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Short Communication

Vulnerability of the marine ecosystem to climate change impacts in the Arabian Gulf—an urgent need for more research

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ABSTRACT

Climate change, represented by ever-rising ocean temperatures, is a mounting threat to the marine ecosystem and its services. This is most evident in the longitudinal and depth-related migrations of the ectothermic species. Although the impacts of climate change on the marine ecosystem of the Arabian Gulf are expected to be exacerbated—owing to its semi-enclosed basin that limits species range shift, extreme environmental conditions, overfishing, and pollution—very few studies have been carried out to evaluate such impacts. Here, we conduct a systematic review of literature over the period 1950–2018 to assess the status of knowledge about climate change impacts on the Arabian Gulf's marine ecosystem and fisheries resources. We found that this region suffers a significant research gap in this critical subject, with only a handful of studies that explicitly addresses the effects of climate change. Our finding raises an urgent need for initiating long-term monitoring programs, along with establishing effective transboundary institutions to advance the current knowledge in climate change.

1. Introduction

One of the most pressing global environmental issues is climate change: warming of both aquatic and terrestrial systems at various spatial and temporal scales; thus, altering biodiversity and jeopardizing ecosystem structures and services (Urban, 2015). Compared with terrestrial ecosystems, the impacts of climate change on the aquatic fauna are likely to be more perilous, since fishes and invertebrates are ectotherms (Sunday et al., 2011). In fisheries context, this suggests that rising temperatures are driving fish stocks to their upper thermal tolerance; subsequently, affecting catch amount and composition by altering species geographical distribution and causing changes in growth, fecundity, and recruitment success (i.e., abundance) (Pörtner and Farrell, 2008). Shifting geographical distributions, for example, have been observed to be depth-related (i.e., moving into deeper waters) and poleward in latitude (Walther et al., 2002). This was evident in the North Sea where, as a response to rising temperatures, more than 60% of small and fast-growing fish species are undergoing latitudinal or depth migrations (Perry et al., 2005). In addition to fisheries, such responses are also expected to compromise marine biodiversity through species local extinctions (i.e., species stop occurring in a particular geographical area) and species invasions (that is, species growing their geographical range to places where they have never existed before). Leadley et al.

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(2010) reported that over the next few decades, climate change would be the most substantial threat to marine biodiversity, even exceeding habitat destruction. Climate change impacts are also expected to be amplified by several anthropogenic effects; notable examples are excessive fishing pressure and habitat loss (Jackson et al., 2001).

Despite these globally documented impacts of climate change on the marine ecosystem and its services, this paper illustrates a serious lack of research to address climate change effects on the Arabian Gulf's (hereafter referred to as 'the Gulf') marine environment and fisheries. This is despite that many projections have been conducted on semi-enclosed basins, suggesting that biodiversity in these basins are the most vulnerable to climate change impacts (e.g., Pozdnyakov et al., 2007; Cheung et al., 2009; Ben Rais Lasram et al., 2010).

We begin by providing an overview of the physical characteristics of the Gulf's marine environment and underscore the major stressors that might amplify climate change impacts. Given that overexploitation escalates the effects of climate change on fish stocks, we then concisely describe the status of the fisheries and the current management regime under which they operate. Next, we illustrate the shortage of research conducted to investigate climate change impacts on the marine ecosystem by carrying out a systematic review of the literature. We conclude by discussing two main issues that—in our view—are pertinent to the current status of knowledge about the impacts of climate change in the Gulf.

2. The marine environment: extreme and polluted

The Gulf lies in Southwest Asia (commonly known as the Arabian Peninsula; Fig. 1), which is a major region of oil and gas production that contributes significantly to the global emissions of CO_2 (Boden et al., 2010). Located in an arid region that is characterized by extremely dry and hot weather, a recent study projected that under a business-as-usual emission scenario (Representative Concentration Pathway 8.5; see Moss et al. (2010) for CO_2 emission scenarios), people living in the Gulf region will encounter great difficulties in doing basic outdoor activities by the end of the century due to the extremely high temperature (Pal and Eltahir, 2015). Likewise, the marine system exhibits severe oceanographic conditions; notably, the world's highest sea temperature with seasonal maxima between 34 and 36 °C, along with abnormal seasonal fluctuations (about 20 °C) and hypersaline seawater (>40 psμ) (Hume et al., 2015). In addition to extreme evaporation, the northern part of the Gulf is experiencing a steady rise in salinity levels, owing to the significant water diversions and dam constructions along the Tigris-Euphrates river basins, which are drastically reducing the discharge of freshwater into the Gulf (Shatt-Al-Arab; Fig. 1). The likely repercussion of such elevated salinity levels is declining trends in the phytoplankton community and fish recruitment (Al-Said et al., 2017; Ben-Hasan et al., 2018a). Other significant anthropogenic stressors include substantial coastal developments, sewage discharge and disposal of brine from desalination plants (Sale et al., 2011; Saeed et al., 2012). Given these extreme physical water properties coupled with various sources of marine pollution, ectotherms inhabiting the

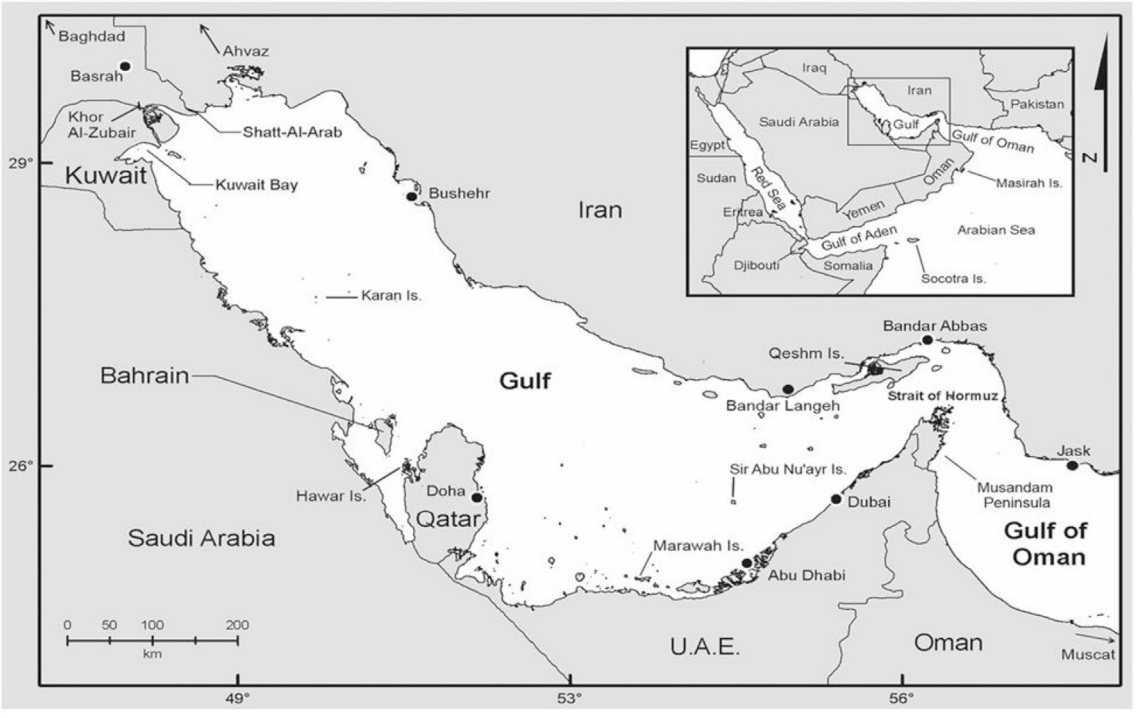

Fig. 1. Map of the Arabian Gulf (adapted from Moore, 2015).

Gulf are already under tremendous pressure—and the conditions are expected to be amplified by climate change (Buchanan et al., 2016). Shirvani et al. (2015) reported an increase of 0.57 °C over the period 1950–2010, raising concerns about the fate of biodiversity in the Gulf.

3. Fisheries and fisheries management

Marine fish resources in the Gulf are second to oil and natural gas productions in their economic importance, contribute to the national food security and support the livelihood of coastal communities (van Lavieren et al., 2011). Despite their importance, fisheries are typically operating under an open-access regime with certain input controls: (i) management regulations are based on the life-history of the exploited fish stocks such as fishing gear restrictions, and spatial and temporal closures; (ii) lack output measures (e.g., catch limits); and (iii) absent license limitation programs. Importantly, management measures are weakly enforced, and fisheries are being subsidized both directly (e.g., fuel subsidies) and indirectly through low-cost labor (see, for example, the case of Kuwait shrimp fishery in Ben-Hasan et al. (2018b)). The total catches from the Gulf fisheries have recently leveled off, after a period of sharp decline (a ~40% reduction of about 300,000 tons between 1997 and 2004; Fig. 2). Also, many studies have reported that fish stocks and fisheries in the Gulf suffer from: (i) overexploitation (e.g., Grandcourt et al., 2005; Niamaimandi et al., 2015; Al-Baz et al., 2018; Jabado et al., 2018); (ii) overcapitalization (Al-Abdulrazzak et al., 2015); and (iii) extremely high discarded bycatch rates (Chen et al., 2012)—all presenting serious conservation problems. Further, most fish stocks in the Gulf are poorly monitored, hence hampering the ability to assess and design recovery plans. As an illustration, because of the lack of primary long-term fisheries data for many of the stocks, the majority of the published studies have applied simple assessment models, like per-recruit analysis, in evaluating the status of fish stocks (e.g., Al-Husaini et al., 2002; Grandcourt et al., 2010); consequently, squandering critical information that could be gained from applying more suitable models such as age-structured and statistical catch-at-age.

In sum, the Gulf's marine living resources are in precarious shape, with little measures being applied to mitigate the unregulated, excessive exploitation. This, in turn, exacerbates the potential impacts of ocean warming on biodiversity; Stuart-Smith et al. (2015) pointed out that keeping fishing pressure low should, to some degree, boosts ecosystem resilience in a warming ocean.

4. Scarcity of research on climate change

To identify research papers that document and/or project climate change impacts on the marine ecosystem and fisheries in the Gulf, we conducted a systematic review of the literature considering peer-reviewed studies in English (only) that were published between 1950 and 2018. To conduct the survey, we used the Web of Science (https://webofknowledge.com) search engine with the following key terms to be shown in the title, abstracts and author keywords: “climate change”; OR “global warming”; OR “ocean warming”; OR “sea warming”; AND “Persian Gulf”; OR “Arabian Gulf”. Out of these key terms, we identified a total of 303 studies. We omitted publications that do not consider the marine ecosystem of the Gulf. We reviewed 97 studies with a focus on those documenting the impacts of climate change on biodiversity and fisheries and/or projected species' responses to these impacts.

Except for a paucity of studies, all reviewed publications have either: (i) indicated no clear pattern of species/habitat response to climate change; (ii) examined characteristics of the Gulf's habitat/species that are associated with extreme environmental conditions; and/or (iii) mentioned terms relevant to climate change or ocean warming for justification or discussion of results (Table 1). Such publications did not discuss climate change impacts explicitly (i.e., documented and/or projected the effects of climate change); therefore, they fall outside the scope of this study.

Concerning the Gulf's marine habitats, our literature search indicated that coral reefs are the most well-studied habitat, where studies with documented and projected climate change impacts though were restricted to reefs off the southwestern Gulf (Riegl, 2003; Riegl and Purkis, 2009; Riegl et al., 2018). While the Gulf's corals inhabit an extreme environment and have shown to be much more resilient than their counterparts elsewhere, observations and modeling indicated that this habitat is already noticeably impacted by climate change through bleaching and disturbance regimes (Riegl, 2003; Riegl and Purkis,

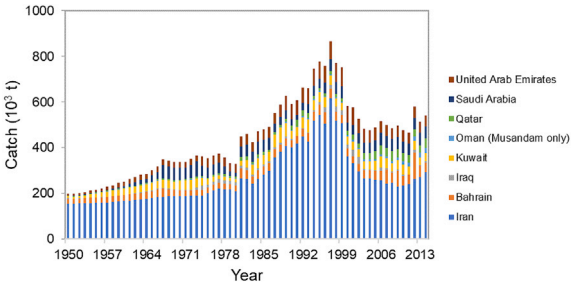

Fig. 2. Annual catches categorized by country in the Arabian Gulf for the period 1950–2014 (source: Al-Abdulrazzak et al., 2015).

Table 1
Examples of the reviewed studies that fall under the main 3 categories: (i) studies that indicated no clear pattern of species/habitat response to climate change; (ii) studies that examined characteristics of the Gulf's habitat/species, which are associated with extreme environmental conditions; and/or (iii) studies that mentioned terms relevant to climate change or ocean warming for justification or discussion of results.

Study	Category (i)	Category (ii)	Category (iii)
Baker et al. (2008) [a]	x	x	
Hume et al. (2013)		x	x
Burt et al. (2011)		x	
D'Angelo et al. (2015)		x	x
Bauman et al. (2011)		x	x
Feary et al. (2010)		x	x
Howells et al. (2016)		x	x
Burt et al. (2013)			x
Bento et al. (2016)		x	x

[a] Among all the reviewed studies, Baker et al. (2008) is the only study that fall under category (i), according the search criteria described in the text.

2009; Riegl et al., 2018). More specifically, increasing in disturbance frequency—like the 2010-2011-2012 and 2017 bleaching events—is projected to drive *Acropora* population to extinction, leading to shifting in community structure (Riegl and Purkis, 2009; Riegl et al., 2018). Deteriorating reef habitats may have profound implications for fisheries that target reef-associated fishes, especially given that reef-dependent fishes constitute about 70% of the fish landings in the Gulf (Grandcourt, 2012).

Our literature review showed that none of the publications had evaluated the impacts of climate change on the corals in the northern Gulf—or other sensitive, crucial marine habitats such as saltmarshes, seagrass meadows, and mangrove forests. Hence, scientific investigations are needed to evaluate the status of those habitats under a warming sea.

Wabnitz et al. (2018), however, evaluated the fate of biodiversity, society and fisheries production under continued business-as-usual emissions. To simulate the future effects of climate change on the biodiversity, the study applied an environmental niche approach, where the modeled species distribution is projected based on the realized niche; that is, relating species presence/absence to environmental data so as to infer the physical factors of the current species range. They found that in 2090, species local extinctions will likely climb to 12% relative to 2010; a consequence of elevated temperature and salinity levels, which drive some species to migrate northward to settle in cooler waters. The study further showed that, with continued warming rates, even those species that shifted their geographical area northwards would suffer range contractions as a result of the *cul de sac* effect (i.e., the geographical features of the Gulf will prevent species from migrating further poleward; Fig. 1). Furthermore, the study reported that the countries in the southwestern Gulf are expected to experience the most severe reduction in catches: about 30% drop in the potential fisheries production by the end of the century.

There are, however, certain shortcomings to the modeling approach. As an illustration, the environmental niche modeling applied in the study uses information on the preferred environmental conditions to predict the distribution of a given species. It fails, however, to take into consideration predator-prey relationship and food web dynamics, physiological adaptation and dispersal capacities, which are integral in understanding species-ecosystems dynamics in the oceans. In addition, Wabnitz et al. (2018) did not include the current anthropogenic effects impacting the Gulf marine system in the climate change projections, which suggest that their findings are conservative. Both trophic interactions and anthropogenic effects can be accounted for in ecosystem-based approaches such as *Ecopath*, *Ecosim*, and *Ecospace* (Villasante et al., 2016)—these routines integrate knowledge on species distribution and abundances, population (e.g., growth and reproduction), community traits (e.g., prey-predator interactions), and are capable of incorporating predictions from regional hydrodynamic-biogeochemical models, which facilitate capturing the dynamics of the anthropogenic stressors (Libralato and Salidoro, 2009; Steenbeek et al., 2013). Overall, although this modeling approach is not without its limitations, such findings provide useful insights for prioritizing adaptation responses to climate change.

5. Concluding remarks

The Gulf's marine ecosystem contributes significantly to food security, livelihood, and economic development; thus, its preservation is socially and economically imperative, along with being an of environmental importance. Unfortunately, our review demonstrated a significant research gap concerning climate change impacts on the marine ecosystem, implying a lack of scientific support for the formulation of effective mitigation and adaptation plans. To make matters worse, the ongoing pressure on the marine system—manifested by unregulated fisheries as well as other major anthropogenic activities—is likely to exacerbate climate change effects.

Although non-exhaustive, we consider two core issues that are impeding the progress of research in climate change impacts on the Gulf's marine ecosystem. First, programs that involve long-term monitoring of primary production, species abundance and composition and environmental drivers (e.g., water temperature, salinity, oxygen) are limited in the Gulf, both spatially and temporally. For example, although Al-Yamani et al. (2017) provided long-term oceanographic data—three decades of temperature and salinity—they were restricted to the northwestern Gulf, which is hardly representative of the entire basin. Similarly, the Gulf region lacks basic fisheries-independent data; notably, time-series of survey abundance data for

almost all exploited species (e.g., Grandcourt et al., 2006; Al-Husaini et al., 2015). While long-term programs that monitor fish catches do exist, they are associated with critical problems: catches are restricted to few species that are economically-valuable (e.g., only recorded for 23 out of 132 known species in Kuwait waters, while the rest are categorized as "others"; Kuwait Central Statistical Bureau, 2016) and/or they are recorded at family level, rather than species level; a case in point is Oman's demersal fish stocks, which are only recorded with generic terms such as grouper, snapper, and seabream (Al-Masroori and Bose, 2016).

Long-term monitoring programs are vital to recognizing climate-driven changes: detect fluctuations in species and community compositions related to climate stressors and facilitate the calibration of numerical models, resulting in robust scientific outcomes that can ultimately influence management actions. Prominent examples of such programs, which have aided in understanding the impacts of climate change on the biodiversity of fish and fisheries, include the Census of Marine Life (http://www.coml.org/); the Continuous Plankton Recorder (McQuatters-Gollop et al., 2015) and the Long-term Monitoring Program surveying Australia's tropical reef (https://www.aims.gov.au/docs/research/monitoring/reef/reefmonitoring.html). Clearly, with the absence of such programs in the Gulf region, scientific research is obstructed from evaluating the effects of climate change, rendering decision-making unguided.

Second, management institutions are not embracing regional collaboration and coordination, although the development of effective transboundary institutions is critical to tackling climate change threats to renewable resources (Food and Agriculture Organization, 2017). For instance, essential environmental data such as Shatt-Al-Arab flow rate data, is not accessible by the regional scientific community, even though such data might help uncover critical insights into the impacts of the reduction of Shatt-Al-Arab on the marine ecosystem and thus motivate mitigation responses at an international level (Al-Yamani et al., 2007). When collaboration exists, it seems that weak regional coordination undermines these collaborative efforts. This is evident in, for example, the failure to manage several straddling fish stocks that are under multilateral agreements—including the silver pomfret (*Pampus argenteus*, shared between Iran, Iraq and Kuwait; Al-Husaini, 2003), the narrow-barred Spanish mackerel (*Scomberomorus commerson*, a homogenous fish stock that occurs in the Gulf basin and Sea of Oman; Hoolihan et al., 2006), and some chondrichthyan stocks (Jabado et al., 2018). The absence of coordination is also exemplified by the Regional Commission for Fisheries, where member countries either provide incomprehensive catch data (i.e., fail to report catches from certain fishing gears) or do not report their catches (as in 2012 where some member countries failed to report their total catches), although its core objectives involve conservation and sustainable exploitation of renewable natural resources (Al-Abdulrazzak and Pauly, 2014).

We acknowledge that there are several barriers to achieving effective transboundary institutions in the Gulf—the greatest might be of political foundation. However, addressing this issue, along with initiating long-term monitoring programs, could greatly contribute to advance the current knowledge in climate change and aid in forming the necessary climate solutions (i.e., mitigation and adaptation measures). Ultimately, this will help in sustaining the goods and services that the marine ecosystem provides. Importantly, we urge the management institutions to confront and mitigate the problems that are scientifically well-understood—including the current excessive extraction of the commercial fish stocks and coastal pollution—to dampen the negative consequence of climate change.

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