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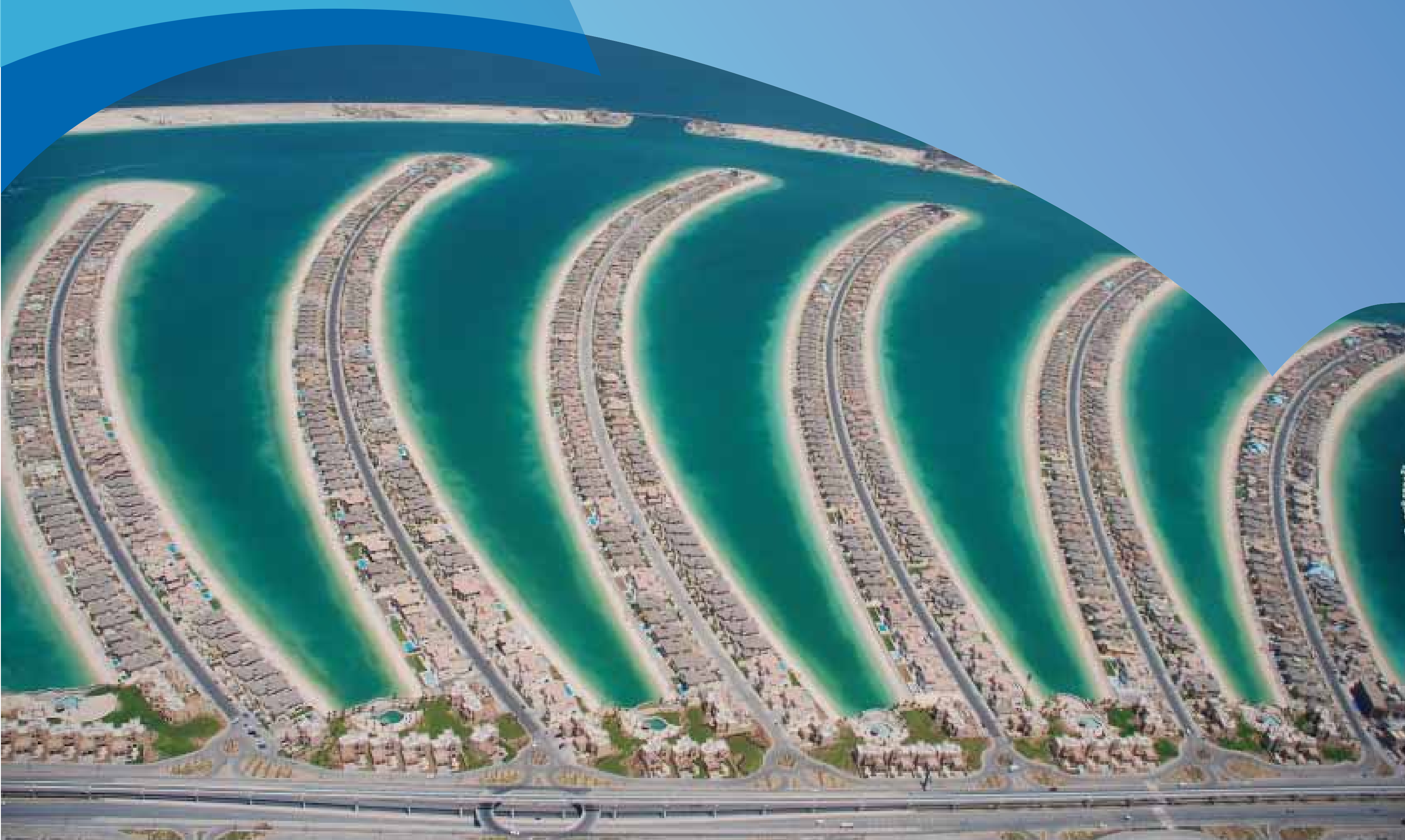
POLICY REPORT

MANAGING THE GROWING IMPACTS OF DEVELOPMENT ON FRAGILE COASTAL AND MARINE ECOSYSTEMS: LESSONS FROM THE GULF

Hanneke Van Lavieren, John Burt, David A. Feary, Geórgenes Cavalcante, Elise Marquis, Lisa Benedetti, Charles Trick, Björn Kjerfve and Peter F. Sale



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FOREWORD

The region around the Persian or Arabian Gulf (simply referred to as the Gulf in this report) has seen remarkable economic and social development in recent years. For example, the scale of development in coastal areas that has occurred in this region is unprecedented and has significantly altered the coastline in many countries. Such development also brings with it numerous opportunities for demonstrating leadership in environmental stewardship and innovations in management of natural resources. This report is an analysis of what these opportunities are and how well the region has responded to them.

We can clearly state the Gulf region has a unique coastal environment, in part influenced by a shallow sea with unusually warm waters. There is scarce information available to date about the human impact on these ecosystems and much less is known about the impacts of global processes like climate change. Overall, there is limited awareness of the importance of ecosystem services drawn from the coastal areas and their significance in sustaining economic growth and human welfare. A manifestation of this limitation is that most countries in the Gulf region have not implemented policies and actions that engender better coastal management. Interestingly, many of these countries have enacted national legislation for marine conservation and have signed various regional and international environmental agreements.

There is a critical gap in the indigenous capacity to understand and respond to the coastal challenges; addressing this gap must be given the highest priority. Such capacity – human, technological and institutional – is crucial for the region to effectively respond to growing competition for coastal resources and potential impacts through human economic activities. It would also reduce the dependence on "imported" technical expertise, which often leads to sub-optimal outcomes. The United Nations system and particularly institutes like UNU-INWEH have been playing a central role in regional efforts to build capacity.

While this report offers a reflection of the coastal challenges on a regional basis, it also draws upon the research work UNU-INWEH undertook through a Dubai-based project entitled Strategic Management of Marine Ecosystems Surrounding the Nakheel Marine Projects (2006-2009). In this unique project, we were able to gather first-hand information about the impact of various anthropogenic stressors – such as pollution, overfishing, risk from invasive species and climate change – when juxtaposed with large-scale off-shore development activities. The data analysis and interaction with a number of institutional partners throughout the Gulf region offered insights into the most important environmental issues currently facing these marine ecosystems. Much of this work has already been published in peer-reviewed journals internationally[1].

We believe that the findings of this report are equally applicable to other coastal regions, although the large-scale coastal developments are so far unique to the Gulf region. Other challenges like rapid urbanization, population growth and intense competition for coastal resources are similar across the board. We must, therefore, invest in better understanding the benefits of healthy marine ecosystems and scale coastal developments accordingly. Improved coastal management will require the adoption of sustainable management approaches, regional coordination and a longer-term holistic outlook. This is as true for the Gulf as it is for any other region.

Dr. Zafar Adeel
Director, UNU-INWEH

[1] e.g., Khan et al. 2002, Al-Jamali et al. 2005, AFED 2009, Hamza and Munawar 2009, Sheppard et al. 2010

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INTRODUCTION

Like many other places in the world, the coastal region of the Persian Gulf (also known as the Arabian Gulf, and hereafter referred to as 'the Gulf') faces continuous environmental degradation. The unprecedented rate and scale of development that has occurred poses numerous environmental challenges and may be the greatest threat facing the Gulf's marine communities in the coming decades as urban populations along it's shores continue to grow. Some Gulf countries have already developed more than 40% of their coastline during the last 20 years. Pressure on coastal ecosystems is especially high in the smaller Gulf countries of Bahrain, Kuwait, Qatar and the UAE, where residents either live entirely, or almost entirely within 100 km of the coast. Development has led to loss and severe degradation of important natural habitats, including mangroves, seagrass beds, and coral reefs. Coastal 'mega-projects' including artificial islands, waterfront cities, ports, marinas and man-made waterways have sometimes been poorly conceived from an environmental perspective, leading to severe pressure on natural environments. Because development has taken place so rapidly there has not been enough time to develop adequate regulatory, technical, and monitoring capacity to guide this growth appropriately. Present trends suggest that development will not be accompanied by appropriately sophisticated policies and mechanisms for minimizing and mitigating deleterious impacts on the environment.

Integrated management plans need to be developed that are forward looking and protect vital coastal ecosystems while permitting economic growth and ensuring a better quality of life for all coastal dwellers. Several Gulf countries are in a unique position to make better choices given the current leadership and availability of financial resources. An excellent opportunity exists for one or more of these nations to provide leadership for a bold, collaborative, comprehensive and long-term initiative for holistic management of the Gulf's coastal ecosystems.

WHY ARE WE INTERESTED IN THE GULF?

The relatively recent economic and social prosperity that the Gulf has experienced, thanks largely to the discovery of oil and a growing tourism industry, has led to a profound transformation from impoverished small desert principalities to ultra-modern nations with expanding coastal cities. The countries bordering the Gulf have an annual growth rate of 2.1%, nearly double the world average of 1.1%. Some of the richest countries in the world are found in this region, including Kuwait, Qatar and the UAE, and no other area in the world has experienced this extent of coastal manipulation in such a short time frame.

The extreme oceanographic and meteorological characteristics that are found in the Gulf have created a unique marine environment with ecosystems that may be resilient to some stressors, but are low in species diversity and particularly sensitive to certain anthropogenic impacts. The unique nature of the Gulf's coastal habitats and their economic importance to communities has not been well appreciated, and coastal development combined with pollution, habitat destruction, and over exploitation of marine biological resources has contributed to their degradation and loss. For example, 70% of original reef cover in the Gulf may be considered lost and a further 27% threatened or at critical stages of degradation.

Exploitation of abundant oil and gas reserves has allowed Gulf nations to undergo unprecedented economic prosperity and population growth, but at a pollution cost. The oil industry has been the primary driver of development in the Gulf region since the 1930s. The high concentration of offshore oil installations, tankers and terminals has made the Gulf's marine and coastal ecosystems some of the most threatened in the world by oil pollution.

Fishery products are, next to oil, the second most important natural resource in this region and the most important renewable resource, yet fisheries stocks are poorly managed and overexploited. Trade in fishery products in the region accounted for US$ 996 million in 2007, and commercial fishing (including aquaculture) employs some 250,000 people in the Gulf region while accounting directly or indirectly for the livelihoods of one million people.

MAJOR THREATS TO THE GULF'S MARINE AND COASTAL ENVIRONMENTS

Behind the glittering skyscrapers: impacts of coastal development

While rapid economic development and population growth have brought widespread prosperity to this region, rampant coastal development has transformed shallow and productive marine habitat into land for homes, recreation and industry, introducing a variety of anthropogenic stressors to the Gulf's natural environment. Growing coastal populations have been accompanied by new infrastructure for manufacturing, transportation, energy processing and consumption, as well as for waste disposal. Relatively little information exists on the short and long-term environmental effects of coastal mega-projects, although it is known that they can result in the creation of novel marine environments previously not seen in the Gulf.

The Gulf region contains the largest man-made islands in the world and this poses numerous environmental challenges. Without good planning and careful consideration for existing coastal features, hydrodynamics and offshore bathymetric conditions, the consequences of such development can be severe and long lasting. Research results from detailed studies conducted by UNU-INWEH during 2006-2009 on off-shore developments in Dubai, UAE, have led to the following conclusions concerning large reclamation mega-projects:

- With appropriate design, breakwaters can act as engineered artificial reefs supporting diverse benthic communities with demography and growth rates comparable to natural reefs. Artificial habitats cannot replace natural ecosystems, but may help mitigate habitat loss and other impacts caused by coastal development;
- Fish abundance and species richness may become higher on breakwaters when compared to surrounding natural reefs, but species composition will differ;
- The direct (burial) and indirect effects of sedimentation and changes in water quality associated with intense development impacts natural reefs substantially. Remaining reefs in the Gulf are likely to degrade or disappear entirely within the next decade unless aggressive steps are taken to ameliorate the impacts of development;

- Dredge and fill procedures not only cause sedimentation and turbidity during periods of construction, but also many years afterwards because of re-suspension of fine sediment;
- Specific design aspects of island development need to be closely evaluated prior to construction to limit negative impacts on water and habitat quality. The widespread preference for designs featuring blind channels that lead to poorly circulating water create a potential risk for eutrophication, anoxia or algal blooms in and around artificial islands.

The loss of productive natural coastal habitat and associated marine life as a result of development is a major environmental issue facing the Gulf today. Coastal development and associated pollution can potentially alter or damage important near shore habitats, disrupt vital ecological pathways and cause permanent loss of nursery grounds for commercial shellfish and fish species. The majority of coastal developments have been constructed with dredged material and there is limited knowledge of the magnitude and scale of potential ecological impacts. However, dredging and disposal of dredged material can lead to decreases in water transparency, increases in suspended matter, and higher rates of sedimentation. Dredging can also remobilize and redistribute contaminants from sediments which may (re)enter vital food webs.

Extensive dredging can significantly alter near-shore bathymetry and sediment distribution while artificial islands can permanently modify water movement and sediment transport; the extent and nature will vary according to island shape and orientation. Coastal development can have a substantial impact on natural patterns of water movement, transport of materials as well as water quality. Careful consideration should be given to existing coastal features, hydrodynamics and offshore bathymetric conditions in planning new coastal projects.

The speed at which development is occurring has already outpaced the ability of some Gulf countries to adequately improve and expand the existing infrastructure for waste management. Large quantities of discharged wastewater substantially heighten the risk of contamination through industrial, agricultural and domestic effluents. Furthermore, increased water use has led to an increase in freshwater flow (and associated materials) re-entering the Gulf, mostly as un- or partially treated wastewater. While the majority of locally produced sewage receives either secondary or tertiary treatment in most GCC countries, untreated and unused treated wastewater is still dumped directly into the Gulf, riverbeds and wetlands, and eventually infiltrates shallow aquifers and enters coastal waters. The physical characteristics and semi-enclosed nature of the Gulf provides ideal conditions for accumulation of pollutants and may even create a 'pollutant trap'. Wastewater from sources such as agriculture, livestock facilities, petrochemical industries, metal and non-metal industries and desalination plants carries toxic compounds (e.g., heavy metals and oil compounds) which eventually get deposited into marine sediments.

In most GCC countries, land available for development is scarce; hence creation of comprehensive land use plans that balance conservation and growth objectives are necessary. Appropriate planning, waste management, and pollution prevention and control are important strategies to minimize the adverse impacts of development on coastal ecosystems. Formal water quality monitoring programs are essential, measures should be taken to prevent or minimize the discharge of pollutants into Gulf waters, and clear policies, guidelines and standards for pollutants should be developed.

Water for energy; energy for water

The Gulf region has one of the greatest demands in the world for power generation and clean freshwater due to rapid population and industrial growth. The resulting volume of wastewater and contaminated effluent brine that is produced is enormous. Of the Gulf's inhabitants, 70 to 90% depend on desalination plants for their freshwater supply and 45% of the world's desalination capacity is found here. Effluents from these plants may adversely affect water quality and aquatic life. Also, predicted increases in freshwater demand means that more desalination plants will be needed, resulting in an increase in discharges. These should be minimized by careful site selection, reducing the use of chlorine in the desalination process (by using less harmful alternatives), and by treating or disposing of wastes properly. With current climate change trends, governments in the Gulf will have to make tough choices and trade-offs on how to manage water resources.

All GCC nations exceed the world average of energy consumption per capita, and the demand for energy has doubled over the last decade due to rapid population growth and urbanization, increasing affluence, and diversifying, but still energy-intensive economies. All this comes at a great environmental cost. High energy consumption rates are driven by subsidies and low usage costs. Nearly 100% of the energy consumed is derived from fossil fuels; five Gulf countries rank among the world's top 50 emitters of carbon dioxide while four have reached the world's top ten list in terms of ecological footprint. Not surprisingly, CO_2 emission rates in the Gulf are more than 3 times greater than the world average. This contribution to global warming has an indirect impact on marine ecosystems throughout the Gulf.

Other anthropogenic stressors on the Gulf's coastal and marine ecosystems

Oil exploration, production, and transport, along with military activities, have been major contributors to pollution in the Gulf. Available information shows that overall, there are persistently high levels of hydrocarbon pollution throughout the Gulf, predominantly along the Iranian coastline. Although some regional and international agreements are in place and have abated oil pollution resulting from transport, exploration and exploitation activities, other sources still pose a risk as they have not been adequately addressed. Limited data are available on the levels of oil pollution originating from land based sources, but with current rates of population growth and increased industrialization it can be expected that levels have only increased.

Given the size of the oil and gas industry in the Gulf, and the potential risk to marine ecosystems from their operations, there should be opportunities to build public/private partnerships that undertake effective research and management initiatives that conserve

Main fish landing site in Abu Dhabi. Credit: Edwin Grandcourt

marine environments while facilitating industrial activities. The full potential of the private sector in this region has yet to be tapped, despite some recent private and public/private initiatives.

Despite existing regulations governing fishing effort in the Gulf, this activity has not been controlled. Many fishery species are in peril due to overexploitation. Environmental degradation and habitat loss caused by coastal development is compounding this threat as it has led to the elimination of important nursery areas for a number of fish species. Overexploitation is mainly due to inadequate enforcement of law, inappropriate management practices and lack of effective transnational policies or global catch limits. The population status of fishery species is difficult to assess due to a lack of consistent data. Policy frameworks are often oriented towards economic development rather than sustainability. Given the multitude of threats facing the Gulf's fish populations, a paradigm shift in the approach to fisheries management is needed.

Growth of marine aquaculture in the Gulf is inevitable given that wild fish stocks are overexploited and the demand for fishery products is increasing rapidly along with human population. The fact that this industry is not yet fully developed provides a unique opportunity for Gulf countries to adopt responsible and sustainable aquaculture methods. There is good potential for aquaculture growth in this region (and it is being encouraged in Bahrain, Qatar, and Kuwait), but current commercial activity is limited. Each country has its own constraints in developing aquaculture, but commonly encountered problems include limited availability of suitable sites, insufficient freshwater resources and lack of endemic marine fingerlings. An expanding marine aquaculture industry will place increasing pressure on already vulnerable ecosystems and native species via pollution, destruction of sensitive habitats, and threats to aquatic biodiversity. New aquaculture initiatives need to be accompanied by comprehensive legal frameworks that regulate activities, adequately conducted EIAs, coordinated research, risk assessments and standard operating procedures.

The introduction of non-native aquatic species to new environments via ballast water is considered one of the greatest threats facing the world's coastal and marine environments. The high shipping traffic in the Gulf means that invasive species potentially pose a high environmental and public health risk. At present, the vast majority of discharged ballast water is untreated and released directly into the Gulf, and other human activities have also accelerated the potential spread of non-native species, e.g., via sewage discharge and aquaculture facilities. Proactive development of transnational policies and regulations to control ballast water discharge in the Gulf is highly advisable. Documented reports of non-native species invasions are limited, and such species may have had limited success because they are not able to survive the naturally extreme environmental conditions that occur in this body of water. Alternatively, the absence of reported occurrences may simply be a result of infrequent environmental monitoring – there is a pressing need for more attention to this matter.

MITIGATING THE IMPACTS OF CLIMATE CHANGE

Countries in the Gulf are among the most vulnerable in the world to the potential impacts of climate change. Projected increases of 2 to 5.5°C in air temperature coupled with a projected decrease in precipitation by the end of the 21st century will lead to shorter winters, hotter and dryer summers, increased weather variability, and more frequent extreme weather events. Although rainfall is predicted to decrease and become more erratic in most Gulf countries, certain models predict increasing precipitation for Bahrain, Qatar, the UAE, and some parts of Oman. This precipitation could lead to a higher risk of flash flooding, erosion, aquifer recharge and storm-water discharge into vulnerable coastal marine systems. Research has shown that Gulf sea surface temperatures have been increasing at a substantially higher rate than the global average of 0.2°C/decade due to the additive effects of local and regional drivers (including oceanographic circulation, wind, freshwater discharge from rivers, and regional dust storms).

The highly populated and predominantly sandy, easily erodible and low lying coastal Gulf countries are especially vulnerable to the impacts of sea level rise through direct inundation, erosion and salt water intrusion. The IPCC estimates that with rising global greenhouse gas emissions and associated warming, global sea levels could rise by 1 to 3 m within this century. Sea level rise will affect each country differently, but studies have predicted that most of the Gulf's coastal areas will be extensively inundated and large parts of shorelines will migrate inland. Qatar and the UAE will be particularly susceptible and other small Gulf countries (Bahrain and Kuwait) are also at risk.

Climate change impacts, especially warming, will place added stress on marine communities in the Gulf, and are likely to result in significant economic costs through impacts on fisheries and aquaculture. The Gulf contains a unique community of organisms that are adapted to withstanding extreme environmental conditions, but natural tolerance to warm temperatures may not be sufficient to endure an increasingly warmer climater. The degree to which Gulf fish communities will be affected by temperature and other environmental changes likely to occur because of climate change remains unclear and further research is needed.

The world, Dubai, UAE. Credit: Hanneke Van Lavieren

Gulf countries need to take urgent action to prepare for the potential impacts of climate change on coastal areas and resources. Encouraging sustainability could begin by addressing the drivers of climate change, e.g., cutting carbon emissions, curbing water use, reducing energy demand, and promoting renewable and environmentally friendly sources of energy. The Arab Forum for Environment and Development (AFED 2009) has stated that virtually no effort has been made to prepare Gulf countries for anticipated climate change challenges. Reliable records on climate patterns in the region are limited and land use and urban planning regulations largely ignore basic adaptation requirements that have been adopted by other nations.

Increased scientific knowledge and greater capacity within the field of climate change is needed to create sound national and regional strategies for adaptation which in turn are incorporated into national and regional development plans. Improved proactive planning, risk assessment, and integrated coastal management (ICM) are needed to increase the resilience of coastal ecosystems to climate change impacts. Policy makers must ensure that climate change adaptation strategies are main-streamed within national development plans are mainstreamed, that there is sufficient political and financial support for climate adaptation measures, that relevant regulations are enforced, and that National Communication reports are submitted regularly to the UNFCCC.

Gulf countries should further commit themselves to adopting national energy efficiency and renewable energy targets and promote the development and use of alternative and renewable energy sources and clean technologies. Incentives should be given to builders, owners and tenants to adopt efficient technologies and appliances to cut energy use. The concept of 'green building' should also be promoted. Some Gulf countries are already implementing various climate friendly policies and measures, with significant research and investment into renewable energy.

CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE COASTAL MANAGEMENT IN THE GULF

We do not take care of that which we do not value. In order to develop effective policies and instruments for management of coastal ecosystems, it is necessary to understand and measure their total value and incorporate this into policy design. The Gulf is of considerable economic importance to the countries that share it, yet there is a general lack of appreciation for its value or recognition of the potential deleterious impacts it faces from coastal development and other anthropogenic stressors. The direct economic value of shipping, and to a lesser extent fisheries, is substantial, with tourism continuously growing in importance in some locations. As a result of persistent undervaluation coupled with lack of awareness, these ecosystems have drawn low investment or even worse, public policies and investments that are channelled into initiatives which promote environmentally inappropriate development. Governments and industry must recognize that the economic value of coastal tourism depends fundamentally upon the presence of healthy marine ecosystems and attractive coastal waters.

Economic prosperity, rapid population growth, and increased utilization of the Gulf are exacerbating a pronounced lack of capacity to provide informed and effective environmental management. There needs to be a concerted effort by committed Gulf leaders to involve the international research community and build effective, long-term collaborative relationships with regional and local universities, so that local expertise in environmental science can be developed. Despite the great wealth of GCC nations, their scientific deficit is substantial both in terms of research activity and advanced education, i.e., few scientists, minimal research funding and limited research output. Only 25% of the college age population enrolls in tertiary education, and educational opportunities in environmental fields, and particularly in marine science, is limited. The tendancy to import technically skilled foreign workers on a temporary basis for specific projects has resulted in environmental issues not receiving the long term attention they deserve.

Female students planting young mangrove trees on Palm Jebel Ali in Dubai. Credit: Ken Drouillard

Gulf countries rank lowest in the world in terms of the innovation and scientific research index, an unsurprising result given the minimal expenditure on scientific research in this region (as percentage of GDP). A stronger science culture within environmental agencies is needed together with the creation and/or strengthening of monitoring programs and scientific databases, preferably at a regional scale. This will require a commitment from governments to increase the funding available for monitoring and research. Regular dissemination and sharing of these data is also needed. Environmental research and monitoring requires the use of standard tools and methodologies to collect data so that comparisons can be made and so that trends are visible.

There is an urgent need in the Gulf region for an Environmental Impact Assessment (EIA) process which is scientifically rigorous, transparent, and applied by regulatory agencies which have the capacity to enforce decisions and ensure compliance. Present use of EIA procedures for near- and off-shore coastal development projects is inadequate due to a range of factors that are also prevalent in many other regions. The general lack of adequate legal and regulatory frameworks, as well as poor institutional arrangements for EIA processes, means there is little incentive for developers in the Gulf to submit EIAs or to undertake effective monitoring or mitigation. Other shortcomings include poor environmental scientific capacity and a lack of accessible environmental data, which are both compounded by the rapid pace of coastal development. The 'baseline' in Gulf EIAs is usually taken from already severely degraded marine ecosystems, and they often comprise little more than a snapshot survey taken over a few days. EIAs often fail to incorporate possible cumulative impacts of nearby coastal development projects in the planning or early construction phases. Public consultation is weak and generated information is often kept confidential. Without public scrutiny, and with weak regulatory procedures, most EIAs are ineffective because assessments are often superficial, based on weak data, and any required mitigation is forgotten both by the developer and the regulatory agency.

Some examples exist where countries in the Gulf have taken steps to mitigate environmental impacts of development projects and increases in marine productivity have been observed. In Kuwait and Qatar, multidisciplinary approaches and design teams including marine civil engineers, oceanographers, architects and biologists have helped limit the negative environmental impacts of certain coastal developments. Such approaches should be given high priority in future deliberations for coastal planning and management, especially taking into account the trend of unsustainable and damaging coastal development that has occurred over the past 15 years.

Gulf nations could substantially improve coastal management and conservation by strengthening the enforcement of regulations governing existing marine protected areas (MPAs). The number of MPAs and the amount of area protected varies considerably among Gulf countries. Of the existing MPAs, only a few have management plans that zone areas of conservation, recreation and development, and enforcement is generally minimal. Considering that the overall health of many coastal ecosystems is at record low levels in the Gulf, MPAs that forbid human activity (strictly protected areas or sanctuaries) may be the only tool left to protect remaining critical areas of coral reefs, seagrass beds and mangroves.

Communication and public awareness are vital components of successful coastal management because they build consensus and support for sustainable management initiatives, and they help engage the public in the decision-making process while also ensuring that government is responsive to environmental needs. The public in this region is generally poorly informed concerning the value of healthy and sustainably managed environments, or the possible impacts that various activities can have on their well being and the health of the environment. It is far too soon to tell if the democratic awakening in this region will to lead to more effective discussion and evaluation of environmental issues, but this could be one significant positive outcome in the future.

MOVING FORWARD: TOWARDS SUSTAINABLE MANAGEMENT OF THE GULF'S COASTAL ENVIRONMENT

Current management strategies in the Gulf are ineffective and not sufficient to ensure the future health of its marine and coastal resources, and given the situation now in place, decision makers will need to take major steps to make any improvement. Although it is true that some countries are performing better than others, each faces similar environmental challenges, especially those facing rapid population growth and coastal development. The fact that governance in the Gulf is characterized by a strongly centralized decision-making process, which limits public participation and places the entire responsibility of environmental protection on government and its agencies, is a significant barrier to overcome.

Effective governance requires sound policies implemented by well-established regulations and procedures, backed up by enforced law. Effective management requires good governance. Gulf nations are party to several regional and international agreements for protection of the marine environment that provide guiding principles for environmental protection and conservation. However, their effectiveness in building sustainable management is questionable and the implementation and enforcement of current agreements requires strengthening. Also, some global and regional agreements cover aspects of development in some way, but coverage is incomplete and incoherent. Furthermore, no existing agreement clearly addresses coastal development issues such as dredging or construction near artificial islands.

At the national level, coastal development should be regulated under the jurisdiction of a single lead agency, and be backed up by integrated, comprehensive and clear laws and policies. Very little existing legislation at the national level is directly linked to coastal development. Instead, fragmented jurisdictions responsible for regulating the development and management of coastal areas has lead to short term, incoherent and small-scale planning, and to development projects that are unsustainable and often improperly structured.

The stated desire of several Gulf leaders to support environmentally sustainable development would be substantially confirmed if they were to initiate a comprehensive, effective, long-term and collaborative environmental management program for the Gulf. To achieve a holistic and integrated approach, countries that share this body of water need to develop a common understanding of anthropogenic threats and establish a shared vision of the strategic importance of the Gulf's habitats and resources. The current lack of cooperation and information exchange means that ecosystem protection and management, as well as assessment of coastal development impacts, are still beyond the priorities and economic agendas of governments in this region. Nevertheless, there are several regional governmental organizations which could facilitate the coordination of policies and cooperation relevant to marine conservation.

An aerial view of Palm Jumeirah, UAE. 2010. Credit: Geórgenes Cavalcante

1 INTRODUCTION

Over two-thirds of the world's largest cities are coastal and nearly 2.2 billion people, or 39% of the world's population, live within 100 km of a coastline (WRI 2001, LOICZ 2002, Duarte et al. 2008). The human burden on coastal ecosystems will increase dramatically within the coming decades (Martinez et al. 2007) as the global population grows from 6.8 to 9.2 billion by 2050, assuming that current urbanization and demographic trends continue (Duxbury and Dickinson 2007). Our coasts have already undergone massive alteration (Airoldi et al. 2005, Burt et al. 2011a) and it is predicted that as much as 91% of all temperate and tropical coasts will be heavily impacted by development by 2050 (UNEP 2008).

The Persian Gulf (also known as the Arabian Gulf[2], and hereafter referred to as 'the Gulf') region is no exception with respect to coastal development. Located in the Middle East, this body of water is bordered by the nations of Iran, Iraq, Kuwait, Saudi Arabia, Bahrain, Qatar, the United Arab Emirates, and Oman (Figure 1). The marine and coastal zones of the Gulf are an integral part of the natural and cultural heritage of these eight countries. However, rapid population growth and associated development over recent decades has altered natural coastal hydrodynamics and has led to severe loss and degradation of important habitats, including mangroves, seagrass beds, and coral reefs (Burt et al. 2008, Sheppard et al. 2010, Sale et al. 2011). The ambitious coastal 'mega-projects' (Box 1) that have been created in this region, including artificial islands, waterfront cities, ports, marinas and artificial waterways, are of an enormous scale, but often poorly conceived from an environmental perspective. The consequent pressure on natural environments has been severe.

In this hot and arid region, marine ecosystems are subject to extreme physical conditions, including high temperatures and salinity, to which they have adapted. This may make them more resilient to some stressors, but this harsh environment has left them low in species diversity compared to other parts of the world. Also,

The Gulf region contains the largest man made islands in the world; this poses numerous environmental challenges (Palm Jumeirah island, Dubai, UAE, 2007). Credit: Imre Solt, Dubai Constructions Update (www.imresolt.com)

[2] This body of water is referred to as both the 'Persian Gulf' and the 'Arabian Gulf', while alternate names provoke controversy. In this document we refer to it as 'the Gulf' (as has been done in a number of scientific publications) because the need to manage our impacts on its environment is far more important than its name. For more information on naming disputes and legal decisions in this region please refer to: http://en.wikipedia.org/wiki/Persian_Gulf_naming_dispute

the Gulf's shallow nature, limited freshwater inflow, and high evaporation rates, especially when considered in the context of likely climate change impacts (IPCC 2007a), make it one of the most fragile ecosystems in the world. There is sufficient cause to believe that marine ecosystems in the Gulf may be particularly sensitive to anthropogenic impacts and especially to the scale of coastal development that has been taking place over the last decades.

Integrated management plans need to be developed that are forward looking and that protect vital coastal ecosystems while permitting economic growth and ensuring a better quality of life for all coastal dwellers. Continued denial of the problems will only make the solutions more difficult to achieve. Several Gulf countries are in a unique position to make better choices given the availability of financial resources and current leadership, and an excellent opportunity exists for one or more of these countries to provide the leadership for a bold, collaborative, comprehensive and long-term initiative for management of the Gulf's coastal ecosystems.

Box 1. What is a 'mega-project'?

Although there is no single globally accepted definition, a **'mega-project'** can be described as follows: a large scale (typically complex) public or private infrastructure project that costs in excess of 1 billion US$, and results in extensive transformation of affected landscapes and ecosystems, and therefore potentially poses a significant risk to the continued production of environmental goods and services. Mega-projects are frequently perceived as national icons of development, critical to the delivery of national and regional development strategies. Across the world more and bigger mega-projects are being planned and built, often with poor performance records in terms of financial and environmental costs and benefits.

Gulf Population Density – 2005

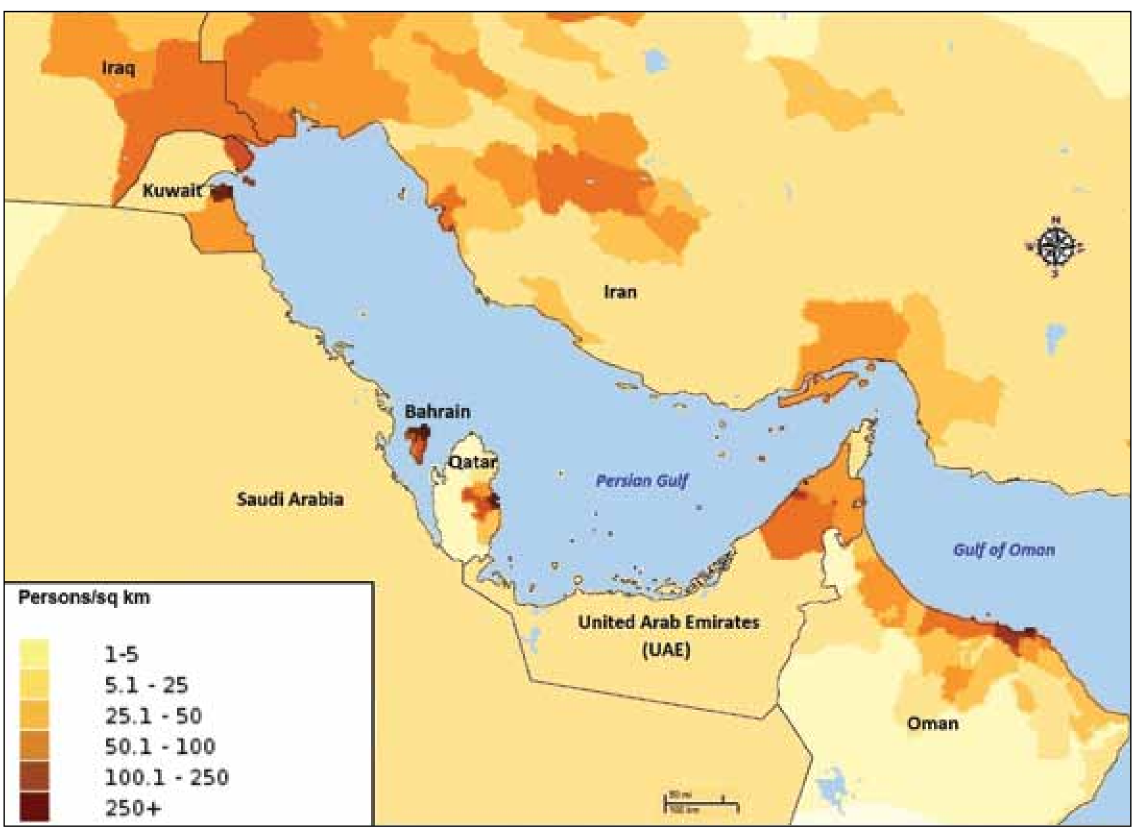

Figure 1. Population density of countries within the Gulf region (Source: CIESIN 2005).

2 WHY ARE WE INTERESTED IN THE GULF?

CHANGING COASTAL POPULATIONS: UNPRECEDENTED PACE OF GROWTH AND DEVELOPMENT

Coastlines in the Gulf region have undergone tremendous change over the last decades as a result of population growth, urbanization and industrialization. No other area in the world has experienced this level of coastal manipulation in such a short time frame. The Gulf is anthropogenically one of the most highly impacted regions in the world (Halpern et al. 2008). The United Nations estimates that the total population of countries bordering the Gulf approached 149 million[3] in 2010, and is estimated to grow to 164 million by 2015 (CIESIN 2005). This represents an annual growth rate of 2.1%, nearly double the world average of 1.1%. The relatively recent economic and social prosperity that the Gulf has experienced, thanks largely to the discovery of oil and a growing tourism industry (Khan 2007), has led to a profound transformation from impoverished small desert principalities to ultra modern nations with great wealth. For example, oil and gas have helped Qatar attain the highest per capita income and the fastest growing economy in the world (GDP per capita) (CIA 2010, IMF 2010); Kuwait and the United Arab Emirates (UAE) are among the richest countries in the world; and Bahrain not only has one of the world's fastest growing economies but is also one of the ten most densely populated countries (Figure 1, 2a, 2b; IMF 2010, UN DESA 2010).

In a very short time frame, the Dubai coastline has been transformed from a mostly deserted beach front with small fishing communities to mile high structures, billion-dollar resorts and man-made mega islands. Similar changes are happening in most other Gulf nations.
Credit: Hanneke Van Lavieren

Rapid coastal development is projected to pose the greatest threat to marine communities in the coming decades as urban populations along the Gulf's shores continue to grow (Khan 2007, Sheppard et al. 2010). Present trends suggest that rapid development will not be accompanied by appropriately sophisticated policies and mechanisms for minimizing and mitigating deleterious impacts on the environment. In a region with some of the richest countries in the world, development has not been limited by lack of finance. Population growth and associated development have placed enormous pressure on coastal ecosystems, especially in the smaller Gulf countries of Bahrain, Kuwait, Qatar and the UAE, where residents either live entirely or almost entirely within

[3]This number includes the total populations of Iran, Iraq and Saudi Arabia, whereas only a part of the population in these countries lives along the Gulf coastline.

100 km of the coast (Figure 2c; Table 1 in Appendix 1). A number of Gulf Cooperation Council (GCC) countries have already developed more than 40% of their shores during the last 20 years to accommodate growing populations (Price and Robinson 1993, ROPME 2003). Building ambitious coastal mega projects has become a part of the development strategy for each GCC state (Table 1; Aldamarki, 2008) that is predominantly geared towards creating investment opportunities, marketing as popular luxury shopping and holiday destinations, and maximum economic growth. This comes at a high environmental cost as these mega projects are adding substantial coastline and beach front property and leading to the degradation and loss of much natural habitat. For example, Sabah Al-Ahmad Sea City (formally known as Al-Khiran Pearl City) in Kuwait, a new city that is being built by excavating low lying, hyper-saline, environmentally impoverished salt flats to create lagoons and islands, will add 6.4 km^2 of land once completed (Table 1). At the completion of this project well over 200 km's of beach front will be added to the original coastline. Similarly, Bahrain expanded its land area by 91 km^2 for industrial, recreational and residential purposes; representing an increase of 11% of Bahrain's original land area of 668 km^2 in 1963 (Zainal 2009). Over the past decade (1999 – 2010) the coastline of Qatar doubled from 563 (CIA 2010) to 1,239 km (Qatar University GIS department). Once completed, four man-made coastal mega-islands (by the developer Nakheel) in the UAE will add 439 km of shoreline (Table 2 in Appendix 1) and approximately 120 km^2 of land (Table 1). The unprecedented rate and scale of development poses numerous environmental challenges. Because development has taken place so rapidly there has not been enough time to develop adequate regulatory, technical, and monitoring capacity to guide this growth appropriately. Furthermore, governments within the Gulf have so far failed to establish clear and effective policies to address the mounting environmental costs associated with this growth.

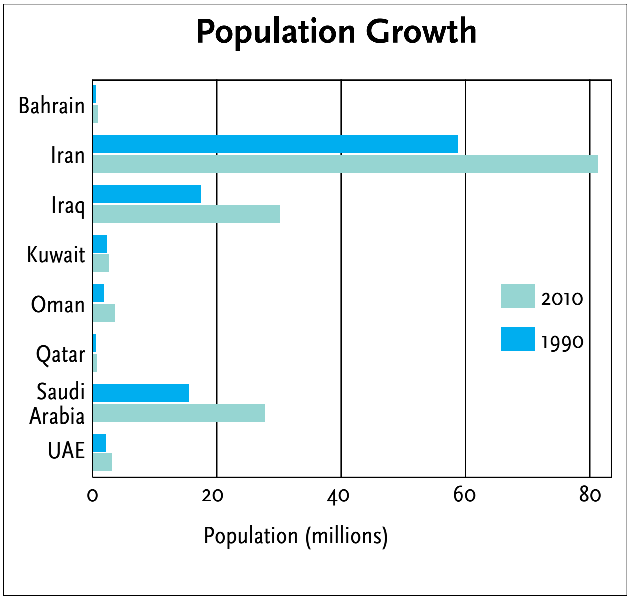

Figure 2a. Total population increase (millions) in the Gulf region from 1990 to 2010. Source: http://esa.un.org/wup2009/unup/

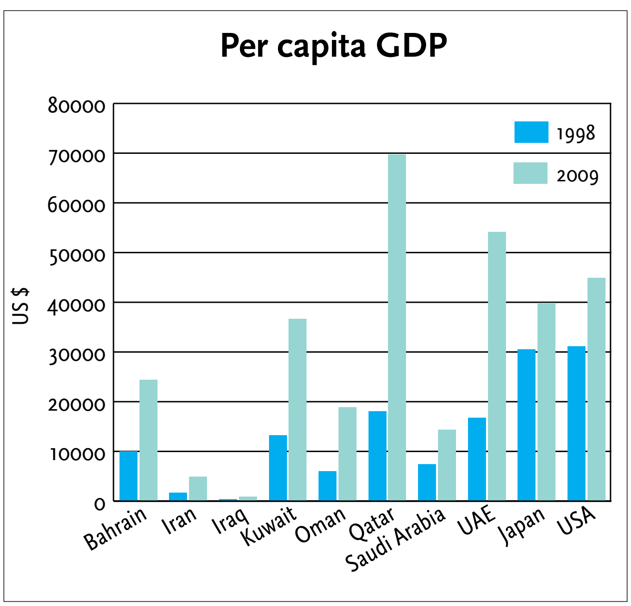

Figure 2b. Increase in GDP (US$) per capita for Gulf nations between 1998 and 2009 (USA and Japan are included for comparison). Source: http://unstats.un.org/unsd/snaama/dnllist.asp

A UNIQUE AND THREATENED COASTAL ENVIRONMENT

The Gulf's extreme oceanographic and meteorological characteristics have created a unique marine environment that is relatively low in species diversity. This region is dominated by some of the most arid coastlines in the world and marine ecosystems in southern parts of the Gulf are characterized by extreme temperatures and salinity levels because of the Gulf's shallow nature (<30 m depth), its relatively small size (226,000 km^2) and restricted water exchange with the Indian Ocean. The Gulf itself stretches 990 km, its width ranges from 56 (across the Strait of Hormuz) to 338 km, and it contains 7,000 to 8,400 km^3 of seawater (El-Gindy and Hegazi

Table 1. Large-scale near-shore coastal developments completed and/or in progress (desalination and power plants not included) for GCC countries. Note: This table is based on the best available information from web sources and may contain incomplete and/or incorrect information.

<table>
<tr><th rowspan="2">Country</th><th rowspan="2">Coastal Development</th><th rowspan="2">Size of Development</th><th rowspan="2">Project Type</th><th colspan="2">Project Status</th><th rowspan="2">Sources</th></tr>
<tr><th>Start Date</th><th>End Date (e = expected)</th></tr>
<tr><td rowspan="8">Bahrain</td><td rowspan="2">Water Garden City</td><td rowspan="2">2.2 km^2</td><td rowspan="2">The city will include residential units, a beach park, a marina, schools, commercial spaces, retail outlets, and leisure facilities</td><td>2010</td><td>2020e</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">Durrat Marina</td><td rowspan="2">3 islands: total of 0.6 km^2</td><td rowspan="2">Mixed use: 400-berth marina, retail, residential (4,000 households) and public spaces</td><td>2008</td><td>2014e</td><td rowspan="2">1,2</td></tr>
<tr><td colspan="2">Completed ahead of schedule</td></tr>
<tr><td rowspan="2">Durrat Al Bahrain (Figure 3)</td><td rowspan="2">20 km^2</td><td rowspan="2">Mixed use: residential, commercial, tourist</td><td>2009</td><td>2015e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Dredging completed in 2007</td></tr>
<tr><td rowspan="2">Diyar Al Muharraq</td><td rowspan="2">12 km^2</td><td rowspan="2">Mixed use: 30,000 residential units to accommodate 100,000 residents</td><td>2010</td><td>2020e</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="4">Kuwait</td><td rowspan="2">Sabah Al-Ahmad Sea City (formally Al-Khiran Pearl City)</td><td rowspan="2">6.4 km^2</td><td rowspan="2">Mixed use: residential</td><td>2010</td><td>2022e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">25 years until completion</td></tr>
<tr><td rowspan="2">Failaka Island</td><td rowspan="2">24 km^2</td><td rowspan="2">Mixed use: holiday resort, hotels, shops, and restaurants</td><td>2010</td><td>2015e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">On hold and facing delays</td></tr>
<tr><td rowspan="6">Oman</td><td rowspan="2">Al Duqm Port – Marine Works</td><td rowspan="2">Breakwater: 7.7 km
Quay: 2.8 km</td><td rowspan="2">New port complex</td><td>2007</td><td>2012e</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">Port of Salalah Expansion</td><td rowspan="2">Additional 1.2 km (not specified what is added)</td><td rowspan="2">Expansion of the General Cargo Terminal including multi-purpose berths, new breakwater, liquids jetty and related facilities</td><td>2010</td><td>2012e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Expansion took place numerous times and still ongoing</td></tr>
<tr><td rowspan="2">Al-Madina Azarqa (Blue City)</td><td rowspan="2">34 km^2</td><td rowspan="2">Blue City will include residential, commercial and business clusters; and a university with capacity of 10,000 students.</td><td>2005</td><td>2020e</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="22">Qatar</td><td rowspan="2">Al Wakra Seaports and Beach Project</td><td rowspan="2">No data available</td><td rowspan="2">Mixed use: expansion of the existing seaport and addition of two sand beaches with touristic and traditional features</td><td>–</td><td>ongoing</td><td rowspan="2">3</td></tr>
<tr><td colspan="2">In progress and pipeline</td></tr>
<tr><td rowspan="2">Lusail City</td><td rowspan="2">38 km^2</td><td rowspan="2">Mixed use: residential, commercial, retail, hospitality, resort, and entertainment venues</td><td>2006</td><td>2012</td><td rowspan="2">4</td></tr>
<tr><td colspan="2">In progress and pipeline</td></tr>
<tr><td rowspan="2">Mesaieed Port Expansion</td><td rowspan="2">No data available</td><td rowspan="2">Expansion of the Gabbro berths (additional cranes and new berth)</td><td>2008</td><td>2010e</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">New Doha International Airport (NDIA) Project</td><td rowspan="2">22 km^2</td><td rowspan="2">Mixed use: >100 ha reserved for commercial and private use including free trade zone, office and business parks, hotels, and retail malls</td><td>2004</td><td>2012e</td><td rowspan="2">3</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">New Doha Port</td><td rowspan="2">20 km^2</td><td rowspan="2">New port – linked to mainland by 8.5 km bridge; 5 general cargo terminals and berths, 4 container terminals and berths, a roll-on/roll-off (Ro/Ro) berth, administration and customs complex and berthing area</td><td>2011</td><td>2023e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">In Design stage</td></tr>
<tr><td rowspan="2">Ras Laffan Dry Dock - Phase 1</td><td rowspan="2">No data available</td><td rowspan="2">Dry dock for repair and maintenance of all vessel types, 5000 ships/ year capacity by 2012 (world's largest hydrocarbon port)</td><td>2008</td><td>2010</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">Ras Laffan Port Expansion</td><td rowspan="2">No data available</td><td rowspan="2">New quay walls, berths, coast guard jetty, admin buildings and electrical substations</td><td>2008</td><td>2010</td><td rowspan="2">2</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">The Pearl-Qatar</td><td rowspan="2">4 km^2 artificial island</td><td rowspan="2">Mixed use: riviera-style man-made peninsula in Doha</td><td>2006</td><td>2011e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Ongoing</td></tr>
<tr><td rowspan="2">The Qatar-Bahrain Friendship Bridge</td><td rowspan="2">40 km (longest marine causeway in the world - 18 km of embankments and 22 km of viaducts and bridges)</td><td rowspan="2">Infrastructure: rail and road connections between Bahrain and Qatar (~50 million passengers/year)</td><td>2010</td><td>2014e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Project on hold</td></tr>
<tr><td rowspan="2">Urjuan, Barwa Al Khor Project</td><td rowspan="2">5.5 km^2</td><td rowspan="2">Mixed use: residential, commercial, leisure, sport and waterfront projects</td><td>2009</td><td>2013e</td><td rowspan="2">6</td></tr>
<tr><td colspan="2">In progress and pipeline</td></tr>
<tr><td rowspan="2">West Bay Lagoon</td><td rowspan="2">Dredging/Excavation: 0.0055 km^3
Depth: 3.41 m</td><td rowspan="2">Mixed use: residential, a hotel, conference center, sports and recreational facilities with extensive public beach access, marina facilities and protective breakwater structures</td><td>1990</td><td>1993</td><td rowspan="2">5</td></tr>
<tr><td colspan="2">Main dredging work finished in 1993, building still ongoing</td></tr>
</table>

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<table>
<tr><th rowspan="2">Country</th><th rowspan="2">Coastal Development</th><th rowspan="2">Size of Development</th><th rowspan="2">Project Type</th><th colspan="2">Project Status</th><th rowspan="2">Sources</th></tr>
<tr><th>Start Date</th><th>End Date (e = expected)</th></tr>
<tr><td rowspan="22">UAE</td><td rowspan="2">Ajman Marina</td><td rowspan="2">240,000 km^2</td><td rowspan="2">Mixed use: residential, hotels, yacht club,</td><td>2008</td><td>2015e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Under construction</td></tr>
<tr><td rowspan="2">Al Raha Beach</td><td rowspan="2">5 km^2</td><td rowspan="2">Mixed use: 11 precincts with hotels, marinas, parks, restaurants and leisure facilities</td><td>2006</td><td>2018e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="2">Dubai Waterfront</td><td rowspan="2">130.1 km^2</td><td rowspan="2">Mixed use: residences, commercial districts, industrial areas, and major tourist attractions</td><td>2010</td><td>2020e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="2">Dubai Maritime City (DMC)</td><td rowspan="2">2.3 km^2</td><td rowspan="2">Mixed use: 6 sectors – marine management, product marketing, marine research & education, recreation, and ship design & manufacturing</td><td>2004</td><td>2009e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Currently 85% complete</td></tr>
<tr><td rowspan="2">Khalifa Port and Industrial Zone (KPIZ) in Taweelah</td><td rowspan="2">100 km^2</td><td rowspan="2">Marine: multi-purpose – world-scale container and industrial port +100 km^2 of industrial, logistics, commercial, educational, and residential special economic and free zones</td><td>2008</td><td>2023e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Under construction (1st phase of Khalifa Port to open in 2010)</td></tr>
<tr><td rowspan="2">La Hoya Bay</td><td rowspan="2">0.014 km^2 - 0.054 km^2</td><td rowspan="2">Residential, 288 apartments (from 50 to 187 m^2)</td><td>2010</td><td>2015e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Completed</td></tr>
<tr><td rowspan="2">Palm Deira</td><td rowspan="2">Total planned area: 46.35 km^2
Length and width: 12.5 x 7.5 km
Fronds (x18): extend from 1.1 - 5.4 km and 320 - 500 m</td><td rowspan="2">Mixed-use: commercial, retail, residential and hospitality offerings</td><td>2010</td><td>2015e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="2">Palm Jebel Ali</td><td rowspan="2">Total area: 12.73 km^2
Distance from shore: 7 km
Width: 7.4 km
Trunk: 2.8 x 0.55 km
Six passages when finished: 2 at the top, 2 on east and west sides, and 2 on back sides - each ~250 m wide
Fronds (x17):
Depth: 5-10 m (between fronds) and 15 m along internal main channel</td><td rowspan="2">Mixed-use: commercial, retail, residential and hospitality offerings</td><td>2003</td><td>2016e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Phase 1 dredging has been completed but project is on hold</td></tr>
<tr><td rowspan="2">Palm Jumeirah</td><td rowspan="2">Total area: 5.6 km^2
Distance from shore: 5.1 km
Width: 5.3 km
Trunk: 2.6 x 0.65 km
Four passages: 0.137 - 0.165 km across the island crescent and 440 m at the base of the trunk
Fronds (x16): 0.6-2 x 0.12 km
Spine: 1.9 km
Depth between fronds: 5-10 m</td><td rowspan="2">Mixed-use: commercial, retail, hotels, residential and hospitality offerings</td><td>2001</td><td>2006</td><td rowspan="2">6</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="2">The Arabian Canal</td><td rowspan="2">Length: 75 km
Width: 150 m
Depth: 6 m</td><td rowspan="2">Marine (world's largest man-made canal) to carry water from coast inland and back to coast</td><td>2008</td><td>2012e</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">Delayed</td></tr>
<tr><td rowspan="2">The World</td><td rowspan="2">300 man-made islands:
Total area: 55 km^2
320 m^3 dredged sand
Width: 9 km
Length: 7 km
Breakwater: 27 km</td><td rowspan="2">Mixed use – residential, resorts, retail, hospitality offerings, and marinas</td><td></td><td>Ongoing</td><td rowspan="2">7</td></tr>
<tr><td colspan="2">Land reclamation completed in 2008</td></tr>
</table>

Sources:

1. http://www.durrat-marina.com/about-durrat-marina.php
2. http://www.constructionweekonline.com
3. General Secretariat for Development Planning (GSDP). 2009. Qatar national vision 2030: advancing sustainable development. QATAR'S Second Human Development Report, Doha, Qatar.
4. http://www.halcrow.com/Our-projects/Project-details/Lusail-Development-Qatar/
5. http://www.gldd.com/ProjectItem.aspx?type=3&id=20
6. http://www.nakheel.com/en/developments
7. http://www.theworld.ae/news_the_world.html

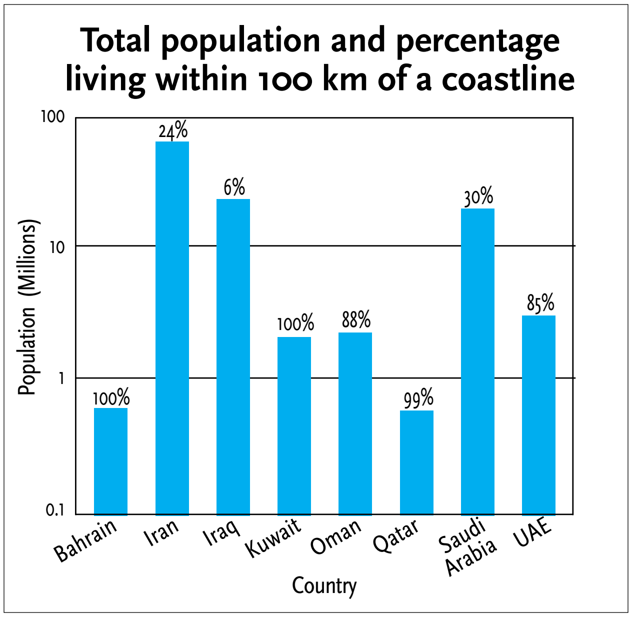

Figure 2c. The total population of each Gulf country with percentage of the population living within 100 km of a coastline in 2000[2]. Source: http://esa.un.org/wup2009/unup/

The Gulf's extreme oceanographic and meteorological characteristics have created a unique marine environment that is relatively low in species diversity

2

1996, Elshorbagy et al. 2006). Its arid climate results in evaporation that is in excess of the average precipitation and river runoff received by the Gulf. The relatively high evaporation combined with restricted exchange with the open ocean leads to the formation of a saline dense water mass (known as 'Gulf Deep Water') and the net flow of water through the Strait of Hormuz is into the Gulf. Sea surface temperatures regularly range over 20°C annually, with temperatures below 15°C occurring in the winter and exceeding 35°C in the summer months (Figure 4a,b). As a result of high evaporation rates, salinity is also extreme and can exceed 43 psu in the southern basin; compared to a typical oceanic salinity of 37 psu

Figure 3. Durrat Al Bahrain, still under construction in Bahrain, will be a new (near shore) mega-island city with 15 interconnected islands that will cover 20 km². Credit: NASA Earth Observatory

(Reynolds 1993, Swift and Bower 2003).These relatively harsh conditions, as well as restricted exchange with the Indian Ocean and its 'young' age (Sheppard et al. 2010), have led to communities of fish, coral, mangrove, and seagrasses that are generally low in species diversity compared to those of the Red Sea or neighboring Gulf of Oman (Table 2).

Despite the Gulf's extreme conditions, ecologically unique and interesting coral reefs exist and coral communities can be found in all countries except Iraq (Figure 4c). Total reef extent and coral diversity are highest along the Iranian shoreline (Peyman et al. 2008), while reef development along the western Gulf is mostly patchy and offshore; some important fringing systems can be found in Abu Dhabi, Qatar, and Saudi Arabia. These coral communities exist at the margins of tolerance to physical conditions, making them sensitive to environmental changes. Other important marine habitats that occur in the Gulf include seagrass meadows and mangrove forests. Mangroves are found along much of the Gulf coastline, with over 90 km^2 documented in Iran and an additional 40 km^2 along Bahrain, the UAE and Saudi Arabia (Spalding et al. 2010). Seagrass beds occur principally in shallow, coastal areas (<10 m depth) where growth is dense while offshore they appear to be patchy and less prevalent (Price and Coles 1992). Despite the low stature, poor diversity and intermittent occurrence

Table 2. Comparison of fish, coral, mangrove, and seagrass species richness in the Gulf, the Gulf of Oman and the Red Sea (Data from: Sheppard 1987, Sheppard and Sheppard 1991, Randall 1995, Froese and Pauly 2010, Sheppard et al. 2010).

Species	Gulf	Gulf of Oman	Red Sea
Fish	535	930	1,225
Coral	68	73	220
Mangrove	1	2	2
Seagrass	3	3	10

Healthy reefs form important food, shelter, and nursery habitat for a variety of marine fauna, including fish, such as this juvenile one-spot seabream, *Diplodus sargus kotschyi*, and the sordid sweetlip, *Plectorhinchus sordidus*, Saih Al-Shaib reef in Dubai. Credit: John Burt

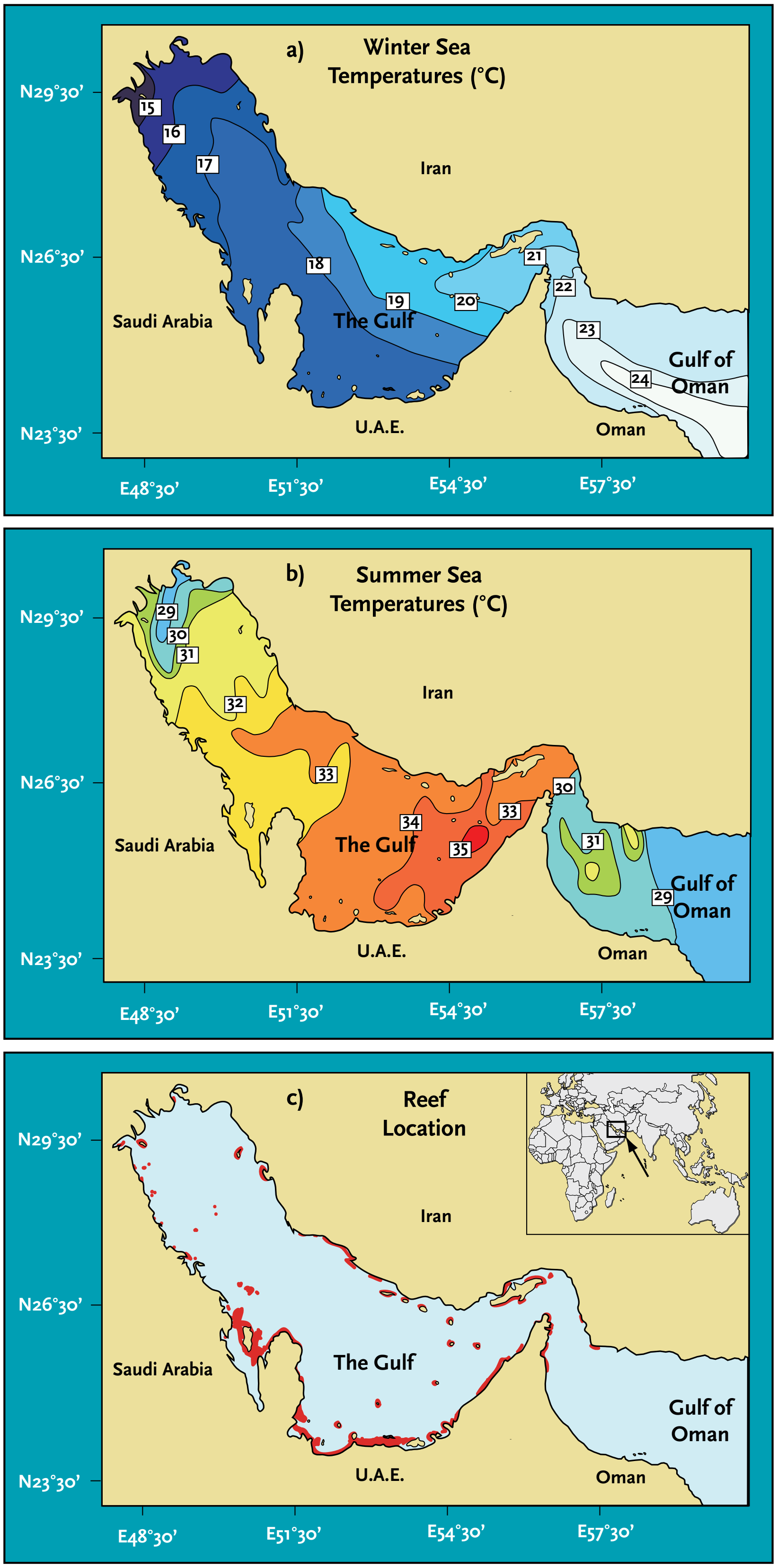

Figure 4. a) Winter and b) summer temperatures (Sea Surface Temperature (SST) °C) in the Gulf, and c) the location of coral reef habitat (Adapted from: Reynolds 1993, Wilkinson 2008).

of mangrove and seagrass areas, their presence throughout this region is of considerable ecological importance as they provide important habitat for a variety of marine life, and act as nurseries for a number of valuable commercial fishery species (Carpenter et al. 1997). Seagrass beds also provide important habitat for the dugong (sea cow) and several sea turtle species.

Increasingly, development together with other natural and anthropogenic stressors (including climate change) has led to extensive loss or degradation of valuable coastal habitat

The unique nature of the Gulf's marine habitats and their importance to coastal communities has not been well appreciated. Increasingly, development together with other natural and anthropogenic stressors (including climate change) has led to extensive loss or degradation of valuable coastal habitat. High temperatures and salinity have often been identified as primary factors limiting reef development in this region (Sheppard et al. 1992, Price et al. 1993). Increasingly however, coastal development combined with pollution, habitat destruction, overexploitation of marine biological resources, and the introduction of invasive species has contributed to their loss and degradation (Al-Muzaini and Jacob 1996, ROPME 2003, Khan 2007, Sheppard et al. 2010). Reefs have been rapidly declining worldwide over the past 50 years, however the Gulf, with only about 1.5% of the worlds reefs, is one of the most grievously affected regions; over 70% of its original 3,800 km² reef cover may be considered lost and a further 27% threatened or at critical stages of degradation (Figure 5, Rezai et al. 2004, Wilkinson 2008, Burke et al. 2011). Coastal development is also taking a toll on inter-tidal mud flats, seagrass and mangrove habitats, with many areas being lost to infilling and reclamation and to dumping of solid and liquid waste (Hegazy 1998). Mangrove habitat in this region has declined substantially due to the impacts of ill-planned coastal development, and only small fragments remain (Spalding et al. 2010). For example, land reclamation and infilling (sometimes illegal) have reduced the total area of mangroves in Tubli Bay, Bahrain, from an original 25 km² to 13 km² in 2006 for the construction of causeways, highways and residential housing (CBD 2006).

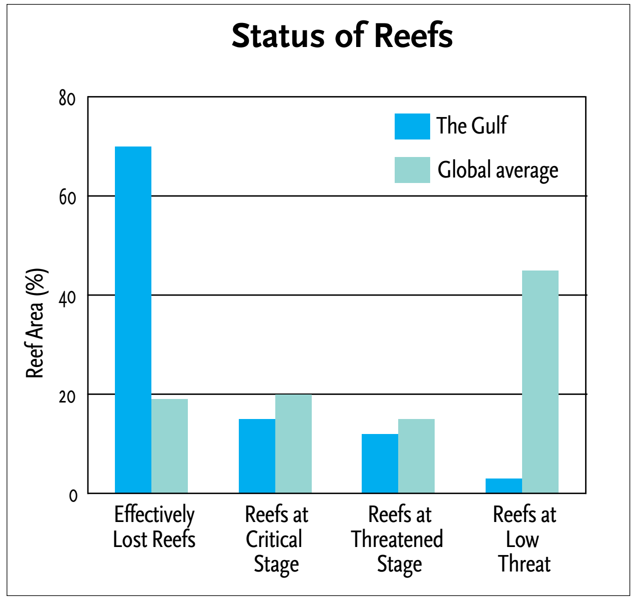

Figure 5. Only 3% of reefs in the Gulf are considered to be relatively undamaged by anthropogenic activities (Wilkinson 2008).

A CENTER FOR OIL

Exploitation of abundant oil and gas reserves has allowed most parts of the Gulf to undergo unprecedented economic prosperity and population growth. The oil industry has been the primary driver of development in the Gulf region since the 1930s, with shipping, commerce and tourism becoming additional drivers in the 1990s. Approximately 800 offshore oil and gas platforms and 25 major oil terminals are situated here with some 25,000 tankers passing the Strait of Hormuz annually (Haapkylai et al. 2007). According to some sources, this region holds approximately 55% of the world's crude oil reserves, and during 2009 the Gulf countries combined produced 31% of the world's oil supply (Table 5; BP p.l.c. 2011). The presence of such large quantities of oil clearly demonstrates the geographical and political importance of this water passage. It contains one of the world's busiest oil tanker routes, with more than 70% of the oil produced in northern areas being transported through the Gulf. Because of this, along with the high concentration of offshore oil installations, tankers and terminals have made the Gulf's marine and coastal ecosystems some of the most threatened in the world by oil pollution.

An oil tanker in Abu Dhabi, UAE (2002). Credit: Edwin Grandcourt

IMPORTANT FISHERY RESOURCES

Only second to oil, fisheries are the next most important natural resource in this region, and the most important renewable resource. The Food and Agriculture Organization of the United Nations (FAO 2010) reports that the catch from the Gulf and Sea of Oman totalled 792,000 tonnes in 2007 and 766,000 tonnes in 2008, and trade in fishery products in the region accounted for US$ 996 million in 2007 (RECOFI 2010). About 50% of the total yield comes from the Gulf (Appendix 1 Table 3; (Appendix 1 Table 3; Figure 6 and 7), and this has been relatively consistent over the past 20 years while total catch has steadily grown. Fishing (including aquaculture) employs some 250,000 people in the Gulf region directly (Appendix 1 Table 3) and is estimated to account directly or indirectly for the livelihoods of one million people (RECOFI 2010). Fisheries in the Gulf are multi-gear, multi-species, and primarily artisanal, but include a small commercial sector with larger vessels engaged in shrimp trawling (144 of 30,000 vessels are shrimp trawlers, RECOFI 2010). Fishing targets demersal species (e.g., emperors and groupers) in the south and west, and shrimp and pelagic fish species, particularly kingfish, *Scomberomorus commersoni,* in the north (Grandcourt *in press*). Tuna and other pelagic finfish are the primary target (about 40% of the catch) in the Sea of Oman (RECOFI 2010).

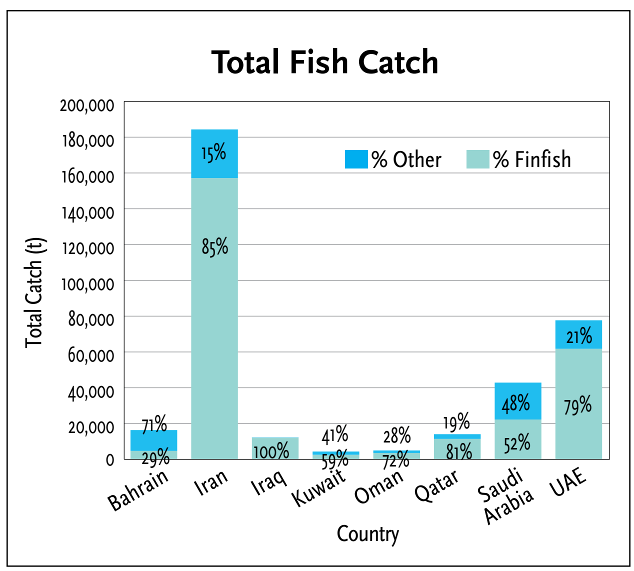

Figure 6. Total (fish) catch by country in the Gulf during 2007 showing fin fish as a proportion of the total of all species (data labels). Note: Total catch (landings) for Oman, Iran, the UAE and Saudi Arabia relate to those derived from Gulf waters only (Source: FAO FishStat Plus 2009).

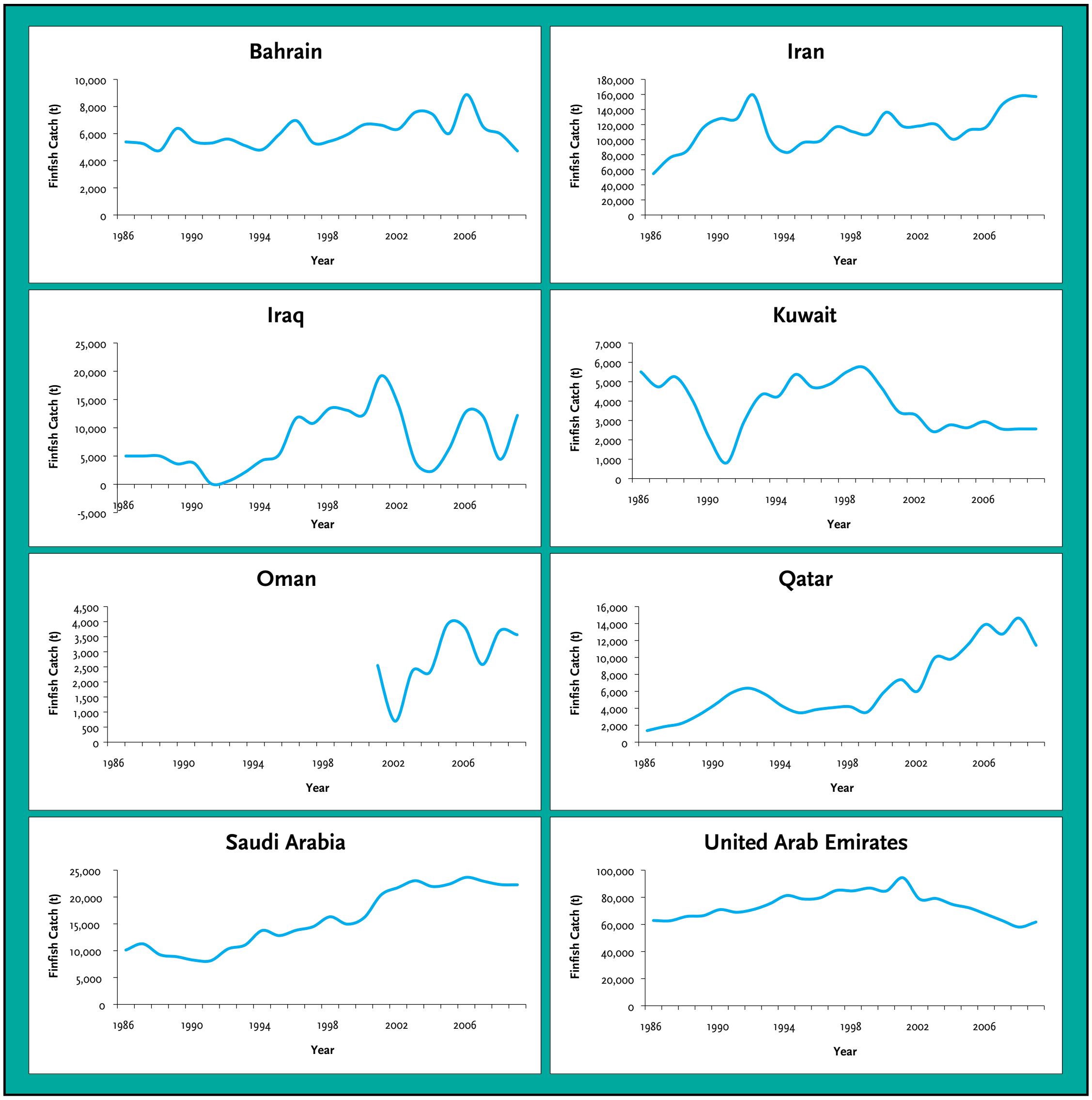

Figure 7. Total annual landed catch of fin fish between 1986 and 2007 per country in the Gulf (Source: FAO FishStat Plus 2009).

3 MAJOR THREATS TO THE GULF'S MARINE AND COASTAL ENVIRONMENTS

BEHIND THE GLITTERING SKYSCRAPERS: IMPACTS OF COASTAL DEVELOPMENT

While rapid economic development and population growth have brought widespread prosperity to this region, the unchecked and massive nature of coastal development has transformed shallow and productive marine habitat into land for homes, recreation and industry, introducing a variety of anthropogenic stressors to the Gulf's natural environment (Figure 8). Growing coastal populations have been accompanied by new infrastructure for manufacturing, transportation, energy processing and consumption, as well as waste disposal. Despite well designed mitigation measures and monitoring programs put in place by some developers, without a holistic and long term management approach, ecological sustainability is unlikely to be achieved (Zainal 2009) and limited information is available on the full environmental impact of these large scale developments on marine ecosystems (Khan 2007, Abuzinada et al. 2008, Hamza and Munawar 2009, Sheppard et al. 2010). Neverthe-

The Atlantis Dubai Hotel during the final stages of construction in 2008. The 1,500 room hotel, aquarium, and theme park occupies a 0.45 km^2 site at the tip of Palm Jumeirah, 6 km seaward of the original coastline. At the front of the hotel is a vessel belonging to one of the numerous international dredging companies operating in Dubai, UAE. Credit: Ken Drouillard

The scale of some coastal developments in the Gulf is enormous; without good planning and careful consideration of existing coastal features, hydrodynamics and offshore bathymetric conditions, the consequences of such developments can be severe and long lasting. View from The World in Dubai, UAE with Dubai skyline in the back ground (2007). Credit: Hanneke Van Lavieren

less, the precautionary principle should be applied given the potentially pervasive and long-lasting effects these developments could have on the health of the entire Gulf (Figure 8; Sheppard et al. 2010).

MODIFICATION AND LOSS OF NATURAL HABITATS

The loss of productive natural coastal habitats and associated marine life as a result of development is a major environmental issue facing the Gulf today (Al-Madany et al. 1991, Khan 2007, Hamza and Munawar 2009, UNEP 2010b). To accommodate expanding industries and rapid population growth during the past decade, large areas of previously ecologically productive coastal environments (e.g., intertidal reef flats, seagrass beds, mangrove forests, fringing coral reefs and sandy embayments) have been degraded, altered or converted into artificial islands, lagoons, canals, marinas, beach front hotels and other infrastructures (Sheppard et al. 2010). Apart from the breakwater rock, construction of the majority of these developments has relied solely on locally dredged marine sediments for material. To date, quantities have been enormous: 94 million m^3 for Palm Jumeirah, 135 million m^3 for Palm Jebel Ali, and 330 million m^3 for The World (Sale et al. 2011). In comparison, 55 million m^3 was dredged (30 million m^3 of which was sand) for construction of the Busan Port in South Korea, the 4th largest container terminal in the world.

Potential impacts on marine ecosystems, including effects from the dredging process (i.e., the removal of productive habitat and its biota from the seafloor), as well as those caused by the process of disposal (Erftemeijer and Lewis 2006) are not yet well understood (Lindeman and Snyder 1999, Nairn et al. 2004). However, Bishop (2002) and Munawar et al. (2002) have shown that land reclamation and dredging has caused permanent loss of primary nursery grounds for commercial shellfish and fish species in the Gulf. Physical removal of substratum along with associated plants and animals from the seabed, and burial due to subsequent deposition of material, are the most likely direct negative effects of dredging and reclamation (Newell et al. 1998). Some benthic habitats are critical to the early developmental stages, survival and growth of many species of fish, lobster, and shrimp, while others serve as spawning and feeding grounds. Coastal development and associated pollution can significantly alter or damage important near shore habitats and disrupt vital pathways for adults between these and offshore habitats. For example, burial of nearshore hard-bottom habitats with dredged sand has been found to significantly lower fish species diversity and abundance and these effects are amplified prior to and during spring and summer periods of peak larval recruitment (Lindeman and Snyder 1999). This could negatively impact an organism's early life stages and indirectly affect the abundance of adults and therefore the dynamics of food webs in which they are embedded; this in turn can impact commercial fisheries. It should be noted, however, that there is very limited knowledge of the actual magnitude and scale of such ecological effects in the Gulf.

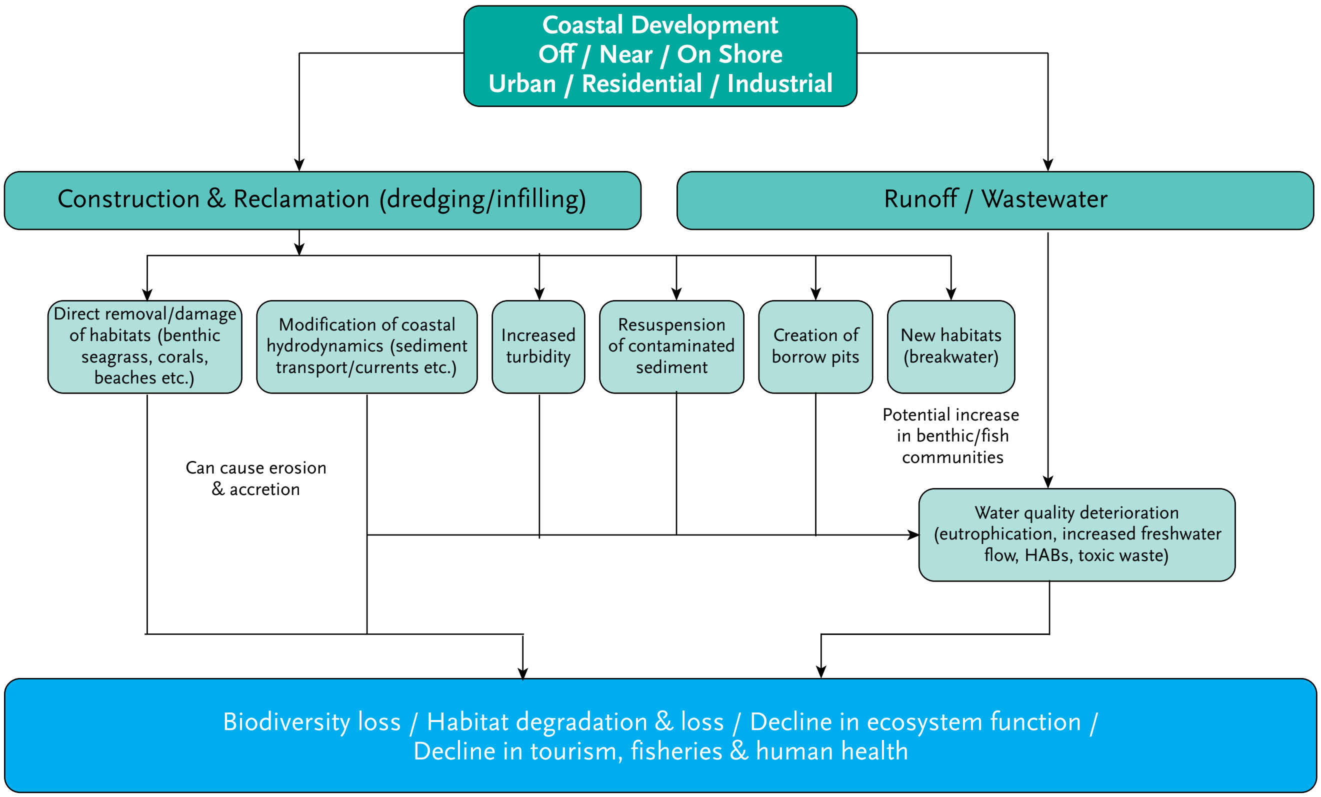

Figure 8. Summary of on-near-off shore coastal development impacts on the Gulf's coastal and marine ecosystems.

Dredging and disposal of dredged material can lead to temporary decreases in water transparency, increases in suspended matter, and higher rates of sedimentation. Elevated sedimentation regimes associated with such activities have been observed to cause stress, decrease growth, reduce cover, alter species composition, and/or inhibit recruitment in a number of marine and coastal ecosystems (Brown et al. 1990). Increased turbidity caused by higher levels of suspended material within the water column affects the amount of light available for photosynthetic activities essential to benthic communities such as seagrasses, algae (Al-Jamali et al. 2005) and particularly sensitive corals (Burt et al. 2009a). High levels of suspended material can also lead to direct loss of benthic fauna through clogging of feeding mechanisms and smothering, especially in filter-feeders like mussels, oysters and other bivalves. Dredging can also result in the remobilization and redistribution of contaminants (e.g., heavy metals such as mercury) from sediments. These contaminants may then (re)enter vital food webs. Finally, dredging can cause changes in an area's bathymetry affecting local circulation and other flow patterns.

COASTAL HYDRODYNAMICS

Coastal development can have a substantial impact on the natural patterns of water movement and how materials are transported, as well as water quality. Extensive dredging can significantly alter near shore bathymetry and sediment distribution while artificial islands can permanently modify water movement and sediment transport; the extent and nature will vary according to island shape and orientation. Interference with natural sediment transport processes (normally wave-driven) can change the shape of a shoreline by increasing erosion and/or deposition of sediments. Altered water movement can lead to accumulation of nutrients and other pollutants and have flow-on effects to benthic infauna and the communities they support (Figure 9). Such alteration can have consequences for coastal ecosystem structure and function, including modification, or even total loss, of particular habitats as well as large-scale and long-term effects on faunal composition. When island construction primarily uses reclaimed sand, the island become a new source of sand for redistribution by wave action, tides and coastal currents, perhaps modifying

Much of the highly prized sandy beaches in Dubai are subject to continuous erosion because of man-made coastal developments which cause interruptions in the predominantly northerly direction of natural sediment transport. Here, sand bags are used to strengthen a beach affected by erosion along the east side of Palm Jumeirah. Credit: Hanneke Van Lavieren

patterns of sedimentation in detrimental ways in downstream locations. In planning and implementation of coastal projects, careful consideration should be given to existing coastal features, hydrodynamics and offshore bathymetric conditions, because the consequences of construction could be long lasting or even permanent assuming erosion of the new land is regularly remediated. For example, the construction of Palm Jumeirah has created many km of beachfront that must be regularly re-shaped and replenished in perpetuity.

Figure 9. Interruptions in natural sediment drift (in this case increased deposition of sediments on the left side of the structure) can modify the natural shape of a shoreline. The red arrow indicates the direction of predominant wave action (Source: 'Umm Suqeim 2 Harbor.' 25°09'08.01' N and 55°11'50.46' E. (Source: Google Earth, 23rd February 2011).

The design and general approach to coastal development currently being applied within the Gulf is expected to introduce and exacerbate environmental risks. The majority of coastal developments here (i.e., the Palms in the UAE, the Pearl in Qatar) have resulted in structures with many blind channels and pathways that constrain water movement. Extensive dredging involved in their construction and general lack of constraints on methods are resulting in changes to turbidity and sedimentation rates. Microtidal systems within lagoonal networks have low mixing capacity in contrast to natural systems that predominantly depend on input (e.g., riverine) and external movement mechanisms (i.e., wind direction and strength) to circulate water. Given an environment that is already close to the upper tolerance limits of temperature and salinity for a broad range of marine species, the creation of environments where water is impounded and potentially made hotter and saltier is fundamentally a bad idea ecologically. Furthermore, most coastal developments in this region are large and complex, making it even more difficult to predict effects on physical processes and consequent environmental responses. This uncertainty requires project design to be flexible so that adjustments can be made to structures during and after construction to minimize ecological impacts. It is also crucial that the physical characteristics, processes and complex interactions occurring in and surrounding such coastal developments are characterized and monitored regularly.

Box 2. Lessons from the field: ecological responses to major coastal developments in Dubai, UAE

THE MAKING OF DUBAI, A MEGA WATERFRONT CITY BUILT IN THE DESERT

The massive scale of development that has occurred around the world is well illustrated in the UAE, but especially in the Emirate of Dubai. The economy of this emirate was initially built on oil (during the 1970s and 1980s) but less than 10% of its GDP now depends on this resource. Motivated by its leader's vision to make this desert state the center of the modern world, Dubai's economy is currently driven by a buzzing financial sector, luxury real estate market, and thriving tourist industry. Between 1995 and 2005 this city's population grew from 674,000 to 1.2 million; reaching nearly 2.1 million in 2010 (http://esa.un.org/unpp). In 2002, as a solution to beachfront property shortages, the government-owned developer Nakheel, began creating large-scale onshore and near-shore man-made islands; referred to collectively as the Nakheel Marine Projects (NMPs). If construction of all planned projects continues unabated, Dubai's natural 72 km coastline (pre 2002; Dubai Municipality 2004) will increase to 1500 km (Figure 10 a,b,c).

The NMPs include: The Palm Jumeirah, The Palm Jebel Ali, The World (Islands), The Palm Deira, and The Dubai Waterfront. These five mega-structures were designed for mixed-use (low-rise residential, high-rise urban, tourism, and marinas) and are intended to house approximately 75,000 (Palm Jumeirah), 3,000,000 (Palm Jebel Ali and the Waterfront) and 200,000 people (Palm Deira) (http://www.nakheel.com/en). The taste for such large scale development has been taken by neighboring emirates including Abu

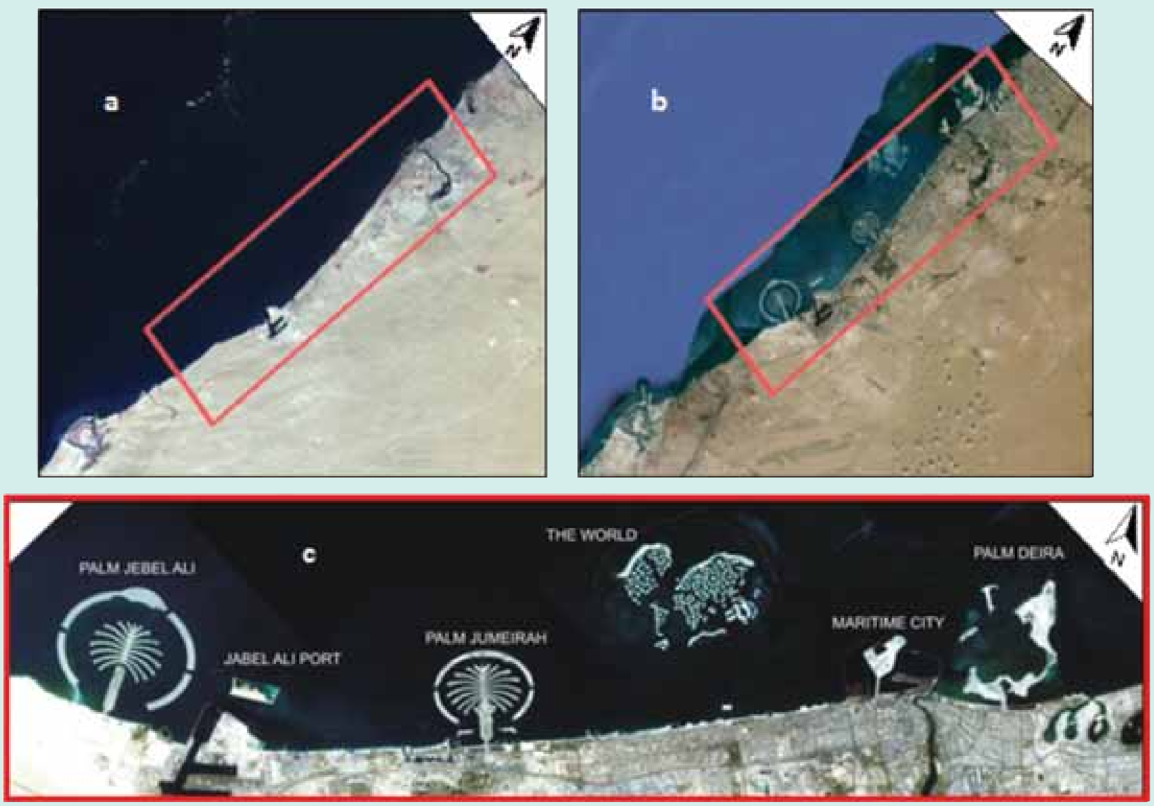

Figure 10 a, b, c. Satellite images of the Dubai coastline in 1990 (a) and 2010 (b, c). Figure 10 c is a close-up of the box in Figure 10 b and displays Dubai's mega coastal developments (Source for Figure 10 a, b: Google Earth 2010; Source for Figure 10 c: Nakheel).

Dhabi, Sharjah, Umm Al-Quwain and Ras Al-Khaimah. Relatively little information exists on their short and long-term environmental effects, yet it is known that the Nakheel Marine Projects result in the creation of novel marine environments that are rare or previously did not exist in this part of the Gulf.

STRATEGIC MANAGEMENT OF MARINE ECOSYSTEMS SURROUNDING THE NAKHEEL MARINE PROJECTS

In 2003, the need to develop appropriate environmental safeguards to minimize risks and ensure the sustained health of aquatic ecosystems surrounding these mega-developments was recognized and Nakheel invited the United Nations University Institute for Water, Environment and Health (UNU-INWEH) to collaborate with its Environment Department to develop a coastal ecosystem management program. What follows is an overview of findings that resulted from studies implemented between 2006-2009 to better understand the nature and dynamics of marine ecosystems present within and around two of the man-made islands: Palm Jumeirah and Palm Jebel Ali.

DEFINITION: An **'artificial island'** or **'man-made island'** is an island or archipelago that has been constructed by people rather than formed by natural means. They are created by dredging and infilling to build entirely new land masses, expand existing islets, construct land above existing reefs, or amalgamate several natural islets into one larger island.

Palm Jumeirah (Figure 11)

Development of Palm Jumeirah began in 2004 and among the NMPs, this is the only one that is essentially completed. This palm shaped island is connected to shore via a 5.1 km long spine that stretches from the mainland to its crescent tip. It is 5.3 km wide and consists of a trunk (2.6 km x 650 m) and 16 fronds (8 on each side); each 120 m wide and between 600 m and 2 km long. There are 16 inter-frondal lagoons

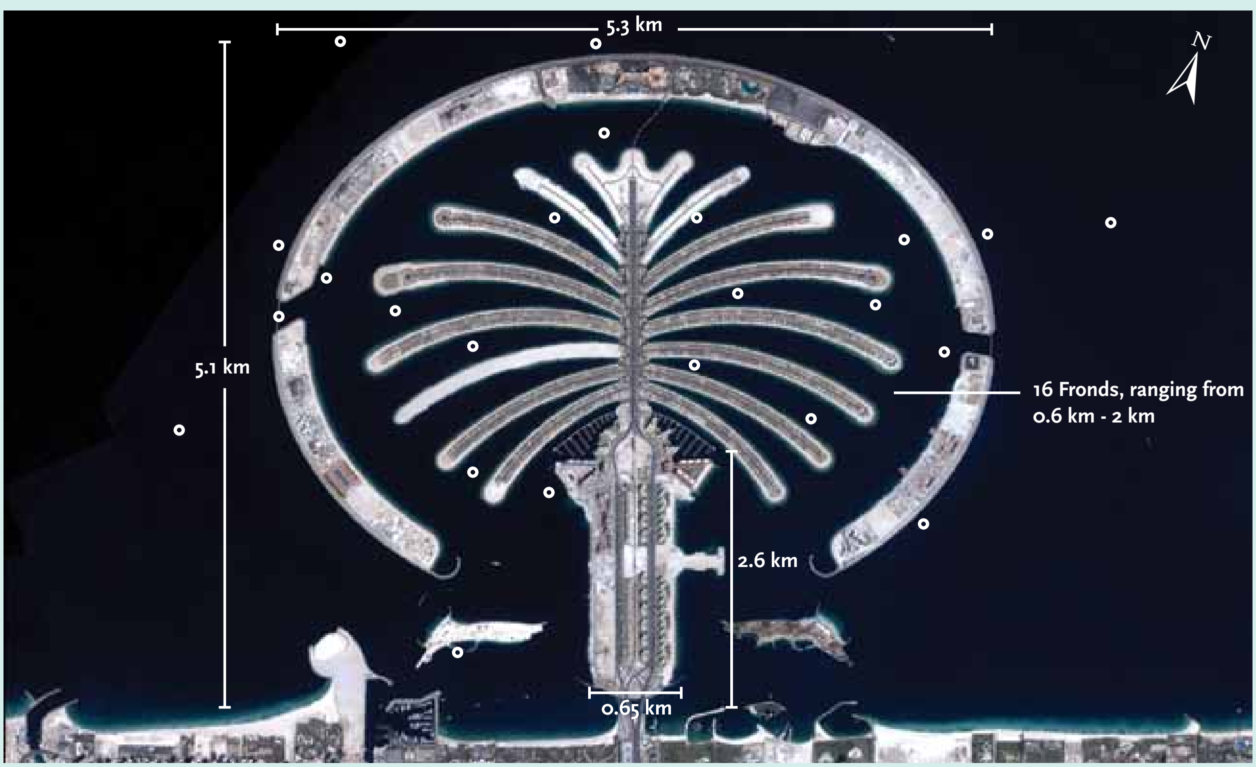

Figure 11. Palm Jumeirah: includes dimensions and points which represent the main monitoring stations for the environmental monitoring program as described further on.

Relatively little information exists on their short and long-term environmental effects, yet it is known that the Nakheel Marine Projects result in the creation of novel marine environments that are rare or previously did not exist in this part of the Gulf

between 5 and 10 m deep. The waters of the main annular lagoon are connected to coastal waters through four passages (145 to 180 m long) that vary in width from 137 to 165 m across the crescent and 440 m at the trunk base on either side. The outer side of the crescent is protected by an elliptical breakwater (11.5 km x 0.3 km) that is made of quarried natural rock. Two small islands, to the left and right of the trunk, are also armoured by breakwaters. Water depths at the seaward and landward extremes of the complex are 12 and 4 m respectively. It has an overall footprint of 23 km², of which the constructed island surface area is 7.9 km². When completed, it will host 1800 residential villas, 2,400 apartments, and 40 hotels, including the completed 1,500-room Atlantis Dubai Hotel which also holds an aquarium and 0.45 km² theme park (http://www.nakheel.com, Aldarmaki 2008).

Palm Jebel Ali (Figure 12)

Upon completion, Palm Jebel Ali will be 50% larger than Palm Jumeirah. Construction began in October 2002 and is ongoing. Its total length from shore to crescent is 7.5 km, it is 7.4 km wide and has 18 fronds (9 on each side) with 16 inter-frondal lagoons. It has a breakwater crescent 12.5 km long and its trunk is 2.8 km x 0.55 km. When completed, the main lagoon will be connected to surrounding coastal waters through six passages approximately 250 m wide: 2 close to the apex, 1 each on east and west sides, and 2 at the foot of the island. Water depth is between 5 and 10 m between the fronds, and approximately 15 m along the main inner channel. The island will have 70 km of beach front, six marinas, a water theme park, Sea World, and 2,000 residential villas.

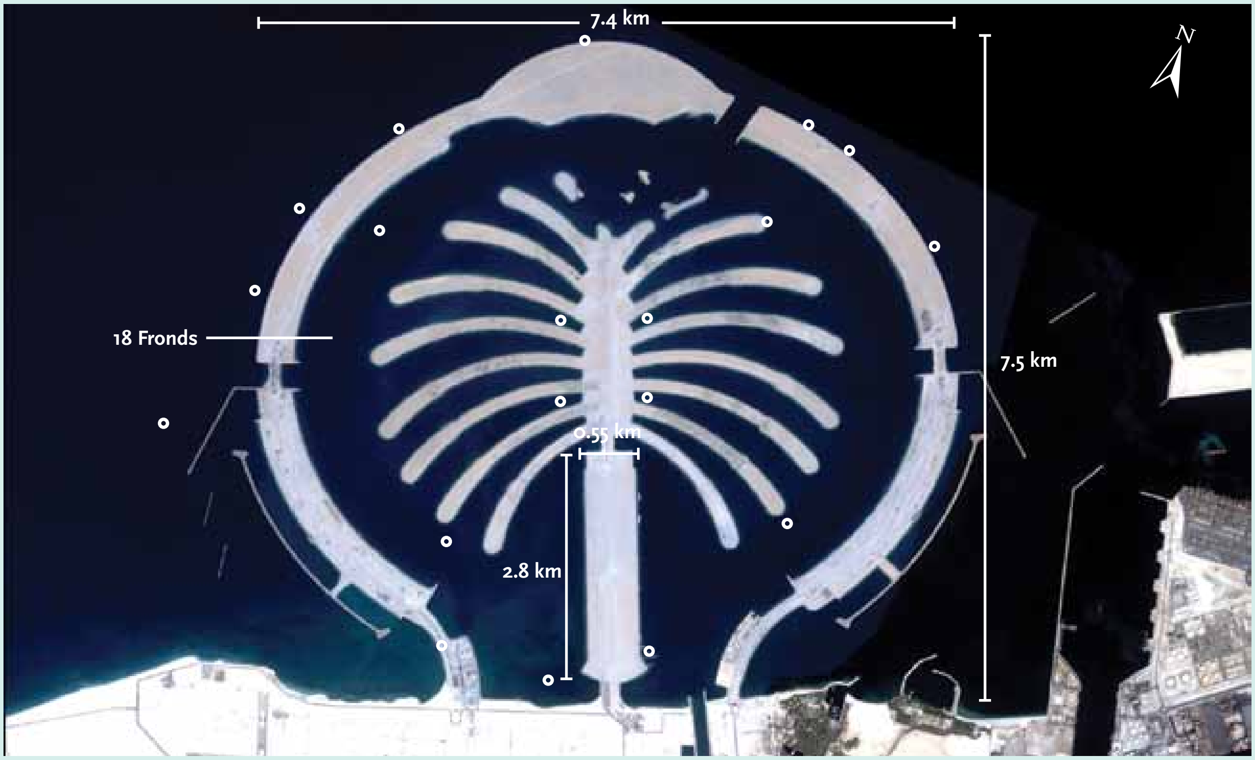

Figure 12. Palm Jebel Ali: includes dimensions and points which represent the main monitoring stations for the environmental monitoring program.

MOVEMENT OF WATER AND SEDIMENTS

Physical processes, water movement, and transport of sediment in and around Palm Jumeirah, were studied and compared to results from previously conducted numerical model simulations. Water currents adjacent to and inside the Palm were found to be predominantly forced by tides, but occasionally modified by local winds and waves. Although the islands obstruct the coast's natural tidal flow, water was relatively well mixed within the island except for the west side of the stem in between the fronds (Figure 13). East and west sides of the island were found to be flushed unequally with residence times of 1.2 and 42 days respectively indicating that water is quickly renewed on the eastern half while the western side remains poorly flushed.

The 42 day residence time is sufficient to cause severe anoxia and serious consequences for marine life. It is suspected that the inter-frondal lagoons, especially those close to the trunk, will be subject to water quality problems such as local eutrophication, depletion of dissolved oxygen, and reduced water transparency. These findings were not predicted by the numerical modeling studies conducted prior to construction (Cavalcante et al. 2011) possibly because the model assumed an idealized uniform bathymetry within the structure. The actual bathymetry is quite variable within the lagoons and ranges from 8 to 18 m in the annular lagoon.

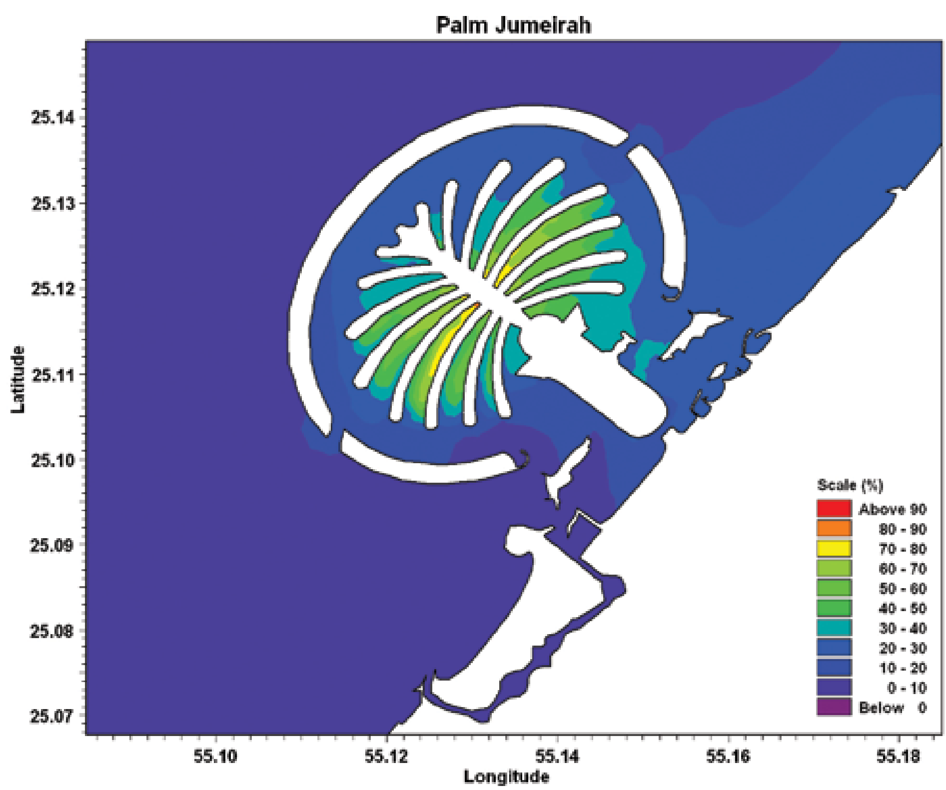

Figure 13. The mean residence time of water within Palm Jumeirah after 15 days. This image shows that (1) flushing is less efficient inside the fronds close to the stem, especially on the west side where water exchange is still only about 50% after 2 weeks and (2) water becomes trapped between fronds which leads to residence times > 2 weeks. Both indicate a potential for water quality problems.

BENTHIC COMMUNITIES

The benthic invertebrate communities that were found around Palm Jumeirah's breakwaters indicate that the benthic footprint of this Palm extends >800 m beyond the outer crescent breakwater (D.A. Feary, unpublished data). This suggests that dredging and filling operations generate sediment plumes and other disturbances that are wide-spread and long-lasting. The orientation of breakwaters was found to have a substantial effect on benthic communities due to patterns of sediment deposition (Burt et al. 2010). Within 800 m, sediment composition was dominated by more silt and fine particles than is typically found on Dubai's inner shelf (D.A. Feary, unpublished data). Windward breakwater communities had lower sediment deposition and higher coral abundance than leeward communities which were dominated by algal turfs and oysters (Burt et al. 2010). It was also found that trench-like borrow pits occur both outside and inside the breakwater and are filled with flocculent, suspended, and sometimes anoxic fine sediment (D.A. Feary, unpublished data) that lifts and is redistributed when exposed to high wave action. Such re-suspension may result in continuous high turbidity thereby reducing photosynthetic activity and impeding the development of benthic communities.

Breakwaters represent engineered artificial reefs where diverse and abundant benthic and fish communities can develop (Airoldi et al. 2005, Burt et al. 2010) and contribute to increasing faunal biomass which in

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Breakwaters represent engineered artificial reefs where diverse and abundant benthic and fish communities are able to develop. Here, a project researcher is studying benthic communities on a breakwater at Palm Jumeirah, Dubai. Credit: John Burt

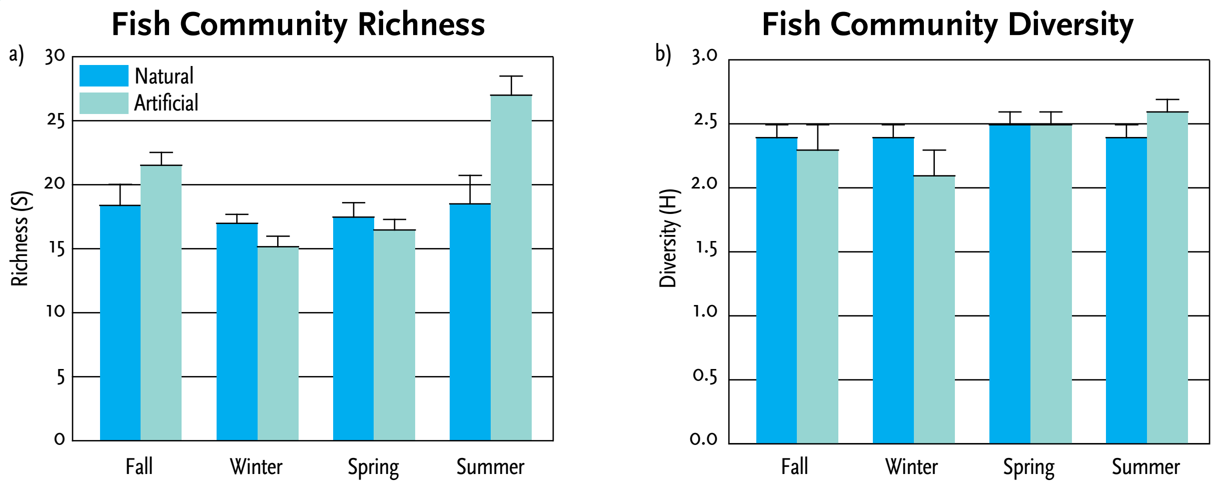

Figure 14. Fish community richness and diversity on breakwaters and natural reefs over four seasons in Dubai, UAE (Adapted from: Burt et al. 2009b).

turn can increase fish populations (Bohnsack 1989). Understanding the types of communities to expect and the sequence of establishment on these man-made reefs is essential for addressing their ecological and management implications. In Dubai, young (<5.5 years) breakwaters are dominated by algae and oysters, while breakwaters >25 years old are dominated by corals (>50% cover); exceeding that seen on natural reefs in this area by 37% (Burt et al. 2010). However, these older coral communities are relatively depauperate with only three species comprising >75% of the coral (Burt et al. 2009b). With appropriate design, such structures can contain coral communities, demography, and growth rates comparable to natural reefs (Burt et al. 2010). Nevertheless, although they become more similar to natural communities over time, these communities still remain distinct (Burt et al. 2011a).

FISH COMMUNITIES

In a study comparing fish communities living on breakwaters to those living on nearby natural reefs, it was found that abundant and diverse fish communities developed on breakwaters, but were different and varied seasonally when compared to those found on natural reefs (Figure 14). Higher densities of reef-associated fish were associated with breakwaters during summer and autumn primarily as a result of adult migration (snappers, angelfishes, and cardinal fishes), with juvenile fish recruiting at comparable levels to both the natural reefs and the breakwaters (Burt et al. 2009b). Predation may also play a role in decreasing the abundance of juveniles and smaller adult fish on breakwaters. Fish communities on natural reefs were stable over the entire year. Fish abundance and species richness was higher on the breakwaters, and species composition differed from that seen on natural reefs. Although the results of this study are limited to a single year of sampling, it has important implications for marine management.

Constructed islands provide new habitat for a broad range of species adapted to rocky shores, reefs, and shallow, sandy lagoons. However, there are substantial and long-term (decadal) effects on fauna due to successional processes, and complex seasonal variations caused by patterns of migration and recruitment. Breakwaters such as those studied in Dubai are not likely to become suitable alternatives to natural coral reef (Burt et al. 2009b). Although they can develop diverse and abundant reef-like communities over long periods of time, the structure of these communities often differs greatly from that seen on natural reefs in the area. Artificial habitats cannot replace natural ecosystems, but may help mitigate habitat loss and other impacts caused by coastal development. In the future it would make sense to develop management programs that include protection of breakwater habitat from commercial, recreational and spear fishing activities.

A healthy reef in Dubai, UAE (2008). These remaining reefs are likely to degrade or disappear entirely within the next decade unless aggressive steps are taken to ameliorate the impacts of development. Credit: John Burt

NATURAL CORAL REEFS

Natural mortality due to the extreme warming events of 1996, 1998, and 2002, led to extensive loss of coral in Dubai. Although substantial recovery occurred by 2007, the direct burial and indirect effects from sedimentation and changes in water quality associated with intense development has substantially impacted Dubai's natural reefs. For example, over 8 km^2 of natural reef habitat was lost as a result of the construction of Palm Jebel Ali, a number of coral patches were lost for the construction of the Dubai Waterfront, and there was further loss and degradation due to the creation of breakwater structures which impede the flushing action of waves on these reefs (Burt et al. 2008, 2009b, 2010). Reefs that still remain are likely to degrade or disappear entirely within the next decade unless aggressive steps are taken to ameliorate the impacts of development. Regular monitoring before, during, and following construction is needed and turbidity and sedimentation caused by development must be controlled. Coral translocation is often promoted as a means to minimize or mitigate such impacts, and a number of large-scale translocation projects have been implemented. However, in the cases we know of, the essential follow-up monitoring needed to evaluate effectiveness has either not been conducted or the results are unavailable. Furthermore, coral translocation seldom has the desired outcome given the high coral mortality, slow growth, decreased fecundity, and other impacts that may occur during translocation and given that in most instances, trivial quantities of coral get relocated relative to the amount being lost to development (Abelson 2006).

WATER QUALITY

Given the low flushing rates in some lagoons, there is a significant risk of water contamination from land-based sources of pollution in and around these artificial islands. In order to provide a baseline dataset from which to compare and reveal changes in water quality over time, measurements were taken for a range of parameters within the Palm Jumeirah lagoon system and at reference sites outside the crescent.

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RESULTS:

- Dissolved oxygen concentrations varied seasonally within the lagoon, remaining ~10% lower than at reference sites, but stayed consistently above the 3.2 mg/L minimum critical for fish survival.
- Temperatures remained under the upper threshold and consistent with reference sites.
- Water within the lagoon was well mixed and provided no evidence of stratification.
- Nitrate levels (plus nitrite) were higher than expected (~5 μM). Levels were not depressed during periods of high phytoplankton growth, suggesting abiotic replacement of N from the sediments.
- Salinity levels were consistent with reference sites. Some seasonal discrepancies were, however, observed within the lagoon with moderated differences up to 1.5 psu.
- Oxygen concentration in sediments at some lagoon sites was depressed by 10-15% between September and October 2009.
- During winter, eastern and western inner lagoons showed higher abundances of phytoplankton (measured as chlorophyll a concentration) than reference sites. Sites located at the frond tips had uniformly higher abundances of phytoplankton throughout the year, indicating a constant nutrient input at these sites.
- Mid-water plankton community abundance and composition differed substantially between the eastern and western sections while those in surrounding waters were relatively constant. Higher abundances of large diatoms occurred on the east (where sheltered conditions prevail) while the western side (subject to winds) contained a lower number of medium sized dinoflagellate species (E. Marquis, unpublished data). The diatom dominance on the east side of Palm Jumeirah was also correlated with higher abundances of copepods. Such differences in plankton community structures indicated dissimilar planktonic food web functioning, with the east side more likely to be favorable to fish and benthic filter feeding needs.

These results indicate that there is a potential risk of eutrophication in and around these artificial islands that may lead to periods of anoxia or algal blooms. Palm Jumeirah is rapidly becoming fully utilized (Cavalcante et al. 2010) and as usage increases we can expect increases in the type and volume of household substances being flushed (i.e., via gardening, car washing etc.) and transported through the eastern and western entrances (Cavalcante et al. 2010). Routine monitoring of water quality parameters that affect ecological health is necessary to ensure that water quality is maintained in the sheltered lagoons of these mega structures.

SUMMARY OF CRITICAL ISSUES:

1) Dredge and fill procedures cause sedimentation and turbidity during extended periods of construction and long afterwards because of re-suspension of fine sediments.
2) Pre-construction evaluation was inadequate; specific design aspects of an island development can introduce significant physical and chemical challenges that may degrade habitat quality and favor undesirable or prevent colonization by desired species of aquatic organisms.
3) These designs can lead to undesirably long retention times which can result in water quality issues.
4) Evident problems at certain times of the year in water quality – low oxygen, high nitrates – could lead to anoxia or algal blooms.
5) Trough-like borrow pits that surround the outer and inner crescents of Palm Jumeirah are an undesirable feature and should be avoided in future projects of this type.
6) These structures damage natural benthic biota and habitat, especially corals.
7) Breakwaters may provide alternative habitat for fish and benthic organisms.
8) The type of material used to construct breakwaters can affect components of the benthic community, including corals, so that constructions using different materials can lead to quite different environmental outcomes.
9) Continued observations are needed of water quality, flow, sedimentation and turbidity patterns as the NMPs age and effects of construction dissipate.

Routine monitoring of a suite of water quality parameters that affect ecological health is necessary to ensure that water quality is maintained within and around complex man made coastal islands, especially with high-population densities. This photo shows a segment of Palm Jumeirah, Dubai. Credit: Alexander Heilner

MORE PEOPLE, MORE POLLUTION

Rapid increases in population density and associated development activities along the Gulf's coasts have substantially heightened the risk of contamination of coastal waters through increased discharge of industrial, agricultural and domestic effluents. The Gulf has been found to be a repository for a wide range of liquid and solid wastes through runoff and effluent from urban centers, agricultural land, and industries (UNEP 1990, 1999, Khan et al. 2002, ROPME 2003, Khan 2007, UNEP 2010b). The physical characteristics and semi-enclosed nature of the Gulf provide ideal conditions for accumulation of pollutants and the Gulf may even be considered a 'pollutant trap' as is common in enclosed and semi-enclosed seas (Healey and Harada 1991, Al-Ghadban 2002, Khan et al. 2002). Unfortunately, it is difficult to accurately estimate the impact on the Gulf environment because we do not know of any publicly available datasets regarding discharge quantity, effluent quality and treatment technologies. Furthermore, for coastal pollution monitoring programs that do exist along the Gulf, available data are often unreliable, scattered and inconsistent (ROPME 2003, Khan 2007).

WASTEWATER

Already, rapid population growth has outpaced the ability of some Gulf countries to adequately improve infrastructure capacity for waste management (Box 3). A recent review of the wastewater treatment capacity in Gulf Cooperation Council (GCC) countries concluded that across much of the region, the existing sewage treatment infrastructure is incapable of meeting today's demands, both in terms of handling volumes and treating effluent according to international standards (MEEB 2009; Insight report GCC Wastewater). The review suggests that sewage treatment capacity will have to more than double from the existing capacity of 4.1 10^6 m^3/day over the next six years. The highest requirements will be in Saudi

Thermal hypersaline effluent from a power/desalination plant in Abu Dhabi is being discharged into the sea (2009). Credit: Edwin Grandcourt

Arabia, followed by the UAE and Kuwait. Until the mid-1980s, raw sewage was often discharged directly into the Gulf's coastal waters, but since then some improvement has been made to infrastructure and management. The quality of sewage effluent released is dependent upon the level of treatment, but the effluent stream usually consists of complex mixtures of metals, oil and grease, persistent organic pollutants (POPs) such as Polycyclic Aromatic Hydrocarbons (PAHs) and organochlorine insecticides, nutrients, viral and bacterial pathogens, plastics and solids (ROPME 1986, Qureshi and Qureshi 1990, UNEP 1999). Although the percentage of total wastewater produced that is treated varies among countries ranging from 7% in Iran to 58% in the UAE, and nearly 100% in Kuwait and Qatar (Table 3), the majority of all locally produced sewage in most GCC countries receives either secondary or tertiary treatment (AFED 2008) and the set discharge standards for domestic wastewater are very close to those recommended by the World Health Organization (WHO). Treated municipal wastewater has become an increasingly significant water source for some Gulf countries (Table 3) such as Oman, Qatar and the UAE, which reuse 100, 86 and 74% of treated wastewater respectively. This water is used for the irrigation of urban gardens, parks, fodder crops, and highway landscaping. However, the full utilization of treated wastewater remains in the early stages of development for most countries where the volume of reused treated wastewater is still far less than the volume of treated wastewater discharge (Table 3); for example, Bah-

Box 3. Illegal dumping of sewage contaminates Dubai's beaches and coastal waters

Over the past decade, the population of Dubai had grown at such a rapid pace that each new subdivision could only be equipped with local primary treatment and holding tanks for sewage instead of being connected to the principal sewage system. Trucks were used to transport the semi-treated effluent to municipal plants for final treatment before being discharged into the Gulf. However, the volume to be treated surpassed the capacity of these municipal plants and resulted in long queues and serious delays for waiting trucks. To evade this, some tankers used storm water drains, designed to only carry rain water to the sea, as a conduit for illegal dumping of this effluent. In 2008, this led to the contamination of several prime tourist beaches with bacteria and human feces, which posed serious health risks to beach-goers. Some measures were taken to deter offenders, including fining and permanent cancellation of vehicle licenses, but only by building increased capacity to treat sewage effluent can a permanent solution be secured. Dubai is now commissioning new waste water treatment facilities to provide the capacity it needs to continue its growth.

Table 3. Wastewater statistics for the Gulf countries.

Country	Wastewater				
	Produced (10^6 m^3/yr)	Treated (10^6 m^3/yr)	Treated (%)	Treated Wastewater Reused (10^6 m^3/yr)	Treated Wastewater Reused (%)
Bahrain	73 (2005)	61.9 (2005)	85	16.3 (2005)	26
Iran	3,075 (2001)	130 (2001)	7	154 (2001)**	70
Iraq	–	–		–	
Kuwait	244 (2003)	250 (2005)	102*	78 (2002)	31*
Oman	90 (2000)	37 (2006)	41*	37 (2006)	100
Qatar	55 (2005)	58 (2006)	105*	43 (2006)	74
Saudi Arabia	730 (2000)	547.5 (2002)	75*	166 (2006)	30*
UAE	500 (1995)	289 (2006)	58*	248 (2005)	86*

Source: World Health Organization 2005; FAO Aquastat 2010
- No information available.
** Information was from different sources and/or years and hence incomparable – these percentages are estimates only.*
***Unofficial reuse with partially treated and raw wastewater, mixed with industrial effluents.*

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rain, Kuwait and Saudi Arabia reuse only around 30%. Despite the fact that some Gulf countries are among the wealthiest in the world and have strict rules for wastewater treatment (UNEP 2001, Sheppard et al. 2010), untreated and un-used treated wastewater is dumped directly into the Gulf or dumped into river beds and wetlands where it then infiltrates into shallow aquifers and eventually enters coastal waters (UNEP 2003). Major industries (e.g., petrochemical), though few in number, produce relatively large quantities of liquid waste every year and most is treated at the primary level only, then mixed with thermal effluents and discharged directly into the Gulf (World Bank 2007). Finally, major rivers in southern Iran and south eastern Iraq have been reported to transport approximately 300,000–500,000 m^3/day of poorly treated wastewater into the Gulf (UNEP 1999).

Uncontrolled population growth together with increasing urbanization and industrialization have substantially heightened the risk of contamination of coastal waters through industrial, agricultural and domestic effluents.

Even tertiary treated effluent is rich in nutrients. Eutrophication of coastal waters due to discharge of treated municipal wastes is particularly acute in Bahrain, Kuwait, Qatar, the UAE, and Oman, where 63 to 94% of the population is concentrated along the coast (Khan et al. 2002). Adverse ecological effects associated with sewage pollution (e.g., hypoxia, toxic algal blooms, and fish kills) have been observed in several areas of the Gulf (Khan 1999, Al-Muzaini and Beg 2002). The amount of sewage discharged in the northern Gulf has been so great that it has been implicated in causing a shift in the dominant forms of plankton (Sheppard et al. 2010). Sewage and agro-based industries have caused increased growth of benthic algae in Bahrain, and in the northwest part of the Gulf off Shatt Al-Arab. Signs of eutrophication have also been observed in Kuwait Bay and the coastal waters of Muscat (Oman), Dhahran (Saudi Arabia) and Abu Dhabi (UAE) (AFED 2008). Oxygen depletion associated with the discharge of large quantities of wastewater in Kuwait Bay led to several major incidents of fish kills, such as those seen in 1999, 2001, and 2004. Red tides have been recorded in Bahrain, Saudi Arabia and the UAE (Box 4) and eutrophication has been indicated as the main cause for these algal blooms (ROPME 2003).

FRESHWATER FLUX

The Shatt Al-Arab is a major source of natural freshwater to the northern Gulf. However, in most parts of this arid region, the natural freshwater flow into the Gulf comes mainly from groundwater aquifers and springs[4] as well as from inputs from treated wastewater. The natural flow of freshwater from subterranean springs and aquifers has dwindled or become progressively more

[4] Both terrestrial and marine freshwater springs are found in the coastal belt of the UAE, Bahrain and Qatar. Many offshore springs have disappeared due to severe extraction of in-land groundwater.

saline because of lowering water tables as a result of depletion and over-use by rapidly growing populations and industries (Louri 1990). The input of freshwater from the rivers in the north of the Gulf is estimated to be between 35 and 133 10^9 m^3/yr (Sheppard et al. 2010). Furthermore, increased water use in this region has in turn led to an increase in the volume of freshwater flow (and associated nutrients and other materials) going back into the Gulf, mostly as un- or partially treated wastewater. Table 3 shows that in some countries up to 75% of treated wastewater is not reused and eventually ends up in the Gulf. Based on the numbers in Table 3, the total volume of this discharged treated wastewater (excluding Iraq and Iran) is estimated at around 4.1 10^9 m^3/year , and with the exception of the northern Gulf, constitutes a substantial portion of all freshwater input along the coast. This will likely have major local impacts on water quality and biological productivity.

TOXIC WASTE

Toxic compounds that have been found in the Gulf may come from various sources including agriculture, livestock facilities, food and chemical manufacturing plants, petrochemical industries, metal and non-metal industries, ship ballast water, auto service stations, seaport activities, and desalination plants (Gevao et al. 2006). These activities create wastewater that carries a variety of chemicals, including heavy metals, oil and petroleum-based compounds, nutrients, and halogenated organics, that later get deposited into marine sediments (Gevao et al. 2006). For example, each year about 188,000 L of liquid industrial waste from manufacturing industries, power and desalination plants and ports are discharged into the Gulf (UNEP/ROWA-GPA 2001). Agricultural runoff carrying organic pollutants can also enter the Gulf through river systems, which may cause localized eutrophication and oxygen deprivation in coastal waters (Gawad et al. 2008). The risk of chemical and hydrocarbon contamination will increase with increased automotive use, boat traffic, and use of chemicals for gardening, along with growing numbers of residents (Howarth 1988, Peierls et al. 1991, Nixon 1995).

The information that is available on the levels of POPs and heavy metals (e.g., organochlorine pesticides, PCBs, and combustion by-products such as PAHs, chlorinated dioxins and furans) is patchy and does not provide a complete picture of their spatial and temporal distribution in the Gulf (UNEP 1999, Fowler 2002, Khan et al. 2002, ROPME 2003, de Mora et al. 2005). In 2004, the GCC put forward the following estimates of hazardous waste quantities during the late 1990s: Bahrain 95,000 tonnes/year; Saudi Arabia 220,000 tonnes/year; Oman 81,000 tonnes/year; Qatar 75,000 tonnes/year; and Kuwait 120,000 tonnes/year. Bivalves have been extensively used for the assessment of a range of contaminants (Fowler et al. 1993, de Mora et al. 2003, 2004, 2005) and the majority of the available data for the Gulf suggests that levels of PCBs and metals are similar or lower compared to other regions (Literathy et al. 1986, Linden et al. 1990, Fowler 2002, de Mora et al. 2005). The highest concentrations of heavy metals have been found along Saudi Arabia's northern shores and the Bay of Kuwait following the 1991 Gulf War (Al-Arfaj and Alam 1993). Hot spots of heavy metals, like mercury, were also identified near old outfalls of chemical plants (Husain 2001), while studies conducted in Kuwait Bay found highly toxic sediments and determined that the benthic food chain was seriously compromised by urban pollution (Khan 2007).

WATER FOR ENERGY, ENERGY FOR WATER

The Gulf region has one of the greatest demands in the world for power generation and clean freshwater due to rapid population and industrial growth. Overall demand for freshwater within the Gulf has been increasing at an alarming rate of 8% per annum (Darwish and Al-Najem 2005). The current rate of water use in the GCC countries is about six times the natural renewal rate (World Bank 2007). Water is supplied almost free of charge to populations in several GCC countries and this has stimulated unprecedented waste of this precious resource, resulting in some of the highest per capita water consumption levels in the world (Dawood 2002). In the case of Qatar, increasing population between 1994 and 2009 led to a 300% increase in water withdrawal (from both renewable sources and desalination) (AFED 2009) whereas the UAE is known to have the third highest freshwater consumption rate in the world. The prevalent under-pricing of water in this region not only encourages waste and use of water for low value-added purposes, but also discourages necessary investment in water saving technologies (World Economic Forum 2010).With one of the most arid climates

Box 4. Harmful algal bloom species (HABs): an emerging threat?

Enclosed shallow inland seas that suffer increased nutrient loading due to human influence are susceptible to invasions and establishment of harmful algal bloom species (HABs). Although the Gulf's physical geography and intensive ship traffic should make it prone to HAB outbreaks, so far such events have been relatively rare and short in duration (e.g., Heil et al. 2001). Despite this, complex coastal developments such as the Palm islands in Dubai, and mega developments in Kuwait (e.g., Sabah Al-Ahmad Sea City (formally Al-Khiran Pearl City)) and Bahrain (e.g., Durrat Al-Bahrain), are at a real risk of reduced water quality which can lead to proliferation of HABs. For example, lagoonal areas that have low flushing rates with surrounding open waters, such as the eastern and western sides of Palm Jumeirah, are especially vulnerable to localized oxygen depletion (anoxia) and HAB development (Bauman et al. 2010).

A number of past incidents illustrate the potential risk of HAB events becoming more frequent in the Gulf. In May 2008, in waters surrounding and within Palm Jumeirah, a bloom of filamentous cyanobacteria, *Trichodesmium* sp. (also called 'sea sawdust'), occurred and formed visible clumps on the water's surface. Although blooms of this species are not a new occurrence here, enclosed aquatic environments such as those of the Palm projects, are likely to favor their proliferation with negative impacts on water quality. In another case, a large (>500 km^2 wide) and prolonged HAB event occurred in southern parts of the Gulf. It actually began in the fall of 2008 in the Gulf of Oman, but expanded north along the Musandam coast and into the Gulf until it reached the shores of Dubai in late 2008. The dominant species was *Cochlodinium polykrikoides,* a fish-killing species common in other parts of the world, but this was the first confirmed report of its occurrence in the Gulf (Richlen et al. 2010). This bloom also negatively impacted marine fauna, especially hard coral communities and associated fish fauna (Bauman et al. 2010), as well as aquaculture, fishing and tourist industries. Although the direct causes of this particular bloom are unknown, research conducted by our Dubai-based team indicate that increased nutrient enrichment due to wastewater discharge, natural oceanographic mechanisms, and the recent invasion by HAB species, perhaps due to ballast water discharge, were contributing factors. Blooms of the same HAB species also appeared along the coast of the UAE in March 2009. The HAB patch that appeared on the east of Palm Jumeirah and in the Palm lagoon led to a sharp decrease in dissolved oxygen levels in the water column, but as soon as it disappeared, oxygen levels returned to normal.

This documented arrival of invasive HAB species in the Gulf should be cause for great concern. Toxic algal species are now resident in many Gulf waters and factors that could lead to new blooms are prevalent within and around complex coastal developments such as the NMPs; particularly since many HAB species form cysts which can lie dormant in the sediments for extended periods before becoming active blooms again when favorable water conditions return. Construction of further enclosed and protected lagoons, increases in anthropogenic discharges, and further invasions via ballast discharge combined with projected episodic warming events (Sheppard et al. 2010) create suitable conditions for HAB development and outbreaks. In an attempt to avoid such events, nutrient discharge should be managed rigorously and regular water quality monitoring including phytoplankton sampling is needed.

Red tide along the coast of Dubai in 2008. Credit: Elise Marquis

Table 4. Freshwater statistics for the Gulf region.

Country	Total Water Withdrawal[1] (10^6 m³/yr)	Desalinated Water Produced (10^6 m³/yr)	Share of Desalinated Water of Total Water Withdrawal (%)
Bahrain	357.4 (2003)	102.4 (2003)	29
Iran	93,300 (2004)	200 (2004)	0.2
Iraq	66,000 (2000)	7.4 (1997)	0[2]
Kuwait	913.2 (2002)	420.0 (2002)	46
Oman	1,321 (2003)	109 (2006)	8[2]
Qatar	444 (2005)	180 (2005)	41
Saudi Arabia	23,666 (2006)	1,033 (2006)	4
UAE	3,998 (2005)	950 (2005)	24

Main source: FAO Aquastat http://www.fao.org/nr/water/aquastat/main/index.stm

[1] *Total water withdrawal = Water withdrawal is the quantity of water removed from available sources (including desalination) for use in any purpose; irrigation and livestock, municipalities, and industry.*

[2] *Either no information was available or information was from different sources and years and hence incomparable.*

on earth and very limited freshwater resources, it is not surprising that 70 to 90% of the Gulf's inhabitants depend on desalination plants for their freshwater supply (AFED 2009), mostly for drinking water. In particular, Qatar and Kuwait almost entirely rely on desalination plants for their drinking water supply; more than 40% of the total water withdrawal is from desalination, whereas in Oman and Saudi Arabia it is less than 10%, and even less in Iraq and Iran (Table 4). The UAE has rapidly increased its capacity for desalination by building several large-scale desalination plants to meet ever-increasing urban water demands. The combined capacity of all desalination plants within the region is about 11 million m³/day, or slightly less than half (45%) the worldwide daily production (approx. 24.5 million m³/day in 2005; Lattemann and Höpner 2008). Contaminated effluent brine that results from the desalination process is at least twice this quantity (Höpner and Lattemann 2002). The main desalination producers in the Gulf are the UAE, Saudi Arabia and Kuwait with 26%, 9% and 7% of the worldwide total seawater desalination capacity respectively (Lattemann and Höpner 2008). The world's largest plant is the Jebel Ali Desalination Plant in Dubai, UAE, with an annual production of 300 million m³. Future demand for freshwater is only increasing in the Gulf and more desalination plants will be needed to satisfy this demand; this means that disposal of brine from desalination plants and heated effluent released from cooling plants will only increase over time. Finally, climate change will also have substantial impacts on the available freshwater resources in this region. Trends of reduced surface water availability, reduced groundwater reserves, and increased occurrence of drought and flood events have been observed in several countries and projections indicate that per capita renewable water resources will drop by half in 2050 (World Bank 2007). These trends will mean tough choices and trade-offs will have to be made on how to manage water resources, testing the ability of governments in the Gulf region to counteract a very real and increasing risk to growth and socio-economic well-being (World Economic Forum 2010).

All GCC nations well exceed the world average of energy consumption per capita (Table 5), and the demand for energy has doubled over the last decade due to rapid population growth and urbanization, increasing affluence, and diversification of, but still energy-intensive, economies. Some countries, such as Saudi Arabia, Kuwait, the UAE, Qatar and Oman, have invested in refining petrochemicals as well as in aluminum smelting to curb over-dependence on oil revenues. However, these economic diversification goals are driving larger power demands and require energy-consuming desalinated water (World Economic Forum 2010). Many countries have even been forced to burn crude oil because they do not have enough natural gas to cope with rising demand; increased standards of living are promoting energy-intensive lifestyles. The level of energy consumption is also driven by subsidies and low residential and commercial electricity rates. Low energy prices, while helping to bring energy to low-income households, can

Power and desalination plant in Jebel Ali, Dubai, UAE. Credit: Airview Aerial Photography

Table 5. Energy profile for the Gulf region.

Country	Energy from Fossil Fuels (%)	Total Oil Production* ($x10^3$/bbl/day)	Share of World Production (%)	Total Oil Consumption ($x10^3$/bbl/day)	Per capita Consumption (bbl/day)	Per Capita Consumption as % More (+) or Less (-) than the World Average**
Bahrain	100	49	0.06	33	0.045	+45
Iran	98.8	4,325	5.29	1,730	0.026	-16
Iraq	99.7	2,423	2.96	295	0.01	-67
Kuwait	100	2,784	3.40	300	0.111	+258
Oman	100	728	0.89	69	0.02	+65
Qatar	100	1,378	1.68	104	0.125	+301
Saudi Arabia	100	10,846	13.26	2,224	0.078	+249
UAE	99.9	2,980	3.64	467	0.097	+213
Gulf Total	–	**25,513**	**31.18**	**5,222**	–	–

* Includes crude oil, shale oil, oil sands and NGLs (the liquid content of natural gas where this is recovered separately); excludes liquid fuels from other sources such as biomass and coal derivatives.

** The world average oil consumption is set at a value of 0%. Therefore all percentage values provided are a comparative value to the world value of 0%. Sources: BP 2009: http://bp.com/statisticalreview; Current Worldwide Oil Production: http://chartsbin.com/view/yp7

also discourage efficient use of electricity in households. For example, 70% of the total energy use in the UAE is attributed to (often inefficient) use of air conditioning (AME Info FZ LLC 2011). Although some countries have recently been developing renewable energy and nuclear projects to keep up with the energy demand, nearly 100% of energy used is derived from fossil fuels (Table 5). Five Gulf countries rank among the world's top 50 emitters of carbon dioxide (Iran 10, Saudi Arabia 14, the UAE 33, Iraq 38, and Kuwait 42) (US EIA 2009) while four have reached the world's top ten list in terms of ecological footprint (UAE ranks 1st at 10.68 global hectares per capita (gha/person); Qatar is in 2nd place (10.51 gha/person); Bahrain is in 3rd place (10.04 gha/person) and Kuwait is in 10th place (6.32 gha/person) (Figure 15; Global Footprint Network 2010). Not surprisingly, CO_2 emission rates in the Gulf are more than 3 times greater than the world average (World Bank 2007). Some plans are in the works to increase oil production in the near future. For example, the UAE plans to increase oil production capacity by 12.5% to 5 million barrels/day by 2014 (IEA). These high levels of energy consumption, and significant carbon and ecological footprints come at a great environmental cost.

Large cogeneration facilities which combine desalination and energy plants for power production predominate in the oil rich GCC countries. To operate properly, these power generators must take in vast quantities of seawater. This can lead to the entanglement of large marine organisms such as fish and turtles on intake screens, as well as the entrainment of smaller organisms right inside plant facilities; both are often fatal and may negatively impact the health of nearby ecosystems (Khordagui 2002). Furthermore, thermal pollution, waste brine, and pre- and post treatment chemicals from desalination and power plants may also be harmful (Al-Rashed and Sherif 2000), but major gaps remain in our understanding of the extent of these threats. Power and desalination plant effluent is reported to make up about 50% of the wastewater discharged into the Gulf (ROPME 2003). These effluents are generally 5°C warmer than receiving waters and the highly saline brine that is released contains chlorine and other substances that may adversely affect water quality (Al-Rashed and Sherif 2000). Traditionally, such effluent is naturally diluted in a 'mixing zone', but dilution in the Gulf is limited since this region lacks frequent rainfall and surface runoff. Salinity concentrations of nearly 50 psu have been recorded in the vicinity of desalination plants compared to an average 40 psu found within other parts of the Gulf (Dawood 2002, Nezlin et al. 2010). Interactions between chlorine and seawater can induce complex chemical reactions that produce highly toxic and persistent compounds, such as alkyl halides, which can result in adverse effects on aquatic life. Clear evidence exists that

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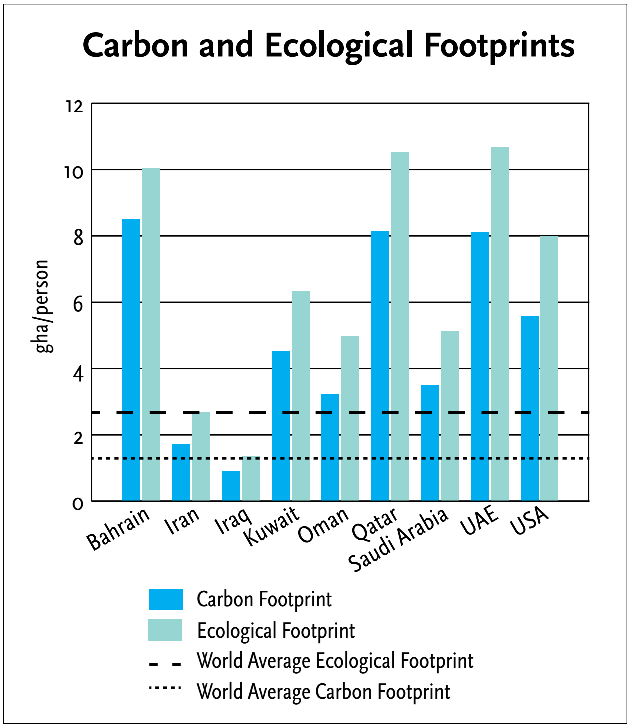

Figure 15. Carbon and ecological footprint data for Gulf countries in 2007 (Source: Global Footprint Network 2010). Note: The ecological footprint is a measure of human demand on the Earth's ecosystems and a standard measurement of a unit's influence on its habitat based on consumption and pollution.

hypersaline wastewaters can also have serious and detrimental effects on the growth and survivorship of marine organisms like cuttlefish (Dupavillon and Gillanders 2009). However, very few studies have examined potential effects on marine fauna in this region (Purnama et al. 2005). Discharge from desalination and power plants should be minimized by avoiding the use of substances like chlorine or substituting with less harmful alternatives, and by treating or disposing of wastes properly. Ideally, discharge sites should also be selected for hydrographical conditions that optimize dilution and dispersion of salt and heat input as well as any residual pollutants (Lattemann and Höpner 2008).

OTHER ANTHROPOGENIC STRESSORS ON THE GULF'S COASTAL AND MARINE ECOSYSTEMS

Along with impacts from coastal development, the Gulf's coastal ecosystems are subjected to a suite of other anthropogenic stressors. These are summarized in Table 6 and discussed briefly in the following sections.

OIL POLLUTION

Oil exploration, production, and transport, along with military activities, have been major contributors to pollution in the Gulf. In fact, the Gulf is reported to carry one of the greatest risks worldwide for oil pollution because of chronic contamination from oil discharged from ports, ballast water, boat terminals, industry, atmospheric fallout, and sewage-plant effluent (Madany et al. 1998). Oil and oil-related chemicals enter into the Gulf from the Shatt Al-Arab (Douabul et al. 1984) and roughly two million barrels of oil are spilled annually from routine discharges of ballast, tanker slops and from 800 oil and gas platforms. Also, around one third of all recorded oil spills >10 million gallons occurs here and smaller scale incidents such as pipeline ruptures and well blowouts are more frequent here than in other parts of the world (ROPME 2003). A particularly major spill occurred during the 1991 Gulf War when an estimated 6–8 million barrels of oil were deliberately dumped (Price and Robinson 1993). This affected over 700 km of coastline from southern Kuwait to northern Saudi Arabia, and large areas of coastal benthic habitat was seriously impacted, although it has shown remarkable recovery since the initial spill (Price 1998). Reliable data on the current distribution and levels of oil pollution are lacking or patchy at best, but available information shows that overall there are persistently high levels of hydrocarbon pollution throughout the Gulf, predominantly along the Iranian coastline (Gevao et al. 2006, Gawad et al. 2008).

Specific regional (Kuwait Convention and its protocols) and international (International Convention for the Prevention of Pollution by Ships, MARPOL 1973/78) agreements under the auspices of the International Maritime Organization (IMO) have resulted in ameliorating anthropogenic input of oil into the marine environment. These Conventions encourage all countries belonging to ROPME (Regional Organisation for the Protection of the Marine Environment) to take appropriate measures to prevent, abate and combat oil pollution resulting from transport, exploration and exploitation activities. They have had some success in improving regional coordination and awareness of the importance of taking measures to prevent and combat oil pollution. For example, a Marine Emergency Mutual Aid center was established in Kuwait in 1978 to coordinate responses to major oils spills and other emergencies in the Gulf. The high risk

Table 6. Summary of anthropogenic threats (excluding climate change) on the Gulf's coastal environment (Gilbert et al. 2002, ROPME 2003, Al-Jamali et al. 2005, AFED 2008, Hamza and Munawar 2009, Sheppard et al. 2010).

Stressor	Direct Causes (anthropogenic)	Root Causes	Main Environmental Impacts	Key Global or Regional Programmes and/or Agreements	Proposed Interventions
Overexploitation	Unsustainable and destructive fishing methods and pressure, lack of sound (long term) data/statistics	Inadequate control and licensing, lack of systematic monitoring/ stock assessment, population and economic growth pressure	Reduction in fish stocks and other marine resources	UNCLOS, the 1995 Agreement on Fish Stocks, FAO	Enforce regulation and penalties, prevent/reduce destructive fishing methods, improve stock assessments and monitoring, deploy vessel monitoring systems
Pollution (other than oil and sediment)	Desalination, tourism, power plants, urban wastewater and sewage, (near shore) urban and coastal development, industry, agriculture, atmospheric deposition	Inadequate infrastructure and waste management policies, poor planning, lack or inappropriate use of guidelines, population and economic growth pressure	Water quality deterioration, marine habitat degradation and loss, seafood contamination, eutrophication, HABs, fisheries losses	ROPME, UNEP GPA, Stockholm Convention (POPs), Basel Convention, Rotterdam Convention, MARPOL 73/78, London Dumping Convention	Develop/implement ICM, improve enforcement of regulations on chemical and heavy metal use, prevent or reduce discharge of solid waste and untreated wastewater, regular monitoring, apply clean production methods and enhance use of Best Available Technologies and Best Management Practices in tourism, agriculture and industry, promote outreach, apply desalination and power plant effluent standards, increase knowledge (research)
Oil pollution	Spills, shipping, refineries, discharge from pipelines, drilling, marinas, urban run off	Inadequate control and patrolling, lack of reception facilities	Water quality deterioration, marine habitat degradation and loss, seafood contamination, fisheries losses	ROPME, MEMAC, IMO MARPOL, UNEP GPA	Improve enforcement of regulations, improve accident and disaster preparedness (enhance MEMAC), navigational control, establish reception facilities
Obstruction of Coastal Processes	Creation of coastal/ off-shore structures	Lack of effective EIA and lack of environmental science input into planning processes	Interruption of coastal currents, changes in sediment transport, reduced water flushing in shallow lagoons, reduced water quality, fish kills and HABS	ROPME, UNEP GPA	Conduct sound EIAs, increase knowledge (research), promote use of science in planning, promote long term planning, use good development practices and guidelines, routine monitoring, integrated and adaptive management approach
Sedimentation	Coastal (urban, tourism, industrial) development (dredging, infilling, reclamation), erosion	Poor planning, lack of awareness and knowledge, no or inadequate EIAs, lack of (enforcement) regulations, population and economic growth pressure	Water quality deterioration, marine habitat degradation and loss, fisheries losses	ROPME, UNEP GPA	Develop/implement ICM, use good development practices and guidelines to conduct sound EIAs, promote outreach, increase knowledge (research)
Fragmentation and habitat loss	Coastal (urban, tourism, industrial) development (dredging, infilling, reclamation), trawling and anchoring, aquaculture	Poor planning, lack of awareness and knowledge, no or inadequate EIAs, inadequate control, population and economic growth pressure	Marine habitat degradation and loss, coastal erosion, fisheries losses, modifications to coastal hydrodynamics	ROPME, UNEP CBD, UNEP GPA, UNESCO WHC, MAB, RAMSAR	MPAs, develop/implement ICM, conduct sound EIAs, use good development practices and guidelines, promote outreach, increase knowledge (research)
Invasive species	Shipping (ballast water), aquaculture	Inadequate control, lack of- or little awareness and knowledge	HABs, marine faunal kills, seafood contamination, habitat loss	IMO Ballast Water Convention, IMO MARPOL, UNEP CBD, UNEP GPA	Inclusion into national laws, follow IMO and Ballast Water Convention guidelines, enforcement of regulation and penalties, promote outreach, increase knowledge (research)

Box 5. Best Development Practices – examples from the region

To demonstrate that even within areas of active development steps can be taken to mitigate environmental impacts and even increase marine productivity, we highlight two cases (Al-Jamali et al. 2005): West Bay Lagoon in Qatar and Sabah Al-Ahmad Sea City (formally Al-Khiran Pearl City), Kuwait. Both these developments raised concerns about their potential to lead to water stagnation and high salinity (Kana 2002) and were therefore subjected to rigorous simulations to optimize tidal and wind flushing as well as stability of internal beaches (Al-Handasah 1994, Ealey et al. 2001).

Qatar

The **West Bay Lagoon in Qatar** was originally a large salt marsh, but earlier coastal construction had transformed it into a hyper-saline shallow pool. Construction of the West Bay Lagoon and associated channels in the early 1990s resulted in a substantial flow-through system, resulting in seawater temperature, salinity and oxygen levels similar to those found in the open sea. In the final design, water depth was reduced from 3 to 2.5 m and islands were enlarged and aligned to create well defined paths of flow within the lagoon (Al-Handasah 1994). This opening up of the lagoon to coastal processes resulted in a gradual increase in the diversity and abundance of benthic infauna. Seagrass was transplanted into the lagoon, leading to substantial increases in the diversity and abundance of macrofauna. Seagrass coverage doubled within a single year. This demonstrates that artificially created lagoons and waterways may be managed to provide nursery areas suitable for fishery stock enhancement (Sheppard et al. 2010). Today, the West Bay Lagoon development includes 11 km^2 of housing, each dwelling with a private beach, and is surrounded by over one million m^2 of lagoon water.

Kuwait

Still under construction, the **Sabah Al-Ahmad Sea City** (formally Al-Khiran Pearl City), just 85 km south of Kuwait City, is projected to be over 40 km^2 in area. It is centered on two hyper-saline inlets and will eventually be home to approximately 100,000 residents. Concerns over this type of coastal development include loss of existing habitat, provision of adequate flushing and water circulation, erosion and channel stabil-

West Bay Lagoon, Qatar (Source: Google Earth 2009).

Sabah Al-Ahmad Sea City (formally Al-Khiran Pearl City), Kuwait (Source: Google Earth).

ity (Kana 2002). Detailed hydrodynamic models that were used for the expansion of the Sabah Al-Ahmad Sea City were based on 15 and 25 year master plans for the phased expansion of the Al-Kiran City to its final capacity of over 100,000 inhabitants (Ealey et al. 2001). Development and construction of Sabah Al-Ahmad Sea City has included the creation of new areas of marine productivity such as new tidal beaches, saltmarshes, mangroves and a greatly expanded sub-tidal benthos (Jones et al. 2007). In addition, similar to the UAE developments, rock revetments and cobble areas have been introduced and have the potential to provide new habitat for hard substratum communities. Recent surveys (Jones et al. 2007) have shown that species diversity in artificial habitats within the development have reached levels similar to those on natural open sea beaches, and in 2007, a higher mean diversity of the Khors (an inlet or estuary) was found than before construction. Water quality measurements and plankton samples demonstrated that sea water in and around this development are of high quality. Comparisons made prior, during and after the majority of construction was completed showed that the total macro species diversity quadrupled by 2007 despite reductions during developmental phases (Jones et al. 2007). Catches of market size grouper and mullet, and planktonic shrimp and fish larvae, were also enhanced by the waterways which act as nurseries for such commercial species.

Multidisciplinary approaches and design teams including marine civil engineers, oceanographers, architects and biologists have contributed to limiting the negative environmental impacts of each of these coastal developments (Al-Handasah 1994, Ealey et al. 2001). This approach has led to designs for good water circulation, including the creation of substantial channels within both developments, which help ensure that stagnation and increased salinity from evaporation is reduced and high water quality standards are maintained. Perhaps such design approaches should be considered a compensatory solution for infill and reclamation, and be given high priority in future deliberations for coastal planning and management. Designs should also take into account expected climate induced sea level rises, make use of land that will be potentially flooded, and also set aside marsh areas to accommodate any future inundation by the sea. Such design approaches should be given high priority in future deliberations for coastal planning and management especially considering the trend of unsustainable and damaging coastal development that has occurred over the past 15 years.(Sheppard et al. 2010).

Artificially created lagoons and waterways may be managed to provide nursery areas suitable for fishery stock enhancement

Bahrain

Bahrain is at the forefront of coastal development with multiple coastal mega projects either under construction, planned or completed. In 2010, in recognition of the potential deleterious environmental impacts of these projects, an initiative was launched to halt illegal land reclamation and sand dredging. Environmental experts and inspectors from Bahrain's Public Commission for the Protection of Marine Resources, Environment and Wildlife, as well as the Coastguard, started using fully equipped boats to patrol areas where reclamation and dredging takes place to ensure that companies follow regulations. In addition, all coastal reclamation activities need to be approved and licensed by the Commission and dredging activities need to be approved and licensed by the Fisheries Directorate (Dredging Today 2010).

for oil pollution in the Gulf has led to its designation as a Special Area under the IMO; this requires countries that share this body of water to develop sound reception facilities for oil and associated wastes and improve the design and operation of tankers. Some successes have also been achieved in curbing input from oil spills and other oil discharges from tankers and in the past few years there has been a sharp decrease in the number of accidents (El-Habr and Hutchinson 2008). However, other sources of oil pollution still pose a risk as they have not been adequately addressed. For example, the threat of spills from offshore and near-shore drilling remains high and problematic since enforcement is the responsibility of the country that conducts drilling (UNEP 1999). Furthermore, it is difficult to get a complete picture of the extent of the problem as very limited data are available on the levels of oil pollution originating from land based sources (e.g., urban runoff, municipal wastes, industry and refineries, and disposal of lubricants). However, with the population growth and increased industrialization that has occurred over the last two decades in this region, it can only be expected that levels have increased (ROPME 2003).

OVEREXPLOITATION

Despite existing regulations governing fishing effort in the Gulf, this activity has not been controlled and many fishery species are in peril because of overexploitation (Grandcourt et al. 2004, 2009b, *in press*). Environmental degradation and habitat loss caused by coastal development is compounding this as it has led to the elimination of important nursery areas for some fish species (Bishop 2002). Inadequate management can be blamed on a number of factors. Despite the creation of ROPME and in particular RECOFI (Regional Commission for Fisheries), which are multi-national bodies mandated to guide management of shared resources in the Gulf, very little progress has been made towards putting effective trans-national policies or global catch limits in place (RECOFI 2010). Also, the administration of laws and regulations has often been lax, and insufficient effort has been expended to record basic data concerning fish catch or stocks. Catch statistics are aggregated to higher taxonomic levels in most cases, and are aggregated inconsistently by country which prohibits effective pooling of data except at even higher taxonomic levels. This makes it very difficult to assess the population status and health of fishery species (ROPME 2003, RECOFI 2010, Grandcourt *in press*). These are problems common to many developing nations, but Gulf countries are not impoverished so RECOFI must move forward before the decline in catch recorded since 2006 continues much further.

Each littoral Gulf state has federal policies, legal instruments and regulations that are specifically focused on fisheries and are administered by management agencies. In some cases, such as in the United Arab Emirates, local government policies, decrees, laws and regulations are also in place. Some fisheries regulations include outright bans, such as those that ban trawling in the UAE and Qatar, or the use of trammel nets in Kuwait. Other regulations include fishing gear restrictions such as minimum mesh sizes for gillnets and traps in Bahrain (Sideek et al. 1999). In Bahrain, destructive fishing gear and materials such as monofilament netting and drift nets have also been banned in order to mitigate the impact of fishing on endangered species such as turtles, dugongs and other marine mammals (Beech 2004). Closed areas and seasons are also implemented, sometimes on a species specific basis. Output regulations include size limits for a number of species, including representatives of the families Siganidae and Serranidae in Bahrain and Serranidae and Lutjanidae in Kuwait (Sideek et al. 1999).

Given the multitude of threats facing the Gulf's fish populations, a paradigm shift in the approach to fisheries management is required

Despite these measures, Morgan reported in a 2006 review of the state of marine capture fisheries that the effectiveness of enforcement of management regulations in the region was generally weak. In the southern Gulf where a variety of regulations were introduced in 2003, in order to rebuild depleted reef fish stocks, stock status indicators for the key species, *Diagramma pictum, Epinephelus coioides* and *Lethrinus nebulosus,* indicated a failure of the regulations to modify gear selectivity, reduce effort or rebuild stocks over a five year period following their introduction. The results of the study suggested that more dramatic management measures, such as fishery closures, may be required in order to achieve stock rebuilding targets (Grandcourt et al. 2009b).

Although fisheries management initiatives in the Gulf were initially triggered by a decline in shrimp fisheries nearly three decades ago, they are still not well developed and are hampered by a lack of appropriate regulations, poor enforcement and inadequate data on most stocks (Sideek et al. 1999). Other constraints include the availability of a cheap migrant labor force and low operating costs which have both encouraged continued exploitation. Policy frameworks are often oriented towards economic development rather than towards sustainability despite the fact that many fish stocks are being overexploited. Furthermore, management based on principles of ecologically sustainable development is rare. There are also limitations with the underlying legislation, which is often designed to serve as a basis for the administration of the fishing industry rather than for the long-term sustainable management of the sector (Morgan 2006). Given the multitude of threats facing the Gulf's fish populations, a paradigm shift in the approach to fisheries management is required.

AQUACULTURE RISKS

Growth of marine aquaculture in the Gulf is inevitable given that wild fish stocks are overexploited and that the demand for fishery products is increasing rapidly along with human population. Research in marine aquaculture in this region began in the late 1970s and has shown that there is good potential for commercial growth (Al-Jamali et al. 2005, RECOFI RAIS website) even though this sector is still considered to be mostly at experimental stages. Current commercial practices include (Table 7): 1) production of postlarval shrimp or fingerling fish, 2) release of juveniles to supplement wild fish stocks, 3) grow-out production, and 4) testing of new species for culture (FAO 2011, RECOFI RAIS website). Iran and Saudi Arabia are leading the way, while commercial activity is almost nonexistent in Bahrain, Iraq, and Qatar. Iran and Saudi Arabia have a well established shrimp industry (Table 7), mainly Indian white shrimp (*Penaeus indicus*), while Kuwait has been using floating sea cages since 1992 to mostly farm gilthead seabream (*Sparus aurata*) and sobaity seabream (*Sparidentex hasta*). Oman is the first in the region to pursue tuna fattening, using yellowfin tuna (*Thunnus albacares*) for export to markets in Japan (FAO 2011).

Each Gulf nation has a lead government agency that oversees the management and development of fisheries

Aquaculture facility in the Gulf. Credit: Unknown

activities, including marine aquaculture, and most have a separate entity under the auspices of the lead institution that coordinates related research. Most have some type of legal framework to regulate activities, and most offer various academic and training programs related to fisheries and marine aquaculture (Table 7). Some are also actively encouraging growth in this sector; e.g., a number of pilot projects are underway in Bahrain and Qatar, and the Kuwaiti government offers yearly subsidies to promote sea cage fish culture. Each country has its own constraints to developing aquaculture and some commonly encountered problems include the limited availability of suitable sites, insufficient freshwater resources and lack of endemic marine fingerlings. To deal with the shortage of land, open-ocean aquaculture is being explored as a new type of marine aquaculture in the Gulf (Almatar and James 2008) where submersible cages are deployed in deep water to produce farmed seafood.

An expanding marine aquaculture industry will place increasing pressure on already vulnerable ecosystems and native species within the Gulf. Environmental risks include loss of natural habitat, pollution, invasive species and introduction of parasites and diseases to wild fish stocks (Folke and Kautsky 1992, Baird 1996). Across the world, large expanses of valuable coastal habitat have been converted into aquaculture ponds; e.g., nearly 50% of all mangrove habitats have been lost to unsustainable shrimp farming (Spalding et al. 2010). The fact that this industry is not yet fully developed provides a unique opportunity for Gulf countries to adopt responsible and sustainable aquaculture methods. In moving forward, countries should adopt a Gulf-wide strategic and collaborative approach, as demonstrated by the

Catch of the day at a fish market in Fujairah, UAE. Credit: EWS-WWF

Regional Aquaculture Information System (RAIS); a web-based information system developed by RECOFI which facilitates exchange of marine aquaculture information and supports a functional network of regional experts. At the national level, a lead agency dedicated to marine aquaculture is needed to address jurisdictional issues and ensure the development of an economically and environmentally sound industry. This will require comprehensive legal frameworks to regulate activities, comprehensive environmental impact assessments (EIAs), coordinated research to determine the most suitable species and sites that pose the least environmental risk, development of standard operating procedures and training, and regular monitoring (e.g., fish health and disease control, and invasive species). Pollution, destruction of sensitive coastal habitats, threats to aquatic biodiversity and socio-economic costs must be balanced against the substantial benefits that aquaculture offers.

AQUATIC INVASIONS

The introduction of non-native aquatic species to new environments via ballast is considered one of the greatest threats facing the world's coastal and marine environments. The approximately 3 to 5 billion tonnes of ballast carried by ships around the world each year is estimated to contain approximately 10,000 species of flora and fauna at any given time, many of which are not native to discharge locations (Carlton 1999). The high shipping volume in the Gulf means that invading species potentially pose a high environmental and public health risk; upwards of 100,000 metric tonnes of seawater per ship is discharged into the Gulf with each return trip (Pughuic 2001). In the last half century, the increased number of commercial vessels, the reduction of chemicals in ballast water, and larger capacity of ballast tanks have improved the survival of marine invaders in transit and thus the number of viable invasive species introductions (Carlton 1985, 1996, Cohen and Carlton 1998). Although there have been several pilot efforts to establish treatment facilities for ballast water in the Gulf to minimize risk of introducing invasives (Nadim et al. 2008), the vast majority of discharged ballast water is untreated and released directly into the Gulf.

Other human activities have further accelerated the spread of non-native species in the Gulf. Sewage discharge and aquaculture facilities, both of which are growing, contribute significant amounts of nutrients into marine environments (Khan 2007, Zainal et al. 2008). Increased nutrient levels have been associated with mass fish kills as a result of harmful algal blooms. For example, the widespread deadly bloom of *Cochlodinium polykrikoides* in the eastern Gulf and Gulf of Oman in late 2008 was due to an invasive species that was likely released in ballast water (Box 4; Bauman et al. 2010, Richlen et al. 2010). Also, the creation of hard-bottom substrates such as breakwaters, seawalls, and oil and gas pipeline platforms may facilitate the spread of introduced species by acting as 'stepping stones' for dispersal across inhospitable natural habitats (Sheehy and Vik 2009, Bulleri and Chapman 2010). Increasing coastal and offshore development also often provides artificial and altered settling habitats, leading to substantial increases in exotic species (Tyrell and Byers 2007).

Although these data suggest that the Gulf is a hotspot for non-native species invasions, documented reports suggest the contrary as only coliform bacteria and dinoflagellate introductions have been officially reported (Bauman et al. 2010, Richlen et al. 2010). This is surprising given the pervasive effects of invasive species in other areas, and especially because of the large volume of ship traffic and amount of ballast water that is discharged into the Gulf. This may simply reflect underreporting due to lack of adequate monitoring programs and the scarcity of baseline data against which to compare current species records. However, it is also likely that invasive species have had limited success in the Gulf because they are not able to survive its naturally extreme environmental conditions (Al-Sayed et al. 2005, Richlen et al. 2010). It has even been suggested that the Gulf's environment may act as an ecological filter and control the survival and establishment of non-native

3

A tanker discharging ballast water in Abu Dhabi (2011). Credit: Edwin Grandcourt

Table 7. Marine aquaculture in the Gulf.

Country	Lead Agency/ Governing Body	Lead Research Agency	Education Opportunities Related to Aquaculture	Legal and Institutional Framework
Bahrain	Directorate of Marine Resources, a member of the General Directorate for the Protection of Marine Resources within the Public Commission for the Protection of Marine Resources, Environment and Wildlife	National Mariculture Centre (NMC), General Directorate for the Protection of Marine Resources	Bahrain Center for Studies and Research: Fisheries and Aquaculture Bahrain University: Marine Science	Royal Decree on Exploitation and Utilization of the Marine Resources, 2002 , includes provisions for controlling the culture of organisms using aquaculture (e.g., licensing and quality)
Iran	Iranian Fisheries Organization (Shilat Iran)	Iranian Fisheries Research Organization (IFRO) 12 research centers working under IFRO conducting fisheries research	Ministry of Science, Research and Technology - fisheries science course within Iranian universities: 8 state and 12 open universities offer bachelor courses, and 4 state and 2 open universities offer master and post-graduate courses in various fields related to fisheries and aquaculture International Sturgeon Research Institute: biotechniques for sturgeon aquaculture Shrimp Research Center of Iran: shrimp aquaculture, fishing, biology and ecology of aquatics in Gulf	Well established Protection and Exploitation of Natural Aquatic Resources Law, 1997 General Guidelines for Aquaculture and Fisheries, adopted in 1999, provides a legal framework
Iraq	General Board for Fish Resource Development			Legal license is required for any fish related work; letter of agreement must be obtained from authorities to start any aquaculture activity
Kuwait	Fisheries Department, Public Authority for Agriculture Affairs and Fish Resources (PAAFR)	Fisheries and Mariculture Department, Kuwait Institute for Scientific Research (KISR)	PAAFR offers training programs and technical guidance on fisheries and aquaculture	Law No. 46 (1980) Specific resolution No. 293 (2005), for aquaculture development Culture of new species is prohibited without prior permission
Oman	General Directorate of Fisheries Research, Ministry of Fisheries Wealth	Aquaculture Center	Fishermen's Training institute in Al-Khaboura: along with other fisheries specializations it offers a diploma with 2 year aquaculture courses for high school graduates Marine Sciences and Fisheries Department, Sultan Qaboos University, offers bachelors, masters and post-graduate degrees in marine sciences and fisheries including aquaculture	Law of Fishing and Protection of Living Aquatic Resources (1982), amended in 1993 and now under 3rd revision
Qatar	Aquaculture Unit of the Fisheries Development Division, Department of Fisheries, Ministry of Environment	Doha Aquaculture Centre	Department of Fisheries recently proposed the construction of its 1st Marine Resources Research Center in Rasmutback Qatar University, graduate course in Marine Sciences	No regulations for aquaculture, but there are common aquaculture rules and regulations in the Gulf Cooperation Council (GCC) - many of which are still under review and discussion between GCC countries
Saudi Arabia	Department of Aquaculture (DA), Office of the Deputy Ministry of Fisheries Affairs, Ministry of Agriculture (MOA)	Fish Farming Center (FFC), Jeddah	Fisheries Research Centers (Eastern Province and the Red Sea) A number of universities offer courses on Fisheries and Aquaculture King Abdul-Azziz University Faculty of Oceanography: Marine science Fish Farming Center: marine shrimp aquaculture program/Aquaculture program for marine tilapia	Royal Decree (No. M/9), 18 November 1987 – not specific to aquaculture, not many rules and regulations governing the sector – gives the MOA responsibility of regulating fishing, investment and protection of living aquatic fisheries
UAE	Ministry of Environment and Water (MOEW)	Marine Environment Research Centre (MERC)	United Arab Emirates University: studies in Tilapia	Federal Law No.23 under Articles 34-38 (aquaculture should not cause pollution, alien species cannot be used without permission and recognized hygienic procedures in fish handling, stocking, packing and transportation must be followed)

Sources: http://www.fao.org/fishery/naso/search/en
http://www.raisaquaculture.net/
http://www.fao.org/fishery/rfb/recofi/en

Commercial Activity	Research and Development
EARLY STAGES	National Mariculture Centre (NMC): 1) Leading producer in the region for juvenile marine finfish species (2008 production from 3 species nearly reached 5 million) 2) Conducts research of commercially important local species: rabbit fish (*Siganus canaliculatus*), sobaity bream (*Sparidentex hasta*), brown-spotted grouper (*Epinephelus coioides*), gilthead seabream (*Sparus aurata*) mangrove snapper (*Lutjanus argentimaculatus*), streaked rabbit fish (*Siganus javus*) and green tiger shrimp (*Penaeus semisulcatus*) 3) Pilot-scale cage projects
2004 shrimp production reached ~ 9,000 tonnes; mostly Indian white prawn (*Penaeus indicus*) produced from 4,253 hectares of coastal ponds	Northern Persian Gulf coast and Gulf of Oman, potential for cage culture estimated ~100,000 tonnes Candidate species: grouper (family: Serranidae), cobia (*Rachycentron canadum*), silver pomferet (*Pampus argenteus*) and fourfinger threadfin (*Eleutheronema tetradactylum*) Breeding and stock enhancement: 1) Shellfish (*Pinctata margaritifera*) - 50 million fingerlings released/5 years in the Gulf and Oman Sea 2) Pharaoh Cuttlefish (*Sepia pharaonis*) - 20 million fingerlings released/5 years in the Gulf 3) Shrimps (*Penaeus merguinsis, P. indicus, P. monodon, P. semisulcatus*) - 40 million fingerlings released/5 years in the Gulf and Oman Sea
NONE	Marine aquaculture has not been developed due to lack of competencies
Marine cages have been used since 1992 – mainly gilthead seabream (*Sparus aurata*), European seabass (*Dicentrarcus labrax*) and sobaity seabream (*Sparidentex hasta*) / also European seabass (*Dicentrarchus labrax*)	PAARF provides yearly subsidies to encourage more investment in marine cage culture KISR has a hatchery where a private company GIAC produces 800,000 fry and exports fingerlings of sobaity, yellowfin seabream (*Acanthopagrus latus*) and orange-spotted grouper (*Epinephelus coioides*) for fish culture in cages
EARLY STAGES Cage culture: sea bream main species being cultured 1st Middle East country active in tuna fattening: 1 large 47,000 m³ cage inBandar Khayran - 14 tonnes yellowfin tuna (*Thunnus albacares*) produced in 2004 Quriyat Aquaculture Company; the only private company operating cage culture	Atlas of suitable sites for aquaculture: 1) Determine suitable sites for aquaculture operations 2) Establish infrastructure needs for commercial aquaculture Breeding of native red seabream/Production of Omani abalone juveniles/Production of cultivated clownfish (as model for finfish cultivation)
EARLY STAGES	Experimental trails: white-spotted spinefoot (*Siganus canaliculatus*), yellowfin seabream (*Acanthopagrus latus*), and greasy grouper (*Epinephelus tauvina*) Larval production of yellowfin seabream and green tiger prawn (*Penaeus semisulactus*) - both used for marine stock enhancement
Highly developed shrimp aquaculture industry: 8,705 tonnes in 2004, a significant increase from just 1 tonne in 1987 Indian white shrimp (*Penaeus indicus*): ~78% of the 2004 total aquaculture production 2004: aquaculture production comprised ~17% (11,172 tonnes) of total fish production (66,591 tonnes); production in seawater culture systems was 8,866 tonnes or 80%	Marine fish culture, especially highly priced species such as grouper, seabream and seabass, to be reared in floating cages in the Red Sea Natural Resources Environment Research Institute: aquatic animal health
EARLY STAGES Sea net cage: off Dibba eastern coast of UAE - main species: gilthead seabream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*) and sobaity seabream (*Sparidentex hasta*)	Fingerling production of popular local species: white-spotted spinefoot (*Siganus canaliculatus*), orange-spotted grouper (*Epinephelus coioides*), large-scale mullet (*Liza macrolepis*) and sobaity seabream (*Sparidentex hasta*) for release into coastal waters Experimental fingerling production of: orange-spotted grouper (*Epinephelus coioides*), sobaity seabream (*Sparidentex hasta*), shrimps (*Penaeus semisulcatus* and *Penaeus indicus*), rabbitfish (*Siganus canaliculatus*), and silver seabream (*Rhabdosargus sarba*)

species through the biological resistance of its native community (Price et al. 1993, Coles 2003), i.e., resident species may have inherent advantages when competing with non-native species because they are best adapted to local conditions (Byers 2002).

The Global Ballast Water Management Programme (GloBallast), which was developed by the International Maritime Organisation (IMO) to deal with invasive organisms introduced through ballast water, spearheaded the development of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* in 2004. This Convention calls on countries to prevent, minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens by 1) ensuring that ports and terminals where cleaning or repair of ballast tanks occurs have adequate reception facilities; 2) promoting scientific research on ballast water management; 3) monitoring the effects of ballast water management under respective jurisdictions; and 4) surveying and certifying ships that meet specific standards. Under this Convention, a ROPME regional action plan for Ballast Water Management was adopted by some member countries (UNEP 2009). Within the framework of the *Protocol Concerning Co-operation in Combating Pollution by Oil and Other Harmful Substances in Cases of Emergency*, MEMAC (Marine Emergency Mutual Aid Centre), in Bahrain, has taken a lead role in implementing this regional action plan. It calls for vessels arriving from outside the Gulf to undergo ballast water exchange while en route, as long as the ship is at least 50 nautical miles from the nearest shore and at a minimum 200 m depth. It remains to be seen whether vessels will strictly adhere to these guidelines. Without regular surveillance or a clear penalty system, success may be limited (ROPME 2003).

Ballast water management and non-native species are not commonly covered under national legislation in this region and there are no clear national institutional mandates and responsibilities that deal with this issue. At a minimum, each Gulf nation should appoint a lead agency with the overall responsibility to oversee the implementation of individual national strategies for ballast water management. This agency could also promote the integration of the strategy into pertinent national policies, monitor and review the effectiveness of implementation, and ensure effective enforcement. Countries should aim to enhance capacity to identify and monitor invasive species through targeted training of staff. Proactive development of transnational policies and regulations to control ballast water discharge in the Gulf will also be necessary.

4 MITIGATING THE IMPACTS OF CLIMATE CHANGE

Countries in the Gulf are among the most vulnerable in the world to the potential impacts of climate change (IPCC 2007b, Elasha 2010). By the end of the 21st century, it is expected that the Gulf region will face a 2 to 5.5°C increase in air temperature coupled with a projected decrease in precipitation of up to 20% (Dasgupta et al. 2007). These projected changes will lead to shorter winters, hotter and dryer summers, a higher occurrence of heat waves, increased weather variability, and more frequent extreme weather events (IPCC 2007b). Although rainfall is predicted to decrease and become more erratic in most Gulf countries, certain models predict increasing precipitation in Bahrain, Qatar, the UAE, and some parts of Oman (IPCC 2007b). This precipitation could arrive as concentrated, short and intense events, leading to a higher risk of flash flooding and nutrient rich storm-water discharges into vulnerable coastal marine systems, severe erosion, and potential negative consequences on aquifer recharge.

The Gulf's densely populated, and predominantly sandy, easily erodible, and low-lying coastal regions are especially vulnerable to the impacts of sea level rise through direct inundation, erosion and salt water intrusion. Infrastructures on offshore developments, such as these villas on the fronds of Palm Jumeirah, are also at risk. Credit: Imre Solt, Dubai Constructions Update (www.imresolt.com)

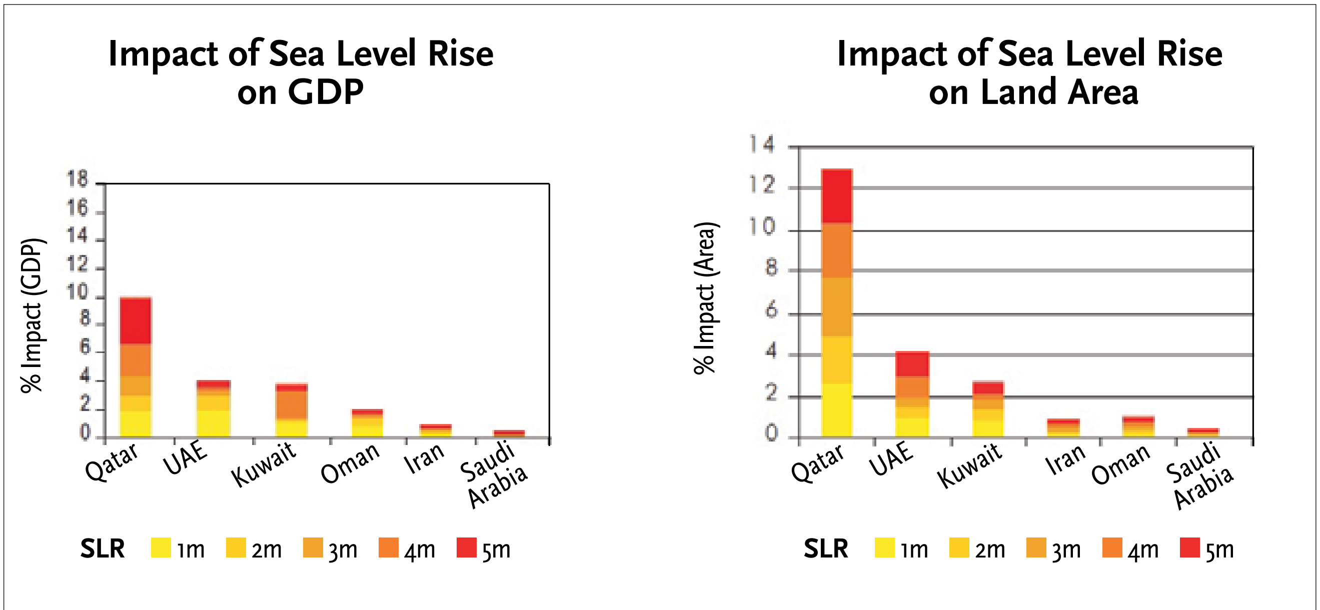

Figure 16. Sea level rise (SLR) scenarios with impacts on a) GDP and b) land areas of 6 Gulf countries (Adapted from: Daspupta et al. 2007).

DISAPPEARING COASTLINES

The Intergovernmental Panel on Climate Change (IPCC) estimates that with rising global greenhouse gas emissions and associated warming, global sea levels could rise by 1 to 3 m within this century. The highly populated and predominantly sandy, easily erodible and low lying coastal Gulf countries are especially vulnerable to the impacts of sea level rise through direct inundation, erosion and salt water intrusion. Individual countries will be affected differently, but studies examining vulnerability have predicted that most of the Gulf's coastal areas will be extensively inundated by the sea and large sections of shorelines will also migrate inland (El Raey 2010). This would adversely affect existing coastal cities and infrastructure, offshore developments, valuable coastal ecosystems, and plans for future development (Figure 16: Dasgupta et al. 2007, Environment Agency of Abu Dhabi 2009, El Raey 2010). Qatar and the UAE would be particularly susceptible. In the case of the UAE, nearly 85% of its population and over 90% of its infrastructure is concentrated in coastal zones. Depending on the particular scenario, the total surface area of land that would be inundated ranges from 1,155 to almost 5,000 km², or roughly between 1 and 6% of the total land area, with substantial differences in impact expected among the Emirates. For example, under the highest sea level rise scenario (5 m), the Emirate of Abu Dhabi would see its shoreline migrate inland by approximately 30 km (Al Raey, 2010, UAE 2010). In Qatar, approximately 3 (1 m rise) to 8% (3 m rise), or more than 13% (5 m rise) of land is likely to be lost as sea level rises. Other Gulf countries are also at great risk; it is predicted that Bahrain's 36 islands will not escape either, and over a quarter of its existing shoreline may be completely inundated by a sea level rise of just 1.5 m (Al Jeneid 2008).

IMPACTS ON COASTAL ECOSYSTEMS

Research has shown that temperatures in the Gulf region have risen more than the global average. Recent work by Al-Rashidi et al. (2009) has shown that between 1985 and 2002 sea surface temperatures in the Gulf increased by approximately 0.5°C/decade. This is substantially higher than the global average of 0.2°C/decade (IPCC 2007a). In enclosed urban coastal areas such as Kuwait Bay, increases have been even higher, i.e., approximately 0.6°C/decade or three times the global average. Recorded increases are greater than global trends because of the additive effects of local and regional drivers which account for 17% and 33% of the observed differences respectively, while global drivers are responsible for the remaining 50%. Regional driv-

Predictions suggest that the maximum thermal tolerance threshold for all coral species globally can be expected to be chronically exceeded. This is a photo of a partially bleached Acropora colony during a positive Sea Surface Temperature (SST) anomaly in October 2010. Credit: Edwin Grandcourt

ers include oceanographic circulation, wind, freshwater discharge from the Tigris and Euphrates rivers, and dust storms. Local drivers include coastal urban and industrial development, as well as effects due to power plants and desalination facilities.

The Gulf contains a unique community of organisms that are adapted to withstanding extreme environmental conditions. Coral and reef fish communities survive at temperatures that are significantly higher here than elsewhere in the world (Feary et al. 2010, Burt et al. 2011b). While the presence of these unique communities provides hope that some marine organisms may be resilient to the impacts of climate change, this must be greeted with caution. Research conducted over the last couple of decades shows that the extreme conditions present in the Gulf have come at a cost; coral and reef fish communities are lower in species diversity and differ in relative abundance when compared to those in surrounding seas (Box 6). In one study, Burt et al. (2008) examined coral recovery in Dubai, a decade after the 1996 and 1998 bleaching events (caused by El Nino; Riegl 2002) which had caused extensive coral loss (Sheppard and Loughland 2002). He found that some species showed substantial recovery. Once identified, habitats containing clearly warm-tolerant species should be given priority for conservation because as temperatures rise they may contribute to the replenishment and recovery of reefs elsewhere in the Gulf. Still, the evident tolerance to warm temperatures may not be sufficient as the climate warms even further. Predictions suggest that globally, the maximum thermal tolerance threshold for all coral species can be expected to be chronically exceeded in future (Hoegh-Guldberg 1999).

Low lying *Sabkha* areas (intertidal salt flats consisting of fine-grained largely wind-blown sediments) are barely above sea level, so are thus highly susceptible to sea water intrusion and salinity changes. The effects of sea level rising and flooding are not yet clear but could lead to mobilization of soft sediment and increased turbidity (Riegl 2003) which could be detrimental to marine life

Coastal wetland lagoons are common along the Gulf's coastlines and provide valuable nursery and/or feeding grounds for a large variety of species. Climate change is anticipated to severely impact these valuable ecosystems (Source: Coastal Development Guidelines, Abu Dhabi).

and also the aesthetic appeal of coastal waters. Seagrass and mangrove habitats are sensitive to fluctuations in water depth, temperature, and salinity. These coastal wetlands provide valuable feeding grounds for a multitude of resident and migratory seabirds and are important to many fish species. Climate change induced sea level rises will lead to inundation of these ecosystems and a gradual retreat to inland areas. However, due to the high population density and extent of coastal development that has already occurred in the Gulf, this retreat will be blocked unless climate change is accounted for in future adaptation planning. If action is not taken, the economic cost of losing these valuable coastal wetlands will be extremely high.

MONSOONAL UPWELLING PATTERNS

The monsoonal upwelling system in the Gulf is known to change in strength and direction when temperature fluctuations occur in the north Atlantic (Gupta et al. 2003). Each summer the monsoonal wind direction is reversed and blows from the southwest across the Arabian Sea cooling the sea surface and leading to coastal and open ocean upwelling that promotes the bloom of various types of flora and fauna (Gupta et al. 2003). Historically, warmer temperature periods in the north Atlantic such as the Medieval Warming increased the magnitude of the south western monsoonal winds while colder periods such as the Younger Dryas had the opposite effect. This suggests that global scale climatic changes will have regional effects in the Gulf (Gupta et al. 2003), though specific details are not yet unclear. While increasing CO_2 concentrations are expected to strengthen the monsoon system because of higher temperatures and increased rainfall, it is also unclear how rising CO_2 will influence the Gulf because of related effects on monsoonal direction (Prell and Kutzbach 1992, Parker and Goudie 2008). Furthermore, any climate change impact will be altered by changes in Gulf productivity caused by riverine discharge and aerosol input of terrestrial dust (Nezlin et al. 2010), this makes any assessment of the effects of climate change on the ecology of the Gulf unclear.

PREPARING FOR THE FUTURE

The Arab Forum for Environment and Development (AFED 2009) has stated that virtually no effort has been made to prepare Gulf countries for anticipated climate change challenges. Specifically, there is neither data gathering nor any research examining the potential impacts of climate change on human health, infrastructure, biodiversity, tourism, and water or food production in the region. Furthermore, within this region reliable records on climate patterns are limited and land use and urban planning regulations largely ignore basic adaptation requirements that have been adopted by nations in other parts of the world. In the face of climate change

Box 6. Reef fish communities and climate change

Gulf reef fish communities have evolved to tolerate extreme environmental conditions and studying these organisms may provide valuable insight into how species may adapt to expected climate change impacts in other parts of the world. In a study conducted by Feary et al. (2010), reef fish communities in the southern Gulf where sea-surface temperatures are extreme (winter 12°C, summer 35°C) were compared to those in the Gulf of Oman where conditions are more moderate (winter 22°C, summer 31°C). Results show that fish assemblages in the southern Gulf are significantly lower in species richness, abundance, and biomass, and were more dominated by smaller (younger, or slower growing) individuals and herbivores than in the Gulf of Oman. The lower species richness was expected due to the relative youth and isolation of the Gulf, as well as its extreme environmental conditions. The shift in size distribution may be a response to differing primary production and/or to the stress imposed by the Gulf's harsh environment, while the increased domination by herbivores suggests a simplified trophic structure. The degree to which these differences are driven by temperature and other likely climatic induced conditions remains unclear and further research is needed.

challenges, Gulf countries need to take urgent action to prepare for the potential negative impacts on coastal areas and resources, particularly to address the effects of sea level rise and changing climate on the functioning of coastal and island-based cities (Nasrallah and Balling 1996, Dasgupta et al. 2007, Elasha 2010, El Raey 2010). In addition to adaptation planning, these wealthy countries should vigorously address their contribution to the release of greenhouse gases as a matter of conscience. Encouraging sustainability in relation to climate change could begin by addressing its drivers, e.g., cutting carbon emissions, curbing water use, reducing energy demand, and promoting renewable and environmentally friendly energy sources.

Increased scientific knowledge and greater capacity within the field of climate change is necessary in the Gulf to create sound national and regional strategies for adaptation which in turn are incorporated into national and regional development plans. Improved proactive planning, risk assessment, and integrated coastal zone management are needed to increase the resilience of coastal ecosystems to climate change impacts. Countries in this region need to build their infrastructure and institutional capability for monitoring, modelling, conducting vulnerability assessments, and enforcing regulations. Policy makers must ensure that there is sufficient political and financial support for these proposed actions. Furthermore, GCC countries are signatories to the UN's Kyoto Climate Change Protocols and the Framework Convention on Climate Change, and governments should ensure that National Communication reports are submitted to the UNFCCC[5] to describe planned mitigation measures. The mainstreaming of climate change adaptation strategies within national development plans and efforts should be fostered, as should the incorporation of climate-sensitive policy components into sectoral, national and regional policy frameworks.

Encouraging sustainability in relation to climate change could begin by addressing its drivers, e.g., cutting carbon emissions, curbing water use, reducing energy demand, and promoting renewable and environmentally friendly energy sources

Gulf countries should commit themselves further to adopting national energy efficiency and renewable energy targets and promote the development and use of alternative and renewable energy sources and clean technologies. Despite being party to the UNFCCC, the GCC countries have no binding emissions targets, and have only quite recently started looking for opportunities to cut emissions and generate carbon credits. These oil producing countries could move further by tapping

[5] Under the provisions of the United Nations Framework Convention on Climate Change (UNFCCC), countries are required to submit National Communication reports every 4-5 years. Only four of the eight Gulf countries have submitted the first report (2003-2005), and only the UAE submitted a second report in 2010. Some countries have not submitted any report despite being party to the Convention. Completion and submission of these reports would be a first step towards fulfilling obligations under the Convention and planning forward to prepare for and mitigate climate change impacts on coastal environments within this region.

into the potential of carbon sequestration and storage through Clean Development Mechanism (CDM) and Carbon Capture and Storage (CCS) projects. Incentives could be given to builders, owners and tenants to adopt efficient technologies and appliances to cut energy use. Also, Gulf countries, especially those belonging to the GCC, could aim to adopt more policies for sustainable transport, including building modern public transport systems to improve energy efficiency and abate vehicle emissions. The concept of 'green building' could also be promoted and future urban expansions could aim to achieve the highest levels of resource efficiency.

A review of the national communication reports to the UNFCCC and current projects and initiatives shows that some Gulf countries are already implementing various climate friendly policies and measures to reduce anthropogenic GHG emissions as well as those which enhance carbon sinks. In a particularly promising development, the newly established International Renewable Energy Agency (IRENA) chose Masdar City in Abu Dhabi as the agency's first headquarters. This community is intended to become a carbon-neutral home to 90,000 residents and a research hub for green energy technology. This is not only very important for the developing world as a whole but will also hopefully lead to significant research and investment in renewable energy in the Arab region. Another positive step is the new building code adopted by Dubai (2009) on greening energy use. This new building code puts into place stringent energy, water and waste-efficiency requirements on future construction projects and existing buildings and also adheres to international green building standards. A third initiative is Estidama, developed by the Abu Dhabi Urban Planning Council (UPC), which focuses on sustainable development. One notable feature of the Estidama program is the Pearl Rating System launched in 2010, which provides a framework for sustainable design, construction and operation of buildings with which all new urban developments in Abu Dhabi must comply (Abu Dhabi Urban Planning Council 2010).

This new building code puts into place stringent energy, water and waste-efficiency requirements on future construction projects and existing buildings and also adheres to international green building standards

5 CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE COASTAL MANAGEMENT IN THE GULF

MANAGEMENT CAPACITY FOR COASTAL ENVIRONMENTS

Economic prosperity, rapid population growth, and increased utilization of the Gulf are exacerbating a pronounced lack of capacity to provide informed and effective environmental management. Within this region, environmental management agencies often lack skilled scientists, laboratories, instrumentation, and financial resources. Most have not yet established a mandate to regulate activities that impact the Gulf, and in some cases, existing laws and regulations are so weak that they do not even clearly delineate jurisdiction among competing government departments. The environmental impact assessment process for proposed projects is also quite weak, to the point that major developments are usually approved following rushed and qualitative baseline surveys which serve as a mere pretense for complete assessments.

Inadequate management capacity appears to stem mainly from the fact that governments in the Gulf do not acknowledge the risks or costs of environmental degradation. The prevailing view seems to be that there is always a technological 'fix' for any problem that arises. This can be traced back to lack of integration of environmental issues in government, public and private sectors, a weak scientific research community, the low importance given to scientific education, and a general lack of interest among students to pursue the environmental sciences as a career. While the corporate sector copes with difficulties in finding local expertise by importing

There are limited opportunities in the Gulf region to attain marine science degrees. Of the graduate programs that do exist, most ignore the need to produce skilled scientists also capable of going into the field to collect data. Credit: Hanneke Van Lavieren

highly qualified foreigners, the transfer of technology and knowledge does not extend to the environmental sphere to nearly the same degree, perhaps because governments are less likely than private for-profit enterprises to import expertise from abroad.

Despite the great wealth of GCC nations, their scientific deficit is substantial in terms of the number of researchers (particularly national scientists), available funding for research and development, and the number of scientific papers published in international peer-reviewed journals. According to the Arab Knowledge Report

(2009), Gulf nations rank below the 50th percentile out of 134 nations for each of these measures. This report also states that in 2005, scientists among Arab nations only produced 1.1% of the peer-reviewed papers that were published worldwide. According to the World Bank Knowledge Assessment Methodology database (KAM 2009), Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the UAE together produced 1,223 publications in 2005. In comparison, Iran published 2,634 and Egypt produced 1,658 that same year (Note: Iraq is not included in KAM). Between 1998-2007, out of the 4 smaller GCC countries (Kuwait, Qatar, Bahrain and the UAE), Kuwait produced the highest number of scientific articles per million inhabitants (267), followed by Qatar (226), Bahrain (189) and the UAE (66) (Arab Knowledge Report 2009). During this same period, out of the larger countries, Iraq produced only 3.8 articles per million inhabitants, followed by Saudi Arabia with 72 and Oman with 117. Out of the total 3,152 publications produced by the 7 Gulf countries during this period, 842 (26.7%) were studies related to environment and agriculture (Arab Knowledge Report 2009). A more recent report on research in the Middle East (Adams et al. 2011) shows that the UAE produced just below 900 papers in 2009, with a notably steep climb in number since 2000. Even among the nations with relatively low publication output (compared to the rest of the region), there is evidence of substantial progress, e.g., Iraq and Qatar more than doubled their output between 2000 and 2009. These changes are a signal of the high potential for scientific activity in this region.

Despite the great wealth of GCC nations, their scientific deficit is substantial in terms of the number of researchers (particularly national scientists), available funding for research and development, and the number of scientific papers published in international peer-reviewed journals

Still, the scientific deficit is unlikely to be remedied anytime soon if current trends continue. Advanced education is a strong prerequisite for effective sustainable development initiatives, yet on average, only 25.1% of the college age population (data not available for Iraq) are enrolled in tertiary education; the national averages

Field experience is an essential part of many environmental degrees, especially in the coastal sciences and management. Cultural barriers to field work combined with general under-valuation of its importance make field work a rare activity in the Gulf. This photo shows female students planting young mangrove trees on Palm Jebel Ali in Dubai (2008). Credit: Ken Drouillard range from 15.9 to 32.1% (KAM 2009). Access to higher education in environmental fields is also limited (Table 8). For example, there are minimal opportunities for marine science degrees and fewer than 10 universities offer training in basic marine ecology or biology (excluding Iran and Iraq). Most of these universities only offer marine training at the undergraduate level, only 5 offer marine science programs at the Masters level, and 2 at the PhD level. Of the universities that do offer graduate programs, most focus on the laboratory sciences and ignore the need to also produce skilled scientists capable of going into the field to collect data, perform experiments, and provide biological samples for laboratory analysis. Table 8 shows that there are also deficiencies in advanced education in the fields of environmental legislation, environmental management, and environmental risk management. One major issue is that the usual preference among talented students are for careers in business, finance, and medicine rather than in fields related to environmental sciences. Another issue is the apparent disinclination of males to pursue tertiary education in Qatar, Kuwait, the UAE, and Bahrain, where the gender parity index falls between 3.30 and 2.40 in favor of females. The bias is somewhat less in Saudi Arabia (index between 1.46 and 1.26), but the general tendency of males to not seek tertiary training plays a significant role in setting the low ranking in tertiary enrollment compared to other regions (Arab Knowledge Report 2009). Enhancement of existing environmental programs in terms of qualification and accreditation may help increase their attractiveness to potential university students. Although some countries acknowledge these deficiencies and are taking steps to remedy the problem (Arab Knowledge Report 2009), it seems likely that the deficiencies in technical and scientific expertise in coastal environmental management will continue for some time.

It will take a concerted effort by committed Gulf leaders to involve the international research community and build effective and long-term collaborative relationships with regional and local universities so that local expertise in environmental science can set root and not disappear when a foreign worker departs

The tremendous growth and modernization that can be seen in the Gulf has been primarily achieved through the (temporary) importation of skilled foreign labor because the required technical, scientific, financial, managerial, and legal expertise is simply not available within the local population. The need to import people with environmental knowledge has not been appreciated to the same extent as other specializations, and the lack of educational opportunities has not produced sufficient numbers of graduates in these fields (Table 8). Consequently, environmental issues in the Gulf do not receive the attention they deserve. Other major issues to overcome are the cultural barriers associated with field work. Due to personal and cultural constraints it is rare for female scientists to conduct field work and the assumption that field work is menial leads to poorly trained assistants being the only scientific staff to ever leave laboratory settings. Furthermore, field work at inshore marine sites is rare because of lack of specialized skills and instrumentation, and because so much of the coastline is in private hands. It will take a concerted effort by committed Gulf leaders to involve the international research community and build effective and long-term collaborative relationships with regional and local universities so that local expertise in environmental science can set root and not disappear when a foreign worker departs.

Capacity development involves much more than enhancing the knowledge and skills of individuals. It depends crucially on the quality of the organisations in which they work and whether these organisations are research active

Capacity development involves much more than enhancing the knowledge and skills of individuals. It depends crucially on the quality of the organisations in which they work and whether these organisations are research active. In turn, the operations of particular organisations are influenced by the enabling environment - the structures of power and influence and the institutions - in which they are embedded. Capacity is not only about skills and procedures, but is also about incentives and governance. The good news is that countries in the region acknowledge that environmental research and education need strengthening (Arab Knowledge Report

Table 8. Universities offering degrees in environment-related studies in a selection of GCC countries. Note: This table is based on the best available information from web sources and may contain incomplete and/or incorrect information (Iran and Iraq not included due to inavailability of data).

Country	University	Level	Program/Major	Degree in marine field
Bahrain	University of Bahrain	MSc	Environment and Sustainable Development	N
		BSc	Biology and Chemistry	N
	Arabian Gulf University	MSc	Environmental Management	N
		MSc	Desert and Arid Land Sciences	N
Kuwait	Kuwait University	BSc	Marine and Environmental Sciences	Y
		BSc	Desert Sciences	N
	American University of Kuwait	BSc, BEng	Environmental studies (minor)	N
Oman	International College of Engineering and Management	BSc	Health, Safety and Environmental Management	N
		BSc	Well Engineering	N
	Sultan Qaboos University	BSc	Environmental Biology	N
			Marine Science and Fisheries	Y
			Soil and Water Management	N
			Water Technology	N
		MSc	Hydrogeology	N
		MSc	Civil Engineering (Water Resources)	N
		BEng	Civil Engineering (environmental)	N
	Nizwa University	BEng	Environmental engineering	N
		BSc	Chemistry	N
Qatar	Qatar University	BSc, MSc	Environmental Science	Y (may focus on Marine Science)
		BSc	Biology and Chemistry	N
Saudi Arabia	King Abdulaziz University	BSc, MSc	Environmental Sciences	N
		BSc, MSc	Marine Sciences (with 4 sub areas)	Y
		BSc	Environmental Design, Meteorology	N
	King Abdullah University of Science and Technology	MSc, PhD	Environmental Science and Engineering	Y (may focus on Marine Science)
		MSc, PhD	Marine Science	Y
	King Fahd University of Petroleum and Minerals	MSc	Environmental Sciences	N
	King Saud University	MSc	Environmental Sciences	N
UAE	Abu Dhabi University	BSc	Environmental Science/Environmental Health and Safety	Y
	American University of Sharjah	BSc	Biology, Environmental Science	N
	British University in Dubai	MSc	Sustainable Design of Built Infrastructure	N
	Masdar Institute of Science and Technology	MSc	Water and Environmental engineering	N
	United Arab Emirates (UAE) University	BSc	Biology	Y (optional oceanography course)
		MSc	Environmental Science	Y (1 course in marine science)
		MSc	Water Resources	N
		PhD	Science/Environmental Biology	N

2009), and that most of these countries are somewhat ahead of other Arab nations in addressing these problems. Nevertheless, it will take many years to rectify the problem.

RELIABLE RESEARCH AND MONITORING DATA

Environmental research and monitoring requires the use of standard tools and methodologies to collect data. These are essential when making comparisons between data and to also ensure that any existing trends are made visible. Gulf countries have the lowest rankings on the innovation and scientific research index in the entire world (Arab Knowledge Report 2009). The main cause for this is the minimal expenditure on scientific research as a percentage of GDP; an average of about 0.2% compared to the world average of 1.4% (and 4% in Japan; ARAB Knowledge Report 2009). Given this generally low level of investment, it is not surprising that there are few government environmental agencies (or technical departments within regulatory agencies) dedicated to compiling, storing and disseminating environmental data and results, limited collaboration between countries, and deficiencies in reliable environmental data. Confidentiality is also a major issue and results from studies are seldomly disseminated adequately throughout the scientific research community. Still, there have been some signs of improvement.

Several assessments of the state of the (marine and coastal) environment in the Gulf region have been conducted, and a number of online databases have been developed. For example, ROPME has published two State of the Marine Environment (SOME) reports (1999, 2003), which provide an overview of environmental characteristics, marine and coastal resources, socio-economic activities affecting the marine environment, accidents and emergencies, marine pollution control and strategies for sustainable development. Two regional level policy-oriented reports, the Arab Environment: Future Challenges Report (2008) and Impact of Climate Change on Arab Countries Report (2009), produced by the Arab Forum for Environment and Development (AFED), were designed to evaluate progress towards sustainable development goals and good environmental quality. In 2010, the Abu Dhabi Environment Agency launched an open access, online Coastal Resources Atlas and Vulnerability Index to aid local policy makers, developers and managers with the development of EIAs, and to assess the potential environmental impacts of new policies and coastal development plans. Finally, UNEP developed the Environment Outlook for the Arab Region: Environment for Development and Human Well-being (2010), based on several years of data. The relatively recent intensification of effort to collect scientific data, and these recent environmental assessments, are positive steps in providing a sound scientific base for environmental policy formulation in the region.

Moving forward will require a stronger science culture within environmental agencies, time-series data for monitoring environmental trends across countries, the creation and/or strengthening of existing scientific databases, preferably at a regional scale, and regular dissemination of these data so that they can be integrated into environmental scientific research efforts across the Gulf

During the last Arab Summit in 2010, governments approved important resolutions to promote the generation and dissemination of scientific knowledge. These resolutions urge Arab countries to cooperate within the field of scientific research, increase expenditure for scientific research to 2.5% of the GDP within the next ten years, encourage government-private partnerships, and establish scientific centers of excellence in socially and economically significant fields such as water, desertification, nutrition, the environment, information technology, etc. While this is encouraging news, it remains to be seen whether government investment in environmental research and monitoring is actually increased in the near future, and more importantly whether the urgent need for continued movement towards openness, sharing and collaboration is finally recognized. Moving forward will require a stronger science culture within environmental agencies, time-series data for monitoring environmental trends across countries, the creation and/or strengthening of existing scientific databases, preferably at a regional scale, and regular dissemination of these data so that they can be integrated into environmental scientific research efforts across the Gulf.

WHAT ARE ENVIRONMENTAL (AND SOCIAL) IMPACT ASSESSMENTS (EIAs)?

An EIA is a systematic process which identifies, predicts and evaluates the environmental and social effects of proposed actions and projects, and helps decision makers decide whether to proceed with a project. EIAs can be carried out for single developments (project EIAs) or for strategic plans, policies and management programs. An EIA should ideally assess cumulative environmental effects which can arise from a project itself, or together with those of other existing or planned developments in surrounding areas (e.g., hotel and residential developments, desalination and power plants, ports, commercial fishery activities, chemical industries, and sewage treatment plants). Good quality EIAs should encourage communication and cooperation between all stakeholders, e.g., designers, regulators, decision makers, government officials, the private sector and the public. Major construction projects around the world are usually subject to an approvals process which requires completion of an EIA. However, policy on EIA varies substantially around the world and in many places practice does not always live up to legislated policy. The development of effective and appropriate methodologies for conducting EIAs is an important topic for consideration in the Gulf.

ASSESSING ENVIRONMENTAL IMPACTS

The use of Environmental Impact Assessment (EIA) procedures for near and off shore coastal development projects in the Gulf is inadequate due to a range of factors that are also prevalent in many other regions. Most of the unsustainable coastal development that has occurred here is a direct result of the absence of an effective regulatory body and nationally legislated EIA process with adequately implemented provisions which control development. The presence of a regulatory body is crucial for 1) ensuring that an EIA is conducted; 2) regulating institutional responsibilities and procedures; and 3) enforcing specific mitigation procedures for developers that result from the EIA. Without clear requirements mandated by national legislation, there is no incentive for developers to submit EIAs or undertake monitoring and mitigation that may be required as a result. The EIA (if present) becomes just another paperwork process, a minor irritant that rarely delays the project schedule.

The use of Environmental Impact Assessment (EIA) procedures for near and off shore coastal development projects in the Gulf is inadequate due to a range of factors that are also prevalent in many other regions

EIAs for any new project normally include 'baseline' surveys that are conducted prior to construction. However, due to the lack of accessible environmental data, and the rapid pace of coastal development, the usual 'baseline' in Gulf EIAs is from already severely degraded marine ecosystems; sometimes after construction has been approved and clearing and leveling of land has already begun. Also, there is frequently insufficient scope of sampling over both space and time; these are needed to determine the natural variability of ecological

The scale and complexity of coastal development projects in the Gulf region should demand rigorous and comprehensive EIAs. This is an aerial view of a marina and Palm Jumeirah in Dubai. Credit: iStockphoto and environmental characteristics. Moreover, the lack of environmental science capacity either in groups charged with providing data for evaluation, or in those charged with evaluation, also weakens the EIA process. Surveys, if performed, are poorly done and assessments are often based on outdated and questionable quality web-based information, leading to inaccurate assessment of environmental status and impacts. Until clear guidance and strict regulations are created and adhered to in the Gulf, EIAs are unlikely to become more rigorous.

A fundamental element of a properly conducted EIA is public participation in the evaluation and decision-making process. However, in most Gulf countries there is very little public consultation and the information generated is often kept confidential for alleged commercial or security reasons. Without public scrutiny, and due to weak regulatory procedures, it should not be surprising that most EIAs in the Gulf are ineffective - assessments are superficial, based on poor data, and required mitigation measures are often forgotten by both the developer and the regulatory agencies. In addition, although EIAs are usually conducted for specific projects, coastal development is so continuous in the Gulf that it is most unwise not to consider the cumulative impacts of existing or new developments still in the planning stages. The cumulative impact of coastal development projects at the scale witnessed in this region are expected to be extensive, especially in shallow enclosed basins already subjected to extreme temperatures and salinity levels (Sheppard et al. 2010).

Without public scrutiny, and due to weak regulatory procedures, it should not be surprising that most EIAs in the Gulf are ineffective - assessments are superficial, based on poor data, and required mitigation measures are often forgotten by both the developer and the regulatory agencies

MAIN SHORTCOMINGS OF EIAs IN THE GULF REGION

(Note: although these are not unique to the Gulf region, their occurrence together is quite unusual)

- Lack of adequate legal and regulatory frameworks and poor institutional arrangements relegate the EIA process to a paperwork exercise that occasionally delays construction;
- The Gulf community tolerates/expects the duration for the EIA process to be quite short - a large project might require 10 weeks compared to one year or more in most developed countries. This leads to use of quick snapshot environmental surveys taken over a few days, and assessment procedures which are superficial. Lack of seasonal and long term data results in a biased understanding of the nature of the environment concerned;
- Assessment of long term impacts is often difficult because of limited available data on long-term environmental dynamics;
- Each country has different rules and regulations for EIA assessments making it nearly impossible for developers or consultants to develop and adopt an appropriate Gulf wide methodology;
- Public hearings are not part of the EIA process and there is insufficient involvement and participation oall interested and affected parties (e.g., government, NGOs, various stakeholder groups, and communities);
- EIA procedures do not include an objective external expert review body to evaluate EIA quality. Approvals are granted by regulatory personnel who may lack scientific credentials;
- Regulatory agencies lack the capacity to effectively monitor and enforce compliance and this reinforces the belief that an EIA is a paperwork exercise;
- Long term monitoring rarely occurs and when conducted is done so superficially. Consequently, post-construction information that could reveal problems does not exist;
- Project design is often altered after approval for construction has been granted and without further EIAs. For example, the water homes component of Palm Jebel Ali island in Dubai did not exist in the original design for which EIAs were conducted;
- Social and economic impacts are assessed only minimally; and,
- In cases where developers are quasi-governmental, or formal government departments and EIA processes are internalized, the capacity to enforce environmental sustainability is weakened even further.

5

Box 7. Critical improvements needed within the Gulf's EIA process:

1) **Improve the approvals process** to ensure that each proposed development is evaluated with due recognition of potential impacts on local marine ecosystems, already approved projects, and long-term community needs.
2) **Improve stakeholder consultation** and ensure all interested parties are included.
3) **Include an external review** by a panel of scientific experts.
4) **Improve the criteria used to assess the adequacy of scientific data** used in the EIA.
5) **Perform long-term monitoring and conduct impact analyses** to properly assess cumulative impacts of completed projects on wider ecosystems.
6) **Ensure that the process is transparent and includes an explicit opportunity for public discussion.**
7) **Strengthen enforcement and compliance** measures with regulations via relevant authorities.
8) **Cooperate with neighboring countries to apply EIA processes** that adequately address transboundary impacts.
9) **Collaborate regionally to harmonize legal and institutional arrangements**, streamline procedures, regulations and standards among countries to build a region wide EIA process.

Despite the current inadequacies, changes have been occurring in the Gulf which should improve the quality and reliability of EIAs. An increasing number of development projects are being financed by companies and institutions from outside the region and this has led to increasing application of international standards for managing the social and environmental risks of a project (e.g., use of Equator Principles, World Bank environmental standards and International Finance Corporation social standards). With foreign institutions leading some projects, there has been movement by local institutions to follow suit in order to maintain credibility. Clear EIA guidelines have been developed specifically for use by Gulf countries in evaluating development projects (e.g., UNEP ROWA 2008, Desalination resource and guidance manual for environmental impact assessments. Authors: Lattemann, S., K.H. Mancy, B.S. Damitz, and K. Hosny). Finally, the growing number of reliable ecosystem valuation studies (e.g., Costanza et al. 1997) has encouraged Gulf governments and agencies to recognize the ecological and economic value of coastal ecosystems and the potential costs associated with their loss. However, there remains an urgent need in the Gulf region for an EIA process that is scientifically rigorous, transparent, and applied by regulatory agencies that have the capacity to enforce decisions and ensure compliance. This is especially true for coastal development projects involving dredging, reclamation, and alteration of coastal bathymetry and ecosystems. This would aid decision-makers in predicting how new developments could change coastal environments and what measures could be taken to minimize any deleterious environmental impacts before authorization for development is granted.

There remains an urgent need in the Gulf region for an EIA process that is scientifically rigorous, transparent, and applied by regulatory agencies that have the capacity to enforce decisions and ensure compliance. This is especially true for coastal development projects involving dredging, reclamation, and alteration of coastal bathymetry and ecosystems

MARINE PROTECTED AREAS (MPAs): AN EFFECTIVE MANAGEMENT TOOL IF USED PROPERLY

According to available sources, there are currently 38 officially designated marine protected areas (MPAs)[6] covering about 18,810.6 km^2 in the Gulf, Strait of Hormuz,

[6] The term MPA is used generically and includes the following designations: Important Bird Area (BirdLife International), Marine Park, Marine Wildlife Sanctuary, National Park, Nature Reserve, Protected Area, Scientific Reserve, Turtle Reserve, UNESCO-MAB Biosphere Reserve, Wetlands of International Importance (Ramsar Convention), Wildlife Refuge, and Wildlife Sanctuary.

Coastal development projects involving dredging, reclamation, and alteration of coastal bathymetry and ecosystems requires long-term monitoring and comprehensive impact analyses to properly assess cumulative impacts on wider marine ecosystems. Material being dredged to create an island in Abu Dhabi (2011). Credit: Edwin Grandcourt

and Gulf of Oman (along the Arabian side), and many more that are still in the planning stages (Appendix 1, Table 4). While most existing MPAs have coastal management plans that zone areas for conservation, recreation and development, many are not well managed and enforcement is minimal (Krupp 2002).

The number of MPAs and amount of area protected varies considerably among Gulf countries. With the longest coastline in the Gulf, Iran leads the way with 15 sites covering a total area of 8,472.3 km^2; 7 of which are designated under the Ramsar Convention as Wetlands of International Importance. In contrast, although Iraq has a relatively small coastline, it does not yet have a single officially designated marine protected area. Also, in the case of Saudi Arabia, so far only one MPA has been officially established. This is despite the fact that 13 suitable sites have been proposed for quite some time; the Meteorology and Environmental Protection Administration (MEPA) identified 11 environmentally sensitive marine areas in 1987 and the National Commission on Wildlife Conservation and Development recommended that a system of protected areas be established within Tarut Bay in 1990 (Cava et al. 1993). Amongst the UAE Emirates, Abu Dhabi has demonstrated the greatest commitment to establishing MPAs. By the end of 2008, the total area of the declared marine protected areas was 5,019 km^2 which represents 5% of the geographical area of the Emirate (Environment Agency Abu Dhabi 2011). For example, the Marawah MPA declared in 2001, is the largest in the region covering a total area of 4,255 km^2. Another important MPA established in Abu Dhabi in late 2005 is Al Yasat. It is composed of a group of four islands and surrounding waters along the northern coast of the UAE which make up a 482 km^2 no-take zone. Dubai has demonstrated less commitment to MPA establishment. In 1998, the municipality of this Emirate gave full legal status to the Jebel Ali Marine Reserve to protect what was once one of the Gulf's richest coral reef ecosystems (Riegl 1998). However, shortly after the reserve was established management was taken away from the Dubai Municipality Protected Areas Unit and passed over to the developer Nakheel for construction of Palm Jebel Ali; this eventually resulted in the loss of over 8 km^2 of the largest coral reef in Dubai (Burt et al. 2008, 2010).

Generally, management regulations that currently govern protected areas in the Gulf routinely forbid commercial fishing other than by artisanal fishermen using traditional gear, or the catch of any dugong, turtle, or marine mammal. There are also some restrictions on construction, dredging, filling, and other shore-based development activities. However, there is little direct information concerning the effectiveness with which these regulations are enforced. Furthermore, few if any of the existing protected areas have management plans and if they do, the related documents are not readily available to the public (QNV 2009). In order to encourage the use of MPAs as a tool to protect marine habitats and species, governments in the Gulf could promote the Hima approach of natural resource conservation. Hima (hima, hema, hujrah or ahmia) is considered a community based environmental resource management system. This traditional approach may have origins over 2,000 years ago in the pre-Islamic period, and was developed as an ancient acknowledgement of the scarcity of renewable resources. This concept could be useful in Arab societies to build understanding and acceptance of protected areas and promote the need to conserve and use marine resources wisely in support of sustainable rural economic development (Child and Grainger 1990).

Considering that the overall health of many coastal habitats is at record low levels in the Gulf (Wilkinson 2008, Sheppard et al. 2010), there can only be hope for recovery if ecosystems remaining in good health are given sufficient protection (WRI 2008, WWF 2008, Burt et al. 2010). As in other parts of the world, MPAs that forbid human activity (strictly protected areas or sanctuaries) may be the only tool left to protect remaining critical coral reef, seagrass and mangrove habitat. Gulf countries could demonstrate that they are balancing economic needs with environmental protection through the designation of more protected areas, especially those that were proposed as sites many years ago. Also, it would be wise to develop networks, rather than isolated MPAs, to offset existing and future threats (Sheppard et al. 2010). By strengthening the enforcement of existing regulations and conducting regular monitoring and patrolling of MPAs, Gulf nations could substantially improve the management and conservation of their marine resources before they are lost any further.

Catch landed on a dhow (traditional sailing vessel) from a basket trap in Abu Dhabi 2006. Credit: Edwin Grandcourt

Box 9. Private sector participation in environmental management

Given the size of the oil and gas industry in the Gulf, and the potential risk these industries pose to marine ecosystems, there should be opportunities to build public/private partnerships that undertake effective research and management initiatives that conserve marine environments while facilitating industrial activities. The full potential of the private sector has yet to be tapped in this region, but the number of private and public/private initiatives has grown rapidly over the last few years. Some examples include leadership in species-specific research (e.g., Qatar Petroleum and Sea Turtles; and Dolphin Energy and Dugongs) and the creation and management of marine reserves (Richer 2008). In the UAE, the Al Maha Resort is an eco-tourist desert resort owned and managed by UAE Emirates Airlines that combines tourism revenue with environmental protection. The ExxonMobil Research Qatar (EMRQ) conducts research and development in the areas of environmental management and safety, particularly in coastal marine ecosystems. In some of its activities it works in partnership with the Environmental Studies Center at Qatar University. These models need to be encouraged and replicated.

USING AVAILABLE COASTAL DEVELOPMENT GUIDELINES

In all GCC countries, land available for development is scarce and creation of comprehensive land use plans that balance conservation and growth objectives is essential. Unfortunately, despite the availability of detailed policies and guidelines which promote sustainable coastal development practices, implementation has often been lacking or insufficient in this region. UN agencies such as UNESCO and UNEP, along with not-for-profit research groups like the Urban Land Institute (ULI), have produced global policy guidelines for coastal development which focus on the need for integrated management approaches, comprehensive environmental impact assessments, the protection and conservation of vulnerable and fragile habitats and species, the use of market-based incentives that encourage sustainable development, the use of appropriate designs, and engagement of all stakeholders (Pawlukiewicz et al. 2007). More detailed guidelines also exist at the regional level, such as the Abu Dhabi Urban Planning Council's (UPC) 2007 Coastal Development Guidelines. The UPC's mandate is to ensure best practices in planning both new and existing urban areas through policies which prohibit 1) physical development within protected/proposed protected areas/national parks; 2) dredging or physical alteration within coastal parks, as well as policies which state that coastal development must be self-sufficient, i.e., served by a public transport system that is powered by 50% or more renewable energy and that wastewater and sewage are treated locally, etc. (Abu Dhabi Urban Planning Council 2007). The fact that these guidelines have recently been developed is promising. With mega-developments sprouting along many of the Gulf's coasts, governments would be wise to adhere to existing (global, regional and/or national) policy guidelines for development to minimize environmental and economic risks.

MANAGING POLLUTION FROM COASTAL DEVELOPMENTS

Appropriate planning, waste management, and pollution prevention and control are important strategies for minimizing the adverse impacts of development on coastal ecosystems. As in other regions, the most effective management approach for abating land-based pollution would be through 'pollution prevention' with national laws supporting end-of-pipe regulations. More specifically, countries should be required to formulate clear policies and implement appropriate measures to prevent discharge of pollutants into Gulf waters, develop clear guidelines, pollution standards and at minimum increase wastewater treatment practices to tertiary treatment prior to discharge. Furthermore, countries should promote the use of best available wastewater treatment technologies and increase the efficiency of recycling. Also, available technologies, treatment standards, and discharge options must be carefully evaluated to determine the most appropriate system for each new development and facility. Clear ambient environmental quality standards that conform to national and international

Construction of the majority of coastal developments in the Gulf has relied on locally dredged marine sediments; a dredger adding base material for The World islands, Dubai, UAE, 2006. Credit: Zafar Adeel

standards should be established and water quality should be monitored routinely.

At the regional level, the Kuwait Convention and its four protocols provide the basis for an integrated regional response to combating pollution in the Gulf. One of the Protocols under this Convention specifically tackles the problem of land-based sources of pollution, i.e., the Protocol for the Protection of the Marine Environment against Pollution from Land-based Sources (1990). In response, ROPME approved a Regional Programme of Action for the Protection of the Marine Environment from Land-Based Activities in 1995 to identify all land-based pollution source categories and their impacts, and set criteria for their management. In addition, a Marine Emergency Mutual Aid Centre (MEMAC) was established in Bahrain in 1982 to facilitate cooperation for combating pollution by oil and other harmful substances in cases of marine emergencies. Since pollution transcends political boundaries it is imperative that Gulf nations create a regional scale program for monitoring and management, especially because this body of water's semi-enclosed and shallow geography, extreme physical environment and relatively low biodiversity make it particularly susceptible (Khan et al. 2002, Price et al. 2002, Khan 2007). It is also important that data be shared in a regional database which is regularly updated; ROPME has a regional pollution database but these data are not accessible to the general public.

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ECONOMIC GAIN VERSUS ENVIRONMENTAL LOSS - VALUING THE GULF`S COASTAL ECOSYSTEMS

We do not take care of that which we do not value. The Gulf is of considerable economic importance to the countries that share it, yet there is a general lack of appreciation for its value or recognition of the potential deleterious impacts it faces from coastal development and other anthropogenic stressors. Until now, no peer-reviewed economic valuations have been published for coastal ecosystems in this region. However, the direct economic value of shipping and to a lesser extent fisheries is substantial, with tourism continuously growing in importance in some locations. The value of the environmental services the Gulf provides - crucial habitat for fishery species, coastal protection, climate amelioration, a source of desalinated water, a sink for wastes and a landscape for tourism and recreation – is many times greater. As examples of likely valuation for these services, the global average value of combined benefits from mangrove ecosystems has been estimated to be up to US$/10^{-2} km^{2}/yr and taken together, coral reef ecosystem services worldwide have an average annual value estimated at US$172 billion, with climate regulation and natural hazard management (including buffering from storms) services valued at 189,000 US$/10^{-2} km^{2}/yr (TEEB 2009).

Despite their critical ecological role and economic importance, the Gulf's coastal ecosystems have been subjected to severe degradation (Burke et al. 2011). As a result of persistent undervaluation coupled with lack of awareness, these ecosystems have drawn low investment or even worse, public policies and investments that are channelled into initiatives which promote intensive development. Development in many Gulf countries is dominated by market forces and market mechanisms where 'economic growth at any cost' is the common approach (Cronin and Pandya 2009). However, governments and industries must recognize that the economic value of coastal tourism depends fundamentally upon the presence of healthy marine ecosystems to ensure esthetically appealing coastal waters. The World Bank estimates that the total annual cost of environmental degradation amounts to 4-9% of GDP for some Gulf countries (World Bank 2008).

Ecological economics is a relatively new field and tools for determining non-market ecosystem services (e.g., gas regulation and waste assimilation) are still being refined (Costanza et al. 1997). However, in order to develop effective policies and instruments for effective coastal ecosystem management it is necessary to understand and measure their total value and incorporate this information into policy design, e.g., into cost-benefit analyses of development plans to better reflect the bio-economic costs of environmentally-harmful projects. Allocating a monetary value to ecosystems may also help overcome fragmentation in cross-sectoral decision making and build a broad alliance between stakeholders by quantifying common interests and mutual dependence, and by providing a scientific basis for assessing trade-offs between development options (Lange and Jiddawi 2009). These approaches may contribute to achieving improved ecological and economic sustainability throughout the region.

COMMUNICATION AND PUBLIC AWARENESS OF ENVIRONMENTAL ISSUES

Communication and public awareness can be vital components of successful coastal management because they help build consensus and support for sustainable management initiatives while also ensuring that governments are responsive to environmental needs. In the Gulf region, the generally low level of environmental knowledge, especially of marine ecosystems, makes the task of communication difficult. Furthermore, the strongly centralized non-participatory form of government reduces the pressure on environmental managers and decision makers to improve communication and public awareness, and well structured, government-led strategies for environmental education and awareness are rare (AFED 2008). In an ideal world, governments encourage public participation in the decision making process and increase the freedom of the media to assess environmental achievements and express any health or environmental concerns, but this world is not the Gulf region in 2011.

As a consequence, the Gulf's public is generally poorly informed concerning the value of healthy and sustainably managed environments, or the possible detrimental impacts of various human activities on their health and the environment. This situation is unlikely

It is far too soon to tell if the democratic awakening in this region will lead to more effective discussion and evaluation of environmental issues, but this may end up being one significant positive outcome

to change until recognition of the need for and value of sustainable environmental management, as well as the risks associated with poor management, is improved amongst government leaders. Although the establishment of functioning civil society remains underdeveloped in this region (Spiess 2009), some successful community awareness initiatives have been carried out by NGOs. Nevertheless, the usual NGO strategy of building grass-roots community support will not be useful on its own. Building awareness among leaders may be simple because there appears to be support for the concept of environmental sustainability and leaders acknowledge the strong economic benefits that come from better environmental management. However, the challenge to gain access is considerable given the current weakness of the environmental community and the widespread lack of understanding, even at high levels, of the risks of proceeding with a business as usual mentality.

The media could play a larger role in improving environmental awareness in the Gulf, but lack of environmental understanding is widespread within this sector as well. Media in the region carry environmental stories, but most are derived from press releases announcing each new development project, and others make alarmist claims for environmental degradation based on superficial knowledge and questionable data. An authoritative press could make a substantial difference in this respect. In the United Arab Emirates, instead of moving towards greater transparency and more effective reporting of environmental issues, there appears to be movement in the opposite direction; a new draft law will make it criminal for the media to publicly damage the country's reputation or economy, and almost certainly stifle any questioning of major development projects along the coast. It is far too soon to tell if the democratic awakening in this region will lead to more effective discussion and evaluation of environmental issues, but this may end up being one significant positive outcome.

6 MOVING FORWARD: TOWARDS SUSTAINABLE MANAGEMENT OF THE GULF'S COASTAL ENVIRONMENT

Current management strategies in the Gulf are ineffective and insufficient to ensure the future health of its marine and coastal resources. Given the situation now in place, decision makers will need to take major steps to improve these strategies. Although it is true that some countries are performing better than others, each faces similar environmental challenges, especially those experiencing rapid population growth and coastal development.

IMPROVING GOVERNANCE OF THE GULF'S COASTAL ENVIRONMENTS

Effective governance requires sound policies that are implemented by well-established regulations and procedures, backed up by enforced law. Effective management requires good governance. A significant body of international, regional and national legislation concerning the protection of coastal environments exists in the Gulf region. While there is room for more legislation, it is mostly implementation and enforcement of current agreements that requires strengthening (UNEP 1999, Khan 2007). However, this has been hindered by prevailing political and administrative structures, a widespread lack of understanding of the nature or value of coastal and marine ecosystems, and the lack of comprehensive environmental data, research plans and assessment reports. The absence of clear environmental vision has also meant that the environmental research that has occurred has had a negligible impact on the development of policies (AFED 2009). Other factors that have hampered policy implementation include frequently changing institutional structures and responsibilities, overlapping authority for environmental management, slow or capricious decision-making processes, and limited power given to environmental institutions to implement regulations (ROPME 2003, Richer 2008). The fact that governance in the Gulf is characterized by a strongly centralized decision-making process, which limits public participation and places the entire responsibility of environmental protection on government and its agencies, is another significant barrier to overcome. Centralized decision-making may be convenient when it comes to permitting rapid creation of law, but the need to build public support for existing laws remains essential if management agencies are to have any chance to apply these laws effectively.

REGIONAL PROTECTION OF THE MARINE ENVIRONMENT

Gulf nations are party to a multitude of regional and international agreements for protection of the marine environment (Table 9) that provide guiding principles for environmental protection and conservation. However, their effectiveness in building sustainable management is questionable. These agreements may have promoted the creation and improvement of national environmental legislation and institutions, but there still appears to be considerable resistance among Gulf nations towards implementing many of their requirements (Khan et al. 2002). A major hurdle in the adoption and implementation of regional agreements is a general lack of political will at both national and regional levels. The tendency of these governments to compete with each other in their development initiatives may also impede regional coordination. A perceived lack of involvement by countries during the drafting of such agreements, the typically slow ratification process, and other factors including a tradition of not regularly working collaboratively with neighbors, are all responsible for this resistance (Hamza and Munawar 2009). For example, the United Nations Convention on the Law of the Sea (UNCLOS 1982) has not yet been ratified by two Gulf countries, and both the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) and the Protocol for the Prevention of Pollution from Ships (MARPOL 73/78) have only been ratified by three countries (Table 9); the latter is surprising considering the high risks associated with pollution from ships in this region. Another major challenge is that commitments are often not met because assigned government institutions often lack institutional and technical capacity and become overloaded with reporting requirements and meetings.

The fact that governance in the Gulf is characterized by a strongly centralized decision-making process, which limits public participation and places the entire responsibility of environmental protection on government and its agencies, is another significant barrier to overcome

A number of high level regional governmental organizations that could facilitate the coordination of policies and cooperation relevant to marine conservation exists in the Gulf region. For example, the Gulf Cooperation Council (GCC), consisting of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the UAE, provides a regional forum where global and regional environmental, development and trade agreements can be addressed. An Environmental Affairs Committee also exists within the GCC which has adopted a unified code of standards for the protection of the environment and deals with any environmental issues that affect the region. The Council of Arab Ministers Responsible for the Environment (CAMRE) is another relevant institution which provides a forum for all environmental ministers in the Arab region to make general policy level decisions.

An aerial view of Palm Jumeirah, UAE. 2010. Credit: Geórgenes Cavalcante

NATIONAL LEGISLATION AND INSTITUTIONAL ARRANGEMENTS

Although the institutions that are responsible for environmental protection differ greatly amongst Gulf countries, they share a number of common weaknesses. These include 1) relatively recent establishment or revision of national environmental laws and authorities; 2) understaffing; 3) limited financial resources; 4) lack of clearly defined institutional mandates and guidance; 5) overlapping jurisdictions; 6) insufficient technical capacity; 7) limited policing power; and 8) limited authority within the administrative hierarchy which limits influence over national policies (Mahmoudi 1997, ROPME

Box 10. Regional Organisation for the Protection of the Marine Environment (ROPME)

ROPME was established in 1979, and includes all eight Gulf countries. It acts as the Secretariat for the Kuwait Convention and Action Plan for the Protection and Development of the Marine Environment and Coastal Areas. This Convention is the basic legal instrument binding each member state to coordinate activities towards the protection of their common marine environment. Much has been written about ROPME and its role in protecting the Gulf (UNEP 1999, Khan et al. 2002, El-Habr and Hutchinson 2008, Nadim et al. 2008, Hamza and Munawar 2009) and here we summarize its main shortcomings, strengths and potential.

The Kuwait Convention imposes a number of responsibilities on its member states, including measures that should be taken at national and regional levels to protect the marine environment from various sources of pollution (e.g., ships and land-based sources) and other human activities (e.g., territorial sea bed exploration and exploitation). Several protocols have been created under this Convention which have played a role in harmonising policies:

- Protocol concerning Regional Co-operation in Combating Pollution by Oil and Other Harmful Substances in Cases of Emergency (1978)
- Protocol concerning Marine Pollution resulting from Exploration and Exploitation of the Continental Shelf (1989)
- Protocol for the Protection of the Marine Environment against Pollution from Land-Based Sources (1990)
- Protocol on the Control of Marine Transboundary Movements and Disposal of Hazardous Wastes and Other Wastes (1998)
- Protocol concerning the conservation of biological diversity and the establishment of protected areas (under preparation)

Despite a number of setbacks (e.g., the Iraq War), ROPME has achieved some progress within the framework of the Kuwait Convention and its protocols, mostly in terms of pollution reduction (El- Habr and Hutchinson 2008). For example, in 1982 the Marine Emergency Mutual Aid Centre (MEMAC) was established in Bahrain to encourage regional cooperation in dealing with spills and other emergency situations. Nevertheless, ROPME could have functioned more effectively if it had not faced hurdles caused by political tension, failure to prioritize environmental threats, insufficient technical and institutional capacity, inability to obtain updated data from individual countries, and poor compliance and enforcement (El-Habr and Hutchinson 2008).

ROPME still has the potential to become an important player in fostering a regional perspective for management of the Gulf, but strong leadership will be required. By drawing upon the important pockets of marine environmental expertise in Qatar, Kuwait and other countries, encouraging participation from the global marine research community, and targeting the critical scientific and governance needs of countries in the region, ROPME could play a major part in ensuring the sustainability of this important body of water. Additional roles for ROPME could include raising environmental awareness among coastal populations through education and media, expanding existing laboratory facilities and research centers that deal with marine environmental issues, improving the training of environmental scientists and technical staff, establishing a regional environmental database and information sharing mechanism, and sharing successful management, compliance and enforcement examples.

Table 9. Regional and international environmental agreements that cover marine and coastal environmental issues; column 4 contains provisions that specifically cover coastal development issues. Note: This table is based on the best available information from web sources.

Agreement	Entry into force	Marine environmental protection	Coastal development issues	Bahrain	Iran	Iraq	Kuwait	Oman	Qatar	Saudi Arabia	UAE	Source
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal *Accession (a); Acceptance (A); Approval (AA); Formal confirmation (c); Ratification; Succession (d)	5 May 1992	YES		15/10/1992	05/01/1993 (a)	02/05/11 (a)	11/10/1993	08/02/1995 (a)	09/08/1995 (a)	07/03/1990	17/11/1992	1
Convention on Biological Diversity (CBD), 1992 *Ratification (rtf); Accession (acs); Acceptance (acp); Approval (apv)	29 Dec 1993	YES -Jakarta Mandate	YES	30/08/1996 (rtf)	06/08/1996 (rtf)	26/10/2009 (acs)	02/08/2002 (rtf)	08/02/1995 (rtf)	21/08/1996 (rtf)	03/10/2001 (acs)	10/02/2000 (rtf)	2
Convention on Migratory Species (CMS) or the Bonn Convention, 1979 *Entry into force	1979	YES	YES	-	1/02/ 2008	-	-	-	-	1/03/ 1991	-	3
Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (under CMS)	2001	YES	YES -Protection of habitats for sea turtles	YES	YES	-	-	YES	-	YES	YES	3
Memorandum of Understanding concerning Conservation Measures - Siberian Crane (under CMS)	1993			-	YES	-	-	-	-	-	-	3
Memorandum of Understanding concerning Conservation Measures - Slender-billed Curlew (under CMS)	1994			-	YES	-	-	YES	-	-	-	3
Memorandum of Understanding on the Conservation and Management of Dugongs and their Habitats throughout their Range (under CMS)	2007	YES	YES -Protection of habitats for Dugongs	YES	-	-	-	-	-	-	YES	3
Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (under CMS)	2008			-	-	-	-	-	-	-	YES	3
Convention on the Conservation of Wildlife and their Natural Habitats in the Countries of the Gulf Cooperation Council	(2003)			YES	-	-	YES	YES	YES	YES	YES	4
Convention on the International Trade of Endangered Species (CITES), 1973 *Ratification (R); Accession (A)	1 July 1975	YES - International trade in specimens of wild animals and plants		-	03/08/1976 (R)	-	12/08/2002 (R)	19/03/2008 (A)	08/05/2001 (A)	12/03/1996 (A)	08/02/1990 (A)	5
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) *Date of ratification or accession	1975	YES - Limit use of oceans as disposal area for waste generated on land		-	13/01/1997	-	-	13/03/1984	-	-	17/11/1975	6
1996 Protocol to the London Convention 1972	24 Mar 2006			-	-	-	-	-	-	02/02/2006 (a)	-	6
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA-Marine) (not legally binding)	1995	YES	YES -Protocol on Physical Alteration and Destruction of Habitats	-	1995	-	1995	1995	1995	1995	-	7
International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), 2004 Note: Entry into force will be 12 months after ratification by 30 States	Adopted 13/02/2004	YES		-	-	-	-	-	-	-	-	8
International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties *Accession (a)	6 May 1975	YES		-	23/10/1997 (a)	-	01/07/1981 (a)	24/04/1985 (a)	31/08/1988 (a)	-	14/03/1984 (a)	8
Protocol Relating to Intervention on the High Seas in Cases of Pollution other than Oil *Accession (a)	30 Mar 1983	YES		-	23/10/1997 (a)	-	-	24/04/1985 (a)	-	-	-	8

International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), 1990 *Accession (a)	13 May 1995	YES		-	25/05/1998 (a)	-	-	26/09/2008 (a)	08/08/2007 (a)	30/10/2009 (a)	-	8
Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution, 1978 * No Signatories without ratification, acceptance, approval or accession"	1 July 1979	YES	YES	01/07/1979	01/07/1979	01/07/1979	01/07/1979	01/07/1979	01/07/1979	01/07/1979	01/07/1979	9
Protocol concerning regional co-operation in combating pollution by oil and other harmful substances in cases of emergency	1 July 1979	YES		01/04/1979	03/03/1980	04/02/1979	07/11/1978	20/03/1997	04/01/1979	**26/12/1981**	01/12/1979	9
Protocol concerning marine pollution resulting from exploration and exploitation of the continental shelf	17 Feb 1990	YES		14/08/1990	30/06/1992	17/02/1990	17/02/1990	17/02/1990	17/02/1990	17/02/1990	**16/07/1990**	9
Protocol for the protection of the marine environment against pollution from land-based sources	2 Jan 1993	YES	YES	6 Parties by 6 Jan 2003	12/09/1993		12/09/**1993**	12/09/**1993**	12/09/**1993**	12/09/**1993**	21/02/**1990** Signed/not ratified	9
Protocol on the control of marine transboundary movements and disposal of hazardous wastes and other wastes	no available info	YES		Five ratifications by 6 January 2003. Two Signatories without ratification, acceptance, or approval. (UAE in 2005)								9
Protocol concerning the conservation of biological diversity and the establishment of protected areas	no available info	YES	YES									9
International Convention for the Prevention of Pollution from Ships, 1973, Amended (Marpol Protocol '78) * Accession (a) Annex I: Prevention of pollution by oil Annex II: Control of pollution by noxious liquid substances	2 Oct 1983	YES		27/07/2007 (a)	25/01/2003 (a)	-	7/11/2007 (a)	13/06/1984 (a)	8/06/2006 (a)	23/08/2005 (a)	15/04/2007 (a)	10
Annex III: Prevention of pollution by harmful substances in packaged form	1 July 1992	YES		-	29/08/2009 (a)	-	7/11/2007 (a)	1/07/1992 (a)	8/06/2006 (a)	23/08/2005 (a)	15/04/2007 (a)	10
Annex IV: Prevention of pollution by sewage from ships	27 Sept 2003	YES		-	29/08/2009 (a)	-	7/11/2007 (a)	27/09/2003 (a)	8/06/2006 (a)	23/08/2005 (a)	15/04/2007 (a)	10
Annex V: Prevention of pollution by garbage from ships	31 Dec 1988	YES		27/07/2007 (a)	25/01/2003 (a)	-	7/11/2007 (a)	31/12/1988 (a)	8/06/2006 (a)	23/08/2005 (a)	16/04/2007 (a)	10
Annex VI: Prevention of Air Pollution from Ships (MARPOL Protocol 97)	19 May 2005	YES		-	29/08/2009 (a)	-	7/11/2007 (a)	-	-	23/08/2005 (a)	-	10
Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) or the 'Kyoto Protocol', 1997 *Ratification Acceptance (A); Accession (a); Approval (AA)	16 Feb 2005			31/01/2006 (a)	22/08/2005 (a)	28/07/2009 (a)	11/03/2005 (a)	19/01/2005 (a)	11/01/2005 (a)	31/01/2005 (a)	26/01/2005 (a)	11
Ramsar Convention on Wetlands, 1971 *Entry into force	1975	YES	YES - Protection of wetlands and mangroves (Sustainable development)	27/02/1998	21/12/1975	17/02/2008	-	-	-	-	29/12/2007	12
Stockholm Convention on Persistent Organic Pollutants * Ratification, Acceptance (A), Approval (AA), Accession (a)	17 May 2004	YES	YES (POPs pollution from coastal development)	31/01/2006	06/02/2006		12/06/2006	19/01/2005	10/12/2004 (a)	14/03/2002 signed	11/07/2002	13
UNESCO World Heritage Convention, 1972 *Ratification (R); Acceptance (Ac); Accession (A)	17 Dec 1975	YES (World Heritage Marine)	YES - protection from development	28/05/1991 (R)	26/02/1975 (Ac)	05/03/1974 (Ac)	06/06/2002 (R)	06/10/1981 (Ac)	12/09/1984 (Ac)	07/08/1978 (Ac)	11/05/2001 (A)	14
UNESCO Man and Biosphere Programme (MAB)	1977	YES	YES - Sustainable development	-	YES	-	-	-	YES	-	YES	15
United Nations Convention on the Law of the Sea, 1982 *Ratification (r); Accession (a); and Signed (s)	16 Nov 1994	Yes		30/05/1985 (r)	10/12/1982 (s)	30/07/1985 (r)	02/05/1986 (r)	17/08/1989 (r)	09/12/2002 (r)	24/04/1996 (r)	10/12/1982 (s)	16
Agreement on Part XI	28 July 1996	Yes		-	-	-	02/08/2002 (a)	26/02/1997 (a)	09/12/2002 (p)	24/04/1996 (P)	-	16
UN Fish Stocks Agreement	11 Dec 2001	YES		-	17/04/1998 (a)	-	-	14/05/2008 (a)	-	-	-	16

*specific coding employed by the various conventions

Sources:
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3. http://www.cms.int/about/part_lst.htm
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13. http://chm.pops.int/Convention/tabid/54/language/en-GB/Default.aspx
14. http://whc.unesco.org/en/statesparties/ and http://whc.unesco.org/en/marine-programme
15. http://www.unesco.org/mab/doc/icc/who_icc.pdf
16. http://www.un.org/Depts/los/reference_files/status2010.pdf

2003). These shortcomings have been serious impediments to effective implementation of environmental law in the Gulf region. Cooperation is needed to unify policies and develop more effective national programs for the protection of the environment (Mahmoudi 1997). Furthermore, it is essential that clear and comprehensive long term national marine policies be created to facilitate sustainable use of resources and assist with the management of future developments that affect marine environments. It is also important that Gulf countries create flexible regulatory systems that evolve over time and are able to address threats and challenges as they arise.

IMPROVED REGULATION FOR COASTAL DEVELOPMENT

Very little existing legislation, at regional and national levels, is directly linked to coastal development. Several agreements may relate in some way, but coverage is incomplete and incoherent (Table 9). At the regional level, coastal development is regulated under the Kuwait Convention (1990) Protocol for the Protection of the Marine Environment against Pollution from Land-Based Sources. This protocol regulates airborne, waterborne or direct discharges from land originating from pipelines, watercourses, or offshore installations not used for exploration and exploitation of the seabed. It also regulates 'wastes generated from coastal development activities which may have a significant impact on the marine environment'. At the international level, UNCLOS, the Global Programme of Action for land-based sources of pollution (UNEP/GPA) and MARPOL 73/78 contain provisions for addressing certain aspects of coastal development (Table 9). However, none clearly address coastal development issues such as dredging or construction near artificial islands. Finally, especially at the national level, no single government agency is directly responsible for regulating the development and management of coastal areas, rather this responsibility is shared by several institutions. Such fragmented jurisdiction leads to short term, incoherent and small scale planning as well as development projects that are unsustainable and often improperly structured.

Fragmented jurisdiction leads to short term, incoherent and small scale planning as well as development projects that are unsustainable and often improperly structured

A UNIFIED APPROACH TO PROTECTING THE GULF'S COASTAL ENVIRONMENTS

To achieve holistic and integrated management of the Gulf's coastal environments (Box 11), countries that share this body of water need to develop a common understanding of existing anthropogenic threats and establish a shared vision of the strategic importance of the Gulf's habitats and resources. Given that neighboring countries face similar coastal management challenges, and many of the region's water systems cross borders, collaborative strategies seem the most logical solution. Central to improving management of the Gulf is the use of adaptive integrated coastal management (ICM) principles, preferably across neighboring countries, to reconcile development pressures in coastal and marine environments with ecological integrity. Regional cooperation is essential to address priority environmental concerns, improve environmental indicators, and exchange experiences and knowledge. However, the Gulf is probably the most politically sensitive water passage in the world and adopting a common approach to environmental management has been difficult. Furthermore, low levels of trust and trans-border cooperation, combined with deficiencies in institutional arrangements for bringing different stakeholders to the table, make it difficult to develop integrated solutions. The present status of coastal ecosystems in this region reflects constraints that are inherently associated with management largely driven by frameworks representing arbitrary jurisdictions of political units at both national and regional levels (Khan 2007). Lack of cooperation and information exchange means that ecosystem protection and management, as well as assessment of coastal development impacts, are still beyond the priorities and economic agenda of governments within the Gulf. A general resistance remains against taking a holistic approach that not only looks at the immediate impacts of a project but also synergies with other projects close by, including those in bordering nations (Krupp et al. 2006, Krupp and Abuzinada 2008).

Some action that has been taken by Gulf countries should be regarded as positive steps towards cooperation. Several regional (and international) level con-

Little legislation exists, at regional and national levels, that is directly linked to coastal development. Considering the extent of construction that has taken place in the Gulf's coastal areas, this heightens the environmental risk. This photo shows the high density of villas built on the fronds of Palm Jumeirah, Dubai, UAE. Credit: http://www.millionface.com/l/latest-pictures-of-palm-jumeirah-at-dubai/

ferences on marine environmental (management) issues have been held, such as the International summit on Coastal and Port Engineering in Developing Countries (COPEDEC 2008) in Dubai, as well as several Marine Conservation Forum meetings organized by the World Wildlife Fund. Moreover, a number of regional

Lack of cooperation and information exchange means that ecosystem protection and management, as well as assessment of coastal development impacts, are still beyond the priorities and economic agenda of governments within the Gulf

science and policy level *fora* for tackling common economic, social, development and environmental concerns have been established. For example, the Arab Forum for Environment and Development (AFED), established in 2006, is a regional non-governmental organization that brings together all parties concerned with the environment and development in the Arab world to discuss regional and national issues and promote environmental policies. AFED also raises environmental awareness through information dissemination and educational programs, and by releasing regular policy level State of the Arab Environment (SAE) reports. The Gulf Cooperation Council (GCC) and Council of the Arab Ministers Responsible for the Environment (CAMRE) have been instrumental in strengthening regional cooperation, formulating environmental policies and developing unified strategies for environmental management challenges in the region. In March 2006, the Arab Summit endorsed the creation of the Arab Environment Facility (AEF), a regional body similar in structure to the Global Environment Facility (GEF). This is a sign that governments in this region are taking the state of the environment more seriously. The Regional Organization for the Protection of the Marine Environment (ROPME) was established to coordinate its Member States' efforts towards joint protection of the Gulf's coastal environments. However, as mentioned earlier, despite certain achievements, much remains to be desired and it is evident that ROPME could play a stronger role in turning what are now dividing factors into unifying causes. The semi-enclosed nature of the Gulf makes a shift from resource management characterized by short-term perspectives on small spatial scales to resource management that is ecosystem-based with long-term perspectives even more urgent (Khan 2007, Sheppard et al. 2010). It would be substantial confirmation of the stated desire of several Gulf leaders to support environmentally sustainable development if they were to take charge and initiate a comprehensive, effective, long-term and collaborative environmental management program for the Gulf.

Box 11. Action needed for developing integrated coastal management (ICM) in the Gulf

Legal requirements

- Identify gaps in legislation that prevent effective management.
- Create and enforce a strong legal and institutional framework, including economic incentives, to reinforce desired behaviors and outcomes.
- Decentralize power to the lowest level appropriate for decision making.
- Minimize delays between policy decisions and implementation.
- Develop strong coastal management constituencies and partnerships at local, national, and regional levels.
- Commit to appropriate levels of funding and staffing for existing or new environmental laws.
- Ensure better compliance to international and regional treaties/Conventions.

Scientific/technical capacity requirements

- Provide opportunities for education, credentials and technology transfer.
- Commit appropriate levels of funding and staffing for environmental management agencies.
- Minimize bureaucratic obstacles to cooperation by amalgamating narrowly defined agencies into national environmental management agencies.
- Recruit highly skilled staff and develop a high-level advisory body with ties to the international environmental science community.
- Design and implement training modules that cover aspects of coastal marine monitoring and management, and target these at environmental management agencies, academic research groups, and NGOs.

Management requirements

- Create an inventory of coastal habitats and resources and establish a baseline on the status and threats to coastal areas (including human population, demographic and socio-economic characteristics).
- Implement a monitoring program to assess pollution levels and coastal reclamation activities, as well as ecological status, physical and chemical character of coastal waters.
- Ensure proactive versus reactive management; determine the short-term and long-term goals for coastal development while considering preservation of the surrounding environment.
- Perform Environmental Impact Assessments (EIAs) for all coastal development projects.
- Integrate tourism into ICM programs to ensure development is within the environmental carrying capacity of the area and conflicts with other coastal activities are minimized.
- Develop a regional level environmental database that is open access.
- Establish Marine Protected Areas (MPAs), including no-take reserves, to protect, preserve and sustainably manage species and ecosystems.
- Build upon existing environmental approvals processes to create an ecologically sound and rigorous set of procedures that are immune to influence by developers, fairly applied, rigorously enforced, and complementary to regulations of adjoining states.
- Convene a regional conference to review the current state of the Gulf's coastal ecosystems.
- Publish a 'State of the Gulf' report every 3-4 years as a baseline from which to measure environmental quality.

Public awareness and support requirements

- Improve the understanding and awareness of the economic, social and cultural value of healthy marine ecosystems.
- Strengthen participation by increasing publically available information and data.
- Design and implement a series of educational modules in aspects of coastal marine science and management and target these at students, government staff, the general public, and all coastal and marine stakeholders.

APPENDICES

APPENDIX 1

Table 1. Population statistics for nations bordering the Gulf. Percent coastal refers to the percent population located within 100 km of the coastline (Sources: CIESIN 2005, UN DESA 2010).

Country Name	GDP (US$) (1998)	GDP (US$) (2009)	Population (1990)	Population (2010)	Population Increase (%) (1990-2010)	Percent Coastal (2000)
Bahrain	10,019.4	24,408.5	489,954	743,574	52	100
Iran	1,615.2	4,863.4	58,434,973	80,809,035	38	24
Iraq	367.3	830.4	17,270,733	29,917,117	73	6
Kuwait	13,199.3	36,668.4	2,143,002	2,472,646	15	100
Oman	6,008.7	18,875.7	1,784,511	3,515,426	97	89
Qatar	18,049.8	69,754.2	453,188	652,681	44	100
Saudi Arabia	7,392.9	14,353.4	15,400,451	27,587,831	79	30
United Arab Emirates	16,752.8	54,137.9	2,014,223	3,055,702	52	85

Table 2. Length of shoreline (km) added to Dubai by four of the Nakheel Marine Projects. These measurements are best estimates and are based on Google Earth maps and measurement tool (accessed July 2011).

Nakheel Marine Project (UAE)	Added shoreline (km)
Palm Jebel Ali (still under construction)	132.8
Palm Jumeirah	90.68
Palm Deira (still under construction)	58.77
World (still under construction)	157.06
Total	439.31

Table 3. Fisheries statistics, including capture production, fish protein consumption, employment, and docked fishery vessels, for individual countries bordering the Gulf (excluding the Gulf of Oman).

Country	Capture Production – Finfish (tonnes)[1]	Capture Production – Other Species* (tonnes)[1]	Total Production (tonnes)[1]	Fish/Animal Protein Consumption Per Capita (%)[2]	Fish/Total Protein Consumption Per Capita (%)[2]	Estimated Employment Primary Sector (including aquaculture)[3]	Docked Fisheries Vessels[4]	Docked Fisheries Vessels[4]
	2009	**2009**	**2009**	**2007**	**2007**	**2000-2004**	**1995-1998**	**2007**
Bahrain	4,720	11,638	16,358	11.4	4.9	6,830	159	1,129
Iran	157,164	27,178	184,342	8.7	2.5	156,470	2,900	7,044
Iraq	12,194	52	12,246	7.6	1.3	25,000	7	400
Kuwait	2,561	1,812	4,373	6.9	3.5	1400	890	936
Oman	3,565	1,410	4,975	21.8	11.2	35,543	56	13,140
Qatar	11,425	2,639	14,064	15.8	6.2	4,721	–	515
Saudi Arabia	22,273	20,608	42,881	8.5	3.4	5,887	170	9,619
UAE	61,760	15,945	77,705	12.8	7.2	18,000	1,517	5,038
Gulf Total	**275,662**	**81,282**	**356,944**	–	–	**253,851**	–	**39,828**
Global Total	**108,019,572**	**54,861,990**	**162,881,562**	**16**	**6**	**44,900,000**	**1,297,017**	–

**Other species denoting crustaceans, molluscs, etc.*

Dash (–) indicates no data available.

Sources:
1. http://www.fao.org/fishery/statistics/software/fishstat/en
2. ftp://ftp.fao.org/FI/CDrom/CD_yearbook_2008/navigation/index_content_food_balance_e.htm
3. http://www.fao.org/fishery/countryprofiles/search/en
4. RECOFI 2010

Table 4. Protected areas with a marine component for each Gulf country (includes the Gulf, Strait of Hormuz, and Gulf of Oman). Designations include Important Bird Area (BirdLife International), Marine Park, Marine Protected Area, Marine Protectorate, Marine Wildlife Sanctuary, National Park, Nature Reserve, Protected Area, Scientific Reserve, Turtle Reserve, UNESCO-MAB Biosphere Reserve, Wetlands of International Importance (Ramsar Convention), Wildlife Refuge, and Wildlife Sanctuary. Note: This table is based on the best available information from web sources and may contain incomplete and/or incorrect information.

Name	Designation	National/ International	Year Established	Reported Area (km²)
Bahrain				
Hawar Islands	Protected Area	National	1995	581.0
	Wetlands of International Importance (Ramsar Convention)	International	1997	
Tubli Bay	Wetlands of International Importance (Ramsar Convention) including Ras Sand Mangrove Natural Reserve (est. in 1988)	International	1997	16.1
Total reported area under official protection				597.1
Iran				
Deltas of Rud-e-Gaz and Rud-e-Hara	Wetlands of International Importance (Ramsar Convention)	International	1975	150.0
Deltas of Rud-e-Gaz and (Rud-e-Hara)	Wetlands of International Importance (Ramsar Convention)	International	1975	150.0
Deltas of Rud-e-Shur, Rud-e-Shirin and Rud-e-Minab	Wetlands of International Importance (Ramsar Convention)	International	1975	450.0
Faror	Protected Area	National	1986	28.48
Govater Bay and Hur-e-Bahu	Wetlands of International Importance (Ramsar Convention) and Important Bird Area (BirdLife International)	International	1999	750.0
Hara	Protected Area	National	1973	865.81
	Khuran Straits, Wetlands of International Importance (Ramsar Convention)	International	1975	
	UNESCO-MAB Biosphere Reserve	International	1976	
Hara-e Khoran	Protected Area	National	2001	25.18
Hara-e Roud-e Gaz	Protected Area	National	2001	169.14
Hara-e Tiab and Minab	Protected Area	National	2001	412.58
Heleh	Protected Area	National	1976	416.42
Kharko	Wildlife Refuge	National	1975	23.98
Mond	Protected Area	National	1975	537.05
Nayband	Marine-Coastal National Park	National	2003	484.0
Shadegan Marshes and Mud flats of Khor-al Amaya and Khor Musa	Wildlife Refuge	National	1975	4000.0
	Wetlands of International Importance (Ramsar Convention)	International		
Sheedvar (Shidvar) Island	Protected Area/Wildlife Refuge	National	1975	0.98
	Wetlands of International Importance (Ramsar Convention) and Important Bird Area (BirdLife International)	International	1999	8.7
Hormoz Island	Other area	National	proposed site	n/a
Qeshm Islands and Bandar Abbas	Marine Park	National	proposed site	n/a
Total reported area under official protection				8472.3
Kuwait				
Doha	Protected Area	National	n/a	4.5
Jal Az-Zor	National Park	National	1990	250.0
Khawr Mufattah	Protected Area	National	1990	n/a
Sulaybia Experimental Station	Scientific reserve	National	1979	20.0
Umm al-Maradim	Marine Park	National	1977	n/a
Al-Khiran Desert	Park	National	proposed site	n/a
Getty Reef	Nature Reserve	National	proposed site	n/a
Kubbar (Jazirat Kubbar)	Protected Area	National	proposed site	6.0
Naval Base Reef	Nature Reserve	National	proposed site	n/a
Qaru	Marine Park	National	proposed site	n/a
Total reported area under official protection				274.5

Name	Designation	National/ International	Year Established	Reported Area (km²)
Oman				
Ra's Al Hadd	Turtle Reserve	National	1996	120.0
Ad Dimaniyat Islands	Nature Reserve	National	1996	203.0
Total reported area under official protection				323.0
Qatar				
Al-Reem	UNESCO-MAB Biosphere Reserve	International	2007	1188.9
Khor Al Udeid Fish Sanctuary	Protected Area	National	1993	120.0
Ras Ushairij Gazelle Conservation Park	Breeding Station	National	1991	16.19
Total reported area under official protection				1325.1
Saudi Arabia				
Dawat Ad-Dafl, Dawat Al-Musallamiyah and Coral Islands	Marine Wildlife Sanctuary	National	1995	2100.0
Abu Ali/Dawhat and Dafi Musallamiyah Complex	Other Area	National	proposed site	n/a
Al Uqayr Bay	Other Area	National	proposed site	n/a
Al-Ahsa	Protected Area	National	proposed site	2700.0
Arabiyah Island	Other Area	National	proposed site	n/a
Harqus Island	Other Area	National	proposed site	n/a
Jabul Letub	National Nature Reserve	National	proposed site	89.0
Jana Island	Other Area	National	proposed site	n/a
Jurayd Island	Other Area	National	proposed site	n/a
Karan Island	Other Area	National	proposed site	n/a
Kurayn Island	Other Area	National	proposed site	n/a
Safaniya/Manifa Bay complex	Other Area	National	proposed site	n/a
South Gulf of Salwah	Other Area	National	proposed site	n/a
Tarut Bay Complex	Other Area	National	proposed site	n/a
Total reported area under official protection				2100.0
United Arab Emirates				
Al Aqa	Marine Protectorate	National	1995	0.74
Al Wathba*	Wetlands Reserve	National	1998	5.0
Al Yasat	Marine Protected Area	National	2005	482.0
Bul Syayeef	Marine Protected Area	National	2007	282.0
Dadna	Marine Protectorate	National	1995	0.07
Jebal Ali	Wildlife Sanctuary	National	1998	80.0
Khor Kalba	Nature Reserve	National	n/a	n/a
Marawah	Marine Protected Area	National	2001	4255
	UNESCO-MAB Biosphere Reserve (first in UAE)	International	2007	605
Ras Al Khawr Wildlife Sanctuary	Wildlife Sanctuary	National	n/a	6.2
Rul Dibba	Marine Protectorate	National	1995	1.99
Abu Dhabi Mangrove and Coastal Wetland	Reserve	National	recommended	15.0
Al Bidiyah	Marine Protectorate	National	proposed	0.58
Rams lagoon	Reserve	National	recommended	n/a
Sir Bu Nair (Sharjah)	n/a	n/a	n/a	n/a
Zirkuh island	Bird Sanctuary	National	recommended	n/a
Total reported area under official protection				5718.6

* declared MPA by Environment Agency Abu Dhabi
n/a information not available

Sources:
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MPA Global: http://www.mpaglobal.org/index.php?action=summary_by_country
Protected Planet: http://protectedplanet.net/
UNESCO-MAB Biosphere Reserves: http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/mab/
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APPENDIX 2

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APPENDIX 3

ACRONYMS AND ABBREVIATIONS

AEF	Arab Environment Facility
AFED	Arab Forum for Environment and Development
CAMRE	Council of Arab Ministers Responsible for the Environment
CBD	Convention on Biological Diversity
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CITES	Convention on the International Trade of Endangered Species
CMS	Convention on Migratory Species
EIA	Environmental Impact Assessment
EMRQ	ExxonMobil Research Qatar
FAO	Food and Agriculture Organization
GCC	Gulf Corporation Council
GEF	Global Environment Facility
GloBallast	Global Ballast Water Management Programme
HAB	Harmful Algal Bloom
ICM	Integrated Coastal Management
IFRO	Iranian Fisheries Research Organization
IMO	International Maritime Organization
IPCC	Inter-governmental Panel on Climate Change
KAM	Knowledge Assessment Methodology
KISR	Kuwait Institute for Scientific Research
MEMAC	Marine Emergency Mutual Aid Centre
MERC	Marine Environment Research Centre (UAE)
MOA	Ministry of Agriculture (Saudi Arabia)
MOEW	Ministry of Environment and Water (UAE)
MPA	Marine Protected Area
NMC	National Mariculture Centre
OPRC	Oil Pollution Preparedness, Response and Co-operation
PAAFR	Public Authority for Agriculture Affairs and Fish Resource (Kuwait)
PAHs	Polycyclic Aromatic Hydrocarbons
PCBS	Poly-Chlorinated Biphenyls
POPs	Persistent Organic Pollutants
RAIS	Regional Aquaculture Information System
RECOFI	Regional Commission for Fisheries
ROPME	Regional Organization for the Protection of the Marine Environment
SAE	State of the Arab Environment
SOME	State of the Marine Environment
SST	Sea Surface Temperature
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNEP-GPA	United Nations Environment Programme - Global Programme of Action
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-MAB	United Nations Educational, Scientific and Cultural Organization - Man and the Biosphere
UNESCO-WHC	United Nations Educational, Scientific and Cultural Organization - World Heritage Convention
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

APPENDIX 4

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The eight countries surrounding the Gulf (referred to as both the Persian and Arabian Gulf) - Bahrain, Kuwait, Iran, Iraq, Oman, Qatar, Saudi Arabia, and the United Arab Emirates - share a valuable marine ecosystem that now risks becoming seriously degraded by a number of anthropogenic impacts. Some of the most rapidly developing countries in the world are found here, and nearly all development is confined to coastal fringes. In many cases, there has not been enough time to develop adequate regulatory, technical, and monitoring capacity necessary to guide this growth appropriately. The Gulf's unique but fragile marine and coastal ecosystems provide valuable services including fishery resources, tourism assets, and oil reserves. Overfishing, pollution, habitat destruction and inappropriate coastal development are placing increasing pressure on these ecosystems at a time when climate change is increasing the physical stresses it already endures.

This policy report highlights the greatest environmental threats facing the Gulf and offers advice to managers and decision makers on how to avoid or mitigate the impacts of coastal development and improve environmental management. The Gulf is a well-delineated body of water in a region with considerable sovereign wealth. There is an opportunity for one or more Gulf nations to provide leadership to build a 'made-in-the-Gulf-region' solution. Although this report is specific to this region, rapid development and population growth are causing similar problems along shorelines in other parts of the world. We believe that this document will serve to inform decision makers across and beyond the Gulf.

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