Critical research needs for identifying future changes in Gulf coral reef ecosystems

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Highlights

•Current knowledge gaps in Gulf coral reef ecosystem assessed by expert opinion.
•Biodiversity, climate change, anthropogenic impacts and economic evaluations dominated questions.
•Provides guidance for future research on coral reef ecosystems within the Gulf.

Abstract

Expert opinion was assessed to identify current knowledge gaps in determining future changes in Arabian/Persian Gulf (thereafter ‘Gulf’) coral reefs. Thirty-one participants submitted 71 research questions that were peer-assessed in terms of scientific importance (i.e., filled a knowledge gap and was a research priority) and efficiency in resource use (i.e., was highly feasible and ecologically broad). Ten research questions, in six major research areas, were highly important for both understanding Gulf coral reef ecosystems and also an efficient use of limited research resources. These questions mirrored global evaluations of the importance of understanding and evaluating biodiversity, determining the potential impacts of climate change, the role of anthropogenic impacts in structuring coral reef communities, and economically evaluating coral reef communities. These questions provide guidance for future research on coral reef ecosystems within the Gulf, and enhance the potential for assessment and management of future changes in this globally significant region.

Keywords

- Persian Gulf;
- Arabian Gulf;
- Coral Reefs;
- Expert;
- Assessment;
- Research Gap

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1. Introduction

The Gulf is a semi-enclosed marginal sea, connected to the Gulf of Oman (also known as the ‘Sea of Oman’) through the 56 km wide Strait of Hormuz (Chao et al., 1992, Sheppard et al., 1992 and Coles, 2003). There has been a rapid and substantial increase in scientific interest within the region, especially its marine environment and the physical extremes in which its marine communities (especially coral reefs) have evolved (reviewed in Khan et al., 2002, Hamza and Munawar, 2009, Sheppard et al., 2010, Sale et al., 2011 and Riegl and Purkis, 2012). In an era of unparalleled changes in global oceanic climate, understanding the potential implications of global changes on ecologically, economically and socially important coastal coral reef ecosystems will be vital in developing adequate management and conservation measures to cope with such changes. Within the Gulf, the coral reef ecosystem is characterized by some of the world’s most extreme environmental conditions, with salinity often >45, and the highest variability in annual temperature encountered by coral reefs globally (Sheppard et al., 1992, Riegl, 2001 and Sheppard and Loughland, 2002). Consequently, investigating coral reefs that exist in marginal environments (i.e. regions that have naturally extreme physical factors structuring their populations) will effectively inform about the limits of adaptation, acclimation, and resilience (Feary et al., 2010, Purkis et al., 2011 and Riegl et al., 2011).

There is increasing interest in developing research programs within the Gulf to understand the importance of physical extremes in structuring its coral reef communities (Feary et al., 2010, Sale et al., 2011, Burt et al., 2011 and Riegl et al., 2011). Thus it is vital that research programs have clear hypotheses and predictions. Most research on coral reef communities within the Gulf has historically been based around baseline assessments, usually associated with large-scale coastal development projects (Price, 1982, Coles and Tarr, 1990, Sheppard et al., 1992, Sheppard et al., 2010, Fadlallah et al., 1993, Harrison, 1995, Coles, 2003, Purkis and Riegl, 2005, Purkis et al., 2005 and Burt et al., 2009). However, recent research has begun to focus on understanding mechanisms important in structuring marine communities, rather than simply categorizing these communities by their biotope (Burt et al., 2008, Burt et al., 2010, Burt et al., 2011, Richlen et al., 2010 and Bauman et al., 2011). In addition, it is important to understand that research being undertaken in the Gulf on its coral reef communities can help with examining questions of global significance. Here we present a list of critical research areas and research questions that would advance our understanding of the potential changes in Gulf coral reef ecosystem. We also summarize current research strengths and weaknesses within the Gulf research community.

2. Methods

Data were obtained by inviting managers and academics to submit up to five questions that represented feasible research projects and information gaps for understanding future changes within Gulf coral reef ecosystem. Academics were invited to participate if they had authored or co-authored at least two peer-reviewed articles or reports on the Gulf or adjacent regions within the last 20 years. Managers were defined as those representing key environmental agencies within countries bordering the Gulf, who were responsible for making management/policy decisions in relation to the environmental management of the Gulf ecosystem. Of 49 individuals invited to contribute, 31 provided 71 distinct questions. This represented expert opinion from people of 30 institutions from seven countries who had conducted, or were conducting, research in the Gulf (all littoral States except Iraq). All invited managers and academics were participants in the ‘Coral Reefs of the Gulf’ conference, Abu Dhabi, February 2012.

Keywords in the 71 questions were used to identify 12 major research areas in the Gulf:

- I. Abiotic interactions/factors structuring Gulf coral reef communities
- II. Anthropogenic activities structuring Gulf coral reef communities
- III. Biological and ecological processes structuring Gulf coral reef communities
- IV. Climate change impacts on Gulf coral reef biology and ecology
- V. Connectivity of Gulf coral reef communities
- VI. Disease biology within Gulf coral reef communities
- VII. Economic evaluation of Gulf coral reef communities
- VIII. Evolution of Gulf coral reef communities
- IX. Marine protected area development
- X. Monitoring and ecological surveys of coral reef community structure within the Gulf
- XI. Oceanographic factors structuring Gulf coral reef communities
- XII. Coral reef restoration and management

Participants were required to rank the 12 areas in order of perceived importance (from 1 to 12 [most to least important]). To examine the range of expertise encompassed within this assessment, but also determine how expertise affected the evaluation of research areas, each participant was asked to list up to three of their ‘research strengths’. Research strengths were used to classify participants into particular research areas. The potential influence of expertise on the perceived importance of research areas was then assessed by examining the relationship between the number of participants within a research area and the median importance score given to that area using linear regression (GLM procedure, SPSS) (*sensu*Wilson et al., 2010). To assess whether the expertise of participants also influenced the breadth of proposed questions, questions were classified into the research areas they related to, and the relationship between the number of participants and the number of questions in an area was determined using linear regression. Research strengths of participants and content of questions often related to more than one research area, and if so, they were classified into multiple areas.

The value of proposed research questions was assessed by asking participants to rate each question (presented in a random order) in terms of four attributes:

I. Does this research identify a gap in our current knowledge base?
II. Is this research question of high priority, needing to be answered immediately?
III. Could this research question be developed into a feasible research project within the Gulf?
IV. Is this research question of broad ecological scope (applicable to multiple species and reefs throughout the Gulf)?

Participants were asked to give each question a score (1 = very low; 2 = low; 3 = medium; 4 = high; 5 = very high) for how well the question addressed each attribute. Attributes 1 and 2 (knowledge gap, priority) were considered a measure of the importance of proposed questions, while attributes 3 and 4 (feasibility, scope) were considered a measure of the resource-efficiency of proposed questions. Median scores of questions within research areas were examined to identify research areas with the most important and resource-efficient questions, and to assess whether the expertise of participants biased their scoring of questions from outside their own research strengths. Individual questions with a median score of either 'high' or 'very high' for all four attributes were identified as critical for understanding future changes in the Gulf, i.e. those questions which were considered both highly important and an efficient use of resources. Questions with a median score of either 'high' or 'very high' for the knowledge gap attribute and at least 'medium' for all other attributes were identified as important for Gulf research, but not critical.

3. Results

3.1. Research areas and participants

There were clear differences in the perceived importance of research areas (Fig. 1). Biological and ecological processes, the potential role of climate change, and anthropogenic activities on coral reefs were considered to be most important, while areas considered least important were disease biology, the evolution of Gulf coral reef communities and the economic evaluation of Gulf coral reef ecosystems (Fig. 1). However, there was an uneven distribution of participants among reported research strengths. Overall, approximately 40% of participants listed their research strengths in the areas of biological, ecological and anthropogenic processes structuring Gulf coral reef communities. Less than 5% of scientists listed their research strengths as being in areas of abiotic interactions, marine population connectivity and coral disease; no participants listed their research strength as economic evaluation of Gulf coral reef ecosystems (Fig. 1). This bias in the designation of research strengths among participants influenced the perceived importance of research areas, with a positive relationship found between the number of scientists in a research area and the median importance score for that research area (R^2 = 0.34, $F_{1,11}$ = 5.137, P = 0.047). However, several research areas with few participants received relatively high median importance scores (Fig. 1). These were climate change impacts on Gulf coral reef communities, development of marine protected areas, understanding abiotic factors that structure Gulf coral reef communities, and the connectivity of Gulf coral reef communities (Fig. 1).

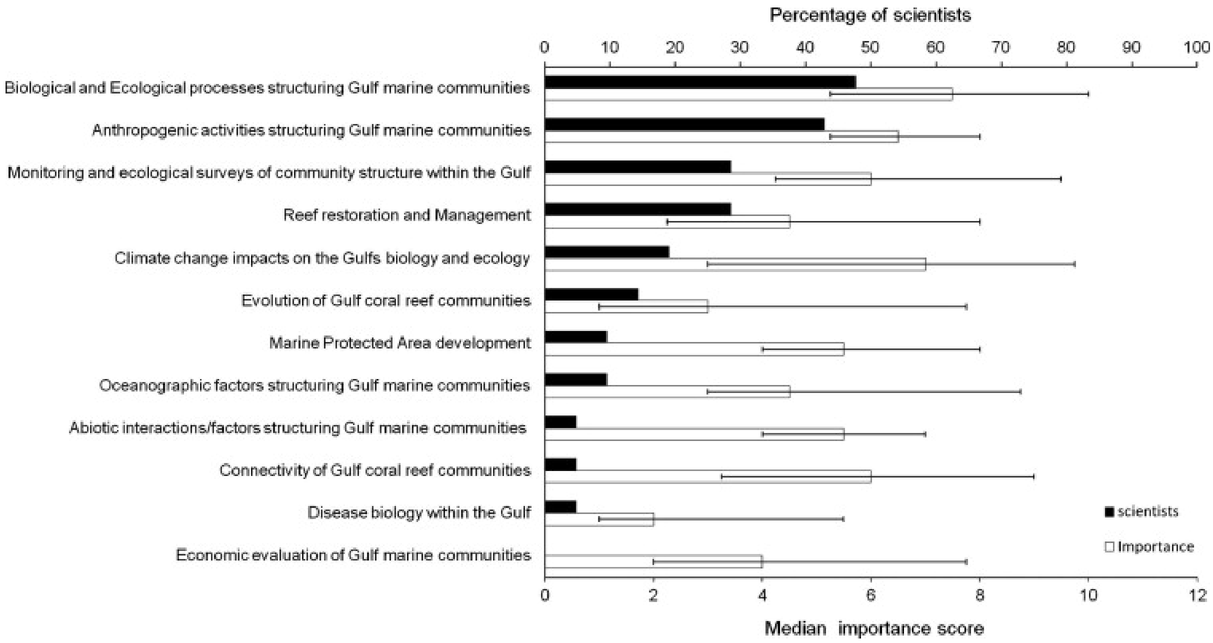

Fig. 1. Research areas of scientists and median importance scores given to these research areas in the Gulf. Error bars represent the 25th and 75th percentile of data.

3.2. Research questions and participants

The median score of research questions among research areas ranged from 'medium' to 'high' in all four evaluation attributes (Fig. 2). Questions that related to the research areas of anthropogenic activities and reef restoration and management received the highest scores across all evaluation categories, and although the area of economic evaluation also appeared to score highly, this represented the results of a single question (Fig. 2, and see Supplementary data). Questions relating to biological and ecological factors, oceanography and coral disease biology received the lowest scores across all evaluation categories (Fig. 2). The low scores for questions relating to biological and ecological processes were unexpected, given the high proportion of participants that listed these research areas as their research strengths (48%). However, such low scores for these questions may relate to the diversity of questions within these research areas (see Supplementary data). Research questions encapsulated a range of topics, including fisheries, coral reef benthic development, larval behavior and ecology, herbivory, analysis of biotypes, etc. Such a wide range of questions within these research areas will have led to substantial disparity in ranking the importance of different questions between participants; such disparity will then have moderated the overall scores for these research areas. The research strengths of participants also influenced the range and scope of research questions proposed, with a positive relationship found between the number of participants working in a research area and the number of research questions relating to that area (R^2 = 0.44, $F_{1,11}$ = 7.909, P = 0.018). Exceptions were the areas of anthropogenic activities and abiotic interactions, which had relatively few, and relatively many, questions compared to the number of participants listing these as their research strengths, respectively (Fig. 3). Despite bias in the types of questions proposed, questions were scored relatively evenly across research areas (Fig. 2).

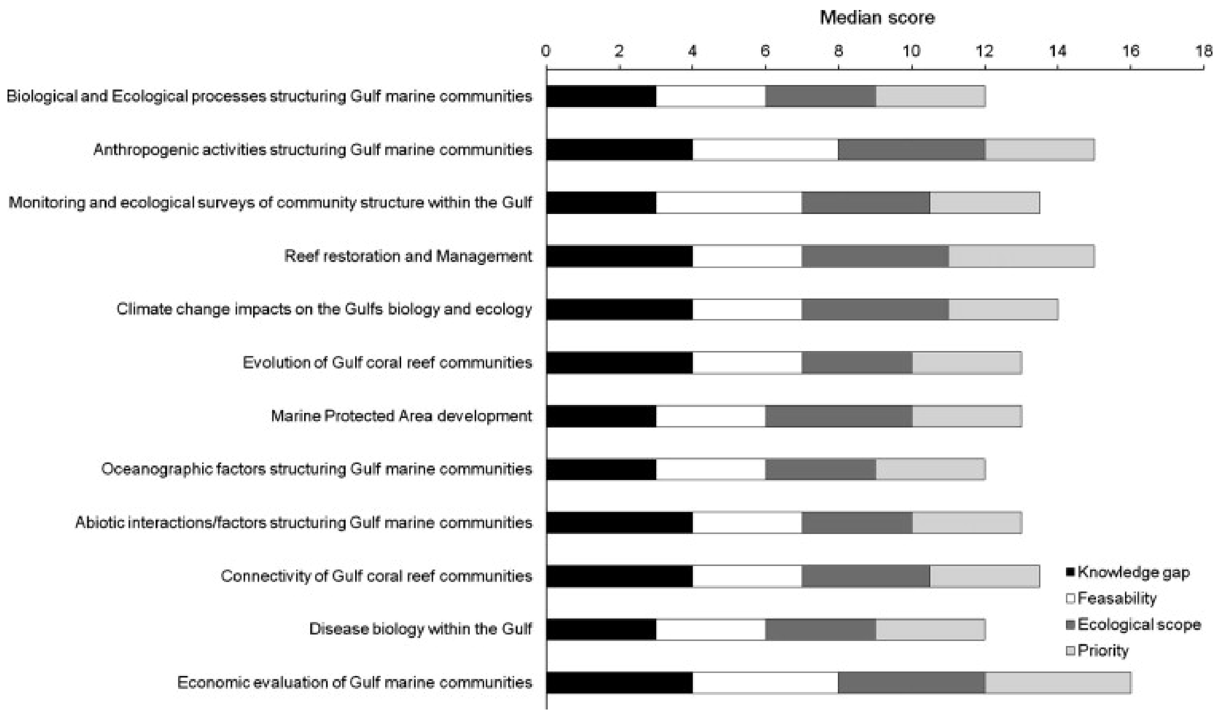

Fig. 2. Median scores given to proposed research questions in four evaluation attributes.

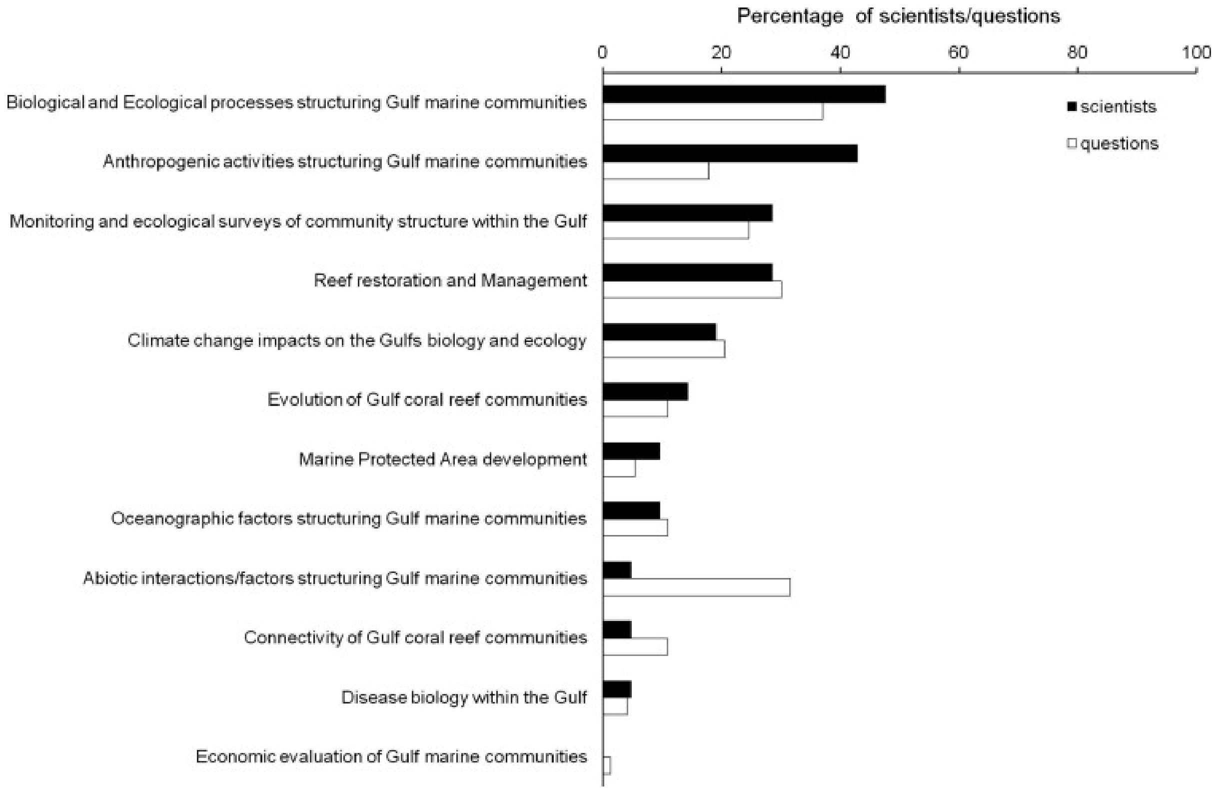

Fig. 3. Research areas of scientists and areas of 71 research questions proposed for the Gulf.

3.3. Scoring of research questions

3.3.1. Critical research questions

Of the 71 research questions, 10 had a median score of 'high' or 'very high' in all four of the assessment attributes: they identified a substantial gap in our current knowledge base, they were judged a high priority, requiring immediate application, they were deemed to be feasible to develop into a research project within the Gulf, and they were considered to be broad in their ecological scope. These 10 questions (in no specific order) are listed below under their research themes.

3.4. Climate change impacts on Gulf biology and ecology

1. Predictions based on experimental and field observations indicate that the combined effects of rising temperatures and ocean acidification could increase the frequency of bleaching events and reduce coral calcification by up to 80% of modern values (Erez et al., 2011). If rates of $CaCO_3$ production by coral and other reef calcifiers cannot keep up with rates of erosion, the majority of coral reefs could switch from net accreting to net eroding structures. Given that the majority of hard corals in the Gulf do not build reefal frameworks, they could potentially be threatened by a shortage of suitable habitat, over next 40–50 years, which they rely for colonization due to changes in water chemistry (Purkis et al., 2011). *What is the present condition of seawater acidity/alkalinity in the Gulf, how do they compare to tropical Pacific Ocean conditions, and how will increased dissolved CO_2affect coral growth in the Gulf?*

2. The Gulf functions as a negative estuary where high evaporation rates causes salinities well above open ocean values that exceed tolerances experimentally determined for corals from other regions. However, even Gulf corals have demonstrated limits to elevated salinity, and it has been shown that both coral species diversity and general benthic diversity decrease with increasing salinity in the Gulf (Coles, 2003). *How will overall and local salinities in the Gulf be affected in the next century by anticipated increasing temperatures due to climate change, and by increased discharge of high salinity brines from massive desalination plants built to provide freshwater to developing Gulf countries?*

3.5. Connectivity of Gulf coral reef populations

1. Research has shown that source populations for coral reefs throughout the Gulf can be substantial distances from sink areas. For example, in Qatar's exclusive economic zone source populations are approximately 110 km offshore to the north and east of Qatar, while within southern UAE there is a distinct west-to-east decline in the abundance of coral recruits (Burt et al., 2011). *What proportion of coral recruits originate from local reefs throughout the Gulf, and what proportion comes from outside the Gulf? Are there distinct source areas of coral planulae for Gulf coral reefs and to what degree is regional connectivity supporting recovery of degraded coral reefs in the Gulf?*
2. The degree to which marine populations are connected has important consequences for how coral reef populations persist, how they respond to natural and anthropogenic disturbances, and how they can be managed (Sale et al., 2005). Currently our understanding of connectivity within the Gulf is grossly limited. *What is the genetic connectivity of coral reef populations at multiple spatial scales within the Gulf?*

3.6. Monitoring and ecological surveys of community structure within the Gulf

1. A problem from which the Gulf suffers is a shifting baseline (Sheppard et al., 2010). The accumulation of many construction projects adds up to major changes even when one project on its own may not (Sale et al., 2011). Today it is difficult to find any meaningful baselines, not only because of ongoing, intensive constructions, but also because of several recent episodes of marine mortality from seawater warming. *Against what measures should reefs be assessed when baseline environmental impact assessment studies wish to measure change? Where in the Gulf is there a good baseline for coral reefs?*
2. The Gulf experiences extreme environmental conditions, with temperatures ranging from ~35 °C in the summer, the largest temperature range known to be experienced by reefs (Kleypas et al., 1999, Purkis and Riegl, 2005, Sheppard et al., 2010 and Riegl et al., 2011). In addition, reefs are exposed to high salinity (>45 ppt in places) and turbidity. Such conditions would result in mass mortality of reef fauna in other regions. There is very limited understanding of the mechanisms used by reef fauna throughout the Gulf to overcome the stress posed by the natural physical environment. *What are the physiological processes enhancing survivorship of reef fauna in the extreme Gulf environment? How does the physiological sensitivity of reef fauna differ temporally and spatially in the Gulf?*

3.7. Marine protected area development

1. There is still a lack of information about the biodiversity of coral reefs in the Gulf. For example, there are approximately 36 species of hard corals found throughout the Iranian region (Wilkinson, 2008), however there is increasing evidence that this number is higher than previously thought (Moradi et al., 2009, Riegl et al., 2012, Shojae et al.,

2010 and Vajed-Samiei et al., in press). Similar pattern also exist for octocorals of the Gulf (Samimi-Namin and van Ofwegen, 2009 and Samimi-Namin et al., 2012). The Gulf is a stressful and disturbed environment with low species richness compared to most parts of the Indian Ocean, but has a high beta-diversity (Price, 2002). Therefore, the identification and conservation of hotspots of coral reef biodiversity is one of the basic priorities in the declining Gulf. *Which coral reef habitats represent the hotspots of biodiversity in the Gulf?*

3.8. Reef restoration and management

1. Given the high level of coastal development in the Gulf region it is essential to develop a toolkit in order to facilitate resilience-based management in coastal development areas (Sale et al., 2011). The current lack of baseline studies makes the assessment, monitoring and management of coastal communities' unclear, allowing ongoing coastal development without control regarding the potential environment impact. *Do we have sufficient knowledge of the biology and ecology of the existing flora and fauna of coral reefs in the Gulf to be able to recommend measures to stabilise their deterioration in the face of future climate change impacts?*

2. Reefs in the Gulf have been impacted by a number of recent severe bleaching events, with limited to no recovery (Baker et al., 2008, Burt et al., 2008 and Burt et al., 2011). Limited recovery may be due to a combination of decreased reproductive output and associated recruitment limitation or high post-settlement mortality as a result of the relatively extreme environmental conditions and/or increases in anthropogenic stressors (Gleason and Hofmann, 2011). This is also likely to vary among taxa as a result of differences in tolerance thresholds. Recent studies across ∼400 km of the southern basin of the Gulf show relatively high densities of coral recruits on tiles, even on some of the most degraded reefs, suggesting that recovery is being inhibited by post-recruitment factors. *What role does coral settlement versus post-settlement mortality play in reef maintenance/ recovery in the Gulf?*

3.9. Economic evaluation of Gulf marine communities

1. The economic valuation of goods and services associated with natural ecosystems has grown rapidly in the past two decades in response to accelerating impacts from human activities and climate change (e.g., Costanza et al., 1997 and Moberg and Folke, 1999). Coral reefs are considered a particularly valuable ecosystem in many tropical countries due to their role in providing food, tourism revenue, nursery habitat, coastal protection, and a suite of other benefits (Berg et al., 1998). Despite rapid growth in this field in recent years, there has been limited development of economic valuation of natural ecosystems in the Gulf. *Given the widespread degradation of reefs due to coastal development, ports, industrial infrastructure and desalination facilities (* Sheppard et al., 2010 and Sale et al., 2011*), it is clear that an economic valuation would be a useful tool for conservation and management. Can economic valuation be used as a tool for coral reef conservation in the Gulf?*

3.9.1. Important research questions

Within the 71 research questions assessed by participants, there were 22 that had a median score of either 'high' or 'very high' in the knowledge gap category, and at least 'medium' in the categories of feasibility, ecological scope and priority. These 22 research questions encapsulated nine of the 12 research areas (see Fig. 1 for full list of research areas), and were dominated by research questions on biological and ecological, climate change and anthropogenic process areas.

3.10. Biological and ecological processes structuring Gulf marine communities

1. There have been substantial changes to southern Gulf reefs following the 1996 and 1998 mass bleaching events (George and John, 1999, Riegl, 2002 and George and John, 2005). Increased abundances and diversity of filter-feeding sessile invertebrate groups (e.g., sponges and tunicates), substantial increases in sea urchin abundance on coralline algal covered dead coral (Riegl et al., 2011) and seaweeds replacing hard corals in some areas (John and George, 2003) have been found. In addition, increases in yellow-bar angelfish abundance and decreases in grouper abundance have been recorded (Feary et al., 2010). *Has the phase-shift from coral-domination on some shallow reefs in the southern Gulf resulted in a marked increase in certain other invertebrate groups? Similarly do changes in physical structure of certain types of coral reef have an impact on more mobile fauna, including fish? What is the impact on coral reef fauna of the recent change from Acropora coral dominance to algal dominance in sheltered shallow reef areas?*
2. Healthy reefs are in a delicate balance between reef growth and reef bioerosion, with net reef production only marginally ahead of net reef loss (Glynn, 1997). In disturbed reefs, bioerosion processes destroy the reef framework faster than it is produced (Glynn, 1997). Given the environmental and anthropogenic stressors present in the Gulf (Sheppard et al., 2010), understanding the dynamics of this balance is essential. *Are the reefs of the Gulf in a healthy dynamic balance between reef growth and reef bio-erosion?*
3. Most reef studies and monitoring programs assess the state of the reefs by estimating the percentage coverage of major benthic organisms, or by examining coral colony size–frequency distributions. Few studies examine the key ecological processes that drive the state variables. The basic processes that determine population dynamics are reproduction, recruitment, post-settlement survival, colony growth, and partial and total mortality. Yet, many of these key ecological processes have rarely been investigated in the Gulf. We still know little about population processes and how they vary spatially, seasonally and under different environmental conditions within the Gulf. We understand even less about differential weightings and sensitivities of populations to slight process changes and the repercussions of those changes on subsequent population trajectories. *What are the key ecological processes structuring Gulf communities?*

3.11. Climate change impacts on Gulf biology and ecology

1. Research suggests that *Symbiodinium* in clade D are common in the Gulf area and at least partially responsible for high thermo-tolerance of Gulf corals (Baker et al., 2004 and Mostafavi et al., 2007), but clade C *Symbiodinium* was recently found to be the prevalent symbiont in Abu Dhabi waters (Hume et al., 2013). How do the different symbionts affect the temperature tolerance of the corals? *What is the molecular basis for thermotolerance in both corals and zooxanthellae, and what are the tradeoffs of hosting clade D (particularly with respect to ocean acidification, and exposure to seasonal low temperatures)? How are clade D symbionts in Gulf corals related to those found in the western Indian Ocean, central-west Pacific (Great Barrier Reef), far eastern Pacific and Caribbean? Who is the key-player in the adaptation to temperature extremes: the zooxanthellae or the host, or is the specific team required?*
2. Some fish species in the Gulf are considered to live within 1 °C of their thermal tolerance limits, at least for some of the year. The tolerance of larval stages may be even more restricted than those of adults, and in some cases, adult distributions may be limited by larval biology (Sheppard et al., 1992). Additionally, demersal reef fish are traditionally considered to undergo little or no seasonal change in abundance because of the relatively constant

environmental regimes that typically characterize tropical waters. However, the distribution and abundance of Gulf reef fish is known to vary seasonally (e.g., Coles and Tarr, 1990 and Burt et al., 2009), as such, the stock delineation boundaries and management units of the fisheries resources in the Gulf are likely to change as fluctuations in sea water temperatures increase. *How will climate change modify the distribution of fisheries resources in the Gulf and what are the associated management implications?*

3. The majority of coral species in the Gulf (assuming that names ascribed to the species are correct) are a subset of the much more diverse Indian/Pacific coral fauna. The elucidation of the ecophysiological and genetic mechanisms underlying their tolerance in particular to high temperatures and high salinities experienced in the Gulf will provide insights as to the potential for adaptation/acclimation of corals in other parts of the oceans. *Is heat tolerance a result of an adaptation to the "hostile" environmental conditions in the Gulf region or is the combination of specific environmental conditions (salinity, macro/micronutrients, temperature fluctuations, etc.) in fact a prerequisite for survival?*

4. Harmful algal bloom events (HABs, commonly called red tides) have been increasing in severity and distribution in the Gulf region, with significant economic, public health, and ecosystem impacts. For example, the 2008 and 2009 *Cochlodinium* red tide devastated coral reefs, wild and aquaculture fisheries, and shut down desalination plants in the Gulf and Strait of Hormuz (Samimi-Namin et al., 2010 and Richlen et al., 2010), while also having substantial negative effects on coral reef communities (Bauman et al., 2010). The continued deterioration of water quality within the Gulf is very likely to lead to more threats of this type, concurrent with the expected expansion of desalination needs within the region. *What mechanisms underlie recent increases in the numbers and diversity of harmful algal blooms in the Gulf? What programs are needed to better document the occurrence and distribution of HAB species and their toxins in the Gulf region, and to develop management and mitigation strategies to reduce impacts to both natural environments and man-made developments?*

3.12. Anthropogenic activities structuring Gulf marine communities

1. A critical concern associated with the extensive growth of Gulf countries is the development of desalination plants, and the hypersaline discharge associated with such plants (Miri and Chouikhi, 2005). Countries bordering the Gulf rely heavily on desalination for potable water (Hoepner and Lattemann, 2002), with some of the largest desalination plants in the world. These plants pump a concentrated saline discharge into coastal waters, which increase salinity, temperature, turbidity and lower oxygen compared to ambient water conditions (Del-Pilar-Ruso et al., 2008). *With such high levels of desalination use, can we define an urban contribution to changes in abiotic conditions within the Gulf? Will such development of desalination plants have a regional and/or national effect on Gulf waters?*

2. Most fisheries in the Gulf are either fully or over exploited (Morgan, 2006 and Grandcourt, 2008) and pressure on the resource base has been exacerbated by habitat loss and fragmentation associated with coastal development (Shallard and Associates, 2003). To date, assessments of fisheries resources in the Gulf have only taken into account the direct impacts of the fisheries themselves. *What are the impacts of habitat loss and fragmentation for fisheries resources in the Gulf?*

3. Recruitment, growth and natural mortality are fundamental demographic processes that structure fish populations and determine productivity. With the increasing use of seawater for desalination and cooling, both salinity and temperature in the Gulf are increasing. As many species are close to their environmental tolerance limits (Sheppard et al., 1992) the physiological implications of these changes may be profound in terms of fisheries productivity. As such, an understanding of how predicted increases in temperature and

salinity will affect demographic processes and fisheries productivity is required for resource management planning and decision-making. *In what way will increases in salinity and temperature impact demographic processes and the productivity of important fisheries resources in the Gulf?*
4. Oil pollution, breakwater construction, sedimentation caused by coastal developments, dredging, fishing, extensive anchor damage and discharge of nutrients and sewage are the major local threats to coral reefs of the Gulf (Halpern et al., 2008, Maghsoudlou et al., 2008, Sheppard et al., 2010 and Wiedenmann et al., 2012). Despite this, there is no comprehensive study regarding the effects of such pressures on the ecosystem and/or colony level characteristics of coral reef communities. *How do local threats affect coral reefs within the Gulf? How do coral communities change through time and space in natural versus impacted sites? What is the capacity and/or resilience of Gulf marine communities to pollution load (e.g., eutrophication)?*

3.13. Connectivity of Gulf coral reef populations

1. Few endemic marine species exist in the Gulf (Sheppard et al., 1992 and Sheppard et al., 2000; Samimi-Namin and van Ofwegen, 2009, Samimi-Namin et al., 2012 and Riegl et al., 2012), yet whether this is because of the relatively recent isolation of the Gulf or because of mixing through the Strait of Hormuz. *How much genetic isolation is there in Gulf species, relative to congeners/conspecifics outside the Gulf?*
2. Two seasonally developing gyral systems exist in the northern and southern Gulf. These have the potential to affect genetic connectivity and thus might result in two isolated connectivity regimes within the Gulf. *Do patterns of genetic connectivity in coral reef communities in the Gulf map onto the physical basis (i.e. surface currents, etc.)?*
3. Although the Gulf is connected to the Indian Ocean through the narrow Strait of Hormuz, the majority of species are of the wide Indo-Pacific distribution. However, it is unclear how much genetic exchange occurs. *Is the Gulf a source of pre-adapted coral and zooxanthellae genotypes that could be used for reef restoration or nurseries at sites elsewhere in the region that are cooler, but warming? What potential exists for the export of thermo-tolerant genotypes of either corals or zooxanthellae) from the Gulf?*

3.14. Monitoring and ecological surveys of community structure within the Gulf

1. The identification of key functional groups of herbivores (both fishes and urchins) that control the establishment and growth of algal communities is important to coral community dynamics. Studies conducted by Mumby et al., 2006, Mumby et al., 2007 and Mumby and Harborne, 2010 on fish and by Carpenter and Edmunds (2006) on urchins showed that elevated grazing activity positively affects the density and diversity of coral recruits settling to reefs. Nevertheless sea urchin grazing can reach destructive levels when densities are high as a result of overfishing or other factors (Bellwood et al., 2004 and Tuya et al., 2005). *What are the key functional groups of herbivores on Gulf reefs and what are the seasonal changes in their abundance and diversity?*

3.15. Abiotic interactions/factors structuring Gulf marine populations

1. Heat flux (from the water to the reef) is strongly linked to flow speed (u) over the reef as well as the temperature gradient (dT). As the Gulf has strong tidal flows, flow speed over the reef may be a dominant controlling factor in temperature associated bleaching effects. *What cross-product (u dT) occurs in the Gulf, and can we relate regions of bleaching with the*

cross product? Given that heat flux (from the water to the reef) is strongly linked to flow speed (u) over the reef as well as the temp gradient (dT), what are the temperature gradients within a Gulf reef and in the water masses over a reef? To what extent does the reef control such gradients?

3.16. Marine protected area development

1. The rate of coral reef degradation in much of the Gulf is so high that there is the possibility of irreversibly losing coral reef habitats in many areas unless we are able to conserve what we have left (Sheppard et al., 2010, Sale et al., 2011 and Van Lavieren et al., 2011). *Are the quantity, size, and placement of marine protected areas in the Gulf sufficient to conserve high value areas, and is enforcement rigorous enough to ensure that these are not paper parks?*
2. There is a need to understand where critical habitats for commercially exploited species are within the Gulf. For a range of species, understanding the important critical habitats are vital in the development of management strategies (i.e., protected areas), to adequately protect such species. In the Gulf the obvious example would be the Hammour *Epinephelus coioides*. *What are the critical nursery habitats for various commercially important species?*
3. Linking conservation benefits of MPAs to overall productivity of marine environments is a global concern (Cicin-Sain and Belfiore, 2005). Several marine protected areas have been established in the Gulf, including those within coral reefs (Krupp, 2002). However, how these areas are contributing to the overall productivity of the Gulf has not been investigated. *Are marine protected areas in the Gulf contributing to the overall biodiversity and productivity of this region? Should new high-priority regions be identified for possible no-take marine reserves within the Gulf?*

3.17. Reef restoration and management

1. Throughout the Gulf artificial reefs are frequently deployed to restore/rehabilitate diversity and productivity of the marine environment. However, the effectiveness of these measures in enhancing productivity is rarely investigated (Feary et al., 2011, Sale et al., 2011 and Burt et al., 2012). *To what extent do coral restoration or rehabilitation activities compensate for loss of quantity or quality of existing species' habitat? Have artificial reefs in the region been successful in restoring significant biodiversity and productivity?*

3.18. Evolution of Gulf coral reef communities

1. Gulf coral reefs have evolved in one of the most extreme environments globally, but also within one of the most isolated shallow-water coral reef systems in world (Sale et al., 2011). *What is the origin and evolution of scleractinian corals in the Gulf?*
2. Given the unique ecological structure of coral reefs within the Gulf, it is vital to understand which genes/loci are under adaptive evolution and which of those contribute to the relative thermo-stability of corals. *Have there been co-evolution of Gulf corals and their symbionts within the Gulf and will this reveal valuable information on their formation and origins? How do coral genotypes match Symbiodinium genotypes and vice versa? How does the genotypic makeup of a coral host influence the assemblage of algae and vice versa? Are there certain genetic combinations that are favoured over others? Can we detect selection at the level of the individual?*

4. Discussion

The synopsis and assessment of critical questions for Gulf coral reef communities identified 10 research questions that were both scientifically important (i.e., filled a knowledge gap and were a priority question to answer), and were also efficient in their resource use (i.e., highly feasible and ecologically broad). These research questions not only encapsulated a range of research shown to be of high relevance to understanding the role of change in structuring Gulf coral reef communities (e.g., Sheppard et al., 2010, Sale et al., 2011 and Riegl and Purkis, 2012), but are also consistent with research identified as globally important in recent reviews on coral reef resilience and conservation. For example, there have been numerous reviews on the role of climate change in structuring benthic tropical communities, with deciphering the role of $CaCO_3$ production in structuring coral reefs deemed vital in the midst of substantial changes in global acid–base regulation (Hoegh-Guldberg, 1999, Hoegh-Guldberg et al., 2007, Hughes et al., 2003 and Baker et al., 2008). In addition, there has been an increase in research arguing for the importance of understanding potential connectivity between source and sink populations within coral reef communities (Jones et al., 1999, Cowen et al., 2000, Dulvy et al., 2003 and Almany et al., 2007), while the interpretation of the marine community structure in light of potential shifts in community 'baseline' is now considered essential in understanding the role of perturbations in structuring marine communities (Pauly, 1995, Folke et al., 2004, Baum and Myers, 2004 and Knowlton and Jackson, 2008). Similar to the recommendations of global reviews, our assessment found that research priorities for coral reef communities in the Gulf were not focused on development-based, or anthropogenic activities, which is surprising given that recent research has focused almost entirely on this area. Recent assessments of the Gulf, which have focused almost entirely on the role of coastal development in structuring Gulf coral reef ecosystems, have shown that cumulative impacts and increasing exploitation are resulting in substantial worsening of the Gulf's health (Sheppard et al., 2010, Sheppard et al., 2012, Sale et al., 2011, Grandcourt, 2012 and Burt et al., 2012).

As shown in several participant-driven research priority assessments, participants are likely to rate research programs more highly if they are broadly similar to their own research strengths (Sutherland et al., 2009 and Wilson et al., 2010). Despite this positive relationship between participant's research strength and their assessment of research needs within the Gulf, there were several research areas that were deemed important for understanding the future Gulf ecosystem, which did not substantially overlap with participant's research strengths. The present assessment has shown that independent of research strength, there is wide interest in understanding the ecological structure of Gulf marine communities, with research questions centered on understanding the biological and ecological processes important in structuring Gulf coral reef communities, in addition to their monitoring and surveys, being some of the most well-developed of research areas. The perceived importance of understanding Gulf marine communities with respect to changing climatic conditions was relatively high, and the number of questions focused on understanding the connectivity of Gulf coral communities was also proportionally higher than expected. However, the research area of abiotic interactions and factors important in structuring Gulf marine communities had the largest difference between the number of proposed questions and the number of participants listing this as their research strength. This difference in the ratio of research strengths to research questions proposed shows the perceived importance of understanding the effect of abiotic factors on Gulf marine communities (Coles, 1988 and Coles, 2003; Riegl, 2001, Swift and Bower, 2003 and Riegl et al., 2011).

This assessment also found that there was substantial interest in understanding the mechanisms controlling the function of Gulf coral reef ecosystems. Although there is a paucity of information on the range of research expertise within the Gulf over the last three decades, the published research on the Gulf region has been focused on monitoring programs, with a distinct lack of research examining the ecological mechanisms important in structuring Gulf coral reef communities (Sheppard et al., 1992, Sheppard et al., 2010, Khan, 2007 and Sale et al., 2011). However, this predominance of monitoring-based research has slowly decreased over the last 10 years, with an increase in the number of publications focusing on more process-orientated research questions (Riegl and Purkis, 2005, Riegl and Purkis, 2009, Feary et al., 2010, Burt et al., 2011, Purkis et al., 2011 and Riegl et al., 2011). This switch in research interest within the Gulf has come about through an increase in the number and diversity of international research institutions developing within the Gulf (Sheppard et al., 2010 and Sale et al., 2011), as well as an international interest in the Gulf as a model for future changes in global ocean climate (Riegl et al., 2011 and Purkis et al., 2011). For example, future climate change scenarios predict increases in tropical oceanic temperatures of 1–3°C by 2099, which will have substantial negative effects on coral reefs globally. However, Gulf corals already exist in this future thermal environment and have survived several severe bleaching events (Riegl, 2001, Riegl, 2002, Riegl, 2003, Burt et al., 2009 and Riegl et al., 2011). In addition, the associated fish communities are relatively diverse and have mean densities comparable to other equatorial reef fish communities (Grandcourt, 2012). Therefore, Gulf coral populations, including the reef associated fauna, may be invaluable for examining the potential phenotypic and genotypic response of tropical reef communities to climate change (Feary et al., 2010, Burt et al., 2011, Purkis et al., 2011, Riegl et al., 2011 and Hume et al., 2013).

4.1. Development of collaborative research within the Gulf

The present publication represents an unprecedented move of the scientific community concerned with marine research in the Gulf to join forces and tackle important scientific problems. Although there is a relatively long history of scientific collaboration within and outside the Gulf region (i.e., recent and ongoing work on various aspects of Symbiodinium and coral taxonomy and ecology, pers comm S. Keshavmurthy), how will the key research areas within this paper be developed to achieve success in the long run? We propose a number of key objectives that may enhance the development of marine research within the Gulf. This by no means a comprehensive review of the methods which will stimulate research within the Gulf, but may map a way forward for Gulf research to achieve success.

The diversity and scope of research questions proposed by participants within the current assessment is indicative of the international scope of researchers working within, and interested in understanding the Gulf coral reef ecosystems. Although all of the participants within this assessment have worked, or are working within the Gulf, approximately 50% of participants are not permanently based in research institutions within the Gulf region (Sale et al., 2011 and Van Lavieren et al., 2011). However, this high level of international expertise is inherent within the Gulf research culture, in which foreign experts remain in the region for months to years, but do not permanently reside in the Gulf (Sale et al., 2011). There needs to be a much stronger intent to bridge the disconnection between the level of international interest in the Gulf and local research expertise. Developing the awareness of marine issues within schools, developing tertiary education that encompasses marine studies, and then developing jobs in marine research are all vital in developing the research expertise within the Gulf.

Effective communication and collaboration among research teams across the region will be required to ensure all key areas of research are investigated, and to avoid redundancy ('doubling up'). In addition to cooperation among individual researchers, there is the need to development cooperative relationships between organizations, both within and across nations (i.e. through the development of MOUs); this is analogous to the objectives set out in the Regional Organization for the Protection of the Marine Environment (ROPME). In addition, government-funded programs promoting the exchange of researchers between nations and provision of funding for collaborative research projects may be used to facilitate international cooperation on Gulf research. Lastly, the organization of regular conferences and workshops for both scientists and resource managers will ensure that development in key areas of Gulf research is quickly and effectively communicated.

Overall there is a need to create a research society within the Gulf that includes various stakeholders concerned with the science and conservation of coral reefs in the Gulf and adjacent regions. In this respect, the Mideast Coral Reef Society (MCRS) Initiative has been launched recently (http://www.mideastcrs.org/). The MCRS initiative is jointly hosted by the New York University Abu Dhabi and the University of Southampton and is funded by the Natural Environment Research Council, UK. This society will be an association of researchers and members of governmental, non-governmental, academic, industry and private sector organizations with an interest in a broad range of aspects of Middle Eastern reefs. The MCRS Initiative is already supported by more than 50 representatives of high profile, international academic and non-academic organizations, and will promote collaboration among researchers and knowledge exchange with stakeholders outside academia with the aim to generate a deep understanding of the functioning of these unique ecosystems, and to promote their conservation and sustainable use.

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Supplementary data 1: Full list of 71 questions posed for assessment

Biological and Ecological processes structuring Persian Gulf marine communities

1. Healthy reefs are in a delicate balance between reef growth and reef bioerosion, with net reef production only marginally ahead of net reef loss (Glynn, 1997). In disturbed reefs, bioerosion processes destroy the reef framework faster than it is produced (Glynn, 1997). Given the environmental and anthropogenic stressors present in the Persian Gulf (Sheppard et al., 2010), understanding the dynamics of this balance is essential. Are the reefs of the Persian Gulf in a healthy dynamic balance between reef growth and reef bio-erosion?
2. In recognition of the importance of grazing on reefs, protection and maintenance of herbivorous species has been suggested as a potential solution to reduce the long-term decline of coral reef communities by decreasing vulnerability and increasing the capacity of coral reefs to resist phase shifts and regenerate when disturbances occur (McCook et al., 2001; Bellwood et al., 2004). It is likely that herbivores will play a crucial role in the resilience and recovery potential of coral reefs in the future as increased temperatures and ocean acidification associated with climate change will result in increasing degradation of reef habitats (Diaz-Pulido et al., 2009; Pandolfi et al., 2011). What is the role of herbivory in structuring benthic communities in the extreme environment of the Persian Gulf?
3. Most reef studies and monitoring programs assess the state of the reefs by estimating the percentage coverage of major benthic organisms, or by examining coral colony size-frequency distributions. Few studies examine the key ecological processes that drive the state variables. The basic processes that determine population dynamics are reproduction, recruitment, post-settlement survival, colony growth, and partial and total mortality. Yet, many of these key ecological processes have rarely been investigated in the Persian Gulf. We still know little about population processes and how they vary spatially, seasonally and under different environmental conditions within the Persian Gulf. We understand even less about differential weightings and sensitivities of populations to slight process changes and the repercussions of those changes on subsequent population trajectories. What are the key ecological processes structuring Persian Gulf communities?
4. Most studies on the ecology of the Persian Gulf have focused on coral reefs and seagrass beds, yet there are other biotypes that are just as significant to coral communities. Oyster beds are an extensive biotope especially throughout the Arabian coast of the Persian Gulf and are geographically intertwined with coral reefs. Exploring the relationship between these two biotypes will ensure better management through the use of protected area networks. What is the relationship between coral reef communities and oyster beds?
5. One of the many poorly studied shallow coral reef-inhabiting groups of organisms in the Persian Gulf is the seaweeds, yet they are some of the first to colonize moribund corals and contribute to siltation which has frequently been diagnosed as a cause of coral death. Despite some coral recovery following a series of episodes of coral death there are still many areas in the southern Persian Gulf where once coral-dominated shallow reef fronts and shoal platforms are now overgrown by seasonally developed

beds of seaweeds. What is the role of the seasonally developed beds of macroalgae in influencing the recovery of coral reefs in the Persian Gulf following episodes of coral mortality: do they inhibit or promote the recovery of corals?

6. The diversity of coralline algae is low in the Persian Gulf, although they are of considerable ecological importance as they rapidly colonize shallow coral skeletons following holobiont death. These coralline algae are not seasonal but are often very conspicuous in the summer when the dense beds of seaweeds (principally brown algae) have largely disappeared. The relatively fast growing corallines play a role in slowing the collapse of dead *Acropora* thickets caused by boring sponges and molluscs. Once the thickets have collapse the corallines help to stabilize coral rubble. Does this covering of coralline algae encourage colonization of the debris and thus help to promote reef recovery? Do coral planulae and other sessile invertebrate groups settle and thrive on actively growing coralline algae and are seasonal factors involved?
7. There have been substantial changes to southern Persian Gulf reefs following the 1996 and 1998 mass bleaching events (Riegl, 2002). Increased abundances and diversity of filter-feeding sessile invertebrate groups (e.g., sponges and tunicates), and substantial increases in sea urchin abundance on coralline algal covered dead coral have been found. In addition, increases in yellow-bar angelfish abundance and decreases in grouper abundance have been recorded. Has the phase-shift from coral-domination on some shallow reefs in the southern Persian Gulf resulted in a marked increase in certain other invertebrate groups? Similarly do changes in physical structure of certain types of coral reef have an impact on more mobile fauna, including fish? What is the impact on coral reef fauna of the recent change from *Acropora* coral dominance to algal dominance in sheltered shallow reef areas?
8. Threats to coral reef communities resulting from disturbance by invasive species have been little studied in the Persian Gulf. Over the last 5 years unofficial reports have shown destruction of northern Persian Gulf coral communities associated with increased invasion of non-endemic species (e.g., tunicates). What are the origins and vectors for non-endemic species to spread in the Persian Gulf? What are the long-term effects of non-endemic species on coral reef communities of the Persian Gulf? Is there a need, and what are the most appropriate methods to control non-endemic species?
9. Throughout the southern Persian Gulf seaweed communities begin to die back in early summer as the seawater temperature rises above about 25°C. In some areas masses of drifting seaweed accumulate on shoal reef tops and over inshore shallow reefs and become entangled around living coral and other reef top organisms and then tend to rot. What is the impact on the possible recovery of inshore coral reefs in the southern Persian Gulf of the recently increased biomass of seasonally developed seaweeds when they decay and drift into the shallows in the summer?

Anthropogenic activities structuring Persian Gulf marine communities

1. A critical concern associated with the extensive growth of Persian Gulf countries is the development of desalination plants, and the hypersaline discharge associated with such plants (Miri and Chouikhi, 2005). Countries bordering the Persian Gulf rely heavily on desalination for potable water (Hoepner and Lattemann, 2003), with some of the largest desalination plants in the world. These plants pump a concentrated saline discharge into coastal waters, which increase salinity, temperature, turbidity and lower oxygen compared to ambient water conditions (Del-Pilar-Ruso et al., 2008). With such high levels of desalination use, can we define an urban contribution

to changes in abiotic conditions within the Persian Gulf? Will such development of desalination plants have a regional and/or national effect on Persian Gulf waters?

2. A range of studies in the Persian Gulf has monitored the recovery of marine organisms after major degradation/disturbance events (e.g. oil spills, bleaching, and coastal reclamation) (Krupp et al., 1996). Conversely, although more than 40 % of the coasts of the Persian Gulf have been modified or developed (Hamza and Munawar, 2009), studies relating to the dynamics of recovery and succession in newly created shores have been limited. What are the dynamics of the recovery process and succession in macrobenthic assemblages in newly created shores?
3. Dredging and reclamation activities are extensive throughout much of the Persian Gulf (Sheppard et al., 2010). For some countries, e.g., Bahrain, it is the strategic option for securing land for the future. Despite the escalation of these activities, responses of macrobenthic assemblages to burial and smothering are rarely quantified in the Persian Gulf. Can the response of macrobenthic assemblages to dredging and reclamation be quantified?
4. Most fisheries in the Persian Gulf are either fully or over exploited (Morgan 2006; Grandcourt 2008) and pressure on the resource base has been exacerbated by habitat loss and fragmentation associated with coastal development (Shallard & Associates, 2003). To date, assessments of fisheries resources in the Persian Gulf have only taken into account the direct impacts of the fisheries themselves. What are the impacts of habitat loss and fragmentation for fisheries resources in the Persian Gulf?
5. Oil pollution, breakwater construction, sedimentation caused by coastal developments, dredging, fishing, extensive anchor damage and discharge of nutrients and sewage are the major local threats to coral reefs of the Persian Gulf (Halpern et al., 2008; Maghsoudlou et al., 2008; Sheppard et al., 2010). Despite this, there is no comprehensive study regarding the effects of such pressures on the ecosystem and/or colony level characteristics of coral reef communities. How do local threats affect coral reefs within the Persian Gulf? How do coral communities change through time and space in natural versus impacted sites? What is the capacity and/or resilience of Persian Gulf marine communities to pollution load (e.g., eutrophication)?
6. Recruitment, growth and natural mortality are fundamental demographic processes that structure fish populations and determine productivity. With the increasing use of seawater for desalination and cooling, both salinity and temperature in the Persian Gulf are increasing. As many species are close to their environmental tolerance limits (Sheppard et al., 1992) the physiological implications of these changes may be profound in terms of fisheries productivity. As such, an understanding of how predicted increases in temperature and salinity will affect demographic processes and fisheries productivity is required for resource management planning and decision-making. In what way will increases in salinity and temperature impact demographic processes and the productivity of important fisheries resources in the Persian Gulf?
7. There has been a substantial increase in the development and construction of artificial reefs, alongside increased degradation of natural reefs in the Persian Gulf (Feary et al 2011). Despite this, there is limited quantitative information on area of natural reef lost versus artificial reef development. A simple, quantitative GIS map is needed to evaluate the extents of each kind of coral reef or other limestone habitat in the Persian Gulf. What areas are involved in terms of reefs lost in the last 20 years vs. artificial reefs added?
8. Throughout the Persian Gulf there have been increasing changes to coral reef communities, with substantial reductions in coral cover and changes in species assemblages (Riegl, 1999, Riegl and Purkis, 2009). For example, *Acropora arabensis*

colonies have declined dramatically in abundance within Kuwait coral reefs, predominantly associated with a substantial coral bleaching episode in 2010. Despite this, there is still little research on the possible mitigation methods for restoring coral reefs. Should we be developing national coral husbandries throughout the GCC countries in order to protect the corals and to provide sources that can act more or less like banks for corals in cases of emergencies?

Monitoring and ecological surveys of community structure within the Persian Gulf

1. A problem from which the Persian Gulf suffers is a shifting baseline (Sheppard et al., 2010). The accumulation of many construction projects adds up to major changes even when one project on its own may not (Sale et al., 2011). Today it is difficult to find any meaningful baselines, not only because of ongoing, intensive constructions, but also because of several recent episodes of marine mortality from seawater warming. Against what measures should reefs be assessed when baseline engineering studies wish to measure change? Where in the Persian Gulf is there a good baseline for coral reefs?
2. Large areas of *Acropora* dominated reefs turned to rubble in the late 1990s and early 2000s. Ironically, some of these were highlighted >40 years ago as being rich reefs, resistant to warm waters. Despite their extent and presumed importance, their fate, recovery or extent of further erosion has apparently not been investigated in many cases, with the focus of research generally now shifting to ?better? reefs elsewhere. Yet their fate (given the large extent) is likely to be important to total Persian Gulf habitat. Of the few that are known, some are known to have remained rubble, some have shifted states to faviid reefs, and some have shown modest or good recovery. The proportions of each are unknown, thus, what proportion is now in a state of net erosion? What is the long term fate of those *Acropora* dominated coral reefs (e.g., within Qatar) which turned to rubble in the last decade, and what total area is involved?
3. Shallow, well-lit, waters make the Persian Gulf well-poised for satellite mapping and indeed much has been done in the last decade. However, the approach has been piecemeal and fragmented, largely because of the diverse mix of industrial and government sponsorship. Little progress has been made in the creation of a centralized GIS database that can be used for management and research. How can we enhance the use of remote sensing and GIS for Persian Gulf research and monitoring?
4. Stable isotopes analysis is a very useful tool in determining the interrelations in a marine ecosystem (Melville and Connolly, 2003). Due to the complex structure of coral communities in the Persian Gulf, it would be interesting to explore the potential of stable isotopes in understanding marine habitats. To what extent can stable isotopes analysis better assist in understanding coral ecology of the Persian Gulf?
5. Studies conducted on some of the northern islands within the Persian Gulf show that Clade D is predominant in this area (Mostafavi et al., 2007). Considering that new studies in Larak Island show Clade A to be the most abundant (Mostafavi et al., *In press*), a study of all corals in this area is required in order to find the link between environmental circumstances and symbiotic types. Will research on the symbionts of coral species found on different islands and depths reveal new results in terms of existing clades and their abundance? Can we detect unique ecotypes that could be playing a part in the phenotypic response of the coral holobiont? What is the amount of genotypic diversity in corals and their *Symbodinium* in the Persian Gulf?

6. The identification of key functional groups of herbivores (both fishes and urchins) that control the establishment and growth of algal communities is important to coral community dynamics. Studies conducted by Mumby et al (2006; 2007) and Mumby and Harborne (2010) on fish and by Carpenter and Edmunds (2006) on urchins showed that elevated grazing activity positively affects the density and diversity of coral recruits settling to reefs. Nevertheless sea urchin grazing can reach destructive levels when densities are high as a result of overfishing or other factors (Bellwood et al., 2004; Tuya et al., 2005). What are the key functional groups of herbivores on Persian Gulf reefs and what are the seasonal changes in their abundance and diversity?
7. There are few taxonomic studies focusing on octocorals in the Persian Gulf. Recent work has shown that the northern Persian Gulf and Iranian coastline have significantly higher octocoral diversity compared to southern Persian Gulf regions (Samimi-Namin and van Ofwegen, 2009). Although such patterns in octocoral diversity may be associated with differences in abiotic factors between Persian Gulf regions, there is still little understanding of the factors important in structuring octocoral communities. How are octocoral communities distributed throughout the Persian Gulf, and what factors are important in driving community structure?
8. There is increasing evidence to suggest that abundant coral communities exist in depths exceeding 30 meters within the southern Persian Gulf region. Are these deeper frameworks typical and how extensive are they? Are they interconnected with the shallow-water ecosystems and are they equally resilient?
9. Whereas the Persian Gulf may seem to provide relatively few different types of reef environments that can be favourable to corals and reef development, there is actually a significant diversity in terms of coral reef assemblages, ranging from isolated or scattered colonies on sedimentary substrate or "hard grounds" to typical three-dimensional bioconstructions. In addition, there is a significant diversity of flora and fauna associated with these habitats. Although some groups are relatively well covered in taxonomic lists and identification guides, other groups have incomplete lists or no identification guides (Clarke and Rowe, 1971; Monniot and Monniot, 1997; Wehe and Fiege, 2002; Al-Yamani and Prusova, 2003). What information is there on the spatial extent and community structure of coral reef communities throughout the Persian Gulf? How much do we know about the biodiversity of corals and other living organisms associated with Persian Gulf reefs?

Climate change impacts on Persian Gulf coral biology and ecology

1. Harmful algal bloom events (HABs, commonly called red tides) have been increasing in severity and distribution in the Persian Gulf region, with significant economic, public health, and ecosystem impacts. For example, the 2008 and 2009 Cochlodinium red tide devastated coral reefs, wild and aquaculture fisheries, and shut down desalination plants in the Persian Gulf and Strait of Hormuz (Burt et al., 2010; Samimi-Namin et al., 2010; Richlen et al., 2010). The continued deterioration of water quality within the Persian Gulf is very likely to lead to more threats of this type, concurrent with the expected expansion of desalination needs within the region. What mechanisms underlie recent increases in the numbers and diversity of harmful algal blooms in the Persian Gulf? What programs are needed to better document the occurrence and distribution of HAB species and their toxins in the Persian Gulf region, and to develop management and mitigation strategies to reduce impacts to both natural environments and man-made developments?

2. High benthic productivity makes the Persian Gulf one of the most productive water bodies in the world as a result of the majority of the sea bed lying within the photic zone (Sheppard et al., 1992). Extensive sea grass beds, macroalgal beds and cyanobacteria mats support rich benthic communities. In addition, widespread mud flats contain organic material that supports abundant infaunal organisms (Carpenter et al., 1997). The waters of the Persian Gulf are also characterized by extreme temperature (11.5 °C to 36 °C) and salinity (37 to 50) ranges which are likely to at least periodically approach or exceed the tolerance limits of many species (Coles, 1988; Coles and Tarr, 1990). Consequently, increases in temperature and salinity have the potential to cause dramatic changes in diversity, ecosystem functions and productivity of these benthic communities. In what way will increases in salinity and temperature impact diversity, ecosystem functions and productivity in the Persian Gulf?
3. Predictions based on experimental and field observations indicate that the combined effects of rising temperatures and ocean acidification could increase the frequency of bleaching events and reduce coral calcification by up to 80% of modern values (Erez et al., 2011). If rates of CaCO3 production by coral and other reef calcifiers cannot keep up with rates of erosion, the majority of coral reefs could switch from net accreting to net eroding structures. Given that the majority of reefs in the Persian Gulf do not build reefal frameworks, corals in the Persian Gulf could potentially be threatened by a shortage of suitable habitat, over next 40-50 years, which they rely for colonization due to changes in water chemistry. What is the present condition of seawater acidity/alkalinity in the Persian Gulf, how do they compare to tropical Pacific Ocean conditions, and how will increased dissolved CO2 affect coral growth in the Persian Gulf?
4. Pronounced differences in coral bleaching is apparent between adjacent areas in the Persian Gulf (i.e., between Abu Dhabi and Qatar). Satellite SST suggests the degree heating pressure to be subtly different, at best between such adjacent sites. Why do these differences exist and how can we understand them?
5. Research suggests that Symbiodinium in clade D are common in the Persian Gulf area and at least partially responsible for high thermo-tolerance of Persian Gulf corals (Baker et al., 2004; Mostafavi et al., 2007), but how do corals which do not contain these symbionts persist in these conditions? What is the molecular basis for thermotolerance in both corals and zooxanthellae, and what are the tradeoffs of hosting clade D (particularly with respect to ocean acidification, and exposure to seasonal low temperatures)? How are clade D symbionts in Persian Gulf corals related to those found in the western Indian Ocean, central-west Pacific (GBR), far eastern pacific and Caribbean? Who is the key-player in the adaptation to temperature extremes: the zooxanthellae or the host, or is the specific team required?
6. Soft bottom benthic communities are by far the most common biotope in the Persian Gulf, yet we still know very little about the biology or productivity of these communities. Apart from response to oil pollution most available information are held in EIAs, which predominantly give a single point in time. What are rates of production, turnover times, population structure and biology for soft benthic communities in the Persian Gulf? What are the physiological constraints and tolerance levels of benthic soft bottom communities within the Persian Gulf?
7. Some fish species in the Persian Gulf are considered to live within 1°C of their thermal tolerance limits, at least for some of the year. The tolerance of larval stages may be even more restricted than those of adults, and in some cases, adult distributions may be limited by larval biology (Sheppard et al., 1992). Additionally,

demersal reef fish are traditionally considered to undergo little or no seasonal change in abundance because of the relatively constant environmental regimes that typically characterize tropical waters. However, the distribution and abundance of Persian Gulf reef fish is known to vary seasonally (e.g., Burt et al., 2009), as such, the stock delineation boundaries and management units of the fisheries resources in the Persian Gulf are likely to change as fluctuations in sea water temperatures increase. How will climate change modify the distribution of fisheries resources in the Persian Gulf and what are the associated management implications?

8. The first documents on clades found in the Persian Gulf date back to early in the decade (Mostafavi et al., 2007) and there is no evidence to indicate whether the abundance of clade D is the result of bleaching events or that this symbiont was always found in these waters. Is the abundance of Clade D related to the recovery period which follows every bleaching event or has this type of zooxanthellae always existed in these waters in such abundance?
9. The Persian Gulf experiences extreme environmental conditions, with temperatures ranging from 35°C in the summer, the largest temperature range known to be experienced by reefs (Kleypas et al., 1999; Sheppard et al., 2010; Riegl et al., 2011). In addition, reefs are exposed to high salinity (>45 ppt in places) and turbidity. Such conditions would result in mass mortality of reef fauna in other regions. Despite well-established physiological effects of environmental extremes in other regions, there is very limited understanding of the mechanisms used by reef fauna throughout the Persian Gulf to overcome the stress posed by the natural physical environment. What are the physiological processes enhancing survivorship of reef fauna in the extreme Persian Gulf environment? How does the physiological sensitivity of reef fauna differ temporally and spatially in the Persian Gulf?
10. The Persian Gulf functions as a negative estuary where high evaporation rates causes salinities well above open ocean values that exceed tolerances experimentally determined for corals from other regions. However, even Persian Gulf corals have demonstrated limits to elevated salinity, and it has been shown that both coral species diversity and general benthic diversity decrease with increasing salinity in the Persian Gulf (Coles, 2003). How will overall and local salinities in the Persian Gulf be affected in the next century by anticipated increasing temperatures due to climate change, and by increased discharge of high salinity brines from massive desalination plants built to provide freshwater to developing Persian Gulf countries?
11. The majority of coral species in the Persian Gulf (assuming that names ascribed to the species are correct) are a subset of the much more diverse Indian/Pacific coral fauna. The elucidation of the ecophysiological and genetic mechanisms underlying their tolerance in particular to high temperatures and high salinities experienced in the Persian Gulf will provide insights as to the potential for adaptation/acclimation of corals in other parts of the oceans. Is heat tolerance a result of an adaptation to the “hostile” environmental conditions in the Persian Gulf region or is the combination of specific environmental conditions (salinity, macro / micronutrients, temperature fluctuations etc.) in fact a prerequisite for survival?
12. There are species-specific differences in the susceptibility of coral species to bleaching effects (Mostafavi et al., 2007). However, understanding the mechanisms that result in differential bleaching and mortality in coral species is lacking for the Persian Gulf. Why do some corals bleach and others don't? Why are some corals resistant to bleaching and/or recover quickly while others bleach and die? Can we refine the threshold temperature anomaly (time and degree) for a lethal D50 for coral species and populations?

Connectivity of Persian Gulf coral reef communities

1. Although the Persian Gulf is connected to the Indian Ocean through the narrow Strait of Hormuz, the majority of species are of the wide Indo-Pacific distribution, however it is unclear how much genetic exchange occurs. Is the Persian Gulf a source of pre-adapted coral and zooxanthellae genotypes that could be used for reef restoration or nurseries at sites elsewhere in the region that are cooler, but warming? What potential exists for the export of thermo-tolerant genotypes of either corals or zooxanthellae) from the Persian Gulf?
2. Few endemic marine species exist in the Persian Gulf (Sheppard et al., 1992; Sheppard, 1998), yet we know little on whether this is because relatively recent isolation or because of mixing through the Strait of Hormuz. How much genetic isolation is there in Persian Gulf species, relative to congeners/conspecifics outside the Persian Gulf?
3. Research has shown that source populations for coral reefs throughout the Persian Gulf can be substantial distances from the sink areas. For example, in the Qatar EEZ source populations are approximately 110 km offshore to the north and east of Qatar, while within the southern UAE there is a distinct west-to-east decline in coral recruit abundance, and hypothetically the source of propagules (Burt et al 2011). What proportion of coral recruits originate from local reefs throughout the Persian Gulf, and what proportion comes from outside the Persian Gulf? Are there distinct source areas of coral planulae for Persian Gulf coral reefs and to what degree is regional connectivity supporting recovery of degraded coral reefs in the Persian Gulf?
4. The degree to which marine populations are connected has important consequences for how coral reef populations persist, how they respond to natural and anthropogenic disturbances, and how they can be managed (Sale et al., 2005). Currently our understanding of connectivity within the Persian Gulf is grossly limited. What is the genetic connectivity of coral reef populations at multiple spatial scales within the Persian Gulf?
5. Two seasonally developing gyral systems exist in the northern and southern Persian Gulf. These have the potential to affect genetic connectivity within the Persian Gulf and thus might result in two isolated connectivity regimes within the Persian Gulf. Do patterns of genetic connectivity in coral reef communities in the Persian Gulf map onto the physical basis (i.e. surface currents etc.)?

Marine Protected Area development

1. There is a need to understand where critical habitats for commercially exploited species are within the Persian Gulf. For a range of species, understanding the important critical habitats are vital in the development of management strategies (i.e., protected areas), to adequately protect such species. In the Persian Gulf the obvious example would be the hammour *Epinephelus coioides*. What are the critical nursery habitats for various commercially important species?
2. Linking conservation benefits of MPAs to overall productivity of marine environments is a global concern (Cicin-Sain and Belfiore, 2005). Several marine protected areas have been established in the Persian Gulf, including those within coral reefs (Krupp, 2002). However, how these areas are contributing to the overall productivity of the Persian Gulf has not been investigated. Are Marine Protected Areas in the Persian Gulf contributing to the overall biodiversity and productivity of

this region? Should new high-priority regions be identified for possible no-take marine reserves within the Persian Gulf?

3. Mitigating the effects of global threats mostly depends on the political collaboration between all nations for a united reduction in emission of greenhouse gases. However reduction in local pressures can reinforce the resistance and resilience (i.e., ability of reef to come back from a lost caused by a disturbance) of coral reefs toward global threats. The most important factors for increasing the resilience of coral reefs are the herbivory by fish and sea urchins (Hughes et al., 2007). Today MPAs with no-take or restricted fishing areas are known as the most practical approaches for conservation of coral reef communities to elevate the resilience of these ecosystems facing with acute disturbances like coral bleaching. What are the effects of local management and Marine Protected Areas on Persian Gulf coral reef communities?
4. The rate of coral reef degradation in much of the Persian Gulf is so high that there is the possibility of irreversibly losing coral reef habitats in many areas unless we are able to conserve what we have left (Sheppard et al., 2010; Sale et al., 2011; van Lavieren et al., 2011). Are the quantity, size, and placement of marine protected areas in the Persian Gulf sufficient to conserve high value areas, and is enforcement rigorous enough to ensure that these are not paper parks?
5. There is still a lack of information about the biodiversity of coral reefs in the Persian Gulf. For example, there are approximately 36 species of hard corals found throughout the Iranian region (Wilkinson, 2008), however there is increasing evidence that more than 37 species of hard coral are found on one of the coastal islands off Iran alone (Moradi et al., 2009; Shojae et al., 2010; Vajed-Samiei et al., In Press). The Persian Gulf is a stressful and disturbed environment with low species richness compared to most parts of the Indian Ocean, but has a high beta-diversity (Price, 2002). Therefore, the identification and conservation of hotspots of coral reef biodiversity is one of the basic priorities in the declining Persian Gulf. Which coral reef habitats represent the hotspots of biodiversity in the Persian Gulf?

Abiotic interactions/factors structuring Persian Gulf marine communities

1. By virtue of topographic highs created by the intrusion of salt domes, the offshore of the Persian Gulf has vast areas of shallow water habitat, much displaying the remnants of formerly lush coral frameworks. The motif of growth differs between true diaperic islands (such as Sir Bani Yas in the United Arab Emirates) and offshore diapiric platform reefs (such as Bu Tinah reef in the United Arab Emirates) (Riegl and Purkis, 2011). The architecture of such systems has geological control and likely impacts the diversity and health of the inhabiting corals. Is this true, and to what degree?
2. Heat flux (from the water to the reef) is strongly link to flow speed (u) over the reef as well as the temperature gradient (dT). As the Persian Gulf has strong tidal flows, flow speed over the reef may be a dominant controlling factor in temperature associated bleaching effects. What cross-product (udT) occurs in the Persian Gulf, and can we relate regions of bleaching with the cross product? Given that heat flux (from the water to the reef) is strongly link to flow speed (u) over the reef as well as the temp gradient (dT), what are the temperature gradients within a Persian Gulf reef and in the water masses over a reef? To what extent does the reef control such gradients?

Oceanographic factors structuring Persian Gulf marine communities

1. During the coral spawning season, the transport direction of surface waters, within which many larvae travel, is of critical importance to connectivity. Depending on large-scale air circulation patterns, there can be important variability in the surface flow direction. The presence or absence of summer shamals can strongly enhance or reduce the potential range of larval dispersion by strengthening or weakening surface drift. Similarly, land-sea breeze regimes could potentially assist in the formation of strong local currents. Climate change has the potential to disrupt these air circulation patterns. How strong is the influence of wind on forcing the transport of surface waters within the Persian Gulf?
2. In general, the surface current within the Persian Gulf is strongest during summer and weakest in the winter (Blain, 2000). This variability depends on the density gradient and degree of stratification generated between the Persian Gulf and the adjacent Persian Gulf of Oman. To what extent are low-frequency currents driven by local-synoptic winds and density driven circulation in the Persian Gulf?
3. Recent studies have shown the formation of eddies on the north-western sector of the Persian Gulf (Thoppil and Hogan, 2010). Eddies are important circulation systems characterized by transporting high chlorophyll, nutrient-rich coastal waters offshore in their periphery, thereby generating regions of enhanced chlorophyll between the eddies. There is a need to identify the areas where eddies occur in the Persian Gulf, observing their size, shape, locations and time of occurrence. When and where do eddies occur in the Persian Gulf?
4. The general circulation of the Persian Gulf is composed of basin- and meso-scale circulation cells (Reynolds, 1993). Although these currents are well established, the details of the possible effects of new mega-scale man-made coastal developments on the regional circulation and its correspondent influence on the Persian Gulf circulation cells are not well understood. Are more complex circulation cells formed in the Persian Gulf than previous to the development? Is there any change in the general circulation of the Persian Gulf following the large increase in coastal developments?
5. The oceanography of the southern Persian Gulf region is predominantly structured by north-eastward circulation, flowing towards the Strait of Hormuz (Cavalcante et al., 2011). The addition of new artificial structures (e.g., Palm Jumeirah and Palm Jebel Ali) within this coastal region may act as a barrier to natural water flow. Recirculation cells are expected to be formed in the areas adjacent to the developments forcing seabed sediment re-suspension and its transport towards adjacent areas. What are the effects (if any) of coastal development on adjacent oceanographic hydrodynamics within the Persian Gulf?

Reef restoration and Management

1. Anecdotal evidence has shown that scleractinian corals can thrive in the presence of crude oil which naturally seeps from cracks in the seabed within the northern Persian Gulf. What are the mechanisms of survival and adaptation among these corals? Can it be attributed to the suite of microbes associated with the corals that have a unique hydrocarbon degradation ability, or do the corals have a unique genetic adaptation to deal with hydrocarbon pollution?
2. As most of the fisheries resources in the Persian Gulf are either fully or over exploited (Morgan 2006; Grandcourt 2008), management authorities are increasingly pressed to consider the use of artificial marine habitats as tools for enhancing productivity.

Comparative investigations of reef fish assemblages on artificial and natural reefs have elucidated ecological characteristics (Burt et al. 2009) that are important for understanding aspects of their potential for biodiversity conservation. Investigations of the comparative production potential of different types of artificial habitats are now required as a basis for informing authorities of their utility as fisheries management tools. To what extent can artificial marine habitats augment fisheries production in the Persian Gulf?

3. Despite the relatively high use of both planned and unplanned artificial reefs within the Persian Gulf there is a paucity of information on the coral reef communities associated with these structures (i.e., predominantly gas and oil facilities) (Feary et al., 2011). Such structures can sustain relatively abundant and diverse coral reef communities (John and George, 2006). What is the ecological structure of coral reef communities associated with gas and oil facilities in the Persian Gulf and how important are these man-made structures in the development and maintenance of such communities?
4. Given the high level of coastal development in the Persian Gulf region it is essential to develop a toolkit in order to facilitate resilience-based management in coastal development areas. The current lack of a baseline studies makes the assessment, monitoring and management of coastal communities unclear, allowing the ongoing coastal development without control regarding the environment impact. Do we have sufficient knowledge of the biology and ecology of the existing flora and fauna of coral reefs in the Persian Gulf to be able to recommend measures to stabilise their deterioration in the face of future climate change impacts?
5. Persian Gulf corals comprise a limited diversity population with an upper temperature tolerance that well exceeds corals elsewhere in the tropical Pacific. This hardiness, probably conferred by thousands of years of adaptation to stressful Persian Gulf temperatures, may represent a potential resource for restoring coral populations and reefs outside the Persian Gulf subject to anticipated mortalities from repeated future bleaching events. It has been suggested that Persian Gulf corals, with their demonstrated high tolerances of heat stress, are a potential resource for transplanting and restoring coral populations outside the Persian Gulf that have succumbed to temperature related widespread mortality. Is this a realistic approach and what precautions should be made to prevent negative impacts? Given the level of effort that would be required and the potential for negative impacts, e.g. introductions of parasites and diseases, hybridization and intra-specific competition, would such manipulation have any real positive results, and what precautions would be necessary to prevent undesirable consequences?
6. Increasingly, coral restoration or relocation are becoming a more widely utilized as a mitigation measure, particularly in EIAs studies conducted for coastal development projects within the Persian Gulf (i.e., pipeline extension and harbour development). Within areas where coral reefs have been degraded by development projects, is restoration or relocation of coral reefs the best way to conserve corals and coral reefs in the Persian Gulf? Can we utilise coral relocation or rehabilitation to restore reefs within the Persian Gulf? Can we find new methods to reproduce corals artificially in the laboratory to aid in coral recovery? Can we artificially reproduce corals in the laboratory to seed degraded reefs in the Persian Gulf?
7. Reefs in the Persian Gulf have been impacted by a number of recent severe bleaching events, with limited to no recovery (Baker et al., 2008; Burt et al., 2008; Burt et al., 2011). Limited recovery may be due to a combination of decreased reproductive output and associated recruitment limitation or high post-settlement mortality as a

result of the relatively extreme environmental conditions and/or increases in anthropogenic stressors (Gleason and Hofmann, 2011). This is also likely to vary among taxa as a result of differences in tolerance thresholds. Recent studies across ~400 km of the southern basin of the Persian Gulf show relatively high densities of coral recruits on tiles, even on some of the most degraded reefs, suggesting that recovery is being inhibited by post-recruitment factors. What role does coral settlement versus post-settlement mortality play in reef maintenance/ recovery in the Persian Gulf?

8. Reefs in the shallow southern Persian Gulf (includes those in Abu Dhabi (UAE), Qatar and Bahrain) exist in areas where the highest summer seawater temperatures are regularly recorded, sometimes for several continuous weeks, as well as exceedingly high salinities (Sheppard and Loughland, 2002; Riegl and Purkis, 2011). As a result of these stresses coral reefs in the southern Persian Gulf suffered the highest coral mortalities over the Persian Gulf during the high summer seawater temperature anomalies of 1996, 1998 and subsequent years (Riegl, 2003; Burt et al., 2008; Riegl et al., 2011). Should studies of the coral reef ecosystems in the southern Persian Gulf be given a higher priority than those elsewhere in the Persian Gulf, as their corals are the most vulnerable to local extinction should average summer seawater temperatures continue to rise?
9. Throughout the Persian Gulf artificial reefs are frequently deployed to restore/rehabilitate diversity and productivity of the marine environment. However, the effectiveness of these measures in enhancing productivity is rarely investigated (Feary et al 2011; Sale et al 2011). To what extent do coral restoration or rehabilitation activities compensate for loss of quantity or quality of existing species' habitat? Have artificial reefs in the region been successful in restoring significant biodiversity and productivity?

Economic evaluation of Persian Gulf marine communities

1. The economic valuation of goods and services associated with natural ecosystems has grown rapidly in the past decade in response to accelerating impacts from human activities and climate change (e.g., Costanza et al., 1997; Moberg and Folke, 1999). Coral reefs are considered a particularly valuable ecosystem in many tropical countries due to their role in providing food, tourism revenue, nursery habitat, coastal protection, and a suite of other benefits (Berg et al., 1998; Brander et al., 2007). Despite rapid growth in this field in recent years, there has been limited development of economic valuation of natural ecosystems in the Persian Gulf. Given the widespread degradation of reefs due to coastal development, ports, industrial infrastructure and desalination facilities (Sheppard et al., 2010; Sale et al., 2011), it is clear that an economic valuation could be a useful tool for conservation and management. Can economic valuation be used as a tool for coral reef conservation in the Persian Gulf?
2. Given the unique ecological structure of coral reefs within the Persian Gulf, it is vital to understand which genes/loci are under adaptive evolution and which of those contribute to the relative thermo-stability of corals. Have there been co-evolution of Persian Gulf corals and their symbionts within the Persian Gulf and will this reveal valuable information on their formation and origins? How do coral genotypes match *Symbiodinium* genotypes and vice versa? How does the genotypic makeup of a coral host influence the assemblage of algae and vice versa? Are there certain genetic

combinations that are favoured over others? Can we detect selection on the level of the individual?

3. Persian Gulf coral reefs have evolved in one of the most extreme environments globally, but also within one of the most isolated shallow-water coral reef systems in world (Sale et al., 2011). Understanding the origin and evolution of scleractinian corals in this region will be vital in developing future conservation and management plans for Persian Gulf coral reefs, as well as understanding the potential for Persian Gulf coral populations to change under future environmental disturbances. What is the origin and evolution of scleractinian corals in the Persian Gulf?

Disease biology within the Persian Gulf

1. Disease has been considered a major threat to coral reefs (Loya, 2004), though it has not been the focus of studies within the Persian Gulf. Understanding whether there is a trend in the distribution of coral diseases across the Persian Gulf might better assist managers in dealing with this challenge and protect the least vulnerable corals in the Persian Gulf. What is the temporal and spatial distribution of coral disease within the Persian Gulf?
2. Due to the uniqueness of Persian Gulf corals, they are expected to harbour unique microbial assemblages. Therefore, it is important to determine the microbial diversity in healthy coral holobiont and the roles they play in maintaining coral health and stability (Rosenberg et al., 2007). What are the principal factors that trigger disease within the Persian Gulf? Is elevated sea water temperature, sedimentation and the decay in water quality important in the development of coral diseases in the Persian Gulf? How do these microbial communities change with time (e.g., throughout seasons)?
3. Some of the microbes in the holobiont are known for their ability to cause speciation in different organisms and for being able to manipulate the genome of others (Suttle, 2007). Viruses are important in this sense. How do viruses interfere with the genetic diversity of the corals and their symbiotic zooxanthellae? And do they have any role in helping corals to adapt to different conditions. Do microbes of the holobiont enhance the innate immunity of corals? How much of the coral resistance to diseases is attributed to the microbes of the healthy holobiont?
4. Understanding the relationship between the coral holobiont and coral diseases are an important subject that needs to be addressed (Rosenberg and Loya, 2004; Bruno et al., 2007), especially as records for coral diseases in the Persian Gulf are scarce and the few that are available focus mainly on coral bleaching. What are the microbial groups present in Persian Gulf corals (eukaryotes, prokaryotes and viruses)? What are the levels of microbial diversity in the tissue, mucus and skeleton of Persian Gulf corals? What are the vector and host densities in the region?