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Troubled waters: Threats and extinction risk of the sharks, rays and chimaeras of the Arabian Sea and adjacent waters

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Abstract

The extinction risk of sharks, rays and chimaeras is higher than that for most other vertebrates due to low intrinsic population growth rates of many species and the

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fishing intensity they face. The Arabian Sea and adjacent waters border some of the most important chondrichthyan fishing and trading nations globally, yet there has been no previous attempt to assess the conservation status of species occurring here. Using IUCN Red List of Threatened Species Categories and Criteria and their guidelines for application at the regional level, we present the first assessment of extinction risk for 153 species of sharks, rays and chimaeras. Results indicate that this region, home to 15% of described chondrichthyans including 30 endemic species, has some of the most threatened chondrichthyan populations in the world. Seventy-eight species (50.9%) were assessed as threatened (Critically Endangered, Endangered or Vulnerable), and 27 species (17.6%) as Near Threatened. Twenty-nine species (19%) were Data Deficient with insufficient information to assess their status. Chondrichthyan populations have significantly declined due to largely uncontrolled and unregulated fisheries combined with habitat degradation. Further, there is limited political will and national and regional capacities to assess, manage, conserve or rebuild stocks. Outside the few deepsea locations that are lightly exploited, the prognosis for the recovery of most species is poor in the near-absence of management. Concerted national and regional management measures are urgently needed to ensure extinctions are avoided, the sustainability of more productive species is secured, and to avoid the continued thinning of the regional food security portfolio.

KEYWORDS
chondrichthyans, extinction risk, fisheries, IUCN Red List, population decline, species diversity

1 | INTRODUCTION

Sharks and their relatives, including rays and chimaeras, are collectively termed chondrichthyan fishes and comprise one of the three classes of fishes (Class Chondrichthyes). Chondrichthyans are a relatively small lineage of approximately 1,250 currently described species (Eschmeyer, Fricke, & van der Laan, 2017) of an evolutionarily distinct conservative group that has functioned successfully in diverse aquatic ecosystems for over 400 million years (Compagno, 1990; Stein et al., 2018). Despite their evolutionary success, there is growing evidence that many species are increasingly threatened with extinction as a result of their conservative life-history traits that make them particularly susceptible to population decline from overfishing and habitat degradation (Dulvy et al., 2008, 2014; Kyne & Simpfendorfer, 2010; Stevens, Bonfil, Dulvy, & Walker, 2000). Although there is considerable variation among species, many chondrichthyans grow slowly, mature relatively late, have a small number of young and have a low natural mortality (Stevens et al., 2000). These characteristics result in very low rates of population increase with little capacity to recover from overfishing, and habitat loss and degradation (Cortés, 2016; Dulvy et al., 2014; Pardo, Kindsvater, Reynolds, & Dulvy, 2016). While the global status of chondrichthyans has come into focus in recent decades, detailed knowledge of the population and conservation status of most of the known species of chondrichthyans remains limited in most regions of the world.

The Arabian Sea and adjacent waters, including the Red Sea, Gulf of Aden, Arabian Sea, Sea of Oman and the "Gulf," are bordered by 20 sovereign states. Fisheries in this region are primarily small-scale although large industrial fleets also operate in the waters of the Arabian Sea and within the exclusive economic zones (EEZs) of several coastal states. Artisanal vessels fish mostly in nearshore coastal waters, with occasional large-scale trips to productive areas, and employ traps (in the "Gulf" and Red Sea), gillnets, hook and line, and longlines. Industrial fisheries employ trawls, longlines and purse seines (see review of regional fisheries in De Young (2006) and Jabado and Spaet (2017)). Fisheries resources in the region are under extreme pressure with several teleost species thought to be fully or over-exploited with reported declines between 40% and 80% in the last 15–20 years (De Young, 2006; Flewwelling & Hosch, 2006; Grandcourt, 2012; Jin, Kite-Powell, Hoagland, & Solow, 2012; Mohamed & Veena, 2016). Within the same period, there has been growing demand for sharks for food security through the provision of animal protein as well as to supply the fin trade, and as a result, fishing effort has increased in traditional shark fisheries (Ali & Sinan, 2014; Bonfil, 2003; Henderson, McIlwain, Al-Oufi, & Al-Sheili, 2007; Jabado, Al Ghais, Hamza, & Henderson, 2015). The Arabian Sea and adjacent waters are now recognized as one of the regions of the world with the largest number of chondrichthyan fishers and traders (Dent & Clarke, 2015; Dulvy et al., 2017; Jabado & Spaet, 2017; Jabado, Al Ghais, Hamza, Henderson, Spaet, et al., 2015). In 2015, regional reported landings of chondrichthyans were estimated at 72,534 t, a decline from a peak in 1996 at 195,490 t (FAO, 2017). Chondrichthyan catches from the "Gulf," Red Sea and particularly Pakistan declined from 2003 to 2011, while those from Oman have risen over this period (Davidson, Krawchuk, & Dulvy, 2015; FAO, 2017). Despite seven countries in the region not reporting their chondrichthyan catches, these landings represent 9.62% of global reported chondrichthyan landings (753,761 t in 2015) with the top shark fishing nations including India, Iran, Pakistan, Oman, Yemen, Somalia and Sri Lanka (Dent & Clarke, 2015; Glaser, Roberts, Mazurek, Hurlburt, & Kane-Hartne, 2015; Herath & Maldeniya, 2013; Jabado & Spaet, 2017).

Although sometimes targeted, chondrichthyan catches in the Arabian Sea and adjacent waters are predominantly the result of incidental capture in fisheries targeting other, more valuable, demersal or pelagic species such as shrimp or tuna (Jabado & Spaet, 2017). Historic fishery landings have been poorly documented in this region, and therefore, the status of most individual exploited chondrichthyan stocks is unknown (e.g. Al-Abdulrazzak & Pauly, 2013). Yet, the available data suggest that chondrichthyan fisheries are heavily exploited, with most species declining in abundance, diversity and size, and overall shark resources having already shown signs of depletion 15–20 years ago (e.g. *Arabian Sea*: Akhilesh et al., 2011; Ali & Sinan, 2014; Henderson, Al-Oufi, & McIlwain, 2004; Moazzam, 2012; Mohamed & Veena, 2016 - *"Gulf"*: Jabado, Al Ghais, Hamza, Robinson, & Henderson, 2016; Moore, McCarthy, Carvalho, & Peirce, 2012; Valinassab, Daryanabard, Dehghani, & Pierce, 2006 - *Red Sea and Gulf of Aden*: Bonfil, 2003; Glaser et al., 2015; PERSGA, 2002; Shaher, 2007; Spaet & Berumen, 2015). The high level of exploitation in the Arabian Sea and adjacent waters is of concern with increasing effort, expanding and intensifying fisheries, and a lack of overall fisheries management or enforcement of existing measures.

Performance analyses reveal that International Union for Conservation of Nature (IUCN) Red List of Threatened Species Criteria are closely aligned to and in harmony with fisheries reference points (Dulvy et al., 2017; Fernandes et al., 2017; Porszt, Peterman, Dulvy, Cooper, & Irvine, 2012). Here, we present results from the first regional assessment of extinction risk of all chondrichthyans in the Arabian Sea and adjacent waters. We aim to (a) evaluate the status of all species using a consistent methodology; (b) identify the major threatening processes that chondrichthyans face in the region; and (c) recommend priority areas for future research, policy actions and appropriate management interventions needed to ensure the long-term survival of these species.

2 | MATERIALS AND METHODS

We first delineate the taxonomic scope and standards of our assessment, before summarizing the IUCN Red List of Threatened Species assessment approach, and the mapping of species distributions.

2.1 | Taxonomic scope

The nomenclature and authorities used for chondrichthyans follow those of the online electronic version of the *Catalog of Fishes* (Eschmeyer et al., 2017) for sharks and chimaeras, and *Rays of the World* (Last et al., 2016) for rays. While over 180 species of chondrichthyans are reported in the regional literature, only the 153 species believed to have resident, breeding populations, were assessed. Species considered as Not Applicable (NA) (IUCN, 2012) for assessment were those occurring at the margins of the study area, those for which the taxonomic validity was uncertain, and those with questionable occurrences in the Arabian Sea and adjacent waters, vagrants and species for which the holotype has been lost or does not exist. All species assessments have been reviewed and published in a comprehensive report (Jabado, Kyne, et al., 2017) with those pertaining to species endemic to the Arabian Sea and adjacent waters published online on the IUCN Red List of Threatened Species as the global assessment for that species (www.iucnredlist.org; IUCN, 2017).

2.2 | Application of the IUCN Red List Categories and Criteria

The IUCN Red List Categories and Criteria (version 3.1) and Guidelines for Application of IUCN Red List Criteria at Regional and National Levels (version 4.0) were applied to the 153 species occurring in the Arabian Sea and adjacent waters (IUCN, 2012, 2016). Data on the taxonomy, distribution, population status, habitat and ecology, major threats and conservation measures for each species were collated from published peer-reviewed papers, government reports and other grey literature, unpublished fisheries data, as well as anecdotal information and expert observations. All draft assessments were prepared during a 5-days regional Red List workshop held in Abu Dhabi, United Arab Emirates (UAE) in February 2017. During the workshop, 22 experts and members of the IUCN Species Survival Commission Shark Specialist Group met to share and synthesize species-specific data and systematically evaluate each species against the IUCN Red List Categories and Criteria.

The eight IUCN Red List Categories of extinction risk considered were: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD) (see IUCN, 2016 for definitions). Categories are assigned objectively based on a number of criteria that indicate levels of extinction risk and include the following: rate of population declines (Criterion A), geographic range size and decline (Criterion B), small population size and decline (Criterion C), very small or restricted population (Criterion D) or quantitative analysis (Criterion E) (IUCN, 2016; Mace et al., 2008). A species qualifies for one of the three threatened categories (CR, EN and VU) by meeting the quantitative threshold for that category in any one of the five criteria (A-E). A category of NT is assigned to species that come close to, but do not fully meet, a threshold for a threatened category under any given criterion. This assessment reflects sufficient concern that they are close to qualifying for, or are likely to qualify for a threatened category in the near future. A species is LC, if when it has been evaluated against the criteria does not qualify for CR, EN, VU or NT. A species is listed as DD if there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status (IUCN, 2016). These categories are used unaltered at the regional level with a few adjustments to account for connectivity with adjacent populations outside the assessment region (IUCN, 2012). A species is Regionally Extinct (RE) if there is no reasonable doubt that the species is extinct in the region, but exists elsewhere in the wild. A species qualifies for NA if it is deemed ineligible for assessment at the regional level (e.g. it is not within its natural range in the region, is a vagrant to the region, or occurs at very low numbers in the region). The proportion of species in each of the IUCN Red List Categories was calculated and is summarized in Table 1.

2.3 | Species mapping

Generalized distribution maps were produced for each species using ArcMap 10.1 (ESRI, 2014), based on known and inferred occurrences. Coastal species maps were generated using a standardized polygon that is either the 200-m isobath or 100 km from the shoreline, whichever is further from the coast. Maps for the oceanic species were digitized by hand using depth and habitat preferences as a broad guide. The maps were first drafted based on regional and global guides (i.e. Adam, Merrett, & Anderson, 1998; Almojil, Moore, & White, 2015; Anderson & Ahmed, 1993; Bianchi, 1985; Bonfil & Abdallah, 2004; Compagno, 2001; De Silva, 2015; Ebert, Fowler, & Compagno, 2013; Jabado & Ebert, 2015; Last & Stevens, 2009; Last et al., 2016; Raje et al., 2007). These were augmented with species-specific records from the literature (including unpublished fisheries and scientific reports) and with photographic records provided by experts at the workshop. Draft maps were reviewed during the workshop and subsequently vetted by taxonomic and regional experts. To determine diversity patterns, maps of regional species richness as well threatened (CR, EN and VU categories), DD and endemic species richness maps were produced.

2.4 | Major threats and species habitat classifications

Each species was coded according to the IUCN Major Threats and Habitats Classification Files (http://www.iucnredlist.org/technical-documents/classification-schemes/

TABLE 1 The number and proportion of all chondrichthyans (sharks, rays and chimaeras) assessed from the Arabian Sea and adjacent waters in each IUCN Red List of Threatened Species Category including the total for the three threatened categories (Critically Endangered, Endangered and Vulnerable) (in bold)

IUCN Red List Category	Red List status All species (%)	Red List status Sharks (%)	Red List status Rays (%)	Red List status Chimaeras (%)
Critically Endangered	14 (9.2)	5 (6.5)	9 (12.2)	0
Endangered	34 (22.2)	17 (22.1)	17 (23)	0
Vulnerable	30 (19.6)	17 (22.1)	13 (17.6)	0
Total threatened	**78 (50.9)**	**39 (50.6)**	**39 (52.7)**	**0**
Near Threatened	27 (17.6)	12 (15.6)	14 (18.9)	1 (50)
Least Concern	19 (12.4)	12 (15.6)	6 (8.1)	1 (50)
Data Deficient	29 (19)	14 (18.2)	15 (20.3)	0

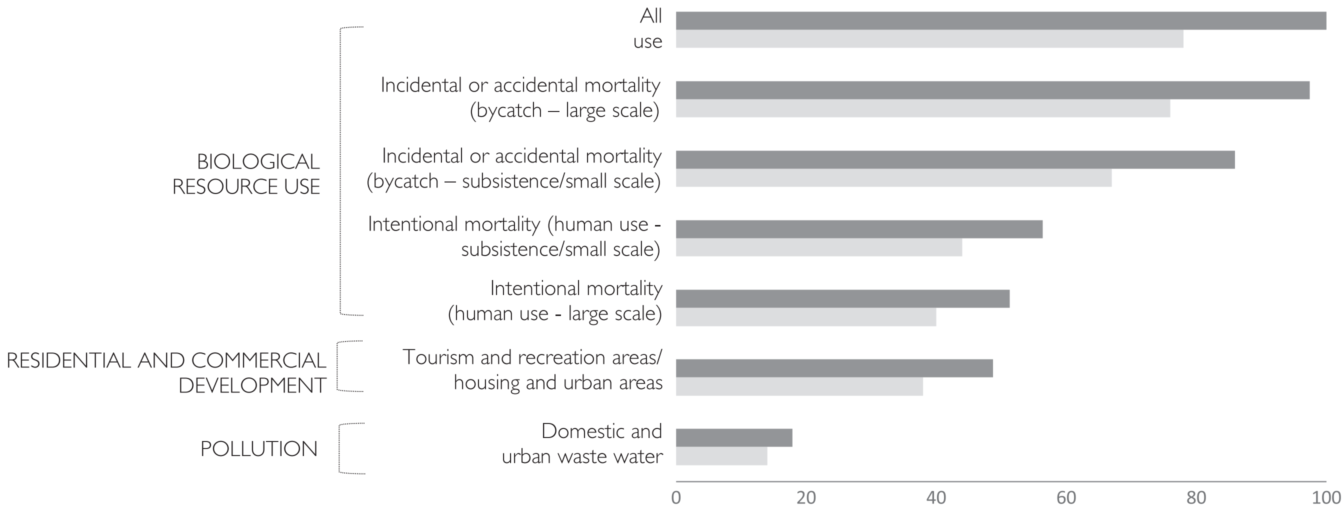

FIGURE 1 The primary threats driving chondrichthyans to extinction in the Arabian Sea and adjacent waters based on the proportion (dark grey) and number (light grey) of threatened species (Critically Endangered, Endangered and Vulnerable) impacted by the threat class. The "all use" category refers to both "intentional" mortality and "incidental" mortality

habitats-classification-scheme-ver3 and http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme). For the purposes of analysis presented here, we assigned chondrichthyans to five unique habitat–lifestyle combinations (coastal and continental shelf, pelagic, meso- and bathypelagic, deep water and freshwater) mainly according to depth distribution and, to a lesser degree, position in the water column (see Dulvy et al., 2014 for details). Upper and lower depth bounds were plotted according the IUCN Red List Categories assigned to each species. Regional threats known to have major impacts on species were coded, although their relative importance for each species was not described. The principal drivers of decline and local extinction risk were then evaluated and summarized for species considered threatened.

3 | RESULTS

3.1 | Species diversity

An estimated 184 chondrichthyan species are reported from the Arabian Sea and adjacent waters, representing 15% of valid described chondrichthyans globally (Eschmeyer et al., 2017). Thirty-one species were considered Not Applicable and were either vagrants (e.g. Megamouth Shark, *Megachasma pelagios*, Megachasmidae), species with questionable regional occurrences (e.g. Pencil Shark, *Hypogaleus hyugaensis*, Triakidae), species at the edge of their range (e.g. Mozambique Numbfish, *Narcine rierai*, Narcinidae), or species requiring further taxonomic revision for validation (e.g. Slender Bamboo Shark, *Chiloscyllium indicum*, Hemiscylliidae) (Ebert et al., 2013; Fernando, Perera, & Ebert, 2015; Last et al., 2016; R. W. Jabado, unpubl. data). As a result, 153 species of chondrichthyans were assessed, comprising 12 orders, 39 families and 84 genera. This included 77 shark species from seven orders, 22 families and 46 genera; 74 species of rays from four orders, 16 families and 37 genera; and two chimaeras from one order, one family and one genus (two species). Of these, 30 species (19.6%) were considered endemic to the Arabian Sea and adjacent waters.

3.2 | Trends in regional chondrichthyan landings

Chondrichthyan population declines in the Arabian Sea and adjacent waters were attributed to several factors, including fishing activities and the effects of habitat loss and environmental degradation (Figure 1). Although there is an increasing number of fishery-dependent surveys in the region, there was a real paucity of published trend information on fisheries catches and reliable species-specific landings data, particularly in the western part of the region in Djibouti, Egypt, Eritrea and Somalia. However, anecdotal evidence along with the available regional data supported large-scale declines in populations of many species. Below, we provide some examples of these declines from various countries.

In Pakistan, data from tuna gillnet vessels, which land approximately 55% of sharks, exhibited an 80% decline in shark landings from 22,471 t in 2002 to 4,660 t in 2011 (Moazzam, 2012). In India, the proportion of sharks in total fish landings declined from 64% in 1985 to 44% in 2013 (Kizhakudan, Zacharia, Thomas, Vivekanandan, & Muktha, 2015). Annual landings of rays by trawlers (which land 98% of rays) operating from New Ferry Wharf, Mumbai, during 1990–2004 ranged from 205.7 t to 765.1 t with an average of 502.8 t constituting nearly 1% of trawl catches (Raje & Zacharia, 2009). The trawling effort nearly doubled from 0.95 million hours (mh) in 1990 to 1.73 mhr in 2004, whereas the catch rate declined by 60% from 0.65 kg/hr in 1990 to 0.24 kg/hr in 2004. Furthermore, several chondrichthyan stocks such as stingrays (Dasyatidae) and blacktip sharks (*Carcharhinus* spp.) declined by 55% from their historical maximum catch or had already collapsed by 2008, respectively (Mohamed & Veena, 2016). In Sri Lanka, shark catches decreased by 30% over

5 years from 13,000 t in 1994 to 9,000 t in 1999 and were steadily declining since 2001 despite increasing effort (Dissanayake, 2005). De Silva (2006) noted that some species of reef-associated sharks such as the Zebra Shark (*Stegostoma fasciatum*, Stegostomatidae), Tawny Nurse Shark (*Nebrius ferrugineus*, Ginglymostomatidae) and Whitetip Reef Shark (*Triaenodon obesus*, Carcharhinidae) had become very rare in Sri Lankan waters due to overfishing. In the Maldives, shark populations were showing signs of decline in the early 1980s and many reef shark stocks in the northern atolls were reportedly overfished while oceanic stocks showed reduced catches (Ali, 2015). Results from interviews with fishermen in the UAE ("Gulf") and Eritrea (Red Sea) highlighted that fishers had seen significant declines in the abundance of sharks over the past two decades (Jabado, Al Ghais, Hamza, & Henderson, 2015; Tesfamichael, Pitcher, & Pauly, 2014). In Eritrea, these patterns of decline in "best" catch rates recorded from fishers (10.3% per year) (years where they landed the largest quantities) were similar to those observed using appraisal methods such as ecosystem modelling (11% per year) (Tesfamichael et al., 2014). Data from the monitoring of fish landing sites in Oman, Saudi Arabia (Red Sea) and the UAE indicated that shark fisheries were heavily exploited with larger, slower-growing species being replaced by smaller, faster-growing species over time (Henderson et al., 2004; Jabado et al., 2016; Spaet & Berumen, 2015). Reports from Iran based on a comparison of results from fisheries-independent trawl surveys in the "Gulf" indicated that the biomass of sharks (particularly whaler sharks, Carcharhinidae) had been decreasing since the 1970s (Valinassab et al., 2006). Whaler sharks (Carcharhinidae, mostly *Carcharhinus* spp.) comprised up to 22% of biomass in 1980–1981, yet 20 years later in 2002, they represented only ~2% (Sivasubramaniam, 1981; Valinassab et al., 2006).

3.3 | Extinction risk

Of the 153 chondrichthyan species assessed, 78 species (50.9%) were classified as threatened (Table 1). These species face an *extremely high* risk of extinction in the wild (CR: 9.2%), a *very high* risk of extinction in the wild (EN: 22.2%) or a *high* risk of extinction in the wild (VU: 19.6%). Twenty-seven species (17.6%) were considered NT. Nineteen species (12.4%) were LC and not considered to be at risk of extinction now or in the foreseeable future. For 29 species (19%), there was insufficient or inadequate information available on their distribution or abundance to make a direct or indirect assessment of their status and these were classified as DD. Of these DD species, 17 were only known from a few records with limited data on their biology and distribution.

Most threatened species were assessed under Criterion A (93.5%, *n* = 78 of 153), which is based on the rate of population decline over the longer time frame of three generation lengths (the median age of parents of the current cohort) or 10 years (IUCN, 2016). This is primarily because the main source of population trend data for chondrichthyans in the region is derived from catch or landings data, and fishery-dependent surveys. The remaining threatened species were assessed using the IUCN geographic range Criterion B (*n* = 2: Aden Torpedo and Red Sea Torpedo (*Torpedo adenensis* and *T. suessi*, Torpedinidae)), or the small population size and decline Criterion C (*n* = 3: Whale Shark (*Rhincodon typus*, Rhincodontidae), Pondicherry Shark (*Carcharhinus hemiodon*, Carcharhinidae) and Ganges Shark (*Glyphis gangeticus*, Carcharhinidae)). No species were assessed under Criteria D or E, as sufficient data to support the presence of a very small or restricted population, and for a fully quantitative assessment (e.g. population viability analysis), were not available.

3.4 | Status by major taxonomic group

Of the 39 families occurring in the region, 22 (56.4%) contain one or more threatened species (Figure 2). Ten of these families (25.6%) contain only threatened species such as sawfishes (Pristidae), giant guitarfishes (Glaucostegidae) and hammerhead sharks (Sphyrnidae), while 71.4% of the whaler sharks (Carcharhinidae) were also considered threatened.

The majority of species assessed as LC and DD occurred in the deepsea (below 200 m), therefore placing the majority of their populations outside the range of most current known fishing pressure (Figure 3). Those with widespread distributions and an abundant population were considered LC, and most of the families with all species considered LC had low diversity (represented by one or two species), limited geographical distributions and were found to be small (<50 cm TL) and not the focus of targeted fisheries. For example, the Shortbelly Catshark (*Apristurus breviventralis*, Scyliorhinidae) was only known from deep waters (1,000–1,120 m) around the Socotra archipelago, Yemen, beyond normal fishing operations. LC species included the kitefin sharks (Dalatiidae: one species), finback catsharks (Proscyllidae: two species), ground sharks (Pseudotriakidae: one species), sawsharks (Pristiophoridae: one species) and cow sharks (Hexanchidae: two species).

Efforts were made to place species into a category other than DD, and these assessments were mostly due to species with a limited number of records, limited geographic distribution and no information on their interaction with fisheries, resulting in a reduced capacity to evaluate their status. For example, the Arabian Catshark (*Bythaelurus alcockii*, Scyliorhinidae) is only known from one specimen caught in the Arabian Sea off Pakistan at a depth of over 1,000 m and its holotype is most likely lost (Compagno, 1990). The Bluespotted Maskray (*Neotrygon caeruleopunctata*, Dasyatidae) was only recently confirmed from the region, and its current taxonomic uncertainty limits a full understanding of the species' range and regional occurrence (Last et al., 2016). Families containing only DD species include the sleeper sharks (Somniosidae), bullhead sharks (Heterodontidae) and lantern sharks (Etmopteridae), each with two species (Figure 4). For the rays, the deepwater stingray (Plesiobatidae) and sixgill stingray (Hexatrygonidae) were also DD. Groups with the highest proportion of DD species include the skates (Rajidae; 80% DD), catsharks (Scyliorhinidae; 55.5% DD) and the torpedo rays (Torpediniformes: Narcinidae, Narkidae and Torpedinidae; 46.1% DD).

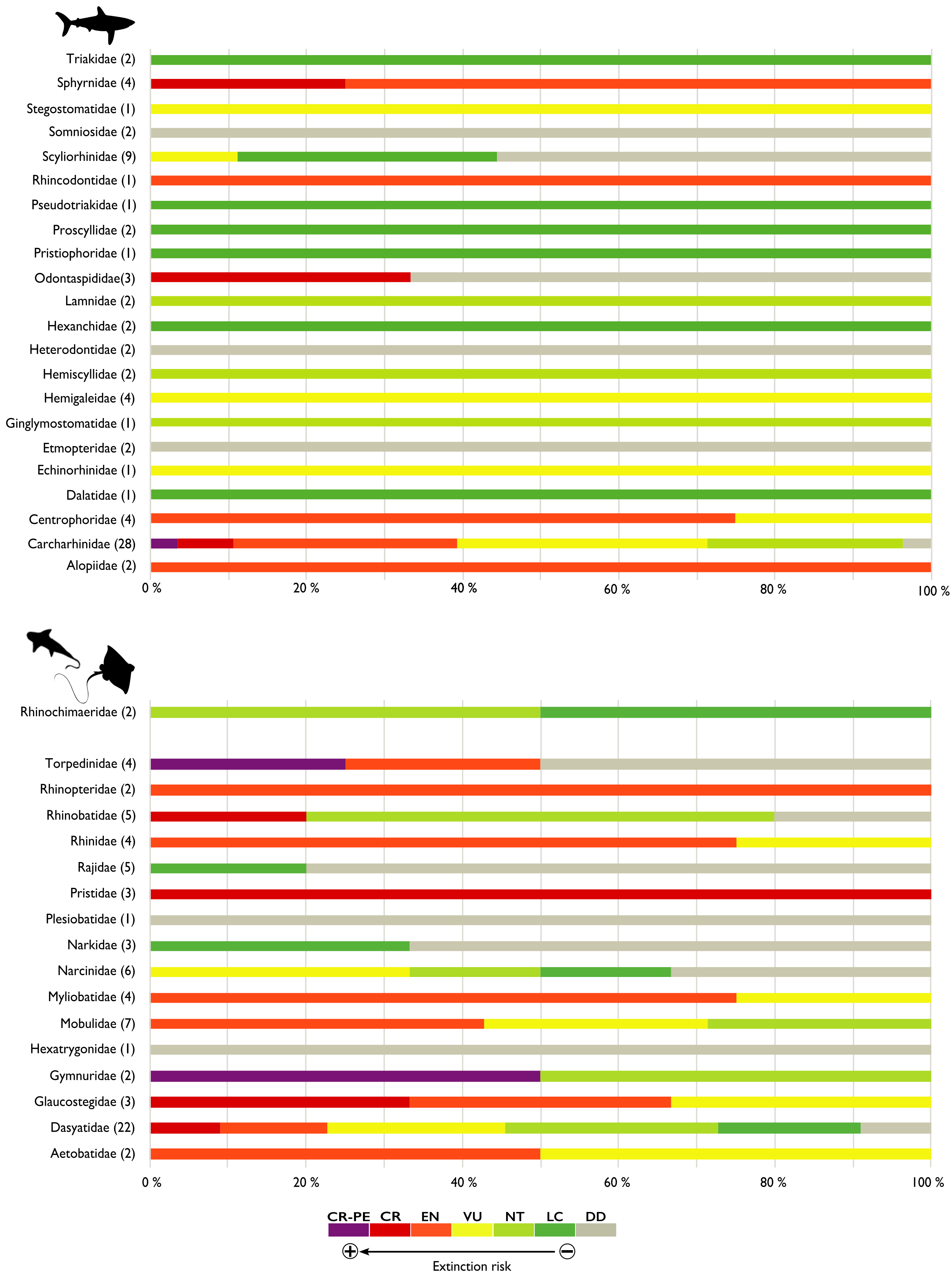

FIGURE 2 Percentage of species from the Arabian Sea and adjacent waters in each IUCN Red List of Threatened Species Category for each family of sharks, rays and chimaeras (the number of species per family is given in brackets)

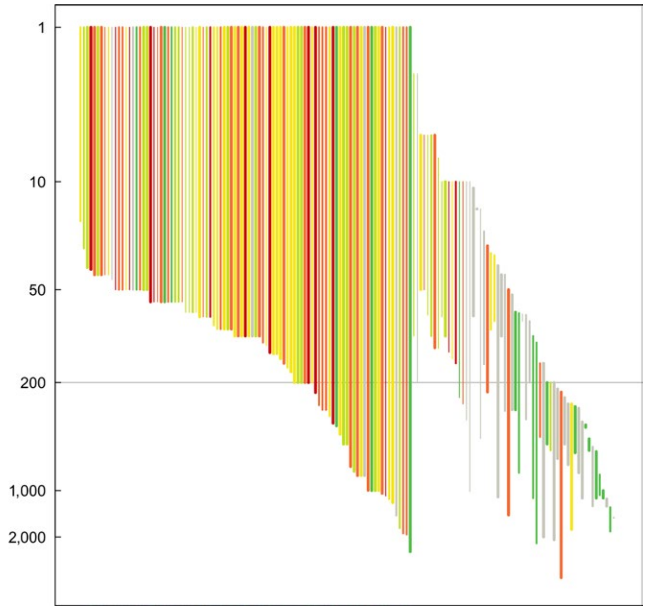

FIGURE 3 IUCN Red List Threat status and the depth distribution of chondrichthyans in the Arabian Sea and adjacent waters. Each vertical line represents the depth range (surface-ward minimum to the maximum reported depth) of each species and is coloured according to threat status: Critically Endangered (red), Endangered (orange), Vulnerable (yellow), Near Threatened (pale green), Least Concern (green) and Data Deficient (grey). Species are ordered left to right by increasing median depth. The depth limit of the continental shelf is indicated by the horizontal grey line at 200 m

Thirty chondrichthyans assessed were endemic to the Arabian Sea and adjacent waters. These endemics comprise three CR (10%), three EN (10%), two VU (6.6%), five NT (16.6%), eight LC (26.6%) and nine DD (30%) species. In total, 26.6% of the endemics are threatened.

3.5 | Spatial analyses

Species richness was highest in nearshore areas throughout the region, in particular along the coast of the Arabian Sea from the Sea of Oman south to Sri Lanka (Figures 5–8). The coasts of Oman and Yemen also exhibited high species richness, which declined towards the deeper waters of the Arabian Sea. The highest concentration of threatened species follows a similar pattern to species richness and also occurs in nearshore areas of the Arabian Sea but also in the "Gulf" and several other locations such as the Maldives and the Sea of Oman.

Areas that emerged as having a relatively high number of endemic species include the "Gulf," the Sea of Oman and the north-west Arabian Sea (Figure 7). No endemic shark species were found to occur in the Red Sea, but endemic species richness was high around the Socotra Archipelago, in the Arabian Sea. For rays, the "Gulf," Sea of Oman and north-west Arabian Sea harboured a high number of endemic species.

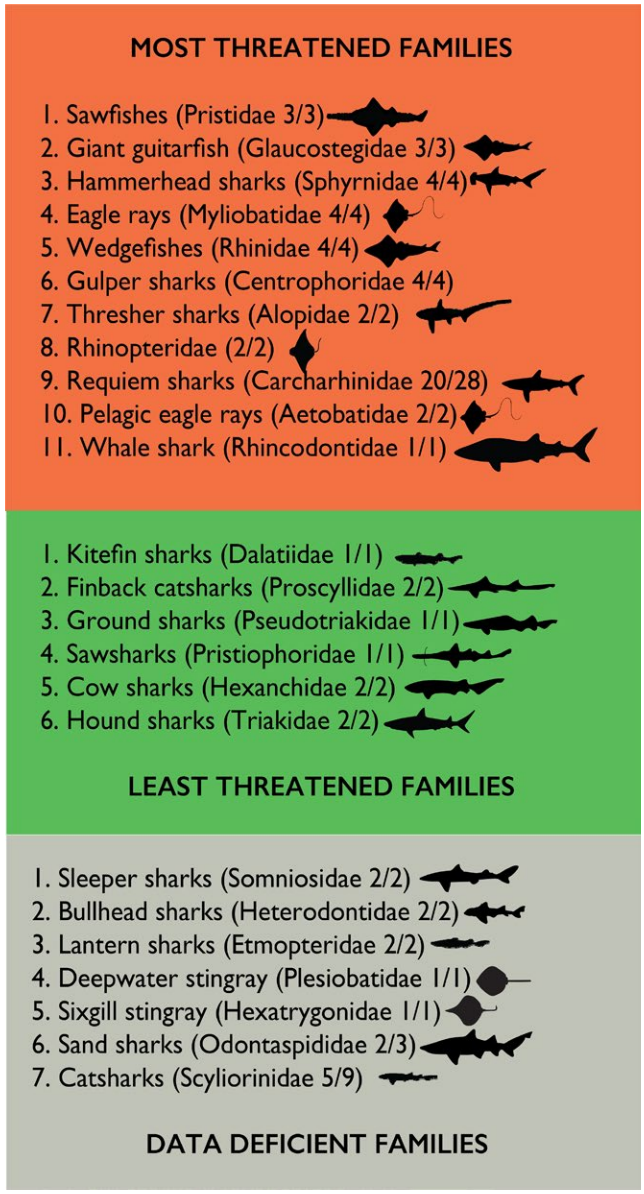

FIGURE 4 The taxonomic families in the Arabian Sea and adjacent waters with the most and least threatened species as well as those with the most Data Deficient species

High concentrations of DD species occur in southern India, Sri Lanka, the Maldives, Oman and Yemen (Figure 8). Areas of low DD species, especially for sharks, include the Red Sea, "Gulf" and Sea of Oman. On the other hand, these regions have higher numbers of DD ray species, particularly off Oman and Yemen.

4 | DISCUSSION

This study is the first regional IUCN Red List assessment of chondrichthyans in the Arabian Sea and adjacent waters and highlights that with 78 of 153 species threatened with an elevated risk of extinction (50.9%), this region has one of the highest proportions

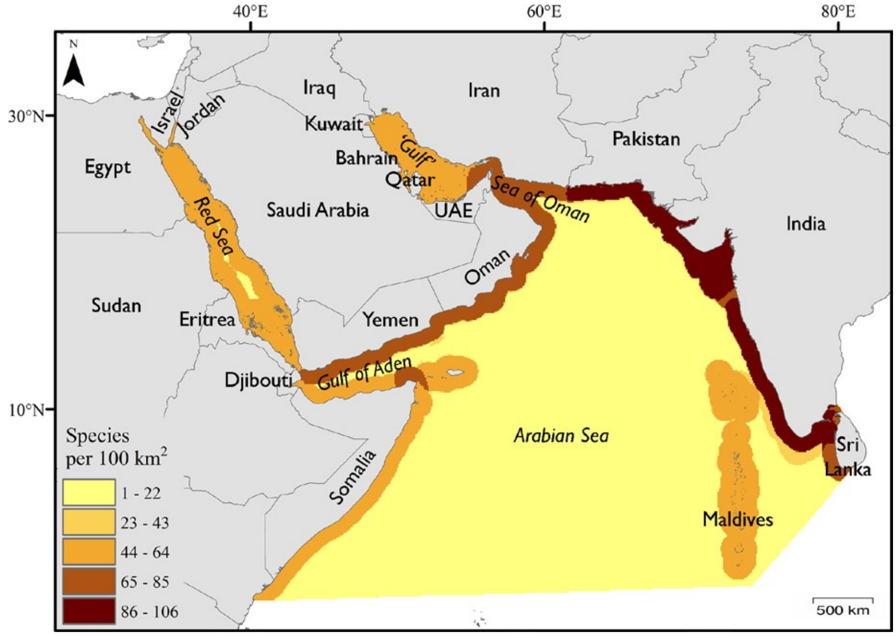

FIGURE 5 Chondrichthyan species richness in the Arabian Sea and adjacent waters

of threatened chondrichthyan species in the world. Even with limited data from many countries, overall results suggest that fisheries, particularly those in the eastern Arabian Sea, are severely affecting chondrichthyan populations. The proportion of threatened species is substantially higher than that from other areas where regional assessments have been conducted (Australia and Oceania: Cavanagh, Kyne, Fowler, Musick, & Bennett, 2003; Northeast Atlantic: Gibson, Valenti, Fordham, & Fowler, 2008; North America, Central America, and Caribbean: Kyne et al., 2012; European: Nieto et al., 2015). Only the Mediterranean region assessment revealed similarly high numbers of threatened chondrichthyan species, where 39 of 73 species were considered threatened (53.4%) (Dulvy, Allen, Ralph, & Walls, 2016). This regional extinction risk proportion is higher than the global assessment where one-quarter of chondrichthyans were predicted to be threatened (24%) (Dulvy et al., 2014). It has been recognized that certain locations have lower extinction risk at the regional scale (e.g. the United States: Kyne et al., 2012; Australia: White & Kyne, 2010) and our findings confirm that the global assessments may be underestimating risk at the regional level, particularly in the northwest Indian Ocean and the Mediterranean Sea.

Our results revealed that despite increasing fishery-dependent and fishery-independent surveys across the region, three species (Tentacled Butterfly Ray (*Gymnura tentaculata*, Gymnuridae), Red Sea Torpedo and Pondicherry Shark) have not been encountered in over 30 years and have been flagged as Critically Endangered–Possibly Extinct, suggesting possible regional extinction. With the poor taxonomic resolution of fisheries landings data across the Arabian Sea and adjacent waters, it is possible that declines or disappearances of the most sensitive species have been masked, and as such, further surveys to determine whether certain species (e.g. Pondicherry Shark) are still extant should be considered a high priority.

4.1 | Threatened species: the need for immediate action

Some of the families considered threatened encompass a disproportionately large amount of evolutionary distinctness (Stein et al., 2018). Of these, the sawfishes (Pristidae) have received the most attention in recent years, with remaining populations considered small and fragmented (Dulvy, Davidson, et al., 2016; Elhassan, 2018; Jabado, Al Baharna, et al., 2017; Moazzam & Osmany, 2014; Moore, 2015). Other species that have not been the focus of research in the region, such as the Sand Tiger Shark (*Carcharias taurus*, Odontaspididae) and the Winghead Shark (*Eusphyra blochii*, Sphyrnidae) have also severely declined in abundance (>80%) across their regional range. Subpopulations of such species, which are likely to be isolated with discrete geographical boundaries, can be threatened at the subpopulation level, despite lower documented population declines on an overall global basis. For these CR species, prohibitions on catch should be implemented without delay, protections enforced, and remaining populations closely monitored to avoid further declines and extinctions.

The proportion of threatened species differed among some of the major groups, pointing to different conservation priorities yet highlighting that immediate species-specific actions are required to ensure some species do not become locally or regionally extinct. Families with high numbers of threatened species and requiring particular attention include the eagle rays (Myliobatidae), wedgefishes (*Rhynchobatus* spp., Rhinidae) and giant guitarfishes (*Glaucostegus* spp., Rhinidae). Most species of eagle rays are generally rare, have low productivity and have restricted ranges, with their whole Arabian Sea and adjacent waters distribution subject to intense and increasing demersal fishing pressure. Indeed, the shallow depth distribution of many demersal or coastal species means that they are

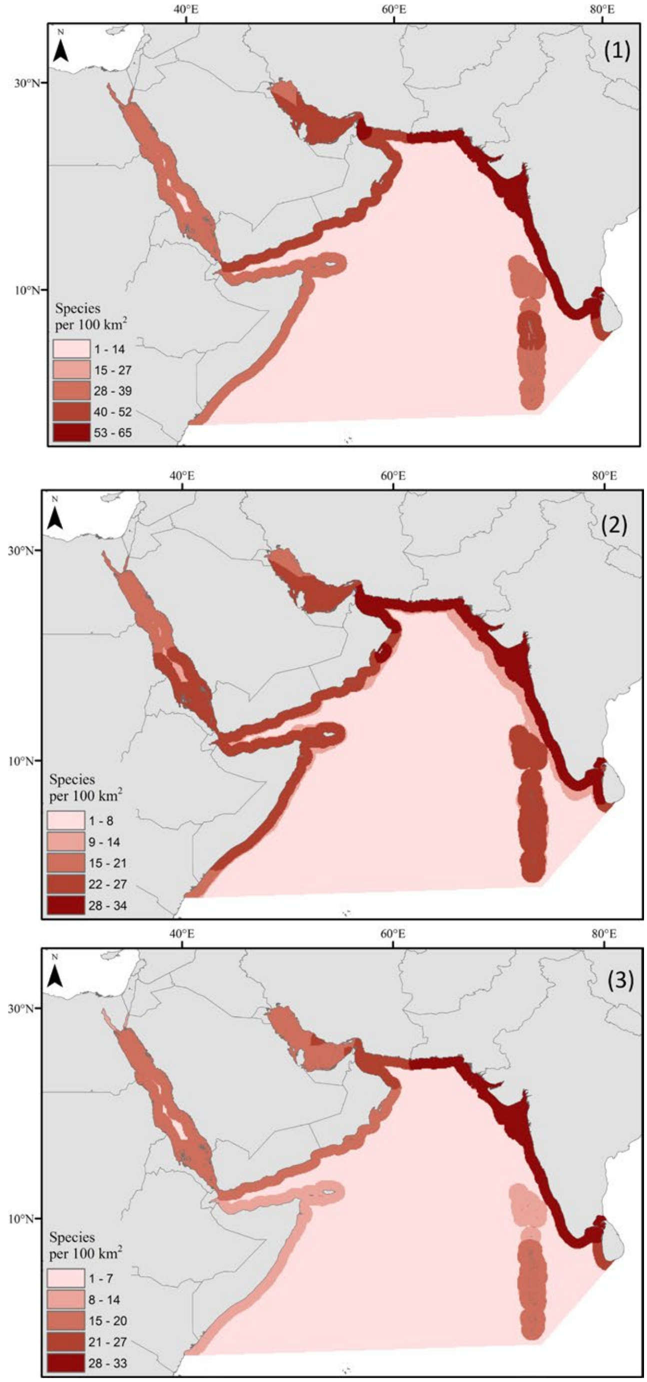

FIGURE 6 Distribution of threatened (Critically Endangered, Endangered and Vulnerable) (1) chondrichthyans, (2) sharks and (3) rays in the Arabian Sea and adjacent waters

unlikely to have a depth refuge from fisheries leading to large declines in populations. Wedgefishes and giant guitarfishes have high value fins, among the most prized in the shark fin market, and this demand has driven major declines in populations in less than a decade (Clarke, Magnussen, Abercrombie, McAllister, & Shivji, 2006; Mohanraj, Rajapackiam, Mohan, Batcha, & Gomathy, 2009; Moore, 2017). For example, landings in Chennai from Tamil Nadu fishermen, who widely fish throughout southern India (including western Indian waters), indicate that wedgefish and guitarfish trawl landings have decreased by 86% in just over 5 years of monitoring (2002–2006) despite increasing fishing effort (Karnad, Gangal, & Karanth, 2013; Mohanraj et al., 2009). Overall, these species are shallow-water inshore and coastal species, are susceptible to a wide range of gears from trawling to gillnets and beach-seines, and their distribution overlaps with intense fishing activities on the continental shelf. The combination of continued and increasing fishing pressure, the large impact of coastal development and destructive practices on their habitats, along with a low resilience to exploitation, threaten populations of these large-bodied species.

4.2 | Near Threatened species: the need for monitoring

Small-bodied guitarfish species, such as the poorly known Bengal Guitarfish (*Rhinobatos annandalei*, Rhinobatidae) and the Spotted Guitarfish (*R. punctifer*), lack species-specific information suggesting declines in populations, range or habitat quality, and were therefore assessed as NT. However, these species occur in shallow shelf waters, where fishing pressure is intense, and are frequently captured in inshore gillnet and trawl fisheries. Similar to larger guitarfish species, it is likely that they are unable to withstand prolonged exploitation, particularly if fishing pressure continues to increase (Mohanraj et al., 2009; Moore, 2017) and declines in landings of many of these species have already been documented (e.g. UAE: R. W. Jabado, unpubl. data).

Other small-bodied (<1 m total length) commercially important species that dominate landings across the region (e.g. the Milk (*Rhizoprionodon acutus*) and Spadenose (*Scoliodon laticaudus*) sharks, Carcharhinidae) did not meet criteria for a threatened category due to suspected population declines of <30% over the past three generations (Henderson et al., 2007; Jabado et al., 2016; Kizhakudan et al., 2015; Moore et al., 2012; Spaet & Berumen, 2015). These species, which are early to mature, are among those that are generally considered to be more resilient than late-maturing and larger ones (Cortés, 2016; Pardo et al., 2016). They are mostly taken as by-catch in artisanal fisheries, utilized for meat consumption and sometimes for their fins, and despite their life history, current levels of exploitation could cause population declines. For example, data from Karnataka in India indicate that stocks of the Spadenose Shark are declining after a peak in landings in 1985 (Mohamed & Veena, 2016). The status of these species should be closely monitored, and management measures such as catch limits must be put in place to avoid their movement into threatened categories.

4.3 | Least Concern species: food security opportunities

Many of the families dominated by LC species have low diversity (represented by one or two species), have limited geographical distributions and/or occur in the deepsea beyond the current range of intensive fisheries. These have a limited regional range in shallow inshore waters with scarce data on their biology but are mostly

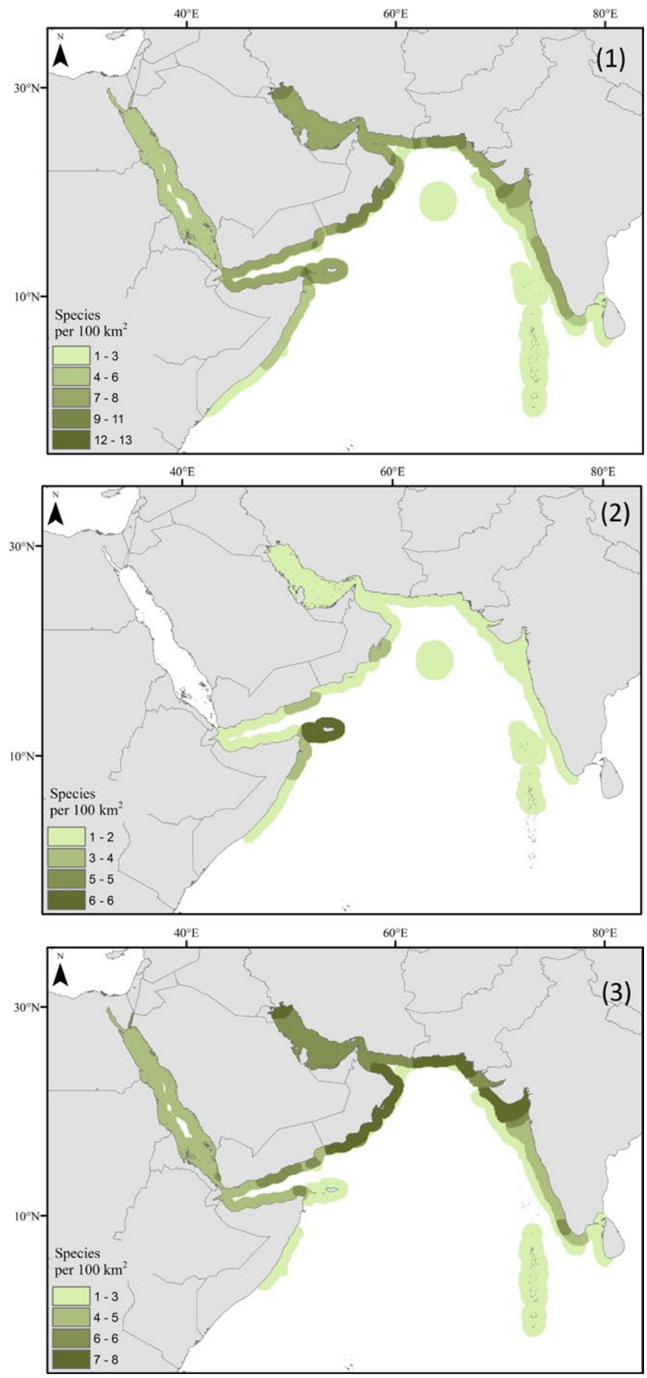

FIGURE 7 Distribution and species richness of (1) chondrichthyans, (2) sharks and (3) rays endemic to the Arabian Sea and adjacent waters

discarded from fisheries in the region. While there is currently no information on postrelease mortality, declines in their populations have not been reported. With an increase in the retention of rays in the region and fisheries expanding to deep waters of the Arabian Sea (Akhilesh et al., 2011; Jabado & Spaet, 2017), these LC species are likely to become increasingly important for ensuring food security and the fisheries interacting with them need to be actively managed to ensure their sustainability.

4.4 | Data Deficient species: addressing knowledge gaps

Patterns of data deficiency in certain species groups should be used to prompt research initiatives across the region. Indeed, Data Deficient listings highlight the need for additional data collection, with the possibility that some species may meet threatened criteria with a better understanding of threats and their populations. This is especially true as many DD species occur within the range of expanding deepsea fisheries that may quickly begin to threaten them (i.e. southwest India). Worldwide, 46% of chondrichthyans are DD, one of the highest documented rates of DD of any taxonomic group to date (Dulvy et al., 2014; Hoffmann et al., 2010). The relatively high proportion of DD species (19%) in the Arabian Sea and adjacent waters highlights the large knowledge gap and the need to increase capacity for chondrichthyan research and monitoring to generate data on which reassessments can be based.

4.5 | Drivers of extinction risk: fisheries and habitat degradation

4.5.1 | Trends in fishing effort

Declining catches in the region are a result of reducing stocks in response to rapidly increasing fishing effort and improved technological efficiency of fishing gear. In Iran, there is increasing fishing effort with the number of fishermen increasing from 70,729 in 1993 to 109,601 in 2002 (Valinassab et al., 2006). In the Red Sea, the number of traditional boats operating more than tripled from about 3,100 to 10,000 between 1988 and 2006 while the number of Yemeni boats and fishermen operating in the Gulf of Aden at least doubled between 1990 and 1999 and reached 74,820 fishermen in 2012 operating on 20,803 vessels (Bruckner, Alnazry, & Faisal, 2011; Shaher, 2007; Ministry of Fish Wealth, Yemen, pers. comm.). Along the west coast of India, over 13,400 gillnetters operate, with many other types of net gear also deployed in coastal areas (CMFRI, 2010). Furthermore, while there were about 6,600 trawlers operating in the Indian state of Gujarat in the early 2000s, this number almost doubled to 11,582 trawlers in 2010 (CMFRI, 2010; Zynudheen, Ninan, Sen, & Badonia, 2004). In Eritrea, catch and effort data shows that fishing effort and catches increased more than twofold from 1996 to 2002, with total catch increasing from approximately 400 to 900 t/year and effort from approximately 420 to 1,600 standardized trips/year (Tsehaye, Machiels, & Nagelkerke, 2007). In India, the mechanization of fishing fleets increased by 57% between 1960 and 1990, contributing to a situation of over-capacity and overfishing (Mohamed & Veena, 2016).

4.5.2 | Emerging trends: deepsea fisheries

The development and rapid expansion of intense deepsea fishing is a growing concern especially in the south-eastern Arabian Sea. Gulper shark stocks (*Centrophorus* spp., Centrophoridae) off the Maldives

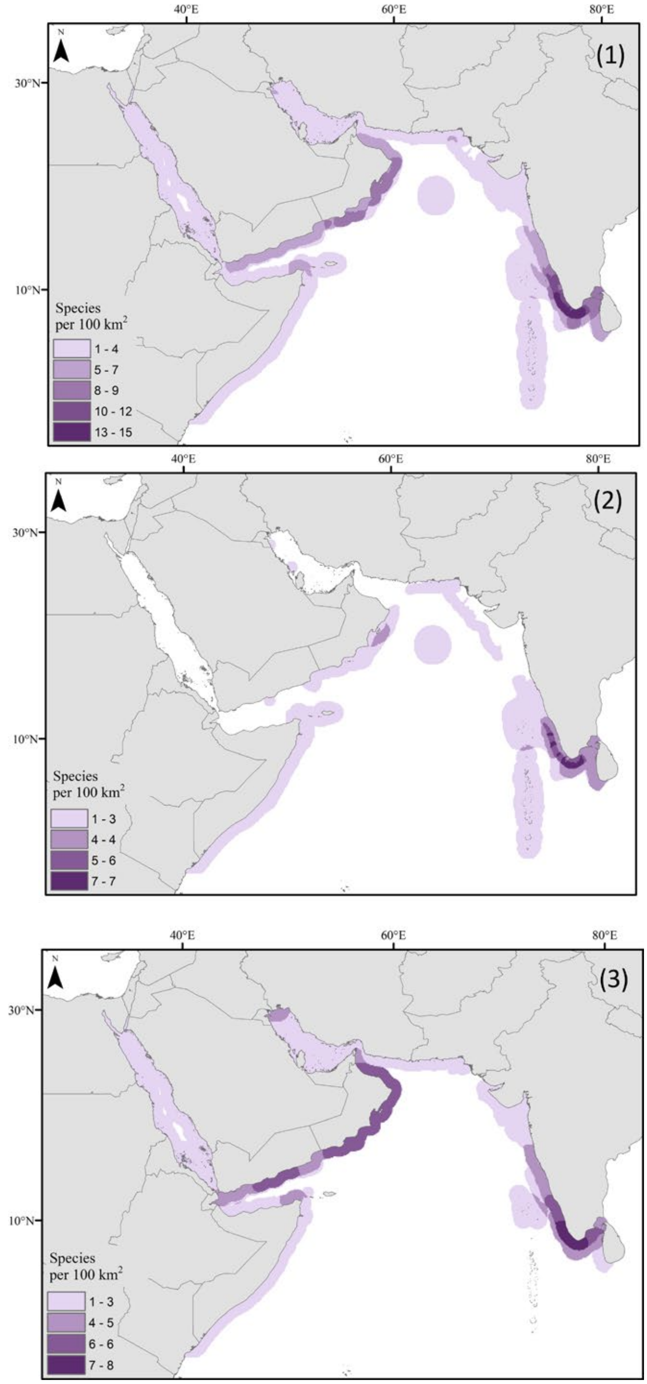

FIGURE 8 Distribution of Data Deficient (1) chondrichthyans, (2) sharks and (3) rays in the Arabian Sea and adjacent waters

collapsed in the early 2000s due to a 20-year targeted fishery to supply the demand for shark liver oil (Ali & Sinan, 2014; Kyne & Simpfendorfer, 2010; Simpfendorfer & Kyne, 2009). During the same period, a targeted gulper shark fishery developed off south-west India for liver oil production, and *Centrophorus* spp. were reported as a major by-catch of the shrimp trawl fishery that expanded to deeper waters (Akhilesh, Bineesh, Ganga, & Pillai, 2013; Akhilesh, White, Bineesh, Ganga, & Pillai, 2013; Akhilesh et al., 2011). Deepsea shark stocks are suspected to have also collapsed in Indian fisheries after a significant increase in landings with an apparent decline in the size of individuals landed between 2002 and 2008 (Akhilesh & Ganga, 2013; Akhilesh, Bineesh, et al., 2013; Akhilesh et al., 2011). These stock declines within a short period of time after the beginning of their exploitation demonstrate that the limited biological productivity of *Centrophorus* spp. restricts their ability to sustain directed or by-catch fishing pressure and makes them highly susceptible to overexploitation (Ali & Sinan, 2014; Garcia, Lucifora, & Myers, 2008; Graham, Andrew, & Hodgson, 2001; Simpfendorfer & Kyne, 2009). Although the gulper shark fishery has ceased off the Maldives, given their life-history population recovery is expected to be very slow (Simpfendorfer & Kyne, 2009).

At the same time, there have been considerable changes in the species composition of landings compared to those reported during the 1980s and 1990s with new deepsea species being recorded such as the Velvet Dogfish (*Zameus squamulosus*, Somniosidae) (Akhilesh, Bineesh, et al., 2013; Akhilesh et al., 2011). Patterns of changes in composition are also reported from Sri Lanka where a targeted deepsea shark fishery using bottom longlines on the continental slope developed in the early 1980s (Herath & Maldeniya, 2013). Because most deepsea trawl fisheries currently only exist off western India and Sri Lanka, it is likely that other deepsea species might find refuge in areas where they occur. For example, the Harlequin Catshark (*Ctenacis fehlmanni*, Proscyllidae) has only been collected in deepwater surveys (over 200 m depth) off Oman and Somalia (Compagno, Dando, & Fowler, 2005; Springer, 1968) and does not appear to currently interact with fisheries. However, as marine fish stocks from nearshore waters off the south-eastern Arabian Sea are heavily exploited, it is likely that fisheries will continue to expand into deeper water with likely incursions into waters outside national EEZs, putting many species under pressure.

4.5.3 | Foreign fleets and pelagic fisheries

In addition to national fisheries, foreign fleets operate in the EEZs of many countries. Considering the warning signs of elevated extinction risk and the small number of species assessed as LC, food security in the region is jeopardized. These concerns are exacerbated by most countries in the region that allow, or have previously allowed, access rights to foreign fleets to operate in their waters (Jabado & Spaet, 2017). Accurate numbers of vessels operating in each countries' territorial waters are not available, but most reports suggest that illegal unregulated fishing occurs with increasing incursions of fleets in waters outside their national jurisdiction. For example, there has been an expansion of industrial trawling in the Red Sea through licences issued to foreign industrial trawlers (particularly off Yemen), which has resulted in the depletion of marine resources (PERSGA, 2002). In Somalia and Yemen, illegal and unregulated fishing by foreign and regional trawlers and longliners is widespread and impacting shark populations (De Young, 2006; Glaser et al., 2015; Moazzam, 2012; Tesfamichael, Rossing, & Saeed, 2012). Glaser et al. (2015) suggest that Somali shark capture production averaged 10,200 t annually between 2005 and 2009. These numbers are comparable to reported landings in Yemen and would make Somalia one of the largest chondrichthyan fishing nations in the Arabian Sea and adjacent waters. Catch estimates when including those of foreign fleets operating in Somali waters (e.g. from Egypt, Greece, Italy, Iran, Japan, Pakistan, South Korea, Sri Lanka and Yemen) reach 26,000 t per year. In history, from 1963 to 1989, the USSR conducted industrial bottom and pelagic trawl fisheries on the Arabian Shelf in Oman, Somalia and Yemen (Gulf of Aden and Socotra Archipelago) under license agreements with coastal countries. Annual catches of elasmobranchs, mostly rays exceeded 4,800 and 4,500 t in 1972 and 1973 respectively, and steadily decreased to <50 t by the end of fisheries reflecting decreased fishing effort and the shifting of targeting from demersal fish to small pelagics (Romanov & Kukharev N.N., unpubl. data).

At least 400 longline vessels and purse seine fleets from countries in the European Union, as well as China, Japan, South Korea and Taiwan, are active in the waters of the north-west Indian Ocean (IOTC, 2013). Pelagic fisheries have operated in the Indian Ocean for more than 50 years with Japanese longliners in the western region since 1954 (Honma & Suzuki, 1972). Taiwanese, USSR and South Korean vessels have fished there since ~1956, 1964 and 1966, respectively (Borodatov, 1968; NMFS, FSFRL 1980). The introduction of large-scale tuna purse seine fisheries in 1982 also increased pressure on pelagic sharks, in particular those associated with fish aggregation devices (FADs) (Filmalter, Capello, Deneubourg, Cowley, & Dagorn, 2013; Romanov, 2002, 2008). The reported volumes of shark by-catch in fisheries targeting tuna and swordfish in the Indian Ocean have been constantly increasing since the early 1990s, peaked at 120,000 t in 1999, and have remained relatively stable since (IOTC, 2016a). Some longline fleets also switched to targeting sharks in later years (Indian Ocean Tuna Commission (IOTC), 2016a). Significant reductions in many pelagic species are thought to have occurred as a result of this intensive pelagic fishing effort (IOTC, 2016b). The major by-catch of foreign longline, purse seine and local driftnet fleets include thresher (*Alopias* spp., Alopiidae), Silky (*Carcharinus falciformis*, Carcharhinidae), Blue (*Prionace glauca*, Carcharhinidae), Oceanic Whitetip (*C. longimanus*, Carcharhinidae), Shortfin Mako (*Isurus oxyrinchus*, Lamnidae) and hammerhead (*Sphyrna* spp.) sharks. In the Indian EEZ, there has been a decline in the catch per unit effort of pelagic sharks from a peak at 2.4 sharks per 100 hooks in 1991 to 0.09 sharks per 100 hooks in 2006 (John & Varghese, 2009), highlighting the need for urgent conservation and management measures.

4.5.4 | Habitat modifications

It is clear that modifications to the natural environment are affecting a variety of species, particularly small coastal sharks and rays, as well as large species that use inshore habitats for breeding and nursery functions (e.g. Jennings, Gruber, Franks, Kessel, & Robertson, 2008). Across the Arabian Sea and adjacent waters, marine habitats have experienced high levels of disturbance and are quickly deteriorating in quality due to major impacts from anthropogenic activities. Red Sea coral cover has markedly declined in the last 30 years, mirroring increased coastal construction (Price et al., 2014). In the "Gulf," major impacts on marine habitats have been documented with the removal of shallow productive areas due to rapid large-scale residential and commercial coastal development, desalination plants, chronic and acute releases of oil (e.g. war-related), and the damming of the Tigris–Euphrates river system (Sheppard et al., 2010). For example, coastal seafilling (sometimes referred to as "land reclamation") has resulted in the almost total loss of mangrove areas around Bahrain (Morgan, 2006). In the broader Arabian Sea, intensive bottom trawling has reduced the complexity of benthic habitats, affecting the epiflora and epifauna and likely reducing the availability of suitable habitats for predators and prey (Bhagirathan et al., 2014; Kaisser, Collie, Hall, Jennings, & Poiner, 2002; Stevens, Walker, Cook, & Fordham, 2005). The Indus River, one of the few estuaries in the Arabian Sea and adjacent waters, has been severely impacted by riparian habitat degradation and pollution (including untreated discharge from industrial and chemical plants), increasing river use, sand mining and the construction of dams and barrages, which have fragmented the habitat, altered flow and affected river productivity (Braulik, Noureen, Arshad, & Reeves, 2015).

Fishermen across the region target shark and ray breeding aggregations and nursery areas, and land high volumes of juveniles of various species including Scalloped Hammerhead (*Sphyna lewini*, Sphyrnidae) and Silky sharks leading to concerns about the potential effects on targeted species (Bonfil, 2003; Henderson et al., 2007; Jabado, Al Ghais, Hamza, & Henderson, 2015; Spaet & Berumen, 2015). Furthermore, some species, such as the Ganges shark, listed as Critically Endangered, have high habitat specificity to estuaries and rivers, which increases their susceptibility to the impacts of human activities. However, mating and nursery areas have not been defined for most species and critical habitats, particularly for offshore, open water, and deepsea species, are virtually unknown.

4.6 | Regional chondrichthyan management

While there has been progress with chondrichthyan management in the region, it remains poorly developed and inconsistent across countries due to stark differences in governance capacity and available data with which to inform policy (De Young, 2006; Pitcher, Kalikoski, Pramod, & Short, 2009). Fisheries in most of the region are managed by input and output controls developed for teleost fisheries, and yet, some have either fully banned the fishing of sharks and/or rays (e.g. Maldives, Saudi Arabia, Sudan) or protected several species (e.g. India, Pakistan, Sri Lanka, UAE) (Ali, 2015; Jabado & Spaet, 2017; Kizhakudan et al., 2015). However, fisheries monitoring is so limited that it is difficult to evaluate whether these measures have been successful. In fact, effective enforcement is a challenge and an ongoing issue for most countries, political will appears to be weak, and current restrictions appear to be inadequate to ensure the long-term survival of many species and populations (see details in Jabado, Kyne, et al., 2017; Jabado & Spaet, 2017).

Regional Fisheries Bodies (RFBs) across the region have generally not adopted or developed actions for chondrichthyan fisheries (Fischer, Erikstein, D'Offay, Guggisberg, & Barone, 2012; Jabado & Spaet, 2017). The Indian Ocean Tuna Commission, of which 10 countries bordering the Arabian Sea are parties to, maintains the most comprehensive suite of measures in relation to other RFBs, when dealing with the conservation and management of a few shark species that have been identified as severely overfished in the region. These measures include the prohibition of the retention of certain species, the collection of elasmobranch catch statistics in fisheries targeting tuna and swordfish, and the stock assessment of sharks (Indian Ocean Tuna Commission (IOTC), 2013). Other RFBs, such as the Regional Commission for Fisheries, Regional Organization for the Protection of the Marine Environment and the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden, have yet to adopt any measures for the conservation and management of sharks (Jabado, Kyne, et al., 2017; Jabado, Al Baharna, et al., 2017). International measures developed through various agreements to ensure sustainable catches, collection of species-specific fisheries data, special protections for threatened species, trade controls and the conservation of biodiversity are slowly being recognized (Fischer et al., 2012; Mundy-Taylor et al., 2014). These range from different sets of binding rules and nonbinding principles that are relevant to chondrichthyan species on a global, regional and national level. Although many Parties to the Convention on the International Trade in Endangered Species of Flora and Fauna (CITES) from the region are increasingly focusing their efforts on capacity-building of enforcement officials, the challenge of effective implementation remains. To circumvent CITES trade controls, black markets have developed, and exporters have resorted to mislabelling products or using new trade routes (Jabado & Spaet, 2017). Furthermore, while two countries (notably India and Sri Lanka) have taken steps to develop nondetriment findings, which are required to justify trade under CITES, overall there is still insufficient knowledge of how various fisheries are impacting species, particularly in data-poor situations.

4.7 | Future directions and recommendations

Chondrichthyan fisheries are of increasing economic and commercial importance in the Arabian Sea and adjacent waters primarily for food security through the provision of animal protein and income from the trade of products such as fins, meat, liver oil, gill plates (Mobulidae) and leather. This is particularly true as most teleost fisheries are over-exploited and chondrichthyans are becoming a valued by-catch of traditional fisheries, with increased retention of all species of sharks and rays (Clarke et al., 2006; Jabado & Spaet, 2017; Lack & Sant, 2011). This demand for fish is expected to increase given the growing animal protein needs, especially in developing countries (Mora et al., 2009). In parallel, populations of some chondrichthyan species in the Arabian Sea and adjacent waters have been so reduced that the only way to rebuild them, and avoid collapse with great certainty, is to shut down major fisheries until stocks are rebuilt to healthy levels. Even if this were possible, recovery would be slow because once collapsed, most fish populations do not recover rapidly, if at all (Hutchings & Reynolds, 2004). But in reality, it is unlikely that governments in the region will respond to documented chondrichthyan declines through measures to reduce fishing, especially considering the economic impact this would have on fishing communities. For example, along India's west coast, over 2 million fishers are involved in this industry and any measures such as bans will have a direct impact on their livelihoods (De Young, 2006). Simpfendorfer & Dulvy (2017) highlight that sustainable chondrichthyan fisheries are possible and require strong science-based management that focuses on protecting species with the lowest biological productivity. Yet, comprehensive management and recovery strategies require a good understanding of species behaviour, habitat, ecology and evolution, which affect population growth at low abundances (Hutchings & Reynolds, 2004). Directed and long-term research efforts in this region towards chondrichthyans are slowly increasing, particularly in India, Iran, Pakistan, Saudi Arabia, Sudan and the UAE. Yet, they lag behind the rest of the region with only snapshots of the current situation available. Furthermore, species-specific population assessments are available for very few species, and mostly only for species that are covered under RFB mandates (e.g. Blue Shark). The continued discovery of new chondrichthyan species within the region, and the need for resolution of taxonomic issues related to even some of the most well-known species, reinforces that research needs to be not only sustained, but increased in the fundamental fields of taxonomy, systematics, life history, ecology and fisheries.

The challenge for nations bordering the Arabian Sea and adjacent waters will be to ensure that precautionary policies are developed and protections are enforced. Indeed, it is often stipulated that fisheries management monitoring, implementation and effectiveness are affected by the economic and development status of a country, with high-income or high-development status countries, having significantly better fisheries management than low-income countries (Davidson et al., 2015; Gutierrez, Hilborn, & Defeo, 2011; Mora et al., 2009; Pitcher et al., 2009), but this might not be the case in the Arabian Sea and adjacent waters. The region is surrounded by some of the richest and poorest nations in the world, and yet, we could argue that the lower- and middle-income economies here have at the least better fisheries monitoring and policy development (Jabado & Spaet, 2017). Indeed, while countries surrounding the "Gulf" and bordering half of the Red Sea have high human development indexes, they remain data-poor due to little survey efforts, as well as a lack of infrastructure to monitor and report chondrichthyan catches (Jabado & Spaet, 2017; UNDP, 2016). On the other hand, India, considered a lower middle-income economy, has the most comprehensive fisheries database dating back to 1947 (CMFRI, 2010; UNPD, 2016).

Data collection and availability are an essential precursor to fisheries management, and we noted several challenges in compiling and analysing fisheries data from this region. First, we found that additional fisheries time-series data sets were available to certain workshop participants that had not been previously made public and disseminated. These showed important declines in batoids and the collapse of many carcharhinid species. Our results should serve to raise red flags calling for conservation actions while there remains a chance of recovery for some species and the prevention of permanent biodiversity loss. Despite long-standing warnings about population declines (e.g. Bonfil, 2003; Devadoss, Kuthalingam, & Thiagaranjan, 1989; Henderson et al., 2007; Valinassab et al., 2006), there is still no mechanism in place to ensure the funding, development and implementation of management plans for chondrichthyans in the region. Governments across the region should be encouraged

TABLE 2 Recommendations for governance and research actions that would contribute to the rebuilding of chondrichthyan populations in the Arabian Sea and adjacent waters

Governance
1. Use the outcomes of these assessments to inform revisions and implementation of relevant national legislation such as catch limits, size limits, and areal and/or seasonal closures (including meaningful penalties for violations);
2. Make provisions for the full protection of chondrichthyan species considered as CR and EN in the region, even when these are not listed on international agreements;
3. Take immediate measures to reduce incidental catches of species assessed as threatened and encourage proper handling techniques and live release;
4. Ensure implementation and compliance with requirements from international agreements (i.e. CMS Appendix I listings for signatory countries and issuance of CITES nondetriment findings for Appendix II species);
5. Propose and support the listing of additional threatened chondrichthyan species under CITES and CMS;
6. Sign and engage in the implementation of the Sharks MoU under CMS;
7. Initiate the development of National Plans of Action for the Conservation and Management of Sharks along with a Regional Shark Plan specifically aimed at increasing cooperation between countries in relation to the conservation and sustainable use of commercially exploited and by-caught chondrichthyans;
8. Establish and enforce MPAs with no-take zones to ensure they provide adequate protection to threatened species, and to alleviate pressure on certain nonmigratory species and on the critical habitats (e.g. breeding and nursery areas, feeding grounds) that are necessary for their conservation;
9. Ensure that the assessment and consenting (e.g. Environmental Impact Assessment process) of marine and coastal developments adequately consider project-specific and cumulative impacts of habitat loss and modification on chondrichthyan species;
10. Implement catch limits in accordance with scientific advice and when sustainable catch levels are uncertain, implement fishing limits based on the precautionary approach;
11. Strengthen finning bans, if applicable, by requiring all sharks taken in all fisheries to be landed with their fins still naturally attached;
12. Propose and work to secure science-based chondrichthyan conservation measures nationally and within RFMOs, especially for fisheries that target or affect species assessed as threatened or NT; and,
13. Engage with RFMOs to fully document fisheries including mapping of areas fished and fishing effort deployed through observer programmes or technologies such as vessel monitoring systems.
Research
1. Develop and facilitate training, particularly in the fields of taxonomy and population monitoring methods (to enable the accurate collection of species-specific landings data) and stock assessment;
2. Collect fisheries-dependent data on artisanal and commercial fisheries, especially data on catch composition, by-catch, landings, discards and catch per unit effort;
3. Improve knowledge of species by expanding fisheries-independent monitoring (especially for threatened and DD species), and ensure that such data are shared with relevant scientific bodies and RFMOs;
4. Conduct basic biological research for deepsea and DD species, particularly those that are commercially exploited;
5. Assess population status and safe fishing levels for chondrichthyan populations through stock assessments and ecological risk assessments with priority given to heavily fished, unassessed populations;
6. Promote research on gear modifications and fishing methods aimed at mitigating chondrichthyan by-catch and discard mortality;
7. Encourage research aiming at identifying and mapping of critical habitats in the region;
8. Establish monitoring schemes for small-scale artisanal and recreational fisheries;
9. Improve species identification for those taxa with threatened species and taxonomic problems, in all data collection activities (including both commercial landings and scientific surveys). This can be achieved through the provision of species identification training to fishers, observers and researchers; and,
10. Evaluate the feasibility of cooperative programmes to promote viable, sustainable livelihood alternatives to chondrichthyan fishing

Note. CITES: Convention on the International Trade in Endangered Species of Flora and Fauna; CMS: Convention on Migratory Species; CR: Critically Endangered; DD: Data Deficient; EN: Endangered; MPA: Marine Protected Area; NT: Near Threatened; RFMO: Regional Fisheries Management Organization.

to publish available information on fisheries catches and make these data available to allow for in-depth analysis of the current status of species. Second, for many countries, when data were available, species-specific information was difficult to obtain for certain species groups with landings reported in aggregate form. At last, the data available were mostly less than three decades old; therefore, maximum reductions over that time frame are likely underestimates, as true historic maxima will have occurred well before fisheries management agencies began collecting data on species abundance (Hutchings & Reynolds, 2004). This limited data availability suggests that impacts on chondrichthyan populations in the region and reductions in stocks could in fact be much greater than reported here. This highlights the importance of effective fisheries monitoring and data dissemination moving forward.

At last, results from these assessments provide an important baseline for monitoring the regional status of chondrichthyans and indicate that encouraging improvements to our knowledge base through concerted research and monitoring should be a priority. It is clear that it is possible to draw together a network of researchers from the region and improve collaboration and engagement. Coalitions now need to further include policy and decision-makers to regulate the exploitation of already depleted stocks and improve enforcement mechanisms. In the light of this newly collated information on chondrichthyans in the Arabian Sea and adjacent waters, a series of governance measures and research priorities that could support the conservation and management of chondrichthyans in the region are proposed in Table 2. This is not meant to be an exhaustive list of recommendations, but any progress made on these actions is likely to deliver conservation benefits to the most threatened species. The highest priorities should be directed at reducing fishing pressure and habitat loss by strengthening law enforcement and building the capacity of local communities to pursue sustainable livelihoods along coastal areas. The future of threatened chondrichthyans in the Arabian Sea and adjacent waters rests in the willingness and the ability of individual countries to take actions in their national waters but also to collaborate with neighbouring nations.

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