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Living on the edge: Vulnerability of coral-dependent fishes in the Gulf

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ABSTRACT

In the Gulf, multiple human impacts and recurrent bleaching events have resulted in serious declines of coral assemblages, particularly in near-shore areas. However, the degree to which the extinction risk of coral-dependent fishes is impacted by these coral declines has been uncertain. Using primary literature and expert knowledge, coral-dependent fishes of the Gulf were identified and species-specific data on the regional distribution, population status, life history characteristics, and major threats were compiled to determine their likelihood of extinction under the IUCN Red List of Threatened Species' Categories and Criteria. Due to the limited area and degraded and fragmented nature of coral assemblages in the Gulf, all coral-dependent fishes (where data was sufficient to assess) were listed at elevated risk of extinction. Cross-boundary collaboration among Gulf States is necessary for effective management and protection of coral assemblages and their associated communities within this globally important region.

1. Introduction

Productive and highly diverse marine ecosystems such as coral reefs are an essential component in shaping the structure of tropical coastal regions. An estimated 25% of all marine species utilize coral habitat, including at least 4000 fish species (Burke et al., 2011; McAllister, 1995; Spalding et al., 2001). In addition, coral reefs and their associated fauna provide substantial societal benefits, through food and livelihoods, tourism, shoreline protection and both realized and potential treatments for disease (Burke et al., 2011). However, coral reefs are highly threatened (Bryant et al., 1998; Burke et al., 2011; Spalding et al., 2001). Localized impacts, such as those from destructive fishing practices, pollution, and land development, are interacting with global climate change and ocean acidification to threaten even the most remote of reefs (Burke et al., 2011). Globally, more than 60% of coral reefs are impacted by localized threats, increasing to 75% when global climate stressors are included (Burke et al., 2011).

The degree to which current and future declines in coral reefs will impact the fish species inhabiting them is likely to depend heavily on the degree to which a species is associated with live coral (Sale, 2015). As an estimated 10% of coral-reef fishes can be classified as "coral dependent" (Pratchett et al., 2008), the existence of intact, live coral may be essential for continued survival of a large range of coral-reef fishes (Munday et al., 2008). While the impact of widespread coral loss extends well beyond the coral-dependent fishes (Jones et al., 2004; Pratchett et al., 2011), the extinction risk of habitat specialists (e.g., coral-dependent fishes) is directly affected by the amount and quality of suitable habitat available (Mace et al., 2008). Coral-dependent fishes are generally categorized by their functional relationship to live coral: 'obligate coral dwellers' live exclusively in live coral throughout their ontogeny (Gardiner and Jones, 2005; Munday et al., 1997), 'corallivores' (facultative and obligate) are species that feed predominantly or exclusively on live coral (Pratchett et al., 2013), while 'coral recruiters' always settle to live coral (Booth and Wellington, 1998; Holbrook et al., 2000; Öhman et al., 1998). For these coral-dependent species, live coral loss may negatively impact their abundance and diversity within coral reef systems (Bellwood et al., 2006; Halford et al., 2004; Kokita and Nakazono, 2001; Munday, 2004; Munday et al., 2008; Pratchett et al., 2006, 2008; Spalding and Jarvis, 2002), and lead to substantial changes in the composition and structure of coral reef fish assemblages (Bellwood et al., 2006; Munday et al., 2008; Pratchett et al., 2008; Sale, 2015).

The Persian/Arabian Gulf (hereafter referred to as 'the Gulf') is a shallow, sub-tropical sea adjacent to the northwestern Indian Ocean (Reynolds, 1993). Its coral reef ecosystem is characterized by some of

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the world's most extreme environmental conditions, including salinity values often >45 ppt, as well as the highest variability in annual temperature encountered by coral reefs globally (Riegl, 2001; Sheppard and Loughland, 2002; Sheppard et al., 1992). In the Gulf, true-reef building framework is reduced due to the Gulf's extreme environment and relatively young age (Purkis and Riegl, 2012; Sheppard et al., 2010). Thus, coral “reefs” in the Gulf are better described as ‘coral assemblages’ (Burt et al., 2014; Purkis and Riegl, 2012; Sheppard et al., 1992).

Various forms of coral assemblages occur in the Gulf. In the northern Gulf (i.e., Iraq, Kuwait, northern Saudi Arabia), near-shore coral assemblages form patch and fringing reef assemblages (Coles and Tarr, 1990; Krupp and Müller, 1994; McCain et al., 1984; Sheppard et al., 1992). However, at the seven offshore islands of Saudi Arabia and Iran in the northern Gulf, coral assemblages form into incipient fringing reefs (i.e., coral cays, Sheppard et al., 1992). These are by far the most complex and extensive coral habitats in the Gulf, and represent much of the only true reefs in the Gulf. In contrast, the near-shore areas within the southern Gulf (i.e., United Arab Emirates, Bahrain, and Qatar) are dominated by coral carpets or biostromes (Burt et al., 2014; Purkis and Riegl, 2012), though patch and fringing reef assemblages are also present (Sheppard et al., 1992, 2010).

In the Gulf, coral assemblages have been heavily degraded as a result of recurrent bleaching events and coastal development activities (Burt et al., 2014; Riegl, 2001). In 1996 and 1998, increased sea-surface temperatures (SSTs) resulted in mass mortality of coral, particularly in *Acropora* dominated areas (Burt et al., 2008, 2013a, 2014; Riegl, 2002; Riegl and Purkis, 2012). While recovery was observed in some areas, recurrent bleaching events in 2002, 2007, 2010, and 2011 impeded and often reversed this recovery (Burt et al., 2008, 2013a, 2014; Riegl and Purkis, 2012). Widespread coastal development over the past 50 years has further exacerbated the degradation of coral assemblages in the Gulf (Burt, 2014; Burt et al., 2014; Sheppard et al., 1992). By the early 1990s, over 40% of the Gulf coasts were modified in some way (Al-Ghadban and Price, 2002). In more recent years, mega-scale development projects creating iconic real estate venues have become increasingly common, resulting in mass reclamation, dredging, and infilling of coastal habitats (Burt, 2014; Burt et al., 2012, 2014; Sheppard et al., 2010). These impacts have been particularly heavy on nearshore coral assemblages, where local declines of greater than 90% of live coral cover have been observed in some areas (Burt et al., 2014), resulting in the reduction of coastal productivity and biological diversity (Al-Ghadban and Price, 2002).

With the extensive degradation of coral-assemblage habitat in the Gulf, more than 85% of the Gulf's natural coral assemblages are threatened (Burke et al., 2011); hence, coral-dependent fishes are of particular concern for conservation. Despite this, there has been little impetus to quantify the total diversity of these fishes within the Gulf fauna, while also determining the regional impacts of such coral degradation on these potentially ‘at risk’ species. Thus, the objectives of this study were to: 1) identify the full diversity of coral-dependent fishes (focusing only on the Infraclass Teleostei) within the Gulf, 2) evaluate the conservation status of these fishes using the IUCN Red List categories and criteria, and 3) examine how the degree of coral dependency at the species level may impact their conservation status within the Gulf region.

2. Methods

2.1. International Union for the Conservation of Nature (IUCN) Red List Process

The IUCN Red List, the global standard for evaluating the conservation status of species, categorizes species according to symptoms of high extinction risk (Mace et al., 2008). The IUCN Red List categories comprise nine levels: Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, and Not Evaluated. A species qualifies for Extinct when there is no reasonable doubt that the last individual has died. A species is listed as Extinct in the Wild when it is extinct in its natural habitat (Subcommittee, 2014). A species qualifies for one of three ‘threatened’ categories (e.g. Critically Endangered, Endangered, or Vulnerable) if it meets the thresholds and conditions for that category in one of five different available criteria (IUCN, 2012a). These five independent criteria are based on different issues related to extinction risk, including rapid population declines, small geographic ranges or very small population sizes (IUCN, 2012a; Mace et al., 2008). A species is listed as Near Threatened if the current data for the species is close to but does not quite meet the thresholds and conditions for a threatened category in one of the five criteria. A species is assigned to Least Concern if there are no known threats to the species or it does not qualify for a threatened category or Near Threatened. A species is assigned to the Data Deficient category if there is inadequate information to apply any of the five criteria. This category is mainly used when there is taxonomic uncertainty, little biological information or insufficient data to quantify the impact of known threats. The Not Evaluated category is used for species that have not yet been evaluated against the five criteria.

Although the IUCN Red List was originally developed for use at the global level, increasing interest in sub-global assessments led to the creation of regional guidelines (IUCN, 2012b). Two additional categories to assess the conservation status of species are used in regional assessments: Regionally Extinct, which refers to species that are considered extinct within the focal region but still exist in the wild elsewhere, and Not Applicable, which refers to species that have not been assessed because they are unsuitable for inclusion in the regional Red List (e.g., introduced species). Regional assessments use the same quantitative thresholds and conditions that are used for global assessments to allow for comparisons across regions (IUCN, 2012b). However, the application of the IUCN Red List Criteria at the regional level can over- or under-estimate a species' extinction risk if extralimital populations influence the regional population dynamics (e.g., via larval dispersal or immigration). Therefore, the regional IUCN Red List category is adjusted to reflect the status of populations occurring outside the focal region if connectivity is high.

Based on regional IUCN Red List methodology (IUCN, 2012b), species assessments for Gulf fishes were conducted with extensive input from scientific experts, including representatives from all Gulf States. A total of 457 species were assessed at two workshops held in Doha, Qatar in 2013 and 2014. Before each assessment workshop, information was compiled regarding each species' taxonomy, population trends, ecology and life history, use and trade, past and existing threats, conservation measures, and generalized distribution based on available literature. Regional and international experts then reviewed each species account, provided additional unpublished data, and were consulted after the workshop if further information was needed, but unavailable at the time of the assessment. Based on the best available data, a species was assigned to an IUCN Red List category (IUCN, 2012a; Subcommittee, 2014). After the assessment workshops, each species account was reviewed by at least two evaluators to ensure data quality and consistency. The species accounts were submitted to the IUCN Red List Unit for a final consistency check prior to publication on the publicly accessible IUCN Red List of Threatened Species website (http://www.iucnredlist.org).

2.2. Coral-dependency categorization

Species-specific information on body size, site-fidelity, home range, territoriality, mobility, depth range, and use of coral assemblages was compiled for all known marine bony fishes within the Gulf (457 species) using primary literature and expert opinion. Each species examined was then designated as coral-associated, which live on or in close association with coral habitats with varying degrees of coral dependency for part or their entire ontogeny (Feary et al., 2007; Munday et al., 2008; Syms and Jones, 2000), or not coral-associated, which are not associated with coral habitats at any point in their ontogeny. Each coral-associated species was then designated as either coral dependent or not coral dependent. The focus of this study was on the coral-dependent fishes.[1] Coral-dependent species were then grouped into one of four major categories: obligate coral dwellers, corallivores, small and territorial coral recruiters, and large and vagile coral recruiters, according to their most prominent functional relationship with live coral. Obligate coral dwellers were species that utilized coral for shelter throughout their ontogeny (Feary et al., 2007). Corallivores were species that fed predominately (facultative) or exclusively (obligate) on the tissues of live corals. Small-bodied species (maximum total length < 25 cm), which exhibit high site fidelity and territoriality, and low emigration success between coral assemblages (i.e., due to predation) were categorized as 'small and territorial coral recruiters'. Large-bodied species (maximum total length > 25 cm), possessing greater mobility than those in the 'small and territorial coral recruiters' category, were categorized as 'large and vagile coral recruiters'.

2.3. Application of IUCN Red List Criteria to coral-dependent fishes

The extinction risk of each coral-dependent species was assessed against all Red List Criteria and found to be potentially threatened under Criterion B, which is based on a species having a small geographical range (maximum of 20,000 km^2) and meeting two of the following three conditions, (i) severely fragmented or known from fewer than ten locations; (ii) experiencing a continuing decline or (iii) extreme fluctuations in its extent of occurrence (EOO), area of occupancy (AOO), quality of habitat, or number of locations, subpopulations, or mature individuals (IUCN, 2012a). Severely fragmented, defined by IUCN, is when most individuals (>50%) of a taxon are found in small and relatively isolated subpopulations between which there is very little dispersal (IUCN, 2012a; Subcommittee, 2014). These subpopulations may be too small to be viable, and thus may go extinct with little probability of being rescued or re-colonized by dispersing individuals. The EOO, as defined by IUCN, is the area contained within the shortest continuous imaginary boundary which could be drawn to encompass all known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy (IUCN, 2012a; Subcommittee, 2014). Thus, EOO includes areas where a species would not be expected to occur, e.g., on land or open ocean. The AOO, defined by IUCN, is the area within a taxon's extent of occurrence, which is occupied by the taxon, excluding cases of vagrancy (Subcommittee, 2014). To calculate AOO, each species' generalized distribution map was cut to the study's area of interest (Gulf UNEP-WCMC coral assemblages) in ArcMap 10.1. To determine EOO, the 'Minimum Bounding Geometry' tool, with convex-hull geometry type, was utilized to create a minimum bounding polygon around each species' AOO and the area of this polygon was calculated (in km^2) using the 'Calculate Geometry' tool. AOO was calculated (in km^2) using the Calculate Geometry tool, which determined the area each species occupied within their respective EOO.

2.4. Spatial analyses of regional distribution

Generalized polygonal distribution maps were created in ArcMap 10.1 by connecting known and suspected (based on expert opinion and inference from surrounding areas) occurrences for each coral-dependent species. Distribution maps were reviewed and updated by experts as needed during each workshop. For the purposes of this study, coral-dependent species distributions were limited to the Gulf, which is defined as the semi-enclosed basin connected to the Gulf of Oman through the Straits of Hormuz (Sheppard et al., 1992) (Fig. 1). The Musandam Peninsula and Straits of Hormuz that border the entrance to the Indian Ocean were excluded from this assessment as the coral and fish assemblages found in these areas are not representative of the diversity and abundance of coral and fish assemblages found within the Gulf (Burt et al., 2011; Feary et al., 2010).

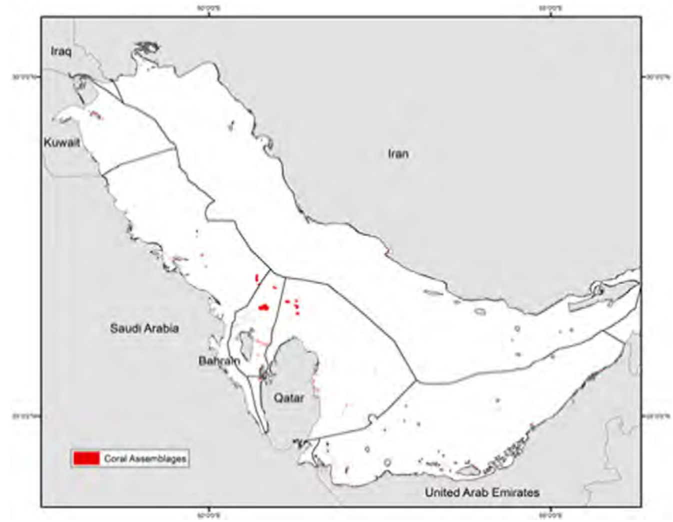

Fig. 1. Map of the coral assemblages in the Gulf with national jurisdictions (study area). Source: United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC et al., 2010).

Coral-assemblage habitat data from United Nations Environment Programme World Conservation Monitoring Centre (Fig. 1: UNEP-WCMC et al., 2010) were utilized to determine the spatial distribution and extent of suitable habitat for coral-dependent fishes. For visualization purposes, a 1-km buffer was placed around the coral-assemblage habitat data (Fig. 2). Coral assemblages around several offshore islands of Saudi Arabia (Jana, Jurayd, and Harqus) and Kuwait (Kubbar), missing from the original UNEP-WCMC coral assemblage data, were added based on descriptions and localities from the published literature (e.g., Basson et al., 1977; Carpenter et al., 1997a).

Species richness analyses determine the number of species represented within a given area (e.g., landscape or region). For this study, species richness analyses were conducted to determine the number of

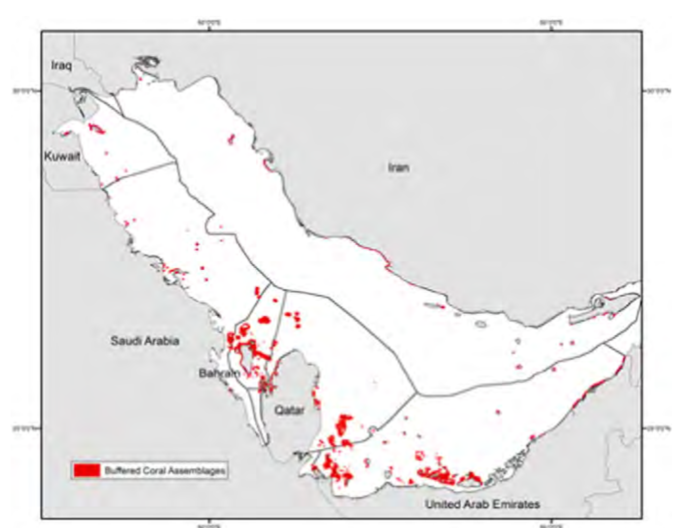

Fig. 2. Map of the coral assemblages in the Gulf with national jurisdictions (study area). Source: United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC et al., 2010). For visualization purposes, a 1-km buffer was placed around the coral assemblages.

[1] A complete summary of the conservation status of all 457 marine bony fishes in the Gulf will be published in the future.

coral-dependent fishes represented on coral habitat within the Gulf. For visualization purposes, prior to conducting the species richness analyses, a 5-km buffer was created around the coral-assemblage habitat data. Each coral-dependent species distribution map was then cut to the buffered coral-assemblage habitat data for the Gulf. All coral-dependent distribution maps were converted to a 1 km by 1 km raster grid and then stacked. Coral-dependent species richness per cell was then calculated by counting the number of overlapping coral-dependent species distributions at each 1 km^2 cell location; this was also completed for only the threatened coral-dependent species (i.e., species that qualified for one of the three 'threatened' categories: 'Critically Endangered', 'Endangered' or 'Vulnerable') to determine if richness patterns were different from that of the original coral-dependent species richness analysis.

3. Results

3.1. Coral-dependency categorization

Of the 457 marine bony fishes known from the Gulf, 241 species representing 53% of the known species within the Gulf were considered to be coral associated; within this, 23 species were categorized as coral dependent, representing 5% of the known species within the Gulf (Table 1). Three species were designated as obligate coral dwellers: the Large Whip Goby (*Bryaninops amplus*) (Allen and Erdmann, 2012; Krupp et al., 2000; Larson, 1985; Myers, 1991; Sih and Chouw, 2009), the Citron Goby (*Gobiodon citrinus*) (Carpenter et al., 1997b; Harold et al., 2008; H. K. Larson pers. comm. 2013), and the Reticulated Coral Goby (*G. reticulatus*) (Carpenter et al., 1997a; Dirnwöber and Herler, 2007; Harold et al., 2008; Randall, 1995). The Large Whip Goby dwells in coral whips of the genus *Junceella*, while the Citron Goby and Reticulated Coral Goby dwell within the branches of large table coral (*Acropora* spp.). Two species, the Arabian Butterflyfish (*Chaetodon melapterus*) and the Dark Butterflyfish (*C. nigropunctatus*) were classified as corallivores (Carpenter et al., 1997a; Feary et al., 2010; Pratchett et al., 2013; Randall, 1995; Shokri et al., 2005), though both depend on live coral at different capacities. The Arabian Butterflyfish is an obligate corallivore, feeding exclusively on live coral tissue, while the Dark Butterflyfish is a facultative corallivore, feeding predominately on live coral tissue, while also supplementing its diet with other non-coral prey items (Pratchett et al., 2013).

The remaining coral-dependent species were divided into two categories: 'small and territorial coral recruiters' and 'large and vagile coral recruiters' (Table 1). Twelve species were designated as 'small and territorial coral recruiters' (Allen and Erdmann, 2012; Allen, 1986, 1991; Anderson and Hafiz, 1995; Broad, 2003; Burt et al., 2009, 2013b; Carpenter et al., 1997a,b; Fishelson et al., 1974; Fouda and El-Sayed, 1996; Heemstra, 1986; Kuiter and Tonozuka, 2001; Lieske and Myers, 1994; Myers, 1991; Randall and Randall, 2001; Randall, 1995; Randall et al., 1994), with the predominant family being the Pomacentridae, which contributed nine species. One species from each of the families Acanthuridae, Chaetodontidae, and Labridae were also included within this designation. Six species were then designated as 'large and vagile coral recruiters' (Broad, 2003; Bruce and Randall, 1984; Carpenter et al., 1997a; Fischer et al., 1990; Myers, 1991; Randall, 1986, 1995; Randall et al., 1990; Sousa and Dias, 1981; J. H. Choat pers. comm. 2013) consisting of five parrotfishes (Scaridae), and the surgeonfish *Acanthurus sohal* (Acanthuridae).

3.2. Regional Red List categorization

Coral assemblages in the Gulf are limited to around 700 km^2 and this represents the maximum AOO for all coral-dependent fishes of the Gulf (Table 1). Coral-dependent fish populations are considered severely fragmented because Gulf coral assemblages are naturally fragmented with no contiguous coral assemblages remaining (Fig. 1). Also, different regions of the Gulf have markedly different reef assemblages and formation types (Burt et al., 2014; Coles and Tarr, 1990; Krupp and Müller, 1994; McCain et al., 1984; Purkis and Riegl, 2012; Sheppard et al., 1992, 2010) and circulation of permanent eddies in the Gulf suggest local entrainment of larvae (Burt et al., 2011; Pous et al., 2004; Reynolds, 1993; Thoppil and Hogan, 2010). There is also an observed continuing decline in the area and/or quality of habitat as much of the Gulf coral-assemblage habitat is considered under continued threat from climate change and coastal development (Burt et al., 2014) impacting its quality and extent (Table 1). Consequently, all fishes

Table 1
List of coral-dependent species in the Gulf, with their coral-dependency categorization, IUCN Regional Red List threatened status, area of occupancy, maximum size, and depth range.

Family	Scientific name	Coral-dependency category	IUCN Red List category	Area of occupancy (in km^2)	Maximum size (in cm)	Depth range (in m)
Chaetodontidae	*Chaetodon melapterus*	CORAL	Vulnerable	700	13 (TL)	3–16
Chaetodontidae	*Chaetodon nigropunctatus*	CORAL	Vulnerable	700	14 (TL)	1–40
Chaetodontidae	*Heniochus acuminatus*	ST RECRUIT	Vulnerable	700	25 (TL)	2–75
Pomacentridae	*Abudefduf vaigiensis*	ST RECRUIT	Vulnerable	700	20 (TL)	1–15
Pomacentridae	*Amphiprion clarkii*	ST RECRUIT	Endangered	175	15 (SL)	1–60
Pomacentridae	*Chromis flavaxilla*	ST RECRUIT	Vulnerable	25–700	7.2 (TL)	0–18
Pomacentridae	*Chromis xanthopterygia*	ST RECRUIT	Endangered	200	11.5 (TL)	5–20
Pomacentridae	*Dascyllus trimaculatus*	ST RECRUIT	Vulnerable	575	11 (SL)	1–55
Pomacentridae	*Neopomacentrus cyanomos*	ST RECRUIT	Vulnerable	700	10 (TL)	5–30
Pomacentridae	*Pomacentrus aquilus*	ST RECRUIT	Endangered	425	12 (TL)	0–15
Pomacentridae	*Pomacentrus leptus*	ST RECRUIT	Endangered	300	7 (TL)	1–10
Pomacentridae	*Pomacentrus trichourus*	ST RECRUIT	Endangered	375	11 (TL)	1–43
Labridae	*Halichoeres marginatus*	ST RECRUIT	Vulnerable	700	17 (TL)	0–30
Scaridae	*Chlorurus sordidus*	LV RECRUIT	Vulnerable	700	40 (TL)	1–50
Scaridae	*Scarus ferrugineus*	LV RECRUIT	Vulnerable	650	41 (TL)	1–60
Scaridae	*Scarus ghobban*	LV RECRUIT	Endangered	375	90 (TL)	2–100
Scaridae	*Scarus persicus*	LV RECRUIT	Vulnerable	650	50 (TL)	2–20
Scaridae	*Scarus psittacus*	LV RECRUIT	Data Deficient	Unknown	30 (TL)	2–25
Gobiidae	*Bryaninops amplus*	DWELL	Data Deficient	1–2000	4.6 (SL)	1–30
Gobiidae	*Gobiodon citrinus*	DWELL	Endangered	35	6.6 (TL)	1.5–25
Gobiidae	*Gobiodon reticulatus*	DWELL	Vulnerable	700	2.1 (TL)	2–33
Acanthuridae	*Acanthurus sohal*	LV RECRUIT	Vulnerable	700	40 (TL)	0–20
Acanthuridae	*Zebrasoma xanthurum*	ST RECRUIT	Vulnerable	700	22 (TL)	1–20

Coral-dependency categories abbreviated as CORAL (corallivore), DWELL (obligate coral dweller), ST RECRUIT (small, territorial coral recruiter), and LV RECRUIT (Large, vagile coral recruiter).

dependent on corals, with sufficient data to assess, meet the thresholds for a threatened species under Criterion B at the regional level.

In addition to the impacts of climate change and coastal development on coral-dependent fishes, the population structure and abundance of large-bodied coral dependents (e.g., scarids) are impacted by various artisanal and commercial fisheries within the Gulf, and can form a substantial part of fisheries bycatch (Grandcourt, 2012). Continued fisheries pressure on large-bodied coral dependents within the Gulf is expected to contribute to the decline in the number of mature individuals (Grandcourt, 2012).

Regional Red List Assessment methodology requires consideration of the potential for immigration of propagules from outside the region (IUCN, 2012b). Oceanographic data suggests there is limited entry of propagules into the Gulf via the Straits of Hormuz (Coles, 2003; Rezai et al., 2004) and the well-documented counter-current circulation within the southern region of the Gulf (Chao et al., 1992) is more likely to facilitate the movement of propagules out of the Gulf (Feary et al., 2012). In addition, the physical extremes of both salinity and temperature throughout the entire Gulf are likely to restrict the survivability of larvae entering the Gulf (Riegl, 2001; Sheppard and Loughland, 2002; Sheppard et al., 1992). Thus, it is unlikely that Gulf populations are receiving enough immigrating propagules to constitute a significant 'rescue effect'. Findings of a genetically isolated population of the highly mobile Indo-Pacific sailfish (*Istiophorus platypterus*) in the Gulf (Hoolihan et al., 2004) also supports limited connectivity through the Straits of Hormuz.

Of the 23 coral-dependent species, seven were considered Endangered at the regional level because their AOO in the Gulf is less than 500 km^2 but more than 10 km^2. Fourteen coral-dependent species were listed as Vulnerable, because their maximum AOO is less than 700 km^2 and is assumed to be greater than 500 km^2. Two species were listed as Data Deficient (*Bryaninops amplus* and *Scarus psittacus*) because their presence in the Gulf is based on a limited number of records. Due to its small size (4.6 cm SL) and cryptic nature, *B. amplus* is known only from nine specimens (Krupp et al., 2000), while *S. psittacus* is only known from a single record that is likely based on a misidentification (Al-Baharna, 1986). Thus, there is little information regarding these species distributions, population trends, and threats in the Gulf. However, with adequate information (and confirmation of the occurrence of *S. psittacus* in the Gulf) their minimum threat category at the regional level would also be Vulnerable. Of the 241 coral-associated fishes for which data were sufficient to assess, around 12% were threatened due to overfishing or restricted range. However, the coral-associated fishes assessed as Data Deficient produce uncertainty in the true proportion threatened (Hoffmann et al., 2010; IUCN, 2011; Schipper et al., 2008), resulting in a range of around 10% (if none of the Data Deficient species were threatened) to 24% (if all of the Data Deficient species were threatened).

3.3. Spatial analyses

Two geographic trends were identified using species richness analyses (Fig. 3). Coral-dependent species diversity was higher in the northern and southern Gulf, with a decrease towards the central and eastern Gulf (Fig. 3a). Species diversity was highest at the nearshore coral assemblages in central Saudi Arabia (near Abu Ali) and in the United Arab Emirates (near Abu Dhabi and Ras Al-Khaimah), and at the offshore islands of Kuwait (Failaka, Kubbar, Qaro, and Umm Al-Maradem) and Saudi Arabia (Jana, Jurayd, Karan, and Kurain).

A similar geographic trend was observed with the number of threatened coral-dependent species, where the greatest number occurred in the northern Gulf, off Kuwait and Saudi Arabia, and in the southern Gulf, off parts of the United Arab Emirates, with a decrease towards the central and eastern parts of the Gulf (Fig. 3b). There was also a decreasing trend in threatened species, with higher numbers of threatened species in near-shore than offshore areas, with the exception of the Iranian coast, which was likely an artifact of study effort.

4. Discussion

4.1. Coral dependency and extinction risk

In the Gulf, a small proportion of marine bony fishes (5% of the total diversity and around 10% of the coral-associated species) were identified as coral dependents. All coral-dependent species (with sufficient data to assess) in the Gulf are at an elevated risk of extinction, based on their limited geographic range and threats from loss of coral-assemblage habitat due to increasing sea surface temperatures (SSTs) and coastal development (Burt et al., 2014). These threats have been particularly severe on near-shore coral-assemblage communities, which are impacted by these threats to a greater extent than offshore coral assemblages, due to their shallow depth and close proximity to the coast. In shallower waters, temperature spikes are more extreme, and the close proximity to the coast subjects these assemblages to the

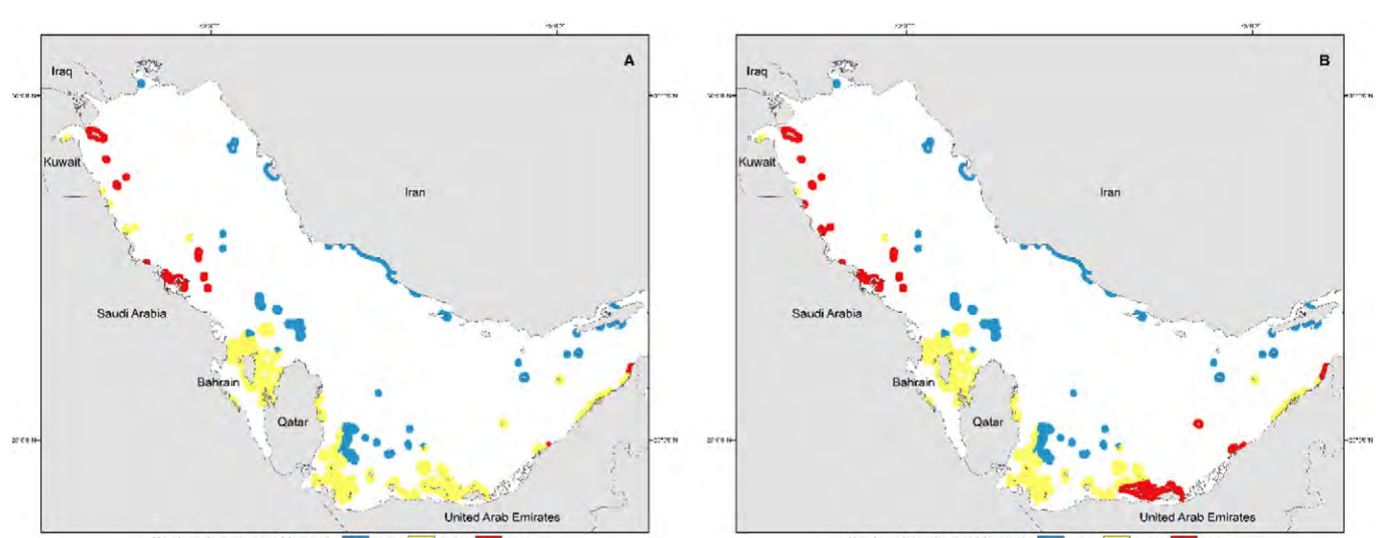

Fig. 3. (a) Species richness of coral-dependent bony fishes of the gulf. (b) Species richness of threatened (vulnerable and endangered) coral-dependent species in area. For visualization purposes, species distributions were cut to a 5-km buffer around the UNEP-WCMC coral-assemblage habitat in the Gulf.

direct and indirect effects of the extensive coastal development within this region (Al-Ghadban and Price, 2002).

Coral-dependent fishes in the Gulf are at a heightened risk of extinction regardless of their dependency on live corals. Obligate coral dwellers, such as *G. citrinus*, are small bodied and show limited mobility, placing them at a higher risk of predation without live coral for refuge (Sih and Chouw, 2009). They may also feed on the mucus of host corals. Obligate coral dwellers range in their specialization, some species associating with a single coral species; others are generalists, associating with a number of coral species (Munday, 2004). Because of their niche requirements, obligate coral dwellers can have smaller population sizes, especially those that are specialists (Munday, 2004). Their range is also restricted to areas where their coral hosts occur. These factors have been shown to have a 'double jeopardy' effect on obligate coral dwellers, increasing their inherent risk of extinction (Munday, 2004). In the Gulf, *G. citrinus* and *G. reticulatus* occur on acroporid branching corals (Harold et al., 2008; Larson, 1985), which are more sensitive to thermal anomalies than more stress-tolerant corals, such as *Porites* and faviid brain corals (Burt et al., 2014). In the southern Gulf, these sensitive corals were nearly wiped out due to recurring temperature extremes that caused several mass bleaching events since the 1990s (Burt et al., 2008, 2013a, 2014). Recovery in these corals has been observed in a few isolated areas (Burt et al., 2008), but has remained limited in most places due to ongoing impacts from recurring thermal anomalies and chronic anthropogenic stressors. Given the high dependency of these obligate coral dwellers on host corals for food and shelter, we can predict that the continued loss of host corals in the Gulf will result in localized extinctions of these fishes.

Corallivores are also at risk of extinction in the Gulf due to the reduced availability of live coral (Pratchett et al., 2013). Live coral tissue comprises the entire diet of *C. melapterus*, thus, this species is highly dependent on the percent cover of live coral (Pratchett et al., 2008), increasing its inherent risk of extinction (Mace et al., 2008). In contrast, *C. nigropunctatus* is somewhat less at risk because it is a facultative corallivore, with <20% of its diet comprising of live coral tissue (Pratchett et al., 2013). This species is also known to feed on sessile invertebrates, such as tunicates and soft corals (Pratchett et al., 2013). Studies have shown that facultative corallivores are able to switch or supplement their diets with other non-coral prey items when preferred coral prey abundance declines or becomes unavailable (Berumen and Pratchett, 2006; Crosby et al., 2013; Graham, 2007; Pratchett et al., 2004, 2006). Thus, given its obligate nature, the impacts of coral loss are more pronounced for *C. melapterus* than for *C. nigropunctatus*, as evidenced by the observed disappearance of *C. melapterus* on dead near-shore and offshore coral assemblages north of Abu Ali, Saudi Arabia (Krupp and Abuzinada, 2008). However, both species are considered Vulnerable to extinction since both are coral dependents and not found in areas without live corals (Carpenter et al., 1997a; Feary et al., 2010; Pratchett et al., 2013; Randall, 1995; Shokri et al., 2005).

We can predict that both small, territorial and large, vagile coral recruiters will be negatively impacted by the loss of corals, with populations likely needing to relocate out of degraded areas. However, the differential ability of species to successfully migrate between habitats following local disturbances will be essential in understanding the species-specific impacts of coral loss on the population survival of fishes within the Gulf. Where coral reefs and assemblages are contiguous, localized loss of live coral might not be as damaging on population abundance of species, due to the high level of shelter and potentially high level of suitable habitat within these coral communities (Chapman and Kramer, 2000; Corless et al., 1998). However, within the Gulf, along with limited distribution of coral assemblages, the dominant coral-assemblage formation are coral carpets or biostromes (Burt et al., 2014; Purkis and Riegl, 2012). These consist of individual coral colonies, separated by large open areas of sandy habitat. Coral-associated fishes, even highly mobile species, are reluctant to cross open areas, which is likely due to the reduced structural habitat complexity and perceived risk of predation (Berkström et al., 2013; Chapman and Kramer, 2000; Nash et al., 2015; Shulman, 1985; Sweatman and Robertson, 1994; Turgeon et al., 2010; Welsh and Bellwood, 2012). Thus, within the Gulf, populations of mobile fishes, technically able to migrate to more favorable habitats, are likely to decline in the face of continued degradation of coral assemblages due to an inability to relocate between degraded and remnant coral habitat.

4.2. Broader implications

In the Gulf, if no measures are taken to halt the loss of coral-assemblage habitat, most populations of species dependent on coral will likely become functionally extinct and no longer serve their ecological role. Each of these species plays a vital role in the health of coral assemblages. For example, corallivores provide a valuable trophic link between corals and higher consumers (Glynn, 2004). Acanthurids, pomacentrids, and scarids are well known to play significant roles as herbivores on coral reefs and assemblages, maintaining ecosystem integrity and resilience (Bellwood et al., 2006; Comeros-Raynal et al., 2012; Hughes et al., 2007; Lewis, 1986). With species diversity relatively low in the Gulf compared to nearby waters (Burt et al., 2011; Feary et al., 2010), the loss of these species' ecological roles could result in drastic changes to the coral and fish community compositions, such as localized phase shifts of coral-dominated assemblages to other alternative states (e.g., algal-dominated assemblages) (Bellwood et al., 2006; Burt et al., 2013a; Comeros-Raynal et al., 2012; Hughes et al., 2007).

Coral-dependent fishes have the potential to be utilized as indicator species for coral-assemblage health. For example, corallivorous butterflyfishes are commonly considered to be useful as indicator species of coral-reef health (Crosby et al., 2013). Declines of these species could be used as an early warning system indicating stress to coral assemblages (Crosby and Reese, 2005; Crosby et al., 2013; Hourigan et al., 1988; Pratchett et al., 2006), which could be highly beneficial in the Gulf to determine the degree of degradation to coral-assemblage habitats throughout.

4.3. Data gaps

Several data gaps were identified during the course of this study. Gulf coral-assemblage data from UNEP-WCMC were utilized. However, this data is outdated and was originally based on anecdotal reports rather than actual mapping exercises. Omissions of coral assemblages were identified, with Harqus, Jana, Jurayd, and Kubbar Islands' coral assemblages added before analyses were conducted. But, there is potential that other omissions were not accounted for. Thus, with ground-truthing, the total area of coral assemblages would likely increase. However, this increase would have to be substantial (~286%) in order to result in a total area estimate larger than the 2000 km^2 AOO threshold for Vulnerable under Criterion B. In addition, these data, many of which were collected from 1999 to 2002, do not account for recent widespread coral declines. However, the total area of coral assemblages would need to have declined by ~30%, since the compilation of these data, to result in an AOO less than 500 km^2, which would qualify all coral-dependent species for Endangered under Criterion B. Thus, to address these uncertainties, an integrated regional mapping effort for Gulf coral assemblages is urgently needed. While several Gulf States have mapped at least some of their coral assemblages, much of the distribution and quality data are out of date given recent bleaching events and anthropogenic impacts, and a Gulf-wide coral-assemblage mapping exercise is pivotal in determining the true distribution of coral assemblages (Grizzle et al., 2016).

Artifacts of study effort were prominent in our analyses. Extensively studied areas, such as Kuwait, Saudi Arabia and the United Arab Emirates, showed high diversity, while lesser studied areas, including numerous offshore areas (e.g., Harqus, Al-Arabiya, Fars Islands) and the Iranian coast, showed lower diversity of coral dependents. However, Al-Arabiya is known to have the most diverse coral-associated fish assemblages of all the Gulf islands (F. Krupp pers. obs.) and the Iranian coast is thought to have some of the most developed coral assemblages (Rezai et al., 2004; Sheppard et al., 1992, 2000, 2010). Unfortunately, many of these areas are not easily accessible to scientists and have yet to be thoroughly surveyed (Rezai et al., 2004; Sheppard et al., 1992, 2000). While these areas are likely underrepresented in our analyses, richness patterns in the remainder of the Gulf are assumed to reflect actual richness of coral-dependents.

Surveys within these poorly studied areas would provide valuable insights into the coral and reef fish assemblages within these areas, as well as provide a more accurate assessment of the Gulf's diversity. They may also increase the information available for the coral-dependent species assessed as Data Deficient, which are highly likely to be threatened; however, until sufficient data on the distribution of these species become available, their status will remain unknown. Thus, there is a need for a biodiversity assessment of Iran's coral assemblages and other poorly studied coral assemblages, perhaps in concert with a Gulf-wide mapping effort as a ground truthing exercise.

4.4. Conservation priorities

Resource constraints are a major limitation for conservation (Wilson et al., 2006). Identifying priority areas for conservation is thus useful to ensure that resources are efficiently utilized. Compared to near-shore coral assemblages in the Gulf, offshore islands contain highly diverse coral-associated fish assemblages and the most extensive coral assemblages because they occur in deeper waters, which experience less extreme temperature and salinity fluctuations, and are not highly impacted by human disturbance (Burt et al., 2014; Coles and Tarr, 1990; Feary et al., 2010; Krupp and Müller, 1994; McCain et al., 1984; Price et al., 1993). Similar results were obtained for this study, where coral dependents were found to be more speciose at offshore islands, particularly in the northern Gulf. In the southern Gulf, less impacted offshore coral assemblages have also been shown to seed degraded near-shore coral populations following the bleaching events of 1996 and 1998 (Burt et al., 2014), and it is presumable that these areas also act as larval source reefs for coral-associated fishes. Thus, if degradation of near-shore habitat is to continue, the conservation of offshore-island reef assemblages is paramount. To determine effective means for the management and protection of these highly productive and critically important habitats in the Gulf, cross-boundary collaboration among Gulf States is necessary (Burt et al., 2014; Krupp, 2002, 2008; Krupp et al., 2006, 2009; Sheppard et al., 2012). Historically, collaboration among Gulf States has been a challenge, even though all riparian countries are members of an intergovernmental marine environmental conservation body, the Regional Organization for the Conservation of the Marine Environment. However, recent initiatives, such as the Mideast Coral Reef Society, promote collaboration among scientists, institutions, non-governmental organizations, and governmental organizations throughout the region. With effective management and protection of these critically important coral assemblage ecosystems, there is the potential to return the threatened species in our findings to a status of 'Least Concern'.

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Contributed reagents/materials/analysis tools: JAB, DAF, FK, GMR, KEC.

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