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Regional extinction risks for marine bony fishes occurring in the Persian/Arabian Gulf☆

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ABSTRACT

The Persian/Arabian Gulf (hereafter, 'the Gulf') is an environmentally extreme sea that is being increasingly affected by climate change and anthropogenic stressors, and concern is growing about the future of marine biodiversity in the region. However, identification of species and habitats most in need of conservation is challenging as comprehensive information on species-specific threats and population statuses is lacking. Through application of the International Union for Conservation of Nature (IUCN) Red List methodology – the global accepted standard for classifying extinction risk at the species level – we evaluated the regional conservation status of 471 species of marine bony fishes in the Gulf. The best estimate of the proportion of regionally threatened marine bony fishes, based on all species for which sufficient data were available for assessment, is 8.2%; this is at least twice the proportion of other regions where such assessments have been undertaken. Primary threats include those related to fisheries and harvesting and those related to coastal development and

☆ Persian or Arabian Gulf. The name of this body of water remains contentious. While the United Nations officially recognizes this water body as the 'Persian Gulf' (United Nations, 2006), the name used by Arab states on the Arabian Peninsula side is 'Arabian Gulf'. Following Sheppard et al. (2010) and Riegl and Purkis (2012), we use 'the Gulf' in the manuscript text in the hope that the removal of the geographic descriptor will avoid offending any readers.

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loss of habitat, impacting 47% and 32% of marine bony fishes, respectively. Such threats are particularly acute in nearshore areas where spatial analyses indicated high species richness. The future of Gulf ecosystems, and the survival of the marine bony fishes, will depend on concerted, collaborative efforts among all Gulf States to develop efficient and effective local and regional marine conservation practices and policies, particularly for species assessed as regionally threatened.

1. Introduction

Biodiversity is essential to humanity and its overall well-being (Millennium Ecosystem Assessment, 2005). Biodiversity influences ecosystem services, which are the suite of benefits such as animal and plant biomass production, habitat provision, and soil formation and retention, that humanity utilizes to sustain itself. However, many human activities, such as urbanization, industrialization, and natural resource extraction, as well as global climate change, are causing biodiversity loss (Diaz et al., 2006). Increasing evidence suggests that the loss of species is detrimental to the persistence and sustainability of Earth's biosphere (Cardinale et al., 2012; Hooper et al., 2012; MacDougall et al., 2013). Thus, to ensure that humanity continues to benefit from the goods and services biodiversity provides, it is important to identify the species and areas of their distributions that are declining and prioritize them for conservation (Brooks et al., 2006).

The International Union for Conservation of Nature (IUCN) Red List is the global standard for evaluating the extinction risk of species, from the local to the global level, with the goal of highlighting taxa threatened with extinction and promoting their conservation (Mace et al., 2008). Extinction risk assessments apply the best available scientific information to assign a species to one of eight extinction risk categories (Mace et al., 2008). These assessments are increasingly used in global and sub-global analyses of species biodiversity and patterns of threat (e.g., Carpenter et al., 2008; Hoffmann et al., 2010; Dulvy et al., 2014), providing decision-makers with vital information on species' conservation status and distribution information that is necessary to make informed decisions about biodiversity conservation (Carpenter et al., 2008; Abdul Malak et al., 2011; Collette et al., 2011; Polidoro et al., 2012). While the coverage of species on the Red List has expanded considerably in recent years, increasing from about 16,000 total species assessed in 2000 to over 93,000 in 2018 (IUCN, 2016b), gaps remain, particularly in the marine environment.

The Persian/Arabian Gulf (hereafter called 'the Gulf') is the semi-enclosed marine basin connected to the Sea of Oman through the Straits of Hormuz (Sheppard et al., 1992). It is a productive marine region with a variety of habitats including coral reefs, mangroves, seagrass beds, and mudflats that can be rich in marine biodiversity (Burt, 2014). However, marine biodiversity and habitat quality in the Gulf are rapidly declining from the synergistic effects of increasing environmental extremes associated with climate change and extensive anthropogenic stressors (Sheppard et al., 2010; Sale et al., 2011). Due to its geography and shallow nature, the Gulf is characterized by some of the world's most extreme environmental conditions (Sheppard et al., 2010). Salinity often exceeds 45 ppt, and annual sea surface temperature (SST) varies by more than 20 °C, from 12 °C in the winter to summer highs of 36 °C (Reynolds, 1993; Coles, 2003). As a result, the Gulf can be considered a 'natural laboratory' (e.g., Burt, 2013; Burt et al., 2014) within which the responses of its inhabitants to climate change, from the molecular to the ecosystem level, can provide a glimpse into the future (Burke et al., 2011; Sheppard et al., 2012). Additionally, anthropogenic stressors, including extensive coastal development (Van Lavieren et al., 2011), overharvesting of fishing stocks (Grandcourt, 2012), oil and gas exploration and production (Carpenter et al., 1997), insufficient management, regulation, and enforcement of related policies (Van Lavieren and Klaus, 2013; Sheppard, 2016) and climate change (Burt et al.,

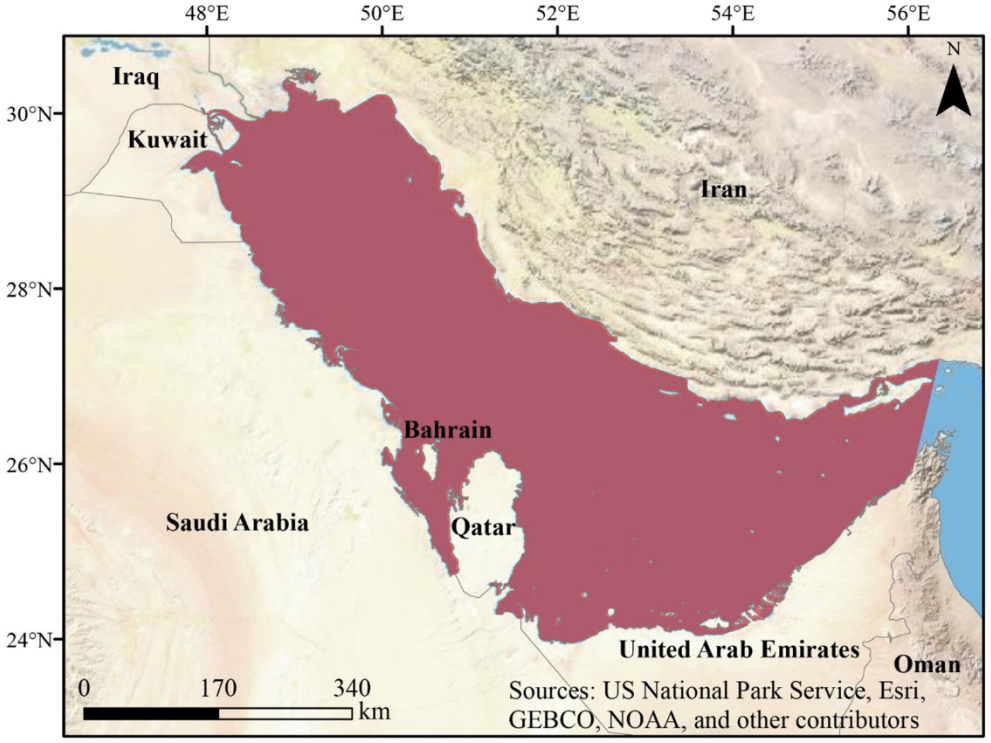

Fig. 1. Map of the Gulf. Shaded area represents the study system.

2011a, 2014) are resulting in degradation of ecosystems and a loss of marine biodiversity (Sheppard et al., 2010; Burt, 2014).

However, without species-specific knowledge of conservation statuses and threats, it is difficult to identify conservation priorities at the level of species and or even habitats. To fill this gap and improve the status of conservation knowledge in the region, we applied the IUCN Red List methodology to the marine bony fishes (infraclass Teleostei) of the Gulf, using the best available information for each species. The specific objectives of this work were to: 1) identify the diversity of marine bony fishes within the Gulf, 2) determine the conservation status for these species using the regional IUCN Red List categories and criteria, 3) identify and highlight primary threats, and 4) determine current species richness patterns within the Gulf.

2. Methods

2.1. Geographic and taxonomic scope

For this work, the Gulf was defined as the semi-enclosed marine basin connected to the Sea of Oman through the Straits of Hormuz (Sheppard et al., 1992; Fig. 1). We excluded the Musandam Peninsula and Straits of Hormuz that border the entrance to the Indian Ocean, as the coral and fish assemblages found in these areas are not representative of the diversity and abundance of coral and fish assemblages present in the Gulf and are more reflective of the Sea of Oman due to prevailing hydrodynamics and environmental conditions (Feary et al., 2010; Burt et al., 2011b).

Species in the infraclass Teleostei – with distributions within the geographic scope of this work – were selected for inclusion based on published scientific literature and consultation with taxonomic experts. Following these criteria, a total of 471 marine bony fishes were identified within the Gulf (Supplementary Online Materials, Table A1) and assessed for their regional extinction risk at two assessment workshops held in Doha, Qatar in 2013 and 2014. The workshops were attended by 34 regional and international scientific experts, including representatives from each of the Gulf states, as well as from scientists from Australia, Japan and the United States with expertise in the Gulf.

2.2. IUCN Red List methodology

The IUCN Red List assessment process is a rigorous and collaborative methodology that includes input from a global network of scientific experts. Each species' assessment goes through a multi-step process that involves data collection, expert workshops, review, and quality control prior to publication on the IUCN Red List website (www.iucnredlist.org). The required and supplemental data are derived from primary and gray literature, as well as unpublished data and personal observations from scientists with expertise in the region or species being assessed. The Red List methodology was developed to be flexible and handle uncertainty; natural variability, vagueness in the terms and definitions used, or measurement error, can affect the classification of a species (IUCN, 2012a). However, the assessments are based on quantitative indicators of symptoms of high extinction risk, not just expert opinion; much of the variability is a result of differences in risk tolerance of the assessors (Collen et al., 2016).

The IUCN Red List Categories comprise eight levels of extinction risk: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). A species is considered EX when there is no reasonable doubt that the last individual of the taxon has died. A species qualifies for EW when there is no reasonable doubt that it is extinct in its natural habitat. A species is listed in one of the 'threatened' categories (e.g., CR, EN, or VU) if it meets the thresholds and conditions for that category in one of the five criteria (IUCN, 2012a). A category of NT is assigned to a species if it is close to qualifying for, or likely to qualify for, a threatened category in the near future. A species is listed as LC if it does not qualify for a threatened or NT category. A species qualifies for DD if there is inadequate information to apply any of the five criteria (i.e., taxonomic uncertainty or insufficient data to quantify the impact of known threats).

Although the IUCN Red List was developed to evaluate the global conservation status of species, it has been adapted to allow for sub-global or regional assessments. Here, we followed the 'Guidelines for Application of IUCN Red List Criteria at Regional and National Levels' to evaluate the Gulf-wide extinction risk of each species; this provides the flexibility for a regional categorization that reflects the status of species aggregated across the Gulf States. It is common for species to have different global and sub-regional categories; for example, if a species is doing well in parts of its range, it may have a regional categorization that is lower than its global category. Regional assessments include two additional categories (Regionally Extinct and Not Applicable) and incorporate the potential effects of non-human mediated immigration of individuals from populations outside the region of interest (IUCN, 2012b). To determine the conservation status of marine bony fishes in the Gulf, three estimates of the proportion of threatened species were calculated. The lower bound assumes none of the DD species are threatened and the upper bound assumes all of the DD species are threatened. In practice, the true proportion of threatened species lies somewhere between these two values; the best estimate, or midpoint, assumes that the DD species are as threatened as the species for which data were sufficient (Hoffmann et al., 2010; IUCN, 2016a). While information is limited to test this assumption, the reassessment of birds and South African amphibians previously listed as DD resulted in roughly the same proportion of threatened species as the species for which data were sufficient (Butchart and Bird, 2010; Measey, 2011).

The criteria by which species are assigned to one of the three threatened categories are based on the two paradigms of extinction risk theory, the small population paradigm – species with small population sizes are inherently at higher risk of extinction and/or undergoing decline; and the declining population paradigm – species with widespread or large populations are declining faster than they are able to recover (Caughley, 1994; Mace et al., 2008). From these paradigms, the five criteria were developed: A) rapid population decline in the past, present, or future; B) small geographic range size; C) small, declining population size; D) very small population size; and E) high probability of extinction in the wild based on quantitative analysis (Mace et al., 2008; IUCN, 2012a). While multiple criteria were needed because not all species exhibit similar extinction risk characteristics (Mace et al., 2008), a species only needs to meet the quantitative thresholds of a single criterion to be designated as threatened.

2.3. Identification of primary threats

An important step in the Red List evaluation process is the identification of threats that have caused, are causing, or will cause a decline in a species' population and/or distribution (Mace et al., 2008; IUCN Standards and Petitions Subcommittee, 2017). During the Red List workshops, experts utilized the available primary and gray literature as well as their personal knowledge of the species to identify the direct stresses and processes that pose threats to the species. For example, if a species was known to occur in fish markets, or landings data were available, the impact of fisheries and harvesting on the species were discussed to determine if these were a threat to the species. In addition, if known, the timing (e.g., past, ongoing, and/or likely to occur in the future), scope (i.e., the proportion of the total population affected), and severity (i.e., overall declines caused by the threat) of each of these threats were provided (IUCN, 2016b). The threats were classified according to a hierarchical structure (CMP, 2016), then aggregated into four categories describing the drivers of decline. This information was then used to highlight the most commonly recorded threats to marine bony fishes within the region.

2.4. Spatial patterns in species richness

Generalized distribution maps were created for each species in ArcMap 10.2 (ESRI, 2014) based on known and inferred occurrences from published literature, online museum records, and expert knowledge of the Gulf region. Each generalized distribution map was reviewed by international experts on the species and the Gulf, with consideration of the distribution of habitats within the Gulf and the preferences of individual species. Prior to the spatial analyses, the generalized distribution polygons were cut to one of four National Geophysical Data Center's ETOPO1 one arc-minute global relief model (Amante and Eakins, 2009) bathymetry layers (0–25, 0–50, 0–75, 0–100 m), based on the lower limit of their known depth range. For species with unknown depth ranges, their distribution polygon was clipped to the 0–100 m bathymetry layer. This approach helped to improve the accuracy of subsequent analyses by standardizing species' distributions and by excluding areas of water deeper than where a species would likely occur; as a result, commission errors are minimized. These generalized distributions allow for the identification of medium to large-scale conservation priorities.

For analyses of species richness, all species' distributions were transformed into the World Cylindrical Equal Area projected coordinate system and converted into 1 km by 1 km raster grid, which was chosen to reduce over-estimation of ranges for restricted-range species. While some restricted-range species may occupy smaller areas than the 1 km^2 cells, a finer resolution was not chosen because of the generalized nature of the distribution information. A cell was considered occupied by a species if the species' distribution polygon filled at least 50% of the cell area and assigned a value of 1. The raster grids for all species, threatened species and DD species were then stacked and species richness patterns were calculated by summing the number of occupations in each 1 km^2 cell. We excluded from the richness analyses 16 species that do not have confirmed ranges in the Gulf, but are likely present there (Supplementary Online Materials, Table A2). Map symbology was classified by Jenks natural breaks into four or five classes with a color scheme of blue to red, where red represents the highest scoring cells.

3. Results

3.1. Regional IUCN Red List status of marine bony fishes in the Gulf

The best estimate of the proportion of regionally threatened marine bony fishes is 8.2% based on all species for which enough data were available for assessment. Accounting for the uncertainty in the true conservation status of the Data Deficient (DD) species results in a range of 6.6% (if none of the 96 DD species are threatened) to 26.8% (if all of the DD species are threatened). Of the 31 species identified as threatened (Table 1), eight (1.7%) are listed as Endangered (EN) and 23 (4.9%) as Vulnerable (VU). The threatened listings were primarily related to restricted range size coupled with an ongoing threat: 23 of the threatened species were listed under criterion B. Six species were listed based on population declines (criterion A) and two were listed because of a very small range and plausible future threat (criterion D). Ten species (2.1%) are listed as Near Threatened (NT), while 335 species (71.1%) are categorized as Least Concern (LC), and approximately another one-fifth (20.2%, 95 species) are categorized as DD.

Three of the 20 orders of marine bony fishes with representative species in the Gulf (Clupeiformes, Mugiliformes, Perciformes) include threatened or Near Threatened species (Fig. 2). The Perciformes, which is also the most speciose order of Gulf marine bony fishes, contains the highest number of threatened species (30 species, representing 9.4%). The eight species in four perciform families (Acanthuridae, Caesionidae, Chaetodontidae, and Stromateidae) are listed as threatened, while the family Pomacentridae includes the highest number of total (11) and threatened (nine) species (Fig. 3). The 17 orders that did not contain threatened or Near Threatened species tended to either have high proportions of Least Concern species, such as the Beloniformes, Pleuronectiformes, Scorpaeniformes or Tetraodontiformes or high proportions of DD species, such as the Anguilliformes and the Syngnathiformes.

3.2. Primary threats to Gulf species

Threats to 338 of the 471 Gulf marine bony fishes were identified. For the remaining species, either no threats were identified (84 species) or threats remain unknown (49 species). However, multiple threats were identified for 150 species, including 26 of the 41 threatened and Near Threatened species.

The most commonly recorded threat was fisheries, including effects due to capture of a target or non-target species (Fig. 4). Together, fisheries affected 219 species, representing 47% of all species and 65% of species for which at least one threat was identified, including 12 of the 31 threatened species and all 10 of the Near Threatened species. Coastal development and habitat loss, including direct and indirect disturbances that result in habitat degradation and loss (e.g., dredging, reclamation, increased sedimentation, and changes in water flow patterns) was the second most commonly recorded threat, affecting 152 species, including 26 threatened and one Near Threatened Species. Less

Table 1
Regionally threatened marine bony fishes in the Gulf, including the IUCN Red List category (EN = Endangered, VU = Vulnerable) and criteria (A = population decline, B = restricted range, D = very restricted range and plausible future threat) and the primary vulnerability or threat that resulted in the threatened status.

Family	Species	Category	Criteria	Vulnerability or Threat
Gobiidae	*Gobiodon citrinus*	EN	B	Coral dependent
Labridae	*Scarus ghobban*	EN	B	Coral dependent
Polynemidae	*Eleutheronema tetradactylum*	EN	A	Fisheries
Pomacentridae	*Amphiprion clarkii*	EN	B	Coral dependent
Pomacentridae	*Chromis xanthopterygia*	EN	B	Coral dependent
Pomacentridae	*Pomacentrus aquilus*	EN	B	Coral dependent
Pomacentridae	*Pomacentrus leptus*	EN	B	Coral dependent
Pomacentridae	*Pomacentrus trichourus*	EN	B	Coral dependent
Acanthuridae	*Acanthurus sohal*	VU	B	Coral dependent
Acanthuridae	*Zebrasoma xanthurum*	VU	B	Coral dependent
Blenniidae	*Alticus kirkii*	VU	D	Restricted range
Blenniidae	*Omobranchus mekranensis*	VU	D	Restricted range
Caesionidae	*Caesio lunaris*	VU	B	Coral associated
Caesionidae	*Caesio varilineata*	VU	B	Coral associated
Chaetodontidae	*Chaetodon melapterus*	VU	B	Coral dependent
Chaetodontidae	*Chaetodon nigropunctatus*	VU	B	Coral dependent
Chaetodontidae	*Heniochus acuminatus*	VU	B	Coral dependent
Epinephelidae	*Epinephelus coioides*	VU	A	Fisheries
Gobiidae	*Gobiodon reticulatus*	VU	B	Coral dependent
Labridae	*Chlorurus sordidus*	VU	B	Coral dependent
Labridae	*Halichoeres marginatus*	VU	B	Coral dependent
Labridae	*Scarus ferrugineus*	VU	B	Coral dependent
Labridae	*Scarus persicus*	VU	B	Coral dependent
Mugilidae	*Liza klunzingeri*	VU	A	Fisheries
Pomacentridae	*Abudefduf vaigiensis*	VU	B	Coral dependent
Pomacentridae	*Chromis flavaxilla*	VU	B	Coral dependent
Pomacentridae	*Dascyllus trimaculatus*	VU	B	Coral dependent
Pomacentridae	*Neopomacentrus cyanomos*	VU	B	Coral dependent
Sciaenidae	*Otolithes ruber*	VU	A	Fisheries
Scombridae	*Scomberomorus commerson*	VU	A	Fisheries
Stromateidae	*Pampus argenteus*	VU	A	Fisheries

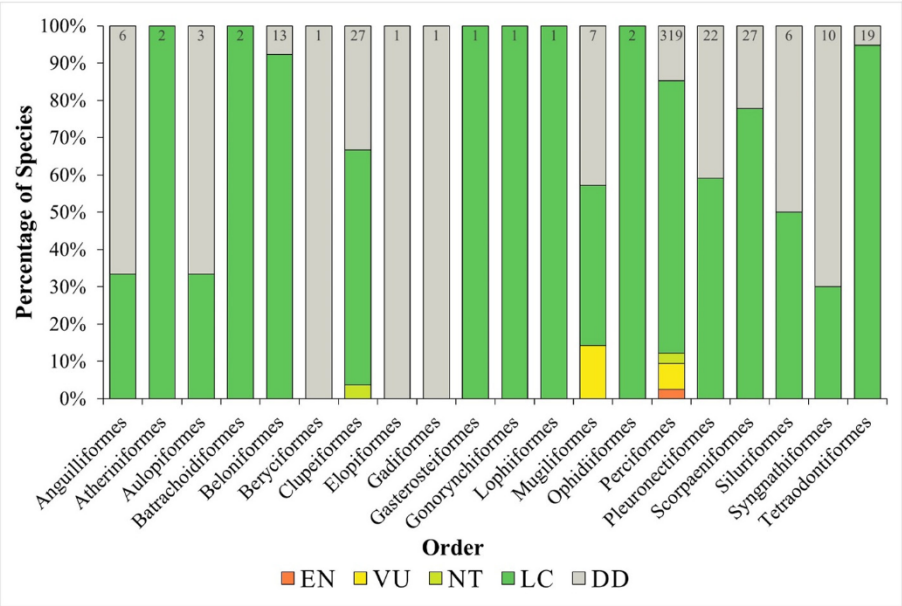

Fig. 2. Proportion of species within regional IUCN Red List category for the 20 orders of marine bony fishes with representatives in the Gulf. The total number of species within each order are shown at the top of each column. Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). None of the species were classified as Extinct (EX), Regionally Extinct (RE), Extinct in the Wild (EW) or Critically Endangered (CR).

commonly reported overall, climate change and extreme temperature events were reported for 33 species, including 24 of the threatened species. Finally, disease and pollution are affecting 17 species, including two threatened and one Near Threatened species.

3.3. Spatial patterns in species richness

Within the Gulf, species richness of marine bony fishes is highest in nearshore areas, in particular in the western Gulf from Iraq to the United Arab Emirates (Fig. 5a). The southeastern coast of Iran near Qeshm Island and many offshore islands (Fars, Iran; Failaka, Kubbar, Qaro, and Umm Al-Maradem, Kuwait; Al-Arabiya, Harqus, Karan, Kurayn, Jana, and Jurayd, Saudi Arabia; Halul, Qatar; and Abu Musa, Sir Bu Naire, and Siri, United Arab Emirates) also exhibit high species richness. Species richness declines towards the deeper waters of the central and northwestern Gulf; this pattern is more gradual in the low-sloping shelf in the western Gulf compared to the sharper drop-off in the eastern Gulf. The highest concentration of threatened species also occurs in the nearshore areas of the western Gulf from Kuwait to the United Arab Emirates and around several offshore islands (Fig. 5b). High concentrations of DD species occur in the northern Gulf from Iraq to Saudi Arabia as well as off Bahrain, the United Arab Emirates, and along much of the Iranian coast (Fig. 5c). Areas of low DD species richness include the central Gulf and offshore areas of Iran.

4. Discussion

The proportion of regionally threatened marine bony fishes in the Gulf is more than twice that of the Mediterranean Sea (Abdul Malak et al., 2011), the northeast Atlantic (Nieto et al., 2015), and the Gulf of Mexico (Linardich et al., 2018). One possible explanation for this difference is the limited area (about 700 km^2: Spalding et al., 2001) of highly threatened coral assemblages in the Gulf (Riegl et al., 2018), which led to the threatened listing of 23 coral-dependent marine bony fishes (Buchanan et al., 2016). In the other geographic areas where regional assessments of marine bony fishes have been undertaken, the area of coral habitat has either been much higher (e.g., 1350 km^2 in the Gulf of Mexico: UNEP-WCMC et al., 2010) or coral-dependent fishes were unknown from that region (e.g., Mediterranean Sea and northeast Atlantic).

The general locality and associated extreme environmental conditions of the Gulf (e.g., Sheppard et al., 2010) may intensify the effects of

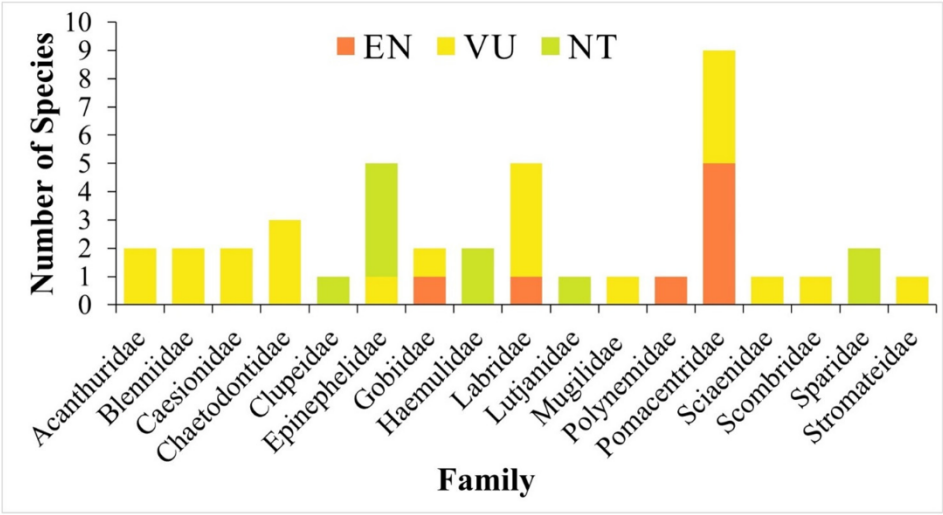

Fig. 3. Number of Endangered (EN), Vulnerable (VU) and Near Threatened (NT) species in each family.

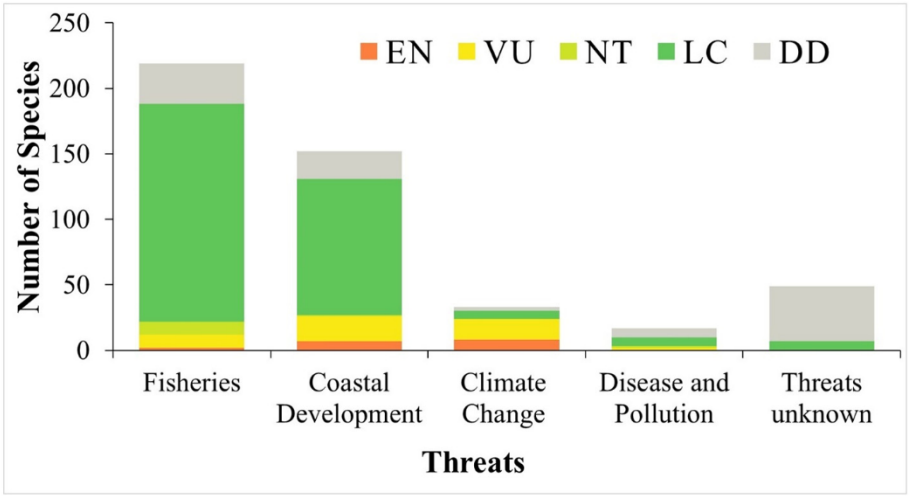

Fig. 4. Number of marine bony fish species within each IUCN Red List category affected by each identified major threat category. Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). None of the species were classified as Extinct (EX), Regionally Extinct (RE), Extinct in the Wild (EW) or Critically Endangered (CR).

increasing SSTs associated with increasing changes in global climate. For example, with the Gulf, recurrent bleaching events are increasing in frequency and magnitude (Riegl and Purkis, 2015), which have resulted in the loss of substantial live coral habitat, particularly *Acropora* dominated areas, reducing the area of this important coral reef fish habitat by more than 90% in some areas (e.g., Riegl, 2002; Burt et al., 2008; Riegl and Purkis, 2012; Burt et al., 2013; Burt, 2014; Riegl et al., 2018). Such widespread losses of these important ecosystem engineers have occurred in multiple Gulf States (e.g., Burt et al., 2013, 2016; Grizzle et al., 2016), reducing the suitable habitat for coral-dependent fishes throughout the majority of the region. Although there is increasing evidence to show that shifts in the latitude or depth of mobile coral reef fish populations may in effect allow species to remain within their preferred temperature regimes (e.g., Feary et al., 2014), the shallow depth, increasing fragmentation of coral reef habitat and minimal oceanographic connectivity with other water bodies outside the Gulf may substantially limit potential areas of refuge for fishes within the Gulf.

Offshore, deep-water habitats may provide refuge for some species (Burt et al., 2016, 2017). However, long-distance migrations across areas with little protection from predators (Krupp and Müller, 1994) and limited availability of suitable habitats such as coral assemblages and seagrasses (Sheppard et al., 1992) at such depths means that successful immigration to these areas is highly unlikely for many species. While fishes already present in deeper waters might initially benefit from the cooler, more stable temperatures, further emigration from these 'cul-de-sacs' is unlikely, potentially resulting in regional extirpation, as has been suggested for cold-water fishes in the Mediterranean Sea (Lasram et al., 2010). Growing and compounding threats may further reduce refuge area suitability, potentially rendering fishes unable to sustain their resident populations.

Overexploitation is the most commonly recorded threat to marine bony fishes in the Gulf, as has been documented in other regions (e.g., Abdul Malak et al., 2011; Nieto et al., 2015; Polidoro et al., 2017; Linardich et al., 2018). In the Gulf, fisheries are the most important renewable resource (Carpenter et al., 1997). Along with their contribution to food security, fisheries are part of the region's cultural heritage and provide a source of income as well as recreational opportunities for the Gulf's coastal population (Sheppard et al., 2010; Al-Abdulrazzak et al., 2015). Fisheries resource management in the Gulf has historically been inadequate; while each state has its own fishery regulations, they are generally weak, not properly enforced, and do not account for the possibility of shared stocks (Bishop, 2002; Grandcourt, 2012). Consequently, many of the Gulf's fisheries are either fully- or over-exploited (Samuel et al., 1987; Sheppard et al., 1992; Morgan, 2006; Grandcourt, 2008, 2012). Despite these limitations, only 22 Gulf fish species have been listed regionally as threatened or Near Threatened due to impacts from overexploitation. These were typically highly valued species, with intrinsic biological characteristics, such as large maximum size, long lifespan, hermaphroditism and formation of mass spawning aggregation, that increase their susceptibility to exploitation. Of the remaining 120 species for which large-scale exploitation was considered a primary threat, 105 were listed regionally as Least Concern. This generally included species with intrinsic biological characteristics, such as small maximum size, short lifespan and high reproductive output, that increase their resilience to exploitation; for example, six of the eight clupeids commonly found in fisheries were listed as Least Concern.

The lack of species-specific landings data from the Gulf States for most exploited species contributed to the relatively few species listed as threatened and Near Threatened on the basis of population declines. Landings from the Gulf region are commonly aggregated at the genus or family level (Sale et al., 2011). For example, the six members of the family Leiognathidae (slipmouths or ponyfishes) in the Gulf are taken as bycatch, often in large quantities because of their schooling behavior (Carpenter et al., 1997). This family has undergone frequent taxonomic changes over the last 15–20 years (Chakrabarty et al., 2010); as a result, species-level identifications are unreliable, and landings are aggregated. Recent research has also shown that one of the most commercially important species in the Gulf ('hammour', *Epinephelus coioides*) is actually made up of three genetically distinct - but morphologically similar - species, making its management as a single stock questionable (Ketchum et al., 2016). This is not just limited to species with taxonomic issues. For example, many flatfishes are taken as bycatch in shrimp trawl fisheries and landed, but species-specific landings data were not available (Munroe, 2015), thus trends in population sizes of individual species could not be quantified. These results highlight a key research and monitoring need: improved landings and effort data at the species level for marine fishes in the Gulf. An important first step would be to improve fishery-dependent catch data by increasing training for fishers in species-level identification of commonly caught fishes and requiring fishers to report all catch, not just the landings. Additionally, the collection of fishing effort data, such as vessel type, quantity and type of gear, and length of trip, would allow for a more accurate assessment of population status. Finally, seasonal or annual fisheries-independent surveys are needed to supplement the data from fisheries-dependent sources. Such surveys would provide essential information on population status, as well as on species-specific biology and ecology (e.g., spatial and temporal patterns in growth and reproduction; ageing; and fishing and natural mortality) that are relevant to understanding a species' susceptibility or resilience to anthropogenic stressors.

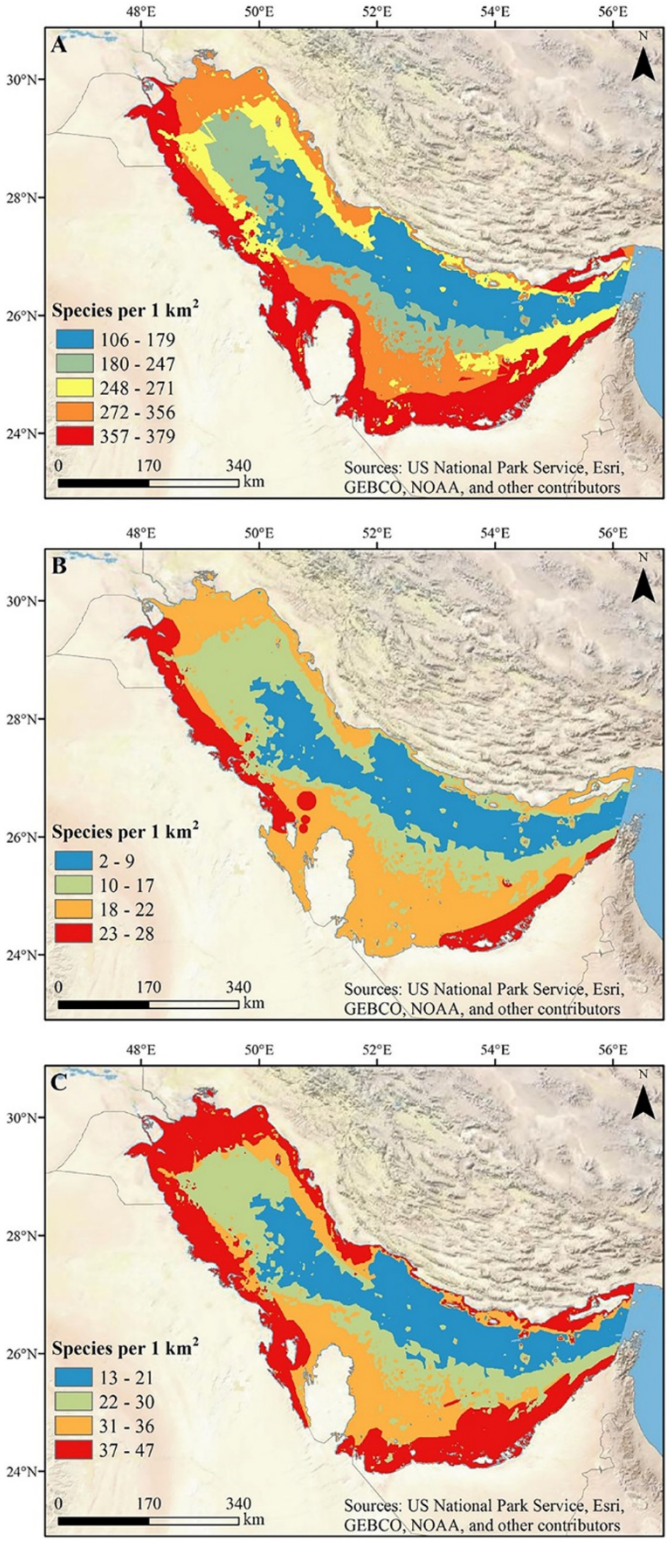

Fig. 5. Number of species per 1 km^2 grid cell for (a) all; (b) threatened; and (c) DD marine bony fishes in the Gulf.

Another source of uncertainty in terms of determining the extinction risk of marine species concerns the species distribution maps and richness analyses presented here, which reduces the scope to effectively assess population status of a range of species. Geographic range maps that focus on determining the bounds of the distribution of species, such as those used here, are typically prone to commission errors (Rondinini et al., 2006). As a result, despite our best efforts in occurrence data compilation and vetting by experts, we may have overestimated the number of species in a given area. Conversely, spatial variability in sampling effort within the region may result in omission errors. For example, Kuwait, Saudi Arabia, and the United Arab Emirates, where extensive fish biodiversity studies have been undertaken, had consistently higher estimates of overall species richness (McCain et al., 1984; Krupp and Almarri, 1996; Burt et al., 2011b). Lesser-studied areas, including several offshore islands (e.g., Harqus, Al-Arabiya, Fars islands) and the Iranian coast, tended to have lower estimates of species richness. However, these areas are thought to have some of the most developed coral and coral-associated fish assemblages (e.g., Al-Arabiya: F. Krupp pers. obs; Iran: Sheppard et al., 1992; Rezai et al., 2004), but they are difficult to access and have yet to be thoroughly studied. Comprehensive surveys of these lesser-studied areas are needed to document the critical habitat and fish assemblages present there. Furthermore, the information gained from such surveys likely increase the available information for species assessed as DD. As our knowledge of the system improves, the assessments can be updated to reflect more recent and accurate information.

The spatial distribution of marine habitats, particularly the corals, mangroves and seagrasses that are home to a diverse assemblage of marine bony fishes, is poorly known. The combination of rapid and widespread coastal development and negative climate-change-related impacts (e.g., bleaching events) introduces substantial error into habitat maps, even those just a few years old. Some Gulf States (e.g., United Arab Emirates) have updated national marine habitat maps (AGEDI, 2013; Grizzle et al., 2016); however, integrated efforts to develop an accurate, high-resolution map of all marine habitats in the Gulf comparable across all Gulf States would provide essential information for Red List assessments of marine species and improve future conservation efforts.

Despite these challenges, results presented herein depict a grim situation in the Gulf. A substantial portion of the marine fish biodiversity is at an elevated risk of extinction, particularly coral-dependent fishes and those exploited in targeted fisheries. Primary threats facing these species, especially those related to climate change and extreme temperature events, are only expected to increase in the future. Potential consequences of these changes to marine fish biodiversity include trophic disturbances (e.g., Duffy et al., 2007) and reduced availability of fish for human consumption (Worm et al., 2006). As a result, an urgent need is at hand to redouble management efforts in the Gulf. Marine species are not bound by political demarcations; thus, cooperation among all Gulf States to manage and conserve the shared biodiversity in the region is essential.

Historically, collaboration between Gulf States has been a challenge (e.g., Krupp, 2002, 2008; Krupp et al., 2006, 2009; Sheppard et al., 2012; Burt, 2013; Feary et al., 2013; Burt et al., 2014; Buchanan et al., 2016; Vaughan and Burt, 2016). However, recent progress has been achieved: collaborative projects and organizations (e.g., Abu Dhabi Global Environmental Data Initiative, Regional Organization for the Protection of the Marine Environment, Regional Commission for Fisheries and the Mideast Coral Reef Society) are creating opportunities for joint efforts between local, national, and international scientists, institutions, non-governmental organizations, governmental organizations, and stakeholders outside of academia (Burt et al., 2014). Continued collaboration among these stakeholders will foster greater understanding of the Gulf's marine ecosystems and promote their conservation and sustainable use – a goal that has both regional and worldwide significance.

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