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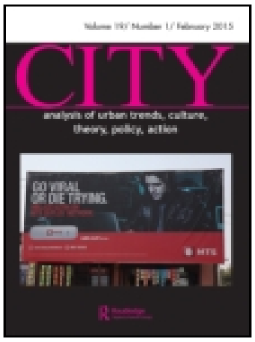

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The environmental costs of coastal urbanization in the Arabian Gulf

John A. Burt

Coastal urbanization has expanded rapidly in recent decades in the Arabian Gulf and this has put increasing pressure on important but underappreciated coastal ecosystems throughout the region. Unlike the relatively barren terrestrial system, coastlines in the Gulf contain a mosaic of highly productive ecosystems, including sabkhas, mudflats, mangrove swamps, seagrasses and coral reefs, among others, that provide food and habitat for diverse ecological communities and support over half a billion dollars in fisheries activities annually. In recent years there has been accelerating loss and degradation of each of these systems as a result of cumulative impacts from coastal development, overfishing, industrial expansion and other population-driven stressors, and the Arabian Gulf is now considered among the most degraded marine eco-regions in the world. The future of this unique and valuable system is now at stake, and only with rapid and dramatic changes in coastal policy, regulation and management can we hope to stem the decline of coastal ecosystems in the Gulf. The highly centralized decision-making framework characteristic of governance in this region should be seen as an advantage in this regard. Improved awareness of the economic, societal and ecological value of the coastal ecosystem among leaders could result in rapid changes in policy direction and financial support for coastal management, resulting in more environmentally sustainable urban development on the Gulf's coasts.

Key words: Arabian Gulf, Persian Gulf, coastal development, coastal management, coral reef, mangrove, seagrass

Over the past half-century, population centers in the Arabian Gulf have evolved from small fishing and trading villages into globally interconnected megacities. This unprecedented growth has drawn the attention of urban scholars interested in the economic, social and political development of cities, and the rapid pace and widespread nature of urbanization in the Gulf served as a natural laboratory of sorts for the study of the evolution of cities as organic entities. Yet as we developed a better understanding of Gulf cities from a socio-economic, political and cultural perspective, we paid much less attention to the environmental ramifications of urbanization in the region.

Although sustainable development has been an area of growth in the Gulf in recent years, much of the discourse has focused on improved building standards and urban planning practices with the underlying motivation being cost reduction, economic efficiency and social benefits, while the preservation of natural ecological resources has been underrepresented. The Arabian Gulf contains a diverse and productive array of coastal ecosystems that, as a result of urban expansion, are being increasingly degraded and sometimes lost altogether. These ecosystems have served important roles in the social and cultural development of coastal communities in the Gulf for millennia, and today underpin the second most important natural resource industry of the region after oil—fisheries—while supporting a far higher diversity of flora and fauna than is found on adjacent land. This paper describes the environmental costs to coastal ecosystems that result from urbanization in the Gulf, and explores perspectives for the future.

Changing populations in the Gulf

The Arabian Gulf (also known as the Persian Gulf or 'the Gulf') is bordered by eight nations that have undergone dramatic economic transformation since the oil boom of the 1970s. A number of Gulf countries now rank among the richest nations with the fastest growing economies in the world, and this economic growth supported a demographic swell: populations more than tripled in size in the past four decades and their annual growth rate (2.1%) is nearly double the global average (1.1%) (van Lavieren et al. 2011). As a result, urbanization increased rapidly in the region, with the most dramatic growth often occurring along the Gulf's coastlines.

Coastal and marine systems have played a central role in the cultural and economic history of societies around the Gulf. Over the past century, many of the small fishing and trading villages that historically peppered the Gulf's coastline grew into sprawling megacities. Today more than 85% of the population lives within 100 km of the coast in five of the eight Gulf countries (Bahrain, Kuwait, Oman, Qatar and the UAE), and it is projected that populations will continue to increase in size and density along the Gulf's coastlines (van Lavieren et al. 2011). As infrastructure expanded to support these growing populations, there has been dramatic modification of the coastal and near-shore habitats throughout the Gulf. In several Gulf countries, urban and industrial areas now occupy over 40% of the shoreline and man-made structures associated with ports and real estate developments have more than doubled the length of natural coastline in several regional coastal cities (Burt et al. 2009a, 2009b; Burt, Bartholomew, and Feary 2012). Unfortunately, coastal urbanization has often outpaced environmental policy and regulation (Sale et al. 2011), and there has been rapid and widespread degradation of important coastal ecosystems throughout the region.

A unique and fragile ecosystem

The Arabian Gulf has a unique natural history that makes its coastal ecosystems unusually fragile and susceptible to impacts from human activities. The Gulf is a young sea that was dry during the last glacial maximum and modern coastlines were formed only in the past 3000–6000 years as ice sheets receded and rising sea levels slowly flooded the Arabian basin through the Strait of Hormuz (Riegl and Purkis 2012). The Gulf is also unusually shallow, with an average depth of only 30 m and large areas along the south and southwestern Gulf that rarely exceed 20 m depth. As a result of this shallow depth, water temperatures in the Gulf vary widely with the seasons. Sea temperatures range over 20°C between winter and summer, and during the summer the Gulf is regularly the hottest sea on earth: its southern waters regularly exceed 35°C (Riegl and Purkis 2012). Due to these elevated temperatures, limited freshwater input from the surrounding arid lands and the relatively restricted exchange of water through the narrow Strait of Hormuz (42 km wide), evaporation is high. As a result, salinity is extreme, regularly exceeding 44 parts per thousand (ppt) in open waters and 70 ppt in lagoonal systems in the southern Gulf (salinity is ~35 ppt in oceans) (Sheppard, Price, and Roberts 1992). In addition, due to the arid nature of the terrestrial system, the Gulf's intertidal zones are subject to extreme conditions: there surface temperatures can exceed 50°C in the summer, with high evaporation rates and salinities that can exceed 100 ppt (Sheppard, Price, and Roberts 1992).

Together, these harsh environmental conditions represent a barrier for life, and as a result only a relatively hardy subset of the Indian Ocean fauna occur in coastal ecosystems in the Gulf. However, while these tolerant species are well adapted to this environment, most species live on the upper margins of their tolerance. Any further pressure (either natural or originating in human activity) can push them over the edge, and result in rapid mortality of organisms across whole ecosystems. Thus, while Gulf fauna are among the hardiest on earth, they are also among the most sensitive to pressures resulting from coastal urbanization.

Important coastal ecosystems in the Gulf

Despite extreme environmental conditions, important coastal ecosystems are found throughout the Gulf including saltmarshes, mudflats, sabkhas (salt flats) and mangrove forests in the intertidal zone as well as algal beds, seagrass meadows and coral reefs in subtidal areas. These coastal ecosystems are arguably the most important natural assets in the Gulf region. They often contain significantly higher biological diversity than the surrounding terrestrial deserts and coastal productivity is six times higher than in offshore ecosystems. Coastal ecosystems also support nearly half a billion dollars in commercial fisheries, the second highest value resource after oil (van Lavieren et al. 2011).

Beaches surrounded many historical coastal villages in the Gulf. As urbanization grew over the past half-century, beaches were often replaced by seawalls, breakwaters and other engineered coastal defense structures. Beaches in the Gulf are generally low sloping, and their intertidal habitats can extend for several kilometers inland from the coast (Sheppard, Price, and Roberts 1992). These large intertidal beach habitats are well known for supporting ghost crabs, seabirds and turtle nesting sites, but the most diverse and abundant fauna actually live in the moist interstices within the beach sand itself. Over 200 species of invertebrates such as snails, worms, crabs and other fauna live in the top 15 cm of beach sand, and densities can exceed 400,000 individuals per square meter (Basson et al. 1977; Sheppard, Price, and Roberts 1992). These interstitial fauna perform important ecological roles in decomposition, nutrient cycling and food web dynamics on coastal beaches throughout the Gulf. They also serve as important food sources for wading birds and foraging crabs.

A variety of important ecosystems often occur in lagoonal systems that occur behind beaches and sand spits. Sabkhas are evaporative coastal salt flats that occur in low lying areas along the southwestern Gulf, making up over 40% of the total area of Bahrain and covering over 6000 km^2 in the UAE and Qatar (Barth and Böer 2002). Due to their extreme temperatures and salinity, diversity in sabkhas is often low. Yet sabkhas are thought to be one of the most productive ecosystems in the Gulf due to their dense algal/cyanobacterial mats. Energy from these mats is cycled through detrital food chains and supports a food web containing a variety of invertebrates, reptiles and mammals which are sabkha specialists and during high tide, sabkhas also provide important foraging habitat for a variety of marine fauna, including a number of commercially important fish and shrimp species (Barth and Böer 2002). In addition to their ecological importance, sabkhas are increasingly being recognized by bioprospectors and environmental engineers for their unique microbial communities that can biodegrade oils and could play a significant role in future oil spill remediation (Lokier 2013).

Mangrove forests are another important coastal ecosystem that is often associated with protected lagoons and intertidal flats. Despite being present in all Gulf countries except Iraq, mangroves cover a total area of only 130 km^2 in the Gulf, three-quarters of which is in Iran (van Lavieren et al. 2011). However, because mangroves constitute the only available evergreen forest in the Gulf's hyper-arid coastal areas, they serve as an important habitat and food source for a variety of marine and terrestrial species. Little of the energy produced by mangroves is directly consumed; falling leaves form instead the foundation of a rich detrital food web where up to 90% of the energy lost as leaves is decomposed and cycled into the food web of the surrounding community (Hegazy 1998). As a result, mangroves support a diversity and abundance of invertebrates that is often considerably higher than in surrounding ecosystems. These invertebrates in turn serve as food sources for foraging fish and diverse migratory bird communities. Mangroves are particularly important as nurseries for a variety of juvenile fish in an area where estuaries are uncommon. For example, it has been shown that over half of tissue growth in a Gulf mangrove-associated shrimp species originated from mangrove sources (Al-Maslamani et al. 2013), and that juvenile phases of several Gulf crab species associate with the root system of mangroves (Naderloo, Türkay, and Sari 2013). Mangroves can also have practical benefits for humanity. Mangrove root systems bind sediments and can control erosion of coastal areas where they occur. By capturing carbon dioxide from the atmosphere and sequestering it in sediments, mangroves can serve as an important carbon sink for atmospheric carbon dioxide. They have also historically served as important fodder crops for domesticated animals and, in pre-oil times, as an important building material in the region (Beech and Hogarth 2002).

Often adjacent to mangrove forests and sabkhas, shallow tidal mudflats are at the lower end of the intertidal zone and are well flushed by tides. Tidal mudflats can extend for large distances from shore and as a result are one of the largest coastal habitats in some parts of the Gulf, covering over half of the coastline in Kuwait, for example (Basson et al. 1977). Thanks to their shallow nature and the abundance of algal mats, mudflats are also highly productive. Their large size and high productivity make them a far greater contributor of energy to food webs in the Gulf than mangrove forests (Price 1993). As in sabkhas and mangrove forests, the energy from the algal mats supports dense communities of invertebrates that feed on the algae and associated organic detritus on the surface (900 individuals/m^2). These invertebrates are in turn preyed upon by crabs, wading birds and fish that move in with the tides to feed off the sea bottom. Diversity of fauna is particularly high in the less saline mudflats in Kuwait and Iran where freshwater input is higher; these mudflats serve as very important nursery grounds for highly valuable commercial shrimp species (Grabe and Lees 1992).

Moving from the intertidal to the subtidal zone, near-shore environments are often dominated by dense and diverse algal beds of seaweeds which can cover over 85% of the sea bottom (McCain et al. 1984). Over 200 species of macroalgae and seaweeds are known to live in the Gulf where they form dense beds that provide a complex three-dimensional structure that serves as important habitat for numerous species of invertebrates and fish as well as a food source for a variety of grazing species (John 2012). During the spring, seaweeds can serve as important spawning and nursery habitats for the many species of fish and shrimp which undergo peak reproduction at this time of year (Sheppard, Price, and Roberts 1992). They can also serve as a foraging habitat for adult shrimp that feed on bivalves and worms associated with the algae (Al-Maslamani et al. 2007).

Seagrass beds are widespread in shallow coastal waters in the western and southern Gulf (less than 10 m depth) and cover a total area of over 10,000 km^2, representing 6% of the total seagrass habitat in the world (Erftemeijer and Shuail 2012). Gulf seagrasses are also important in terms of biodiversity: they support over 500 species of invertebrates, as well as migratory populations of green turtles and the second largest population of dugongs in the world (Erftemeijer and Shuail 2012). As such, seagrass beds are considered the most diverse coastal ecosystem in the Gulf outside of coral reefs (Basson et al. 1977). Seagrass beds serve as both a direct food source for herbivores as well as an indirect source of energy for members of the detrital food web and densities of fauna in seagrasses can exceed 50,000 individuals per square meter, with a biomass that is three times higher than in the surrounding sandy sea bottom (Coles and McCain 1990). Seagrasses are also critically important in supporting juvenile and adult phases of a number of species of commercially important fish, shrimp and pearl oysters and it has been estimated that seagrass beds support in excess of 4800 kg of fisheries production per square kilometer (Price, Sheppard, and Roberts 1993). In addition to these ecological and economic benefits, seagrasses are an important carbon sink that have the potential to mitigate the impacts of climate change. Their sheer size (more than 10,000 km^2) makes their value in this regard considerably larger than that of mangroves (130 km^2). The importance of seagrasses in carbon sequestration is particularly amplified in the Gulf, since the surrounding land contains limited natural vegetation to act as carbon sinks. Recent research estimated that seagrasses in the Gulf have pulled approximately 400 million kilograms of carbon from the atmosphere and fixed it in living seagrass tissues, while nearly 5 billion kilograms of carbon have been sequestered in the underlying sediments (Campbell et al. 2014).

Coral reefs cover approximately 3800 km^2 in the Gulf and make up 8% of the total reef habitat in the world (van Lavieren et al. 2011). Corals in the Gulf generally live on hard-bottom rocky habitat in shallow coastal seas (less than 10 m) and around offshore islands. These corals do not build reef frameworks over time and are better described as ‘coral carpets’ whose growth is held in check by the Gulf’s extreme environmental conditions. Although low in diversity (around 60 species) because of the high latitude and extreme environmental conditions, coral communities in the Gulf seem to contain the most diverse invertebrates and fish of all coastal ecosystems in the Gulf (Sheppard, Price, and Roberts 1992). Such non-coral invertebrates as sponges, anemones, worms, mollusks and sea squirts are commonly associated with reefs in the Gulf, as well as algae and seaweeds, fish and other vertebrates such as sea snakes and hawksbill turtles (Sheppard, Price, and Roberts 1992; Burt et al. 2011; Feary et al. 2012).

Like other coastal ecosystems, coral reefs provide the biogenic structure, food resources and shelter that serve as an important nursery habitat for juveniles, and as a foraging area for adult fish and crustaceans. A recent study in the UAE has shown that coral reefs support a fish biomass of up to 290 metric tons per square kilometer, which is dramatically higher than the 0.8–1.4 metric tons per square kilometer living in soft-sediment habitats (Grandcourt 2012). Coral reefs are thus critically important for supporting not only diversity but also the highly valuable commercial fisheries industry, which is worth US$500 million per year. The fisheries industry supports the livelihood of nearly a million people and is the Gulf’s second most important natural resource after oil (van Lavieren et al. 2011). Coral reefs in the Gulf are also of high value for the study of global warming: the Gulf’s high-temperature environment is increasingly being used as a model to study how future climate change might affect reefs elsewhere, as their temperatures increase in the coming century (Feary et al. 2013; Burt 2013; Burt, van Lavieren, and Feary 2014).

Recent studies compared communities of corals and coral reef fishes in the Gulf with those in more benign environments to predict future changes in other regions (Feary et al. 2010; Burt et al. 2011; Bauman et al. 2013) and scientists are increasingly studying Gulf reef fauna to understand what mechanisms allow corals here to survive temperatures that would be lethal anywhere else in the world (Hume et al. 2013; Burt, van Lavieren, and Feary 2014).

Urbanization and its impacts on the Gulf's coastal ecosystems

Marine coastal ecosystems in the region are diverse and contribute much more to biodiversity than the arid terrestrial systems that border the Gulf. Yet recent urban expansion has put increasing pressure on these invaluable and fragile ecosystems (Figure 1).

Coastal infilling, reclamation and dredging were used to expand urban areas throughout the Gulf (Figure 2), an evolution that resulted in the degradation of coastal ecosystems. Nearly two-thirds of the Gulf's sabkhas were lost to development as a result of direct physical destruction and of the indirect changes channelization caused in tidal flushing (Lokier 2013). Mangroves have become far less extensive in the past half-century because of extensive coastal development and because of the extraction of the freshwater they need to survive (Sheppard et al. 2010). In many areas, beaches have been infilled and transformed into seawalls, which triggered a loss of critical nesting habitats for endangered migratory turtles. Around a number of cities, mudflats were considered 'worthless swamps' that have been degraded and lost as a result of coastal infilling and reclamation. Expanding industrial development and coastal reclamation has also caused widespread degradation and fragmentation of thousands of hectares of seagrass beds that serve as important migratory habitats for turtles and dugongs (Sheppard et al. 2010; Erftemeijer and Shuail 2012). Coral reefs have been buried by large-scale offshore real estate developments or impacted by the sedimentation resulting from more distant reclamation (Burt, Bartholomew, and Usseglio 2008; Burt et al. 2013). Channels have been cut directly through them for industrial purposes and reefs have had seismic explosives discharged across their surface for oil and gas exploration (Zainal, Dalby, and Robinson 1993). Over 70% of the Gulf's coral reefs are now considered 'effectively lost' (Wilkinson 2008).

Coastal development is the single most important factor impacting coastal ecosystems in the Gulf, but other human pressures add to the burden. Overfishing is widespread throughout the Gulf, and a variety of commercially important fish and shrimp species are being harvested well beyond their sustainable levels (Grandcourt 2012). Some species provide important ecological services, such as grazing on the algae that compete with corals on reefs, and the decline of these species through overfishing can result in the widespread and long-term degradation of whole ecosystems. In addition, nearly half of the world's desalinated water supply is produced in the Gulf (more than 5 billion m^3 annually), with over 1000 cubic meters per second of waste brine discharged back into the Gulf. Discharge plumes often have elevated temperature and salinity and contain a variety of toxic pollutants, and these plumes can extend for several kilometers from outfalls causing environmental impacts to near-shore coastal ecosystems (Lattemann and Höpner 2008; Dawoud and Al-Mulla 2012). Underpinning the increased population growth and urbanization in the region is an oil industry that produces nearly a third of the world's current supply of oil through 800 offshore platforms supported by 25,000 annual tanker shipments (van Lavieren et al. 2011). Oil's most dramatic impacts occurred during the 1991 Gulf War when a 10.8 million barrel oil spill covering thousands of square kilometers of the Gulf caused widespread impacts in

Figure 1 Examples of large-scale coastal development in the Arabian Gulf. From top left: Tarut Bay in Saudi Arabia, Durrat Al Bahrain in Bahrain, the new and old town of Doha, Qatar, the Palm Jumeirah and The World developments in Dubai, UAE, and Kuwait City, Kuwait (Imagery courtesy of NASA Earth Observatory/International Space Station Program).

intertidal habitats (Price 1998), and today chronic oil pollution from ballast discharge, industrial spillage, ship collisions and related causes continue to affect coastal ecosystems (Naser 2011). Continued growth in shipping activity, oil production and sewage discharge that will occur alongside urban expansion is likely to be linked to increased occurrence of harmful algal blooms, excess nutrient input, oxygen deficiency and increased heavy metal and organic pollution (Sheppard et al. 2010; van Lavieren et al. 2011; Sale et al. 2011).

Along with coastal development, these other population-related stressors have contributed to the degradation and loss of coastal ecosystems throughout the region and the Arabian Gulf is now considered among the most heavily impacted marine eco-regions in the world (Figure 3; Halpern et al. 2008). Each of these individual stressors poses a risk to the fragile ecology of the Gulf's coastal ecosystems. However, taken together their cumulative impacts could trigger the collapse of those productive habitats that for millennia have supported coastal populations—unless there are rapid changes to policy, regulation and management of coastal environments (Burt, van Lavieren, and Feary 2014).

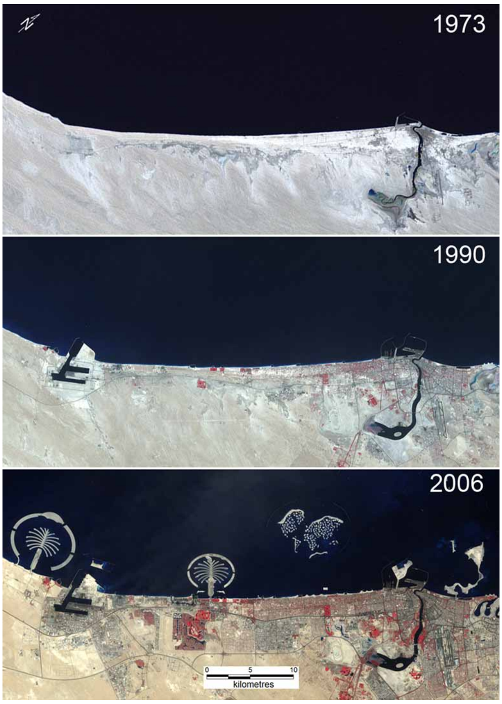

Figure 2 Coastal change in Dubai, UAE, between 1973 and 2006 (Imagery courtesy of NASA Earth Observatory/Landsat Project Science Office).

The future of coastal ecosystems in the Gulf

The decline of coastal urban ecosystems in the Gulf has been lamented since large-scale development began in the early 1980s, but calls for improved management and regulation have become increasingly vocal in the past few years (Sheppard et al. 2010; van Lavieren et al. 2011; Sale et al. 2011). The number of conservation and management publications in the Gulf doubled between 2007 and 2012, and now conservation is among the most studied themes in marine science in the region (Burt 2013). Recent surveys showed that regionally active scientists considered the management of anthropogenic impacts to be among the highest priorities for immediate action (Feary et al. 2013). There is also an increasing recognition that coastal development has social costs, and that these costs are primarily borne by the less advantaged segments of society that continue to use the coast and its resources to support their livelihood. These members of society are increasingly under economic pressure as a result of mismanagement of coastal fisheries and degradation of coastal habitats, and they are increasingly under social and political pressure to relocate from their traditional coastal villages (voluntarily or otherwise) to make way for ultramodern coastal real estate projects. Thus, unless addressed soon, the environmental degradation resulting from coastal urbanization has the potential to grow into a problematic social issue for governments in the Gulf.

Management intervention thus far has been sporadic, but has shown a capacity for success. The total area of seagrass in the UAE has expanded significantly since the banning of destructive shrimp trawling (Howari et al. 2009). Meanwhile, mangrove forests are expanding in those locations where restoration and/or protection programs have been instituted (Saito et al. 2003; Howari et al. 2009). There is also increasing evidence that coastal development projects—if built in appropriate sites and construction impacts minimized—can enhance local abundance and biodiversity (Burt et al. 2009b; Burt, Bartholomew, and Feary 2012; Burt et al. 2013). Moreover, the number and total size of marine protected areas in the Gulf have more than doubled in the past two decades, and now represent 8% of the region's maritime area (Van Lavieren and Klaus 2013).

These isolated success stories are encouraging, but only the engagement of the highest state authorities may trigger meaningful and long-lasting improvements in coastal management. Improving awareness of the value and importance of coastal ecosystems among senior leadership in Gulf countries should be considered a critical first step towards enacting positive change (Sale et al. 2011). The engagement of these decision-makers could trigger comprehensive improvements in the legislative and regulatory framework guiding coastal urbanization and environmental conservation. While such

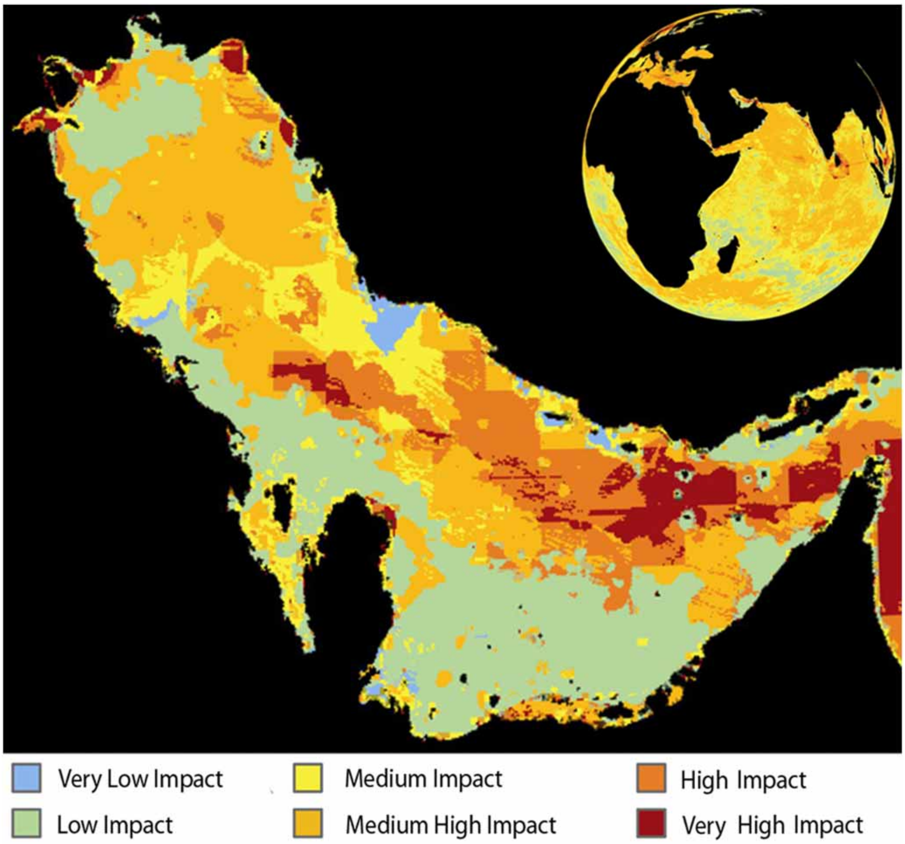

Figure 3 Human impacts on marine ecosystems in the Gulf due to human drivers such as fishing activity, oil extraction, shipping, pollution, climate change and population pressure (Adapted from Halpern et al. 2008. Reprinted with permission of AAAS [American Association for the Advancement of Science]).

an approach could lead to immediate improvements, over the long term it would need to be supported by a strengthening of technical capacity in the region (van Lavieren et al. 2011). Currently, the majority of technical expertise is provided by international consultants and imported expatriate experts and there are few programs in coastal management and marine science within regional universities (van Lavieren et al. 2011; Burt 2013); as a result the stakeholders that have the most to gain from involvement—Gulf nationals—are underrepresented in the field of coastal assessment and management. The expansion of technical programs in these areas is needed to engage local stakeholders in the long-term development of their coastline that protects its ecological assets.

We enter a period where the decline of coastal ecosystems in some parts of the Gulf may be irreversible if left unchecked. The opportunity does exist for one or more Gulf countries to make bold and effective changes in improving the management of coastal urbanization, and to promote the conservation of the ecosystems that line the coasts of this remarkable and unique young sea.

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