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Elasmobranchs of the western Arabian Gulf: Diversity, status, and implications for conservation

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Abstract :

In spite of the ecological services provided by elasmobranchs, their diversity and populations are significantly declining even before appropriate assessments are conducted. This paper presents information on elasmobranch diversity in the Saudi waters of the Arabian Gulf based on fishery-independent and dependent surveys. A total of 369 individual sharks and batoids were collected from 119 out of 228 trawl stations surveyed between 2013 and 2016. Gymnura poecilura and Carcharhinus dussumieri were the most dominant batoid and shark species, respectively. The catch per unit area indicated the waters around Jana Island as a hotspot of elasmobranchs. A total of 135 surveys at the landing sites and fish markets from 2016 to 2020 showed that 88% of elasmobranchs (out of 4,055 individuals recorded) were caught by gill nets. Sharks were the most abundant (> 80 %) with three dominant species: Carcharhinus sorrah, C. humani, and C. limbatus. In total, 47 species of elasmobranchs (24 sharks and 23 batoids) belonging to 16 families and 5 orders were recorded from a possible 58 total species predicted by species richness extrapolators (Chao 1). High values of Margalef richness (> 2) and Shannon-Wiener index (3-4) suggested rich diversity of elasmobranchs in the study area with homogeneous distribution over the years and seasons as shown by cluster and similarity profile analysis. Of the 47 species recorded, six species were Critically Endangered regionally, six Endangered, and seven species Vulnerable according to the IUCN Red List of Threatened Species, necessitating proper management and conservation measures.

Keywords : Batoid, sharks, diversity, conservation, fishery, management

Introduction

Sharks and batoids are members of the class Elasmobranchii, which is distributed worldwide in the tropical, subtropical, temperate, and cold waters. They are found from the coastal to offshore waters except in the freshwater habitats (Gemaque et al., 2017). Their fundamental role as top predators is crucial for the health of marine ecosystems through their regulatory role on the structure and function of marine communities (Chapman et al., 2006; Heithaus et al., 2008; Bornatowski et al., 2014). However, elasmobranchs are one of the most threatened groups of marine wildlife because of their reproductive traits and long-life span (Stevens et al., 2000; Lucifora et al., 2011; Gemaque et al., 2017). An estimated 71% reduction in biomass of elasmobranchs globally has been estimated since the 1970s with around 75% of the species threatened with extinction (Pacoureau et al., 2021).

The Arabian Gulf (also known as the Persian Gulf, hereinafter referred to as the 'Gulf') is known for its fossil fuel reserves. It witnesses a flurry of activities associated with the expansion of oil exploration and production. In addition, the Gulf is considered an extreme environment due to high evaporation rate, high salinity, low rainfall, and extreme temperatures (Reynolds, 1993; Almazroui et al., 2013; Naser, 2014; Pal and Eltahir, 2015; Hasanean and Almazroui, 2015). Therefore, the marine environment of the Gulf is reported to be under increased pressure (Sheppard et al., 2010; Jabado et al., 2015b; Rabaoui et al., 2015; Vaughan et al., 2019). In spite of the extreme environmental conditions and the increasing anthropogenic pressures in this region, the Gulf still hosts various habitats such as coral reefs, seagrass meadows and mangroves, and rich fish and shellfish biodiversity (Rabaoui et al., 2015, 2017, 2019, 2021a & b; Lin et al., 2021a, b & c).

Among the different zoological groups living in the Gulf, elasmobranchs are still very poorly known, and their biodiversity is not yet fully documented, in particular in the Saudi waters. Given the anthropogenic pressures posing on the Gulf environment, the protection of elasmobranchs and sustainability of their fisheries is challenging without strong information on their biodiversity and distribution. Compared to the Red Sea where elasmobranchs have been already assessed as overexploited (Sheppard et al., 2010; Qurban et al., 2012; Naser, 2014; Spaet and Berumen, 2015), knowledge on the status of elasmobranchs in the Gulf are still limited and patchy. An interview-based survey conducted in the United Arab Emirates (UAE) showed that sharks have been overexploited in the southern Gulf (Jabado et al., 2015a) and that elasmobranchs are facing the risk of regional extinction in the Gulf (Jabado et al., 2017a; Moore, 2017; Jabado, 2018). The present work was conducted with this concern, and it aims at *i*) characterizing the elasmobranch community in the Saudi waters of the Gulf based on fishery-independent and dependent surveys, *ii*) reviewing the conservation status of these taxa, and *iii*) making recommendations for strengthening management plans for these natural resources.

Materials and methods

Fishery-independent surveys

Four trawling surveys were conducted between 2013 and 2016 using a chartered commercial outrigger. To adequately cover the entire territorial waters of Saudi Arabia in the Gulf, sampling was done in 228 stations (Fig. 1). The trawl surveys were conducted on a commercial outrigger *Afrah* in 2013 and 2016 (Rabaoui et al., 2015) and on a research vessel *RV Bahith II* in 2014 and 2015. We compared the length distributions of the fish from both fleets to assess the catchability of elasmobranchs. The differences were observed only on extremely small-sized fish (total length < 30 mm), which was greatly smaller than the observed elasmobranch (> 300 mm). Therefore, we assumed that the catchability of elasmobranchs was similar between the two fleets.

All the trawling operations were conducted following a standard operation protocol. Trawling was done during the daytime with the speed of three knots for 30 minutes. At each station, the total catch consisting of fishes, invertebrates, and sea snakes was weighed. The total number of individuals and total weight of all elasmobranchs were recorded species-wise after photographing and identification. Specimens collected were identified following the identification keys of Carpenter et al. (1997), Ebert et al. (2013), Almojil et al. (2015), Jabado and Ebert (2015), and Last et al. (2016).

In addition, data on the occurrence of the blotched fantail ray, *Taeniurops meyeni*, and the whale shark, *Rhincodon typus*, were collected through a series of boat-based observational surveys conducted between 2014 and 2020. These surveys were conducted as part of another study on the migration patterns of *R. typus*. (Table 1; Hsu et al., *unpublished data*). The scientists were on a commercial boat and navigated to areas where *R. typus* was previously observed. The team patrolled around this area and assessed the occurrence of *R. typus* by visual observation.

Fishery-dependent surveys

Landing surveys

Elasmobranch landings from the commercial fisheries were surveyed over the 135 visits to fishing ports and fish auction markets at Manifa, Jubail and Qatif between March 2016 and February 2020 (Fig. 1). The team identified the elasmobranchs species and recorded species-specific landing in numbers and weights every month. The gears used to catch elasmobranchs, such as trawl and gill nets, longlines, traps, trolling and handlines, were also recorded.

Data analysis

The catch per unit area (CPUA, ind./km^2) and biomass per unit area (BPUA, kg/km^2) were calculated as the abundance and biomass index for the fishery-independent surveys (Ghotbeddin et al., 2014; Scanlon, 2018):

CPUA = catch in numbers × [trawling speed × trawling time × net-width)]$^{-1}$

BPUA = catch in biomass × [trawling speed × trawling time × net-width)]$^{-1}$

As the elasmobranch CPUA and BPUA did not meet the normality assumptions according to the Shapiro-Wilk test (Abundance: n = 119, W = 0.609, P < 0.001; Biomass: n = 119, W = 0.665, P < 0.001), the nonparametric Wilcoxon test was performed to compare the CPUA and BPUA of stations close to oil and gas facilities with that of stations far from such facilities.

A one-way non-parametric permutational multivariate analysis of variance (PERMANOVA) was used to test for shifts in elasmobranch community in relation to years, latitude (26.5-29.0 °N by 0.5 degree), longitude (48.5-51.0 °E by 0.5 degree), and CPUA ranges (0- >500 ind./km^2 by 100 ind./km^2) on fishery-independent surveys. Species compositions between the landings and fishery-independent surveys were also compared by PERMANOVA. This analysis was conducted in package *vegan* (Oksanen et al., 2019) in R (R Core Team, 2021) with 999 permutations (Anderson, 2001).

In landing surveys, weighing all specimens was not always feasible. On such occasions, we randomly selected sub-samples of more than 10 individuals for each species from the landings and calculated their average weights to estimate the total biomass of each species. In the case of species with a single individual records such as *Chiloscyllium arabicum* and *Himantura leopard* and with which it was not possible to take measurements, we used the average weights from the trawl surveys where they were collected. Seasons were defined as spring (March-May), summer (June-August), autumn (September-November), and winter (December-February) following Jabado et al. (2015b). Assemblage of elasmobranchs during the various years, seasons, and gears (gill net, longline, trawl, trap, other hook and line gears, and unknown gears) was compared employing Similarity Profile Analysis over Bray-Curtis similarity matrix using PRIMER 7 (Version 7.0.13).

The diversity of elasmobranchs was assessed through various ecological parameters such as Shannon-Wiener diversity index (H'log$_2$), Margalef richness index (d), Pielou's evenness index (J'), and Simpson dominance index (λ'). Chao 1 estimator was used to estimate the lower limit of the species richness.

To estimate the actual number of elasmobranch species in the region, a species accumulation curve was drawn using a variety of estimators, such as Chao 1, Chao 2, Jackknife 1, Jackknife 2, Bootstrap, and Michaelis Menton (MM) employing PRIMER 7.

The number of species listed in the literature for the Gulf countries since 1999 combined with fishermen's and social media reports with images sufficient to identify the species was used to determine the presence-absence of the species in six Gulf countries (Saudi Arabia, Bahrain, Kuwait, Qatar, UAE, and Iran). Hierarchical cluster analysis was applied to assess the degree of elasmobranch community similarity among these countries based on Jaccard's similarity index and Ward's algorithm (ward. D2) using R.

Results

<u>Fishery-independent surveys</u>

A total of 369 elasmobranch specimens were collected from 119 out of 228 trawled stations. Among these, 324 individuals were weighed with a total weight of 1,178 kg. The estimated total weight of all 369 individuals was 1386 kg (Table S1). Elasmobranchs formed 12.9% of the total catch in biomass. When the stations with no elasmobranch catches were excluded, the elasmobranch biomass was in the range of 0.1-80.6% of the total biomass with an average of 19.7% (± SD 20.5%) of the total catch. During these surveys, a total of 24 elasmobranch species (7 sharks and 17 batoids) were identified in addition to two batoid species of doubtful identification (Table 1, Table S1, Fig. S1). In terms of abundance, the total catch was dominated by the single gymnurid species, *Gymnura poecilura*, which constituted 37.7% of the total number of individuals, followed by dasyatids (20.6%) and carcharhinids (15.2%). Species such as *G. poecilura*, *Carcharhinus dussumieri*, and *Brevitrygon walga* constituted respectively 37.7%, 13.0%, and 11.1% of the total number of individuals. In terms of biomass, dasyatids (38.0%), gymnurids (25.1%), and carcharhinids (12.7%) contributed more than 75% of the total weight. The dominant species were *G. poecilura* (25.1%), *C. dussumieri* (12.1%), and *H. leoparda* (11.1%) (Fig. 2 A & B; Table S1). In the Saudi waters of the Gulf, the most commonly distributed species were *G. poecilura* and *C. dussumieri* (Table S1). Elasmobranch community structure did not vary significantly with respect to latitude, longitude, and year among 0.5×0.5-degree cells (Table 2).

In general, high values of CPUA (> 800 ind./km^2) were observed around the offshore island of Jana (Fig. 3A). Low CPUA values were recorded along the coastal and offshore waters of Ras Tanura with an average (±SD) of 149.4±209.9 ind./km^2 (Fig. 3A). The high BPUA values (>1,500 kg/km^2) were found in three areas: Jana Island waters, Manifa-Safaniya offshore waters, and the southeastern waters close to the border between Saudi Arabia and Bahrain with an average of 550.8±834.3 kg/km^2 (Fig. 3B). Our results suggested that the habitats around Jana Island act as a hotspot for elasmobranch abundance. Large-sized elasmobranchs occurred mainly in the areas off Manifa to Safaniya, and in the southeastern waters.

No significant differences were observed in CPUAs between the areas with and without marine facilities for both perimeters of 5 and 10 km (Wilcoxon test, 5 km: W_{119} = 2106.5, P = 0.37; 10 km: W_{119} = 2368, P = 0.40). Similarly, no significant differences were found in BPUA at an α level = 0.05 (5 km: W_{119} = 2181.5, P = 0.08; 10 km: W_{119} = 2215.5, P = 0.09).

Landing surveys

In total, 4,055 elasmobranchs were recorded during the 135 monthly visits conducted between March 2016 and February 2020 to fish landings sites and fish auction markets. Out of these, 3,554 specimens (87.6%) were caught by gill nets, 323 (8.0%) by hook and line, 151 (3.7%) by trawl net, and two specimens (0.1%) by traps. The remaining 25 individuals (0.6%) were caught by unknown gears. A total of 38 species of elasmobranchs was recorded, including 22 sharks, 14 batoids, and 2 un-identified species (Table 1; Table S2; Fig. S1). Sharks contributed the majority of the landings in both abundance (85.6%) and biomass (84.1%) (Table S2). In terms of abundance, carcharhinids were dominant and contributed 80.2%, followed by rhinopterids (8.6%) and myliobatids (4.4%). In terms of biomass, carcharhinids also prevailed the total landings (72.2%), followed by rhinopterids (10.3%) and sphyrnids (10.2%). In terms of spatial occurrence, carcharhinids were the most common group followed by sphyrnids (Table S2). At species level, highest abundance values were recorded with *C. humani* and *C. sorrah* (21.1% and 19.6% of the total number of landed elasmobranchs, respectively). The contributions of *Rhizoprionodon acutus* (10.7%) and *Rhinoptera jayakari* (8.6%) were comparatively lower. In terms of biomass, *C. sorrah* contributed the most with 22.3% of the total landings, followed by *C. humani* (14.4%) and *C. limbatus* (10.4%) (Fig. 2B; Table S2). Significant difference in the structure of elasmobranch community was found between fishery-independent surveys and landing surveys (PERMANOVA: F = 37.819, P < 0.001).

Diversity indices

In total, 45 elasmobranch species (24 shark species + 21 batoid species + 2 un-identified species) belonging to 16 families and 5 orders were recorded during this study (considering all survey types conducted in the Saudi waters of the Gulf.

The number of species in the fisheries-independent surveys conducted during 2013-2016 ranged between 10 (in 2015) and 15 (in both 2013 and 2016). Overall, Chao 1 predicted the occurrence of 58 species. While the highest values of Margalef richness (4.29), Shannon-Wiener diversity (3.73), and Pielou's evenness (0.95) were recorded in 2016, the lowest records were found in 2015. An opposite trend was observed with the Simpson dominance index (λ'), with the highest record (0.117) in 2015 and the lowest (0.049) in 2016 (Table S3). Species assemblage did not differ significantly among the years (Similarity Profile Analysis, π = 0.99, P = 0.896).

The number of species varied among seasons with 21 in autumn and 32 in winter in the fishery-dependent surveys. Similar seasonal variations were observed with elasmobranch abundance, with the lowest (545 individuals) and highest (1435 individuals) values recorded in incidences in autumn and winter, respectively. The diversity indices taken into consideration also followed the same seasonal patterns showing the lowest records in autumn and the highest in winter or spring (Table S4). However, the elasmobranch assemblage did not differ significantly among the seasons (Similarity Profile Analysis, $\pi = 1.78$, $P = 0.088$). Some shark species caught in winter, such as *C. arabicum*, *Mustelus mosis*, *Paragaleus randalli*, *Loxodon macrorhinus*, *C. melanopterus*, and *Sphyrna lewini* as well as the batoids *Rhynchobatus australiae*, *Glaucostegus halavi*, *Rhinobatos* sp., *Pastinachus ater*, *G. poecilura*, *Aetobatus flagellum*, and *Aetomylaeus milvus* were conspicuous by their absence during autumn. Similarly, species such as *Hemipristis elongate* and *A. ocellatus* caught during autumn were never found during winter.

Gear-wise analysis of data collected during the years 2016-2020 showed that the lowest and highest number of species and individuals were collected in traps (2 species, 2 specimens) and gill nets (35 species, 3565 specimens), respectively (Table S5; Fig. S2). Similarly, minimum and maximum values of Margalef richness and Shannon diversity were also recorded with catches of these fishing gears. In the case of Shannon's diversity index, the highest value was recorded with the catches of longline. While the highest records of Pielou's evenness and dominance index were found with the catches of traps and hook and line, respectively, the lowest records were noted with gill nets and traps, respectively (Table S5). The species compositions were significantly different among fishing gears ($\pi = 8.29$, $P = 0.001$; Fig. 4A), except between the trawl and longline ($\pi = 0$, $P = > 0.9$, Fig. 4A).

Taking into consideration the gear-wise data, the elasmobranch community structure was found to vary significantly among seasons and trawling/non-trawling periods (Table 3). However, when the trawl landings data were excluded, no significant changes were revealed among the trawling and non-trawling periods. The significant seasonal changes in the elasmobranch community structure indicate that elasmobranch landings varied among seasons (Table 3). Although carcharhinids prevailed in the catches throughout the year, they showed low percentages in the gillnet and longline catches during spring and summer. It is also worth noting that no guitarfishes (rhynchobatids and rhinobatids) were recorded in summer, and that myliobatids were mainly caught by trawls and longlines. In addition, hammerhead sharks (sphyrnids) were mainly caught by hook and line (Figs. S2 and S3).

<u>Similarity in the elasmobranch communities among the Gulf countries</u>

Historical data showed the occurrence of 45 species of elasmobranchs in the Saudi waters, 29 species in Kuwait, 26 species in Bahrain, 25 species in Qatar, 27 species in Iran, and 47 species in UAE, totaling 70 species in the Gulf (Table 1). The Jaccard's similarity index among the Gulf countries showed higher similarity in the elasmobranch community between Bahrain and Qatar (0.65; Table 4). Lower similarity was found between the communities occurring in Iran and UAE (0.25; Table 4). The dendrogram showed two groups in different intra-similarity levels: one group with high similarity formed by the elasmobranch communities occurring in the waters of Kuwait, Saudi Arabia, and Bahrain (Western Arabian Gulf countries), and the other with less similarity formed by the communities occurring in the Qatari, Iranian, and Emirati waters (Fig. 4B).

Discussion

Knowledge on elasmobranch diversity remained fragmentary in the Gulf region despite several studies conducted in various countries (Vossoughi and Vossoughi, 1999; Moore et al., 2012; Moore and Peirce, 2013; Niamaimandi et al., 2014; Jabado et al., 2015b; Bishop et al., 2016). The present study attempted to fill this knowledge gap. Employing both fisheries-independent and dependent data, the occurrence of 47 elasmobranch species in the Saudi waters of the Gulf is reported (Table 1, S1, S2). Jabado et al. (2015b) found in UAE higher species richness of elasmobranchs based on fisheries data than what was previously thought. Landing survey data showed higher records of species richness, diversity, and evenness index compared to those of fisheries-independent surveys conducted using a single fishing gear. Margalef species richness (2.71-6.18) and Shannon-Wiener diversity (3.01-4.4) values recorded in this study were on the higher side. Higher Margalef richness value of above 2.05 and Shannon diversity in the range of 3-4 indicated that the elasmobranch diversity and community structure occurring in the Saudi waters of the Gulf are in good status, as per the Water Framework Directive of the European Union (Borja et al., 2004).

It is crucial to integrate multiple surveys like a long-term and continuous monitoring of landings and various fishery-independent surveys to reveal the full picture of the elasmobranchs in the Saudi waters of the Arabian Gulf. The occurrence of only one shark and five batoid species in the fishery-independent trawl surveys lend support to the fisheries-dependent landing site surveys as species like *C. arabicum* and *Stegostoma fasciatum* are always discarded offshore due to low market value, as well as covered a large part of uncommon fishing areas. In the fishery independent surveys, batoids formed 78.6% in terms of abundance. However, in the fishery dependent surveys, batoids formed only 14.4%. On the contrary, the fishery-independent survey using trawl net might also miss specimens due to gear selectivity as 16 shark and three batoid species documented in the landing surveys were never encountered in the fishery-independent surveys (Table 1). Moreover, we documented *R. typus* and *T. meyeni* in boat surveys, further widening the spatial coverage of this study.

The species recorded in the study area included six regionally Critically Endangered (CR), six Endangered (EN), and seven Vulnerable (VU) species as per the IUCN (International Union for Conservation of Nature) Red List of Threatened Species (Table 1; Jabado et al., 2017b; IUCN, 2020). Due to poor knowledge on the ecology, biology, and population status of these species, ecological risk assessment could not be done besides adopting appropriate management plans (Moore, 2012; Rastgoo et al., 2016; Raeisi et al., 2017; Rastgoo et al., 2018). *C. limbatus*, *C. sorrah*, *R. acutus*, and *S. lewini* are the four heavily exploited species in the Arabian Peninsula (Spaet et al., 2015) and were found to be dominant in the commercial catches (except *S. lewini*). *C. sorrah* contributed more in terms of biomass and ranked second in terms of abundance. *C. limbatus* was the second most dominant species in terms of biomass. *R. acutus* ranked third in terms of abundance (Fig. 2B, Table S2). The biology and population status of these species besides the two endemic species of the Gulf, *C. humani* and *R. jayakari*, which were recorded for the first time in this study, should also be studied to know their stock structure and to draw management plans (Fig. 2B, Table S2). Due to the secluded nature of the Western Gulf region, conservation of elasmobranch diversity and resources has to be prioritized (Lucifora et al., 2011).

Higher similarity in elasmobranch assemblages between the Kuwaiti, Saudi, and Bahraini waters (Jaccard's index; 0.49-0.65, average 0.57) revealed homogenous distribution of shark species in this contiguous waterbody (Table 2, Fig. 4B). The higher turnover of species in Iran and UAE waters is attributed to proximity with the Strait of Hormuz that connects the Gulf to the Arabian Sea. These facts suggest the need for regional collaboration and cooperation between these countries to protect and conserve the elasmobranch resources. Moreover, the recent capture of the longcomb sawfish (*Pristis sijsron*) from Fasht al Jārim, north off Bahrain (March 2018; Fig. S4) confirmed that this Critically Endangered species is still present in the Arabian Gulf, in particular in the Saudi-Bahraini waters. This necessitates appropriate management plan for protecting this species.

The waters around Jana Island were found to be an elasmobranch hotspot in the Saudi Gulf waters, showing the ecological importance of this island. It is the second largest coral Island in the Saudi waters of the Arabian Gulf (after Karan Island; Miller et al., 2019), which hosts a great biodiversity of fish and shellfish that might attract elasmobranchs (Lin et al., 2021a, b & c). Al Merghani et al. (2000) also reported that the waters of Jana Island constitute an important habitat for marine turtles. Because of its closeness to the coast and as it hosts various megafauna species in its waters, Jana Island has been exposed to various human activities such as sport fishing and tourist diving, impacting the local fauna, including elasmobranchs as observed during our field observations. In view of these facts, establishment of a marine protected area must be considered to protect the biodiversity of the ecologically important Jana Island. In the same sense, Manifa-Safaniya complex was also found to host an important biodiversity of elasmobranchs, most likely because this region hosts important seagrass meadows and a great shellfish and fish associated community (Rabaoui et al., 2015, 2017, 2021a). These faunistic assemblages are likely to attract megafauna species such as marine mammals and elasmobranchs (Rabaoui et al., 2021b).

As per the findings of the present study, the Saudi waters were found to host the second richest elasmobranch diversity in the Gulf region (Tables 1 and 4). The elasmobranch biomass was also found to be higher than that of the Iranian waters (Ghotbeddin et al., 2014; Niamaimandi et al., 2014). The average depth of the Gulf is around 35 m, with a high range of variation in sea surface temperature between winter and summer (15 - 36°C), and salinity exceeding 43 psu (Naser, 2014). In such an extreme environment, Saudi Arabia has a relatively high elasmobranch diversity, species richness, and biomass in the Gulf. One of the important reasons for this may be the presence of higher number of oil platforms which restrict fishing operations in their vicinity and thus, serve as the biggest "de facto MPA" (marine protected area) in the Gulf (Rabaoui et al., 2015). The elasmobranchs occurring in these areas seem to feed on the fish and shellfish assemblages associated with these marine structures. In other areas of the Gulf, tuna also gather under or close to marine platforms, probably to spawn in these locations. This suggests the role of marine platforms as fish aggregating devices, which indirectly attract megafauna such as *R. typus* for feeding (Robinson et al., 2013).

Saudi Arabia has banned shark fishing in the Red Sea and the Gulf since 2008 and requires fishermen to release all the sharks alive when caught (Jabado et al., 2017b). Also closed season for trawl fishing has been implemented for years (Jabado et al., 2017b). However, gill net happens to be the main gear for the capture of elasmobranchs in the Gulf based on the present data. A similar study conducted in the Mediterranean Sea showed that illegal fishing of elasmobranchs is a reality (Giovos et al., 2020). Moreover, small sized pregnant specimens of many species of elasmobranch were caught through gill nets (H. H. Hsu *pers. comm.*). Therefore, bringing additional limitations on the gear design (like mesh size) and fishing ban for gill net (fishing season) in addition to the creation of MPAs (covering Jana Island) are recommended to protect elasmobranch diversity in the Saudi Arabian waters of the Gulf.

Conclusion

The set of information provided in this manuscript shows the diversity and community structure of elasmobranchs occurring in the Saudi waters of the Gulf. The important ecological roles played by the offshore island of Jana and the northern offshore marine structures are also highlighted. This study also showed that many threatened species are being caught by the local fisheries, necessitating adoption of an adequate and urgent management and conservation plan. Further detailed studies are still needed for to better understand the ecological importance of elasmobranch community and its interactions with the other components of the Gulf ecosystem.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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Table 1. Taxonomic list of elasmobranch species in the Arabian Gulf based on literature, fisherman's reports, and social media, with specimens encountered after 1998. IUCN Red List Status is also included (CR: Critically Endangered; EN: Endangered; NT: Near Threatened; VU: Vulnerable; LC: Least Concern; DD: Data Deficient; NE: Not Evaluated). X: species present

Family/Species	IUCN global status	IUCN Arabian Sea status	Kuwait	Saudi Arabia	Bahrain	Qatar	Gulf Iran waters	Gulf UAE waters
Hemiscylliidae								
Chiloscyllium arabicum	NT	NE	X	X[a, b]	X	X	X	X
Chiloscyllium griseum	NT	NT						X
Chiloscyllium punctatum	NT	NE					X	
Ginglymostomatidae								
Nebrius ferrugineus	VU	NT						X
Stegostomatidae								
Stegostoma fasciatum	EN	VU		X[a]				X
Rhincodontidae								
Rhincodon typus	EN	EN		X	X	X	X	X
Odontaspididae								
Carcharias taurus	VU	CR						X
Triakidae								
Mustelus mosis	NT	LC	X	X[b]	X	X		X
Hemigaleidae								
Chaenogaleus macrostoma	VU	VU	X	X[b]	X	X	X	X
Hemipristis elongata	VU	VU	X	X[b]	X	X		X
Paragaleus randalli	NT	VU	X	X[b]	X	X		X
Carcharhinidae								
Carcharhinus amblyrhynchoides	NT	VU	X	X[b]				X
Carcharhinus amblyrhynchos	NT	EN						X
Carcharhinus amboinensis	DD	VU	X	X[b]	X	X		X
Carcharhinus brevipinna	NT	VU		X[b]	X			X

To be continued

Continued

Carcharhinus dussumieri	EN	EN	X	X[a, b]	X	X	X	X
Carcharhinus falciformis	VU	NT						X
Carcharhinus humani	DD	DD		X[a, b]				X
Carcharhinus leiodon	EN	NE	X	X[b]				X
Carcharhinus leucas	NT	EN	X	X[b]		X	X	X
Carcharhinus limbatus	NT	VU	X	X[b]	X	X		X
Carcharhinus macloti	NT	NT	X	X[a, b]	X		X	X
Carcharhinus melanopterus	NT	VU		X[b]				X
Carcharhinus plumbeus	VU	EN						X
Carcharhinus sorrah	NT	VU	X	X[a, b]	X	X		X
Galeocerdo cuvier	NT	VU						X
Loxodon macrorhinus	LC	NT		X[b]	X	X	X	X
Negaprion acutidens	VU	EN		X[b]				X
Rhizoprionodon acutus	LC	NT	X	X[a, b]	X	X	X	X
Rhizoprionodon oligolinx	LC	NT	X	X[b]	X			X
Sphyrnidae								
Sphyrna lewini	CR	EN		X[b]				X
Sphyrna mokarran	CR	EN	X	X[b]	X	X		X
Pristidae								
Anoxypristis cuspidata	EN	CR					X	
Pristis zijsron	CR	CR			X			X
Rhina ancylostoma	CR	VU		X[a]				X
Rhynchobatidae								
Rhynchobatus australiae	CR	EN		X[a, b]				
Rhynchobatus djiddensis	CR	EN	X		X	X	X	
Rhynchobatus laevis	CR	EN		X[a, b]				X
Rhinobatidae								

To be continued

Continued

Acroteriobatus omanensis	DD	NE						X
Acroteriobatus salalah	NT	NE						X
Glaucostegus granulatus	CR	EN	X				X	X
Glaucostegus halavi	CR	NE		X[a, b]	X			X
Rhinobatos annandalei	DD	NT					X	X
Rhinobatos punctifer	NT	NE		X[a, b]	X	X	X	X
Rhinobatos schlegelii	DD	NE					X	
Torpedinidae								
Torpedo sinuspersici	DD	DD		X[a]			X	
Dasyatidae								
Bathytoshia lata	LC	DD		X[a]				
Brevitrygon walga	NT	NE	X	X[a]		X	X	
Himantura leoparda	VU	VU		X[a, b]				X
Himantura uarnak	VU	VU	X	X[a]	X	X	X	X
Maculabatis gerrardi	VU	EN					X	
Maculabatis randalli	LC	NE	X	X[a, b]	X		X	X
Pateobatis fai	VU	NT						X
Pastinachus ater	LC	NT		X[a, b]				
Pastinachus sephen	NT	NE	X	X[a]	X	X	X	
Taeniurops meyeni	VU	NT		X				X
Gymnuridae								
Gymnura poecilura	NT	NT	X	X[a, b]	X	X	X	X
Myliobatidae								
Aetobatus flagellum	EN	EN	X	X[b]			X	
Aetobatus ocellatus	VU	VU	X	X[a, b]		X	X	X
Aetomylaeus milvus	EN	NE	X	X[b]	X	X	X	
Aetomylaeus nichofii	VU	VU	X	X[a, b]	X	X	X	

To be continued

Continued

Rhinopteridae						
Rhinoptera javanica	VU	EN	X			X
Rhinoptera jayakari	NE	EN	X	X[a, b]	X	
Mobulidae						
Mobula eregoodootenkee	NT	NT			X	
Mobula kuhlii	DD	NT		X[b]		
References	Jabado et al. (2017b); IUCN (2020)		Vossoughi and Vosoughi (1999); Moore et al. (2010); Moore et al. (2012); Moore and Peirce (2013); Robinson et al. (2013); Ghotbeddin et al. (2014); Jabado et al. (2015b); Bishop et al. (2016); Rastgoo et al. (2016); Raeisi et al. (2017); Rastgoo and Navarro (2017); YouTube (2017); Jabado (2018); Jabado et al. (2018); UAE (2018); *Present Study*			

a: Species documented from fishery-independent surveys; b: species documented from landing surveys.

Table 2. Permutational multivariate analysis of variance (PERMANOVA) of elasmobranch community data based on fishery-independent surveys. Lat.: latitude range; Lon.: longitude range; CPUA: catch per unit area range; df: degree of freedom; *F*: *F*-value; *P*: *P*-value.

Factor	**Year × Lat.**	**Year × Lon.**	**Year × CPUA**	**CPUA × Lat.**	**CPUA × Lon.**	**Lat. × Lon.**
df	11	7	10	7	3	3
F	0.796	0.725	0.793	0.742	0.854	0.896
P	0.923	0.952	0.927	0.934	0.674	0.595

Table 3. Permutational multivariate analysis of variance (PERMANOVA) of elasmobranch communities among fishing gears, seasons, and trawling/non-trawling periods based on landing surveys. df: degree of freedom; *F*: *F*-value; *P*: *P*-value.

Factor	**Trawl included**		**Trawl excluded**	
	Gear × Period	**Gear × Season**	**Gear × Period**	**Gear × Season**
df	3	10	3	6
F	1.361	1.311	1.205	1.395
P	0.033	0.003	0.15	0.01

Table 4. Jaccard's similarity index values illustrating the degree of similarity in the species composition among countries in the Arabian Gulf.

	Kuwait	**Saudi Arabia**	**Bahrain**	**Qatar**	**Iran**	**UAE**
Number of species	29	45	26	25	27	47
Kuwait	*	0.54	0.57	0.64	0.47	0.38
Saudi Arabia	*	*	0.51	0.49	0.36	0.59
Bahrain	*	*	*	0.65	0.39	0.43
Qatar	*	*	*	*	0.44	0.33
Iran	*	*	*	*	*	0.25
UAE	*	*	*	*	*	*

Figure Captions

Fig. 1. Study area showing the location of the trawled stations in the Saudi waters of the Arabian Gulf, within the fishery-independent surveys conducted between 2013 and 2016. Dot lines show Saudi exclusive economic zone boundary.

Fig. 2. Pie-charts showing the contribution of various species of elasmobranchs to the total catch in terms of numbers and weights for (A) fishery-independent surveys and (B) landing surveys. The number prior to the species means the rank of the contribution from high to low. Species order showed counterclockwise in the pie-charts.

Fig. 3. Distribution of elasmobranch catch per unit area in terms of abundance (A) and biomass (B) data collected during the fishery-independent surveys conducted between 2013 and 2016.

Fig. 4. (A) Gear-wise similarity of elasmobranch diversity based on the data collected during the 135 landing sites visits conducted between March 2016 and February 2020. (B) Hierarchical cluster analysis of the elasmobranch assemblages recorded in the six Gulf countries based on the presence-absence of elasmobranch taxa and Jaccard's similarity index.

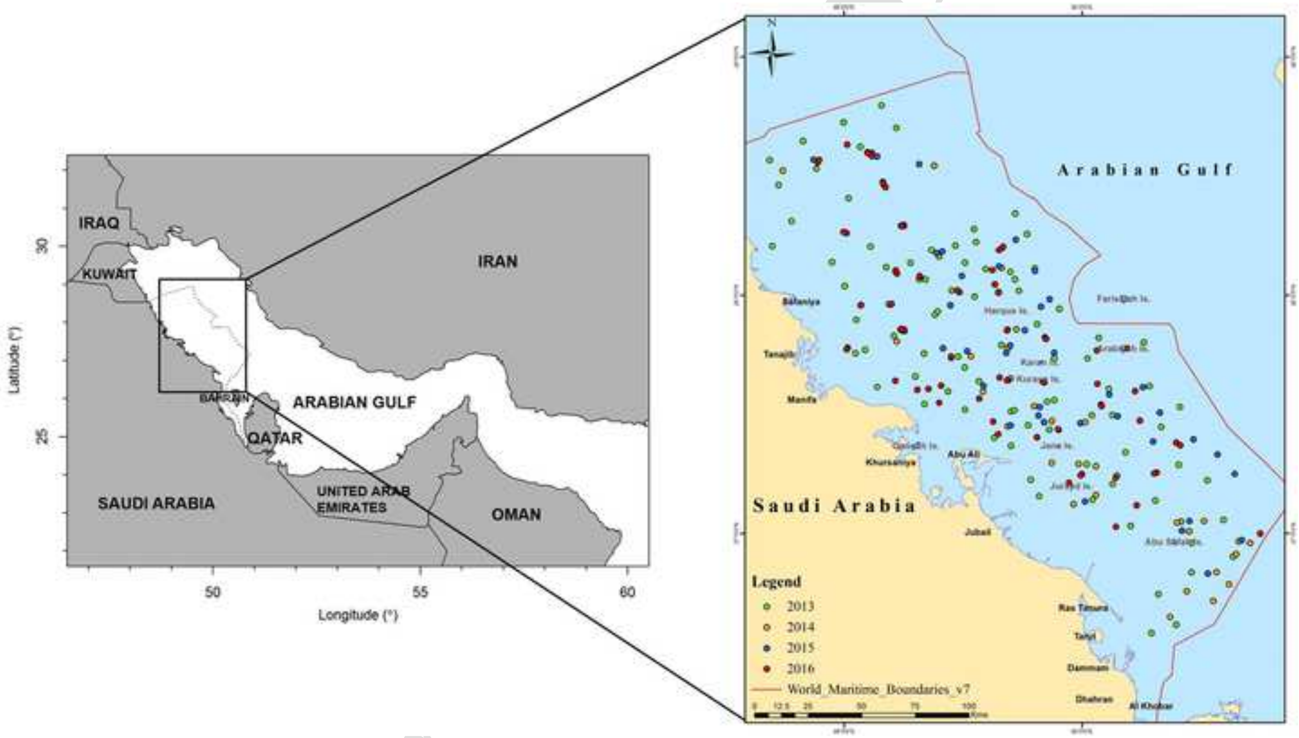
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Figure

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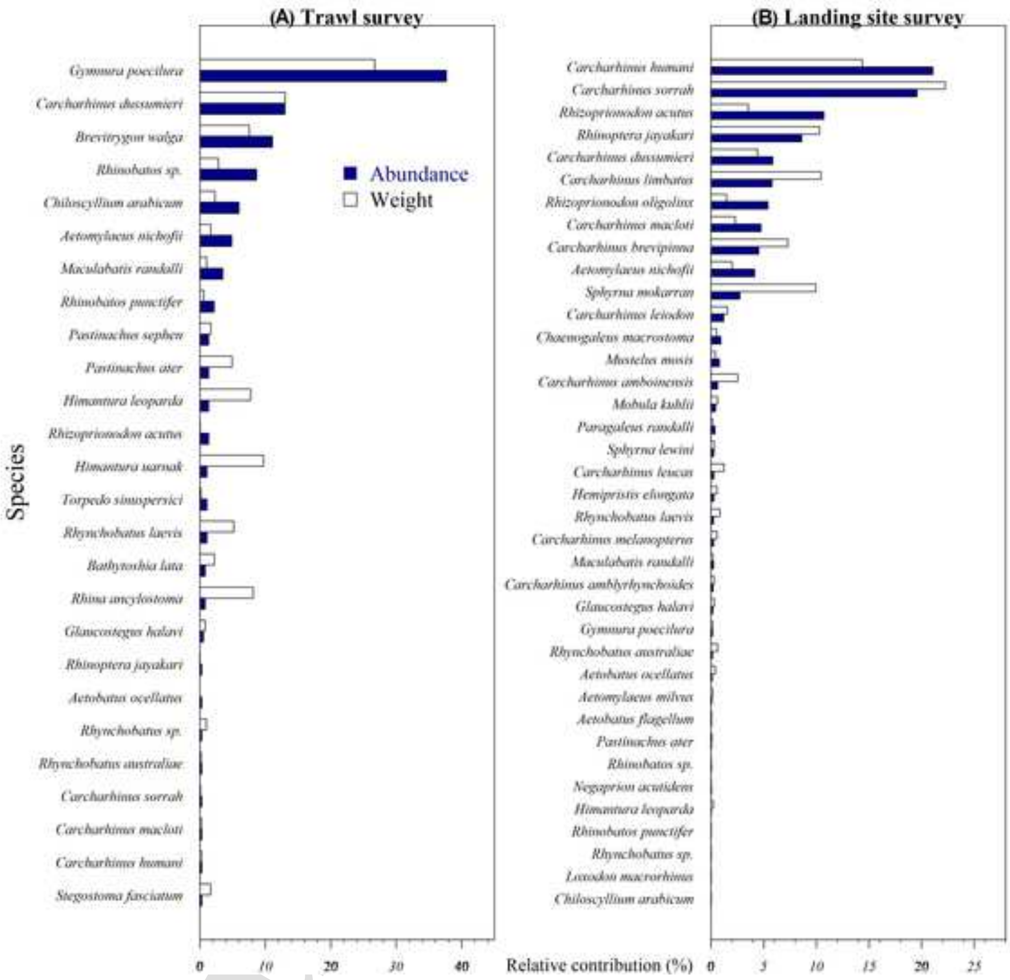

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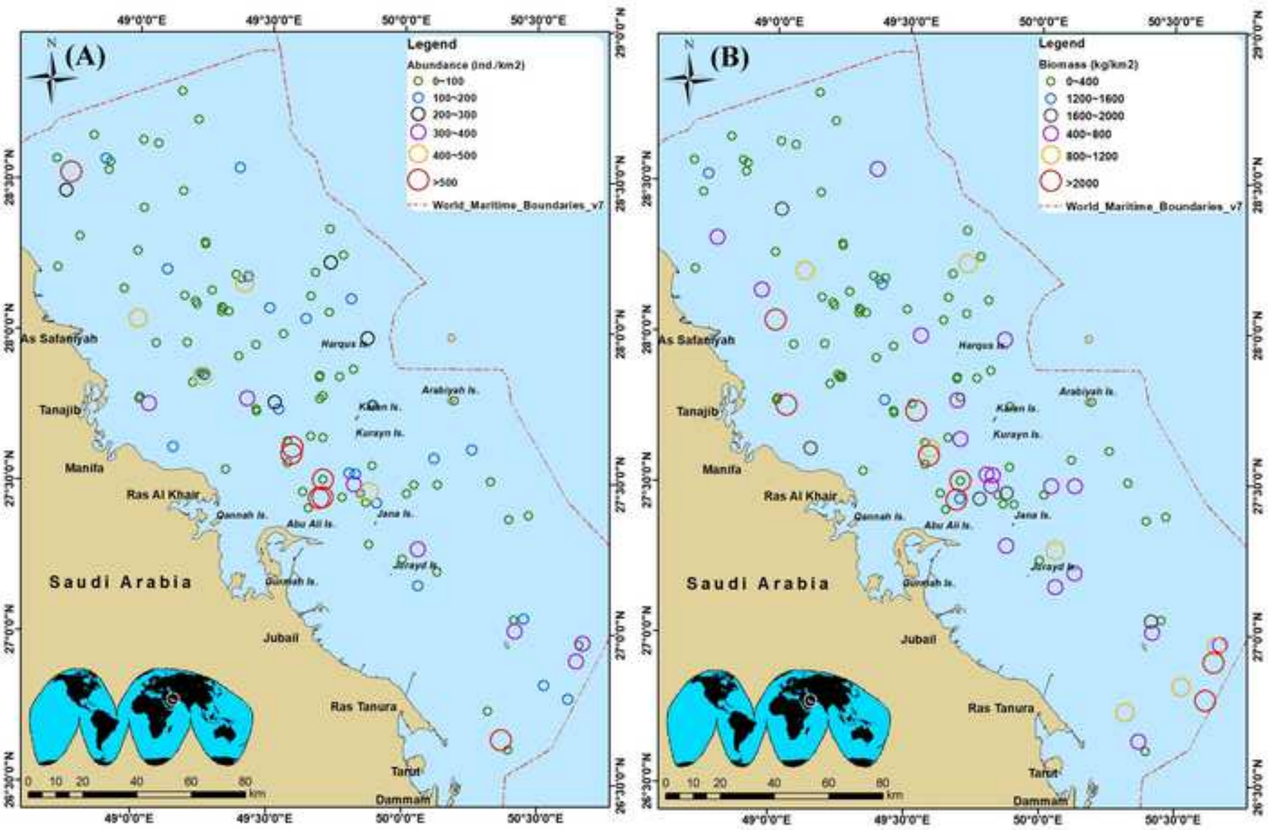
(A)
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Abundance (ind./km2)
0~100
100~200
200~300
300~400
400~500
>500
World_Maritime_Boundaries_v7
49°0'0"E
49°30'0"E
50°0'0"E
50°30'0"E
29°0'0"N
28°30'0"N
28°0'0"N
27°30'0"N
27°0'0"N
26°30'0"N
As Safaniyah
Tanajib
Manifa
Ras Al Khair
Harqus Is.
Arabiyah Is.
Karan Is.
Kurayn Is.
Jana Is.
Abu Ali Is.
Qannah Is.
Jurayd Is.
Gurmah Is.
Saudi Arabia
Jubail
Ras Tanura
Tarut
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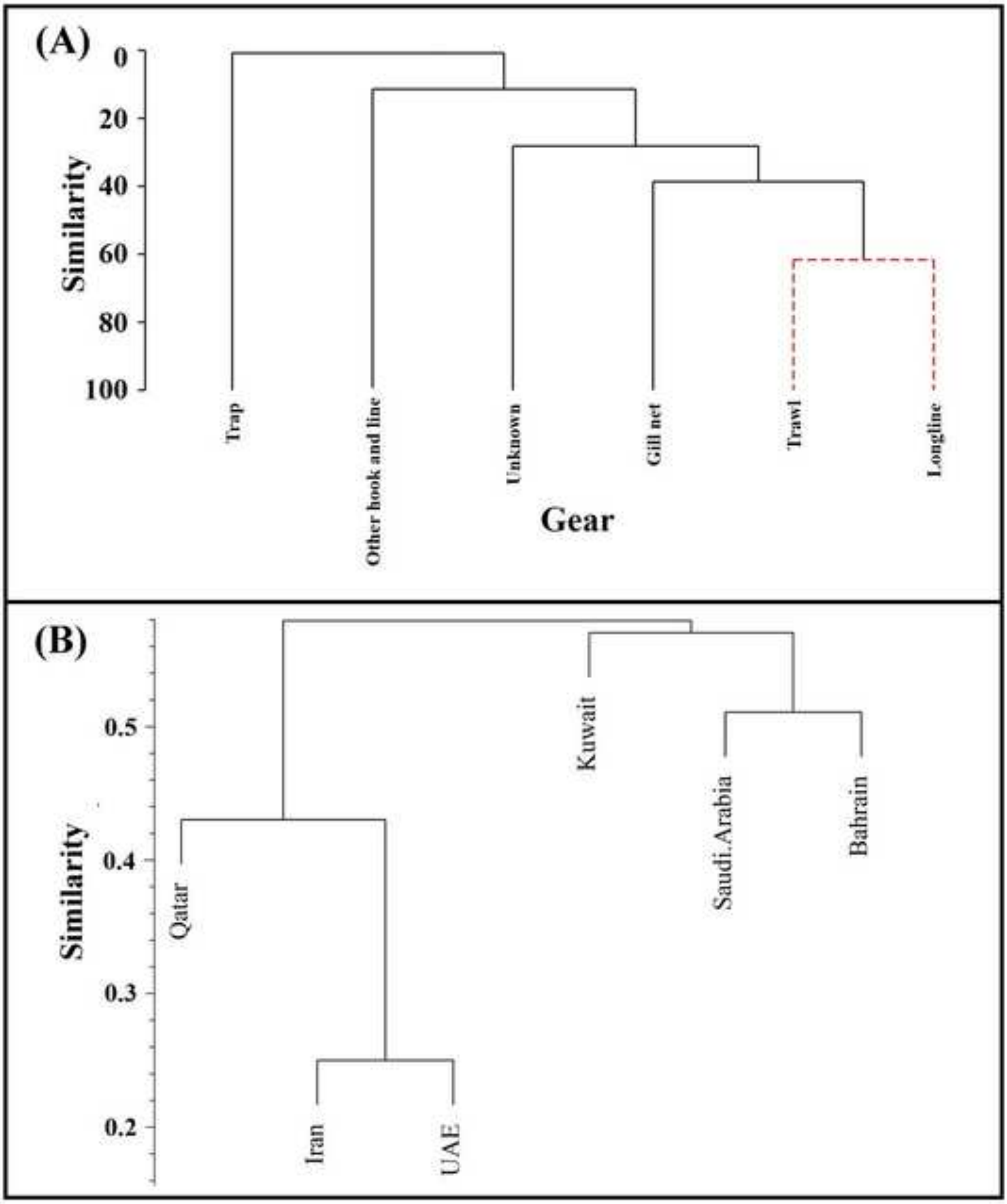
0 10 20 40 60 80 km
(B)
Legend
Biomass (kg/km2)
0~400
1200~1600
1600~2000
400~800
800~1200
>2000
World_Maritime_Boundaries_v7

Figure


(A)
Similarity
0
20
40
60
80
100
Trap
Other hook and line
Unknown
Gill net
Trawl
Longline
Gear
(B)
Similarity
0.5
0.4
0.3
0.2
Qatar
Iran
UAE
Kuwait
Saudi.Arabia
Bahrain

Credit Author Statement

HH, YJ, and LR conceived the idea of this study. YJ and LR contributed to the data collection during the 2013 and 2015 trawling surveys; HH, ZN and PP contributed to the data collection during the 2016 trawling survey and 2016-2020 landing surveys. HH, YJ, and LY analyzed data. HH wrote the first draft of the manuscript. All co-authors contributed to the interpretation of the results and editing the manuscript. LR supervised the project administration.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: