, the techniques, logistics, legalities and other matters may vary within the UAE, and that any activity should take into account the time and resources require to adhere to all legal requirements.

9.1. OPTION 1: SMALL-SCALE COMMUNITY OYSTER RESTORATION

The following option has been based on work conducted in marina environments as part of the Solent Oyster Restoration Project and provides an overview of estimated costs (Table 7). It should be noted that although the general principle is similar, techniques will vary from those used with the European native oyster (*Ostrea edulis*) and associated costs are likely to vary due to numerous factors.

This should be viewed as a small-scale option that can be developed initially as an educational and outreach tool but with the understanding that it will complement larger restoration activities in the longer term. Relying on this option alone is unlikely to enable ecologically meaningful restoration to take place.

Table 7. Financial estimations for Option 1 per annum.

Item(s)	Description	Estimated Costs/annum (£)
Full-time Project Manager	Staff costs	35,000
Full-Time Project Officer	Staff costs	25,000
Technical/Scientific Advisor (part-time)	Staff costs	10,000
Staff personal clothing and safety equipment	Life jackets, knee pads, gloves, safety boots and other protective clothing	500 pp (one off cost) (3x for costings)
Volunteer clothing and safety equipment	Life jackets, knee pads, gloves	150 pp (one off cost) (10x for costings)
Staff Transport and Subsistence	Transport to and from sites Subsistence during site visits	5,000
Conference fees and expenses	Attendance at conferences to present the project findings	1,000
Baseline surveys and subsequent annual monitoring	Mapping and quantifying existing populations of oysters in the restoration areas	70,000
Oyster spat/larvae collection devices	Rope, coupelles or other devices required to allow for oyster recruitment	10,000

Pontoon installations:	One hatch with three attachments	1,000 per installation (15x for costings)
Oyster nurseries	Lantern net, panel net or alternative mechanisms used to suspend oysters beneath pontoons	
Pontoon modifications	Access hatch cut into existing walkways	
	Cross beam and clips inserted beneath pontoons to suspend oysters	
Pontoon signage material	Information boards placed at marina/pontoon entrances to provide information about the project	2,000
Cleaning equipment	Pressure washer or hose and attachments	150
Van hire or van purchasing	To transport oysters, equipment and staff	10,000
Boat costs (including skipper and crew)	To deploy and collect larval collection devices	10,000
Monitoring equipment		10,000
Sourcing, storage and cleaning of shell material		40,000
Project meetings	Room hire for regular working group meetings	2,000
Media and comms		10,000
Educational material	Project leaflets, banners, classroom materials	1,000
Exhibitions and festivals	Project stands at various festivals and exhibitions	500
Equipment servicing	Life jacket servicing	10 per unit
Miscellaneous	Unaccounted items	10,000
	Total	**£270,000-£300,000**

9.2. OPTION 2: LARGE-SCALE OYSTER REEF RESTORATION

The following option has been based on work conducted as part of several project around the world and provides an overview of estimated costs (Table 8). It should be noted that although the general principle is similar, techniques will vary from those used with other species and associated costs are likely to vary due to numerous factors. The costings of various items will be dependent on the scale at which the restorative activities take place.

This should be viewed as a long-term option that can be developed initially as an educational and outreach tool but with the understanding that it will require a longer vision to achieving ecologically meaningful restoration. With supply of native pearl oysters not currently available on a commercial scale it is likely that Option 1 will be required to achieve Option 2.

A comparison can be drawn from the case study of Windara Reef in South Australia, where the phase one pilot study of the project (4ha) received $600,000 AUS of funding in 2014 and phase two larger scale (20ha) deployment received $3.7 million AUS of funding in 2016 over the project timeline (Figure 25). This reef construction took place in an area with a ready supply of oysters from the aquaculture industry and therefore did not incur costs associated with longer term production or collection which would be required for a project in Dubai.

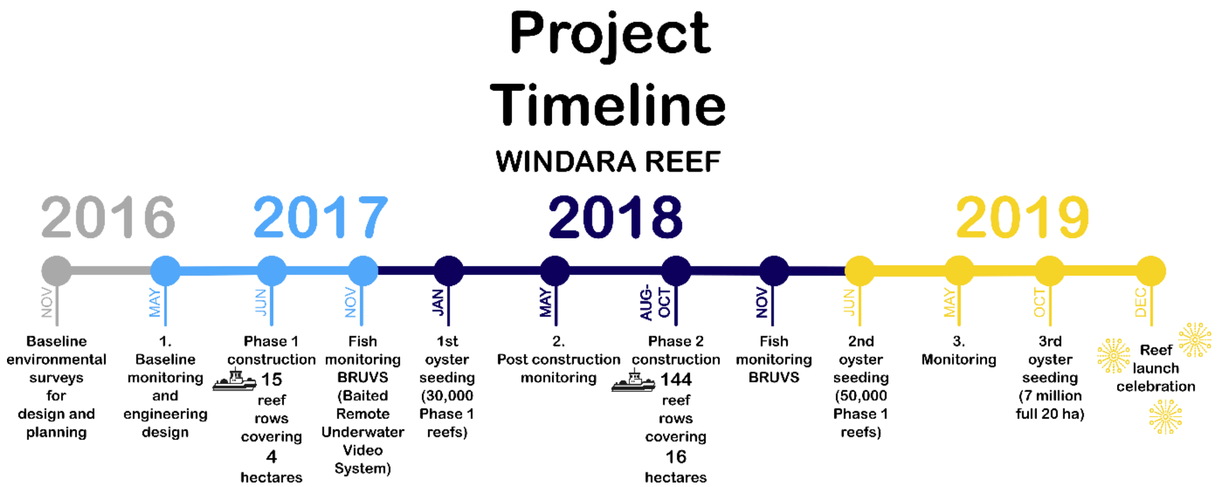


Figure 25. Project timeline for Windara Reef, South Australia. Source: Anita Nedosyko, The Nature Conservancy.

Table 8. Financial estimations for Option 2 per annum.

Item(s)	Description	Estimated Costs/annum (£)
Full-time Project Manager	Staff costs	35,000

Full-Time Project Officer	Staff costs	25,000
Technical/Scientific Advisor (part-time)	Staff costs	10,000
Staff personal clothing and safety equipment	Life jackets, knee pads, gloves, safety boots and other protective clothing	500 pp (one off cost) (3x for costings)
Volunteer clothing and safety equipment	Life jackets, knee pads, gloves	150 pp (one off cost) (10x for costings)
Staff Transport and Subsistence	Transport to and from sites Subsistence during site visits	5,000
Conference fees and expenses	Attendance at conferences to present the project findings	1,000
Baseline surveys and subsequent annual monitoring	Mapping and quantifying existing populations of oysters in the restoration areas	70,000
Oyster spat/larvae collection devices	Rope, coupelles or other devices required to allow for oyster recruitment	10,000
Pontoon installations:	One hatch with three attachments	1,000 per installation (15x for costings)
Oyster nurseries	Lantern net, panel net or alternative mechanisms used to suspend oysters beneath pontoons	
Pontoon modifications	Access hatch cut into existing walkways Cross beam and clips inserted beneath pontoons to suspend oysters	
Pontoon signage material	Information boards placed at marina/pontoon entrances to provide information about the project	2,000
Cleaning equipment	Pressure washer or hose and attachments	150 or; 50

Van hire or van purchasing	To transport oysters, equipment and staff	10,000
Boat costs (including skipper and crew)	To deploy and collect larval collection devices	10,000
Aggregate material	Locally sourced stone that can be deployed in a reef formation to accommodate oysters	500,000
Barge costs (including skipper and crew)	To deploy large amounts of aggregates	200,000
Monitoring equipment		10,000
Sourcing, storage and cleaning of shell material		40,000
Project meetings	Room hire for regular working group meetings	2,000
Media and comms		10,000
Educational material	Project leaflets, banners, classroom materials	1,000
Exhibitions and festivals	Project stands at various festivals and exhibitions	500
Equipment servicing	Life jacket servicing	100 per unit
Miscellaneous	Unaccounted items	10,000
	Total	**Approx. £1 million**

9.3. RECOMMENDED OPTION: SEASCAPE OR ECOSYSTEM RESTORATION

An ecosystem or seascape scale approach involving the restoration of several habitat types is highly recommended to obtain maximum ecological and cultural benefits. Most ecological restoration work worldwide is moving towards a seascape scale and embracing this from the outset will enable restorative work to progress quickly, putting Dubai on the global radar for restorative action.

This level of commitment does require significant financial investment (probably in the tens of millions) and can only be achieved over a long period (likely decades). However, the benefits of such an approach could be phenomenal. Improvements to nutrient remediation, carbon sequestration, water filtration and biodiversity are just a few of the benefits these restored habitats can generate.

Initially, five to ten million pounds (GBP) (approximately twenty-five to fifty million Emirati Dirham (AED) should be invested for the first three years of a project. A similar level of expenditure is required thereafter, until the project goals have been achieved. Regular evaluation would ensure that this investment is being directed appropriately, with adaptive measures taken as and when required.

Numerous project partners could be involved to combine expertise and authority, at the same time enhancing funding opportunities.

The prospect for such a project is extremely exciting.

10.CONCLUSION

There is huge potential for the restoration of coastal habitats in the UAE, especially in and around Dubai.

The approach being adopted globally - based on having a real-world large-scale impact - is that of seascape or ecosystem scale restoration, involving multiple species and habitats to reinstate the connectivity of the coastal environment.

Significant long-term investment and management will be required for restoration to be successful at an ecologically meaningful scale. Expectations for success should be aligned to this time frame, with numerous milestones expected throughout.

Many of the lessons learned and techniques employed in the Solent could be replicated in Dubai, streamlining the overall process and maximising the benefits of activities. The range of ecosystem services that can be improved through restoration aligns with many of the cultural and ecological values of local communities. Project communications should be tailored to increasing local desire for engagement, generating a long-term sense of ownership within the community.

Conversations with critical stakeholders highlighted the strong willingness and enthusiasm for such a project, this should be harnessed to drive efforts forward. Having multiple partners involved in the working group enlarges the total pool of knowledge available and the potential reach of any project.

BLUE's logistical skills, practical experience and overall knowledge in this field could successfully develop a restoration project beyond the feasibility phase, taking real steps to restore a coastline that is in desperate need of intervention. With DP World extremely well positioned to enable this and bring together all relevant stakeholders, a team of experts could be assembled by BLUE to move to the next phase, setting a valuable example for the whole Gulf region. This project could be pivotal for Dubai.

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