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Demographic Characteristics of Elasmobranch Fishes in the Khor Faridah Region (Abu Dhabi) Using a Stereo-BRUVS Approach

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Abstract

The elasmobranch fauna was studied in the Khor Faridah region of Abu Dhabi, which is a mangrove-dominated inshore habitat historically reported to host a diversity of elasmobranch species. A stereo-baited remote underwater video system (Stereo-BRUVS) survey was conducted from September 2021 to August 2022 to assess the species diversity and relative abundance of elasmobranch fishes. A total of 12 elasmobranch taxa were encountered during the study, consisting of five rays (Myliobatiformes), four sharks (Selachii), two wedgefish and one guitarfish (Rhinopristiformes). The area was dominated by honeycomb-patterned rays in the genus *Himantura* and the Critically Endangered Arabic whipray *Maculabatis arabica*. Since *Himantura uarnak* and *H. leoparda* could not be reliably distinguished from footage, all sex- and size-based results are reported for a combined *Himantura* species complex and should be interpreted cautiously. Furthermore, the broad size range of individuals found in the area highlights its importance to all life stages of these taxa. This underlines the need for a conservation strategy to avoid detrimental changes to the elasmobranch fauna due to ongoing coastal development.

Keywords: anthropogenic pressure; conservation; critical habitats; critically endangered; stereo-BRUVS survey

1. Introduction

Populations of elasmobranch fishes (sharks, skates, and rays) have undergone dramatic declines on a global scale in recent decades [1,2]. These animals face numerous threats ranging from direct and indirect capture in fisheries to habitat degradation and loss [3,4]. Although industrial commercial fisheries have the greatest impact on elasmobranch populations [5], artisanal fisheries and anthropogenic activities on a local scale are also of concern [6–8]. A high diversity of elasmobranch species has been reported from the Persian (Arabian) Gulf, herein 'the Gulf'. For instance, Hsu et al. [9] reported the presence of 47 elasmobranch species in the western Gulf, highlighting the region's significant biodiversity. Similarly, Navarro et al. [10] investigated the trophic ecology of 33 elasmobranch species in the Gulf and Gulf of Oman, emphasizing the ecological importance of these areas. Despite these contributions, contemporary biological and ecological data remain limited,

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underscoring the need for further research to assess the current status of elasmobranch populations in the region [9,11,12].

Fishery management in the Gulf region is complicated by numerous national jurisdictions, and existing regulations may not be based on relevant biological or ecological data due to little or no data availability [12]. Thus, many elasmobranch species within the Gulf are considered threatened, critically endangered, or data-deficient by the International Union for the Conservation of Nature (IUCN) [13]. Moreover, most accessible data are fishery-dependent and based solely on landing-site surveys [6,11,14–16]. Consequently, only species of commercial interest are monitored; therefore, acquiring fishery-independent data is crucial.

The Gulf is recognised to reach the highest marine water temperature globally [17], and models predict a substantial decline in fishery catches in the United Arab Emirates (U.A.E.) due to increased salinity and temperature and decreased dissolved oxygen, driven by climate change [18]. Contemporary data investigating species biology and ecology are needed to provide baseline knowledge that enables effective conservation management and the detection of long-term changes over time.

Stereo-baited remote underwater video systems (Stereo-BRUVS) offer a non-invasive and non-destructive method for data collection, suitable for cases when species are endangered and physical capture is not essential [19–21]. BRUVS use bait, generally a locally sourced sardine type [22], to attract carnivorous fishes in the area. This technique has been successfully utilised in studies focusing on relative abundance, size distribution, and species diversity [23–26].

Considering the rapid rate of coastal development in the U.A.E., shallow coastal areas are of particular concern for conservation purposes [27]. Moreover, except for one extensive BRUVS survey investigating the open waters within the Gulf conducted by Jabado et al. [28] little research has been performed on the marine biodiversity in this region. Therefore, the present study was undertaken to assess the current elasmobranch fauna in the Khor Faridah region of Abu Dhabi (U.A.E.). This is an extensive mangrove-dominated area to the east of Abu Dhabi city, which is known to be utilised by at least two critically endangered elasmobranch species [29]. Moreover, historic accounts of the area's elasmobranch fauna further indicate that a number of ray and shark species were commonly encountered there (J. Al Romaithi, pers. com., 2022). The same source also reported that juvenile sicklefin lemon sharks *Negaprion acutidens* (Rüppel, 1837) were particularly common.

2. Materials and Methods

This study focused on the wider Khor Faridah region, a 137 km^2 area characterised by sheltered mangrove forests and seagrass meadows interspersed with sandflats and channels that connect to the open waters of the Gulf (Figure 1). Based on these characteristics, the study area was divided into three strata, i.e., the inside shallow 'IS' (0 to 3 m depth), the inside deep 'ID' (>3 m depth) and the area along the coastline outside 'OU' (0 to 10 m).

Nine Stereo-BRUVSs were constructed, each with two Lightdow 4k cameras (1920 × 1080 resolution and 60FPS) 50 cm apart facing the bait canister. The frame was also equipped with a third camera (same manufacturer and settings) facing the opposite direction to provide a nearly 360° window of observation (Figure 2). The cameras were calibrated using Cal-Software v3.23 and a 1000 × 1000 mm calibration cube from SeaGis Pty Ltd. (Bacchus Marsh, VIC 3340, Australia). The bait for each deployment was 1 kg of blended and chopped Indian oil sardine (*Sardinella longiceps*) procured from local fish markets.

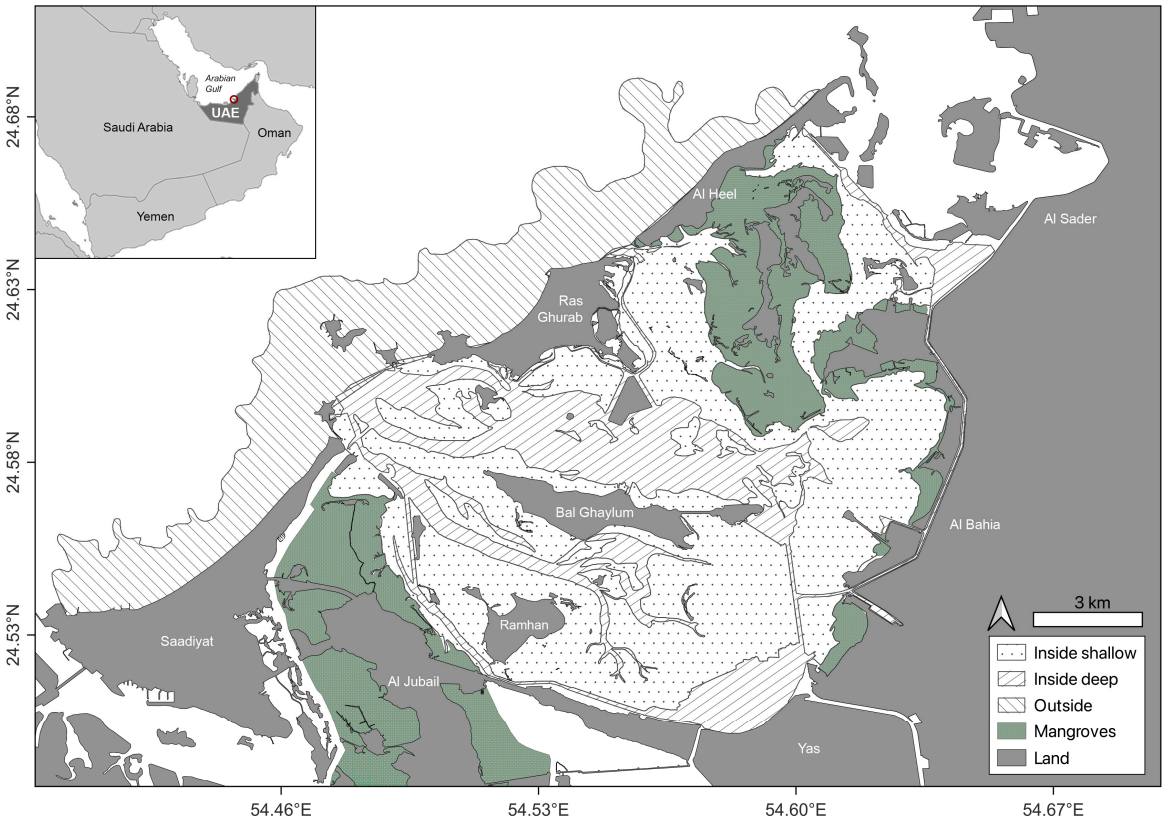


Figure 1. Study area in the Khor Faridah region on the eastern side of Abu Dhabi (United Arab Emirates). Sampling strata are illustrated according to pattern.

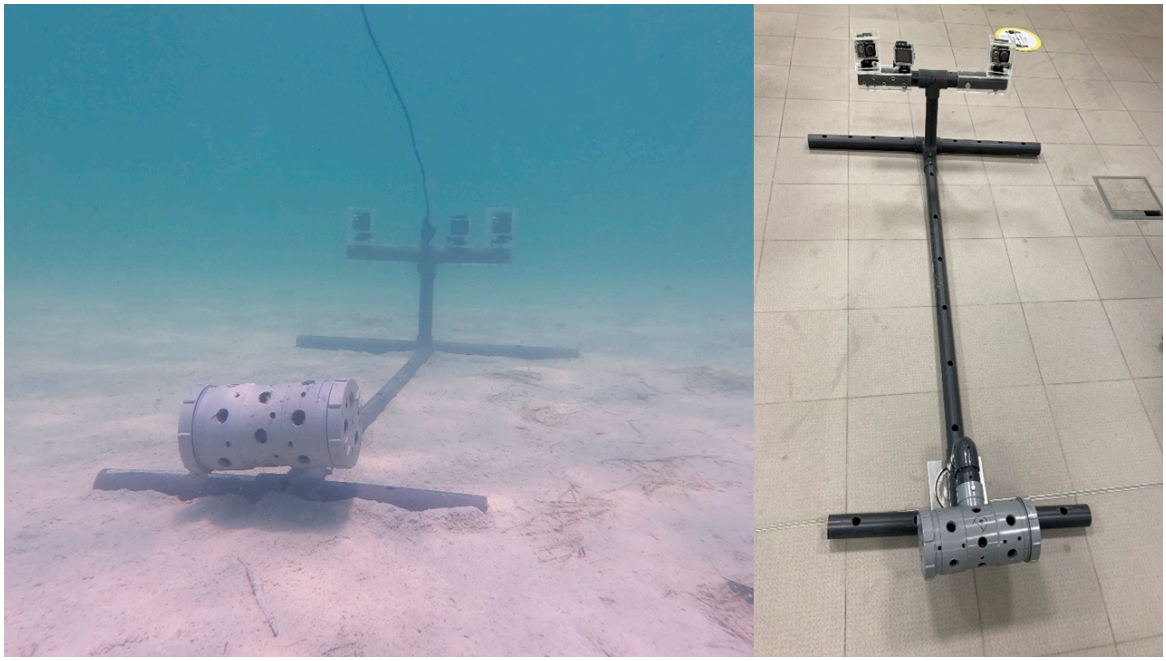


Figure 2. Stereo-BRUVS design that was used for an elasmobranch survey in the Khor Faridah region in Abu Dhabi, United Arab Emirates. The frame was equipped with two cameras placed 500 mm apart on the base bar facing the bait box at a five-degree inward angle. A third camera facing the opposite side provided a window of observation of approximately 360°.

A stratified sampling approach was adopted based on the area of each stratum, wherein there were 18 monthly deployments in stratum IS, nine deployments in stra-

tum ID and nine deployments in stratum OU, providing a total of 432 deployments during daylight hours across the entire study area and project duration (September 2021 to August 2022). Each deployment lasted for 105 min based to the camera battery life, with the deployment locations randomly generated in QGIS version 3.24 (Open-Source Geospatial Foundation OSGeo, Beaverton, OR, USA). Figure 3 provides an example frame from the stereo-BRUVS footage, illustrating the typical field of view and image quality used for species identification and measurements. Video footage was analysed with EventMeasure software v5.22 from SeaGIS. The MaxN approach to estimate relative abundance was used [30,31]; however, this measure was adapted if individuals were determined to be distinct animals entering the window of observation at different times based on obvious size differences, sex differences, or body markings. In such cases, observations were treated as separate records [32]. Upon video analysis the most dominant habitat type in the field of observation was documented and assigned to the deployment ID. Habitat type was divided into five categories; 'Seagrass' (dominated by seagrass meadows and macro algae, 'Sand' (bare sand, interspersed with little complexity), 'Patch reef' (isolated coral structures surrounded by rubble or sand), 'Mud flats' (soft, fine-grained sediment dominated by silt and clay), 'Rocky reef' (rocky structure that provides relief and functions ecologically like a reef, without living corals).



Figure 3. Representative image of a stereo-BRUVS deployment in the Khor Faridah region, Abu Dhabi, United Arab Emirates, illustrating a *Maculabatis arabica* specimen.

Habitat composition was summarised using the proportion of deployments associated with each habitat type within each stratum. To quantify compositional dissimilarity among strata, we applied the Bray–Curtis index to deployment-level habitat type data. Pairwise dissimilarities were calculated among strata, and their significance was tested using a Permanova-style permutation test (999 iterations), in which strata labels were randomly reassigned across deployments to generate a null distribution of dissimilarities.

The relative abundance of animals was represented as observation per unit effort (OPUE) [33] and reported as the number of animals per hour. The observed individuals were identified to species, following Ebert et al. [34] and Last et al. [35]. Within the study area under consideration, honeycomb-patterned rays in the genus *Himantura* likely

encompass at least two species, i.e., the coach whipray *Himantura uarnak* (Gmelin, 1789) and the leopard whipray *Himantura leoparda* Manjaji-Matsumoto & Last, 2008. Visual distinction of these species is highly unreliable in juveniles and commonly problematic even in adults [36,37]. Consequently, the analysis treated these observations as a single taxon, namely the *Himantura* complex.

Sex was determined based on the presence or absence of claspers, and size was estimated using the Eventmeasure software v5.22. In the case of sharks and shark-like rays, the total length (L_T) is reported, and in the case of rays, the disc width (W_D) is reported. Moreover, maximum visibility was measured at each deployment using the Eventmeasure software v5.22. Using this approach, the furthest object clearly visible was marked on both camera screens and the distance between the base bar and the selected point was measured to the nearest cm.

Immediately before each deployment, water depth was measured using a handheld depth sounder (Vexilar Inc. LP8-1, Bloomington, MN, USA). The water temperature was measured at the midpoint of the water column using a multiparameter meter (model HI98194, Hanna Instruments Inc., Woonsocket, RI 02895, USA). Tidal condition was also observed and noted as flood, ebb, or slack.

The relationship between water temperature and observation per unit effort (OPUE) using Pearson's correlation. Species diversity of elasmobranchs across deployments were calculated using the Simpson's diversity index ($1 - D$) and the effective number (reciprocal of the Simpson's Index), representing the number of equally common species required to achieve the observed value of the Simpson diversity. The index was first calculated across all deployments combined (overall diversity), and then separately within each stratum and habitat type.

To visualize sampling completeness, a species (taxon) accumulation curve was constructed using each stereo-BRUVS deployment as a sampling unit. For each deployment, taxa were treated as incidence data (presence/absence), such that a taxon was counted once per deployment regardless of the number of individuals observed.

All statistical analyses were performed using Jamovi version 2.3.21.0 (The Jamovi project 2022, Sydney, Australia). Data were first tested for normality using the Shapiro–Wilk test. When data did not conform to normal distributions or homogeneity of variance, non-parametric alternatives were applied. Specifically, Mann–Whitney U tests were used for comparisons between two groups, while Kruskal–Wallis tests were employed for comparisons among more than two groups. When Kruskal–Wallis results were significant, appropriate post hoc multiple comparisons (Dwass–Steel–Critchlow–Flinger) were conducted to identify which groups differed. These approaches were chosen because they are robust to non-normal distributions and small or uneven sample sizes, which are common in BRUVS survey data.

Spatial use patterns were examined with kernel density estimation (KDE), using deployment coordinates and occurrence per unit effort (OPUE, individuals/h) as weights. KDEs were calculated in UTM Zone 40N (EPSG: 32640) on 400–600 cell grids with a Gaussian kernel and bandwidth selected via Scott's rule. Density surfaces were transformed back to geographic coordinates (EPSG: 4326) and clipped to the Khor Faridah study polygon. Utilization distribution (UD) contours at 50%, 75%, and 95% cumulative probability were extracted to delineate core and broader areas of use.

All means are reported ± standard deviation (SD) and medians are reported with interquartile range (IQR). All graphs were constructed using SigmaPlot version 11.0 (Systat Software, Inc., San Jose, CA 94303, USA), and maps were generated using QGIS version 3.24 (Open-Source Geospatial Foundation OSGeo, Beaverton, Oregon, USA).

3. Results

In total, 432 Stereo-BRUVS were deployed over the course of the study. Of these, 416 produced usable footage, and the remaining 16 experienced either poor visibility conditions or camera malfunctions. This resulted in 99 ID, 211 IS, and 106 OU deployments. When the area of each stratum is considered, this effort yielded 2.9 deployments/km^2 in the ID, 3.1 deployments/km^2 in the IS and 3.2 deployments/km^2 in the OU stratum. Although the deployment duration was 105 min, variable camera battery life resulted in a mean deployment time per Stereo-BRUV of 104.95 with a standard deviation of 2.46 min (ID), 104.19 with a standard deviation of 3.71 min (IS) and 104.41 with a standard deviation of 4.87 min (OU). The deployment duration was not found to differ significantly between the three strata (one–way ANOVA, $n = 416$, $p > 0.05$). Although the amount of bait remaining at the end of the deployment was variable, there was always at least some bait remaining, suggesting that the BRUVS were fishing continually throughout the deployment.

Habitat composition differed clearly among strata, where both inside strata, IS and ID, were dominated by Seagrass habitat type, followed by Sand and the OU was dominated by the habitat type Sand with over 75% of deployments (Table 1). These proportional differences in habitat type among strata were highly significant ($\chi^2 = 103.01$, df = 8, $p < 0.001$). Pairwise post hoc χ^2 tests confirmed that habitat composition differed significantly between all strata. Inside shallow sites differed from inside deep sites ($\chi^2 = 1957.0$, df = 4, $p < 0.001$), while both inside strata also differed strongly from the outside stratum (inside deep vs. outside: $\chi^2 = 4471.9$, df = 4, $p < 0.001$; inside shallow vs. outside: $\chi^2 = 4177.9$, df = 4, $p < 0.001$). These results indicate that each stratum was compositionally distinct in terms of relative habitat representation.

Table 1. Proportion of Stereo-BRUVS deployments (%) by habitat type within each strata, namely Seagrass, Mud flat, Patch reef, Rocky reef and Sand. Survey was conducted in the Khor Fardiah region, Abu Dhabi, United Arab Emirates.

Strata	Seagrass (%)	Mud Flat (%)	Patch Reef (%)	Rocky Reef (%)	Sand (%)
ID	39.8	10.2	2.0	17.4	30.6
IS	58.3	1.4	1.4	5.2	33.7
OU	17.0	0.0	1.9	4.7	76.4

The maximum visibility among deployments varied between 1.2–11.8 m with a median of 3.2 m (IQR = 1.8 m). Despite the wide range in maximum visibility, no correlation between maximum visibility and OPUE was found (Spearman rank correlation, $n = 407$, $p > 0.05$). The same was true for the tidal condition; no significant difference was found between the flood and ebb tides in relation to the OPUE (Mann–Whitney U-test, $n = 399$, $p > 0.05$).

Water temperature varied throughout this study, with a median temperature of 29.0 °C ((IQR): IS = 9.5 °C, ID = 9.0 °C, OU = 8.8 °C) in all three strata; however, IS reported the highest and lowest water temperatures at 38.9 °C and 16.3 °C, respectively. While the data record a wide thermal range among different times of year across the study area, no significant difference in temperature among strata nor habitat types was found (one–way ANOVA = 2.30, df = 2, $p > 0.05$, in all cases).

Elasmobranchs were encountered on 50.8% of deployments, with the number of individuals observed per deployment ranging from one to eight. In total, 383 elasmobranch encounters were recorded, representing 12 nominal species. This consisted of five ray species (*Myliobatiformes*), four shark species (*Selachii*), two wedgefish species, and one guitarfish species (*Rhinopristiformes*). However, 16 of the 383 encounters were rays that could not be identified beyond family (i.e., Dasyatidae) owing to the distance from the camera.

Patterns of species diversity reflect a Simpson diversity index of $1 - D = 0.50$, with an effective number of two, indicating a community dominated by a few common taxa. Strata-level analyses revealed a clear spatial pattern. The IS had the lowest diversity (Simpson's index $1 - D = 0.38$; effective species ≈ 1.6), while ID were moderately diverse ($1 - D = 0.53$; $\approx$2.1 effective species), whereas the OU stratum supported the highest diversity ($1 - D = 0.73$; $\approx$3.7 effective species), reflecting a greater richness (11 species) among taxa.

When partitioned by habitat type, diversity varied considerably. Patch reef and Rocky reef habitats exhibited the highest Simpson values ($1 - D = 0.83$ and $1 - D = 0.81$, respectively), with effective species numbers of ~6.0 and ~5.2. Bray–Curtis dissimilarity values based on habitat composition supported these trends. The two inside strata were relatively similar (0.22 dissimilarity), whereas outside sites differed substantially from both inside deep ($BC_{dissimilarity} = 0.46$) and inside shallow ($BC_{dissimilarity} = 0.43$). Pairwise Permanova-style permutation tests confirmed that these differences were statistically significant between outside and both inside strata ($p = 0.001$), while the difference between inside deep and inside shallow was not significant ($p = 0.109$).

The species assemblage was strongly dominated by rays, particularly the *Himantura* species complex and *Maculabatis arabica* was first described in 2016 [38] with sharks and wedgefishes encountered infrequently (Table 2). Overall IS documented the highest overall OPUE with 0.65 Ind/h, followed by OU with 0.5 Ind/h, while the ID stratum recorded the lowest OPUE at 0.42 ind./h. Patterns of relative abundance varied by stratum, with *Himantura* and *M. arabica* more common in IS and *Chiloscyllium arabicum* Gubanov, 1980 more common in OU. While the outside stratum was more monotonous in habitat composition, with over 75% represented by plain sand, it nevertheless recorded the highest species richness among strata, encountering all taxa except for *Carcharhinus melanopterus* (Quoy & Gaimard 1824). However, low encounter rates for most taxa limited interpretation of fine-scale spatial preferences across the study area.

Moreover, temperature did not show any association with overall OPUE or species richness (Spearman rank correlation; OPUE: $\rho = 0.11$, $p > 0.05$; species richness: $\rho = 0.06$, $p > 0.05$). Species-specific analyses likewise revealed no significant relationships between OPUE and temperature for either *Himantura* species complex ($n = 145$, $\rho = -0.02$, $p > 0.05$) or *M. arabica* ($n = 53$, $\rho = -0.19$, $p > 0.05$).

Observations were dominated by the *Himantura* complex, the taxon was encountered throughout the study area (Figure 4) and there was no significant difference in OPUE between strata (Kruskal–Wallis, $n = 250$, $p > 0.05$). The depth distribution of this species complex was 0.5–8.8 m with a median depth of 1.5 m (IQR = 2.1 m). The second most abundant species, *M. arabica* displayed a similarly broad spatial distribution as the *Himantura* complex, and its abundance did not differ between strata (Kruskal–Wallis, $n = 416$, $p > 0.05$). However, it was encountered in a slightly narrower depth range (0.5–6.0 m) than *Himantura*, and a shallower median depth of 1.25 m (IQR = 1.73 m). Notably, most encounters with this species occurred in the vicinity of deeper channels (Figure 5). All other species were encountered considerably less frequently than *Himantura* and *M. arabica* (Table 2). Although *C. arabicum* was moderately abundant, its spatial distribution was mostly limited to the OU stratum (Figure 6), with depths ranging from 1.6 m 5.9 m. The spatial distributions and depth records of the remaining species were variable (Figure 6 and Table 3); however, they were encountered too infrequently to infer any trend.

Table 2. Species relative abundance expressed as observation per unit effort (individuals/h) overall and per stratum in the Khor Fardiah region, Abu Dhabi, United Arab Emirates.

Species	OPUE			
	Overall	ID	IS	OU
Himantura complex	0.345	0.271	0.469	0.168
Maculabatis arabica	0.088	0.064	0.120	0.049
Chiloscyllium arabicum	0.032	0.017	0.005	0.098
Pastinachus sp.	0.011	0.023	0.008	0.005
Glaucostegus halavi	0.011	0.006	0.003	0.033
Pateobatis fai	0.006	0.000	0.008	0.005
Aetobatus ocellatus	0.004	0.017	0.000	0.000
Carcharhinus limbatus	0.003	0.000	0.003	0.005
Carcharhinus melanopterus	0.003	0.006	0.000	0.005
Rhynchobatus spp.	0.001	0.000	0.000	0.005
Rhynchobatus djiddensis	0.001	0.000	0.000	0.005
Negaprion acutidens	0.001	0.000	0.000	0.005
Unidentified Dasyatidae	0.022	0.012	0.030	0.016

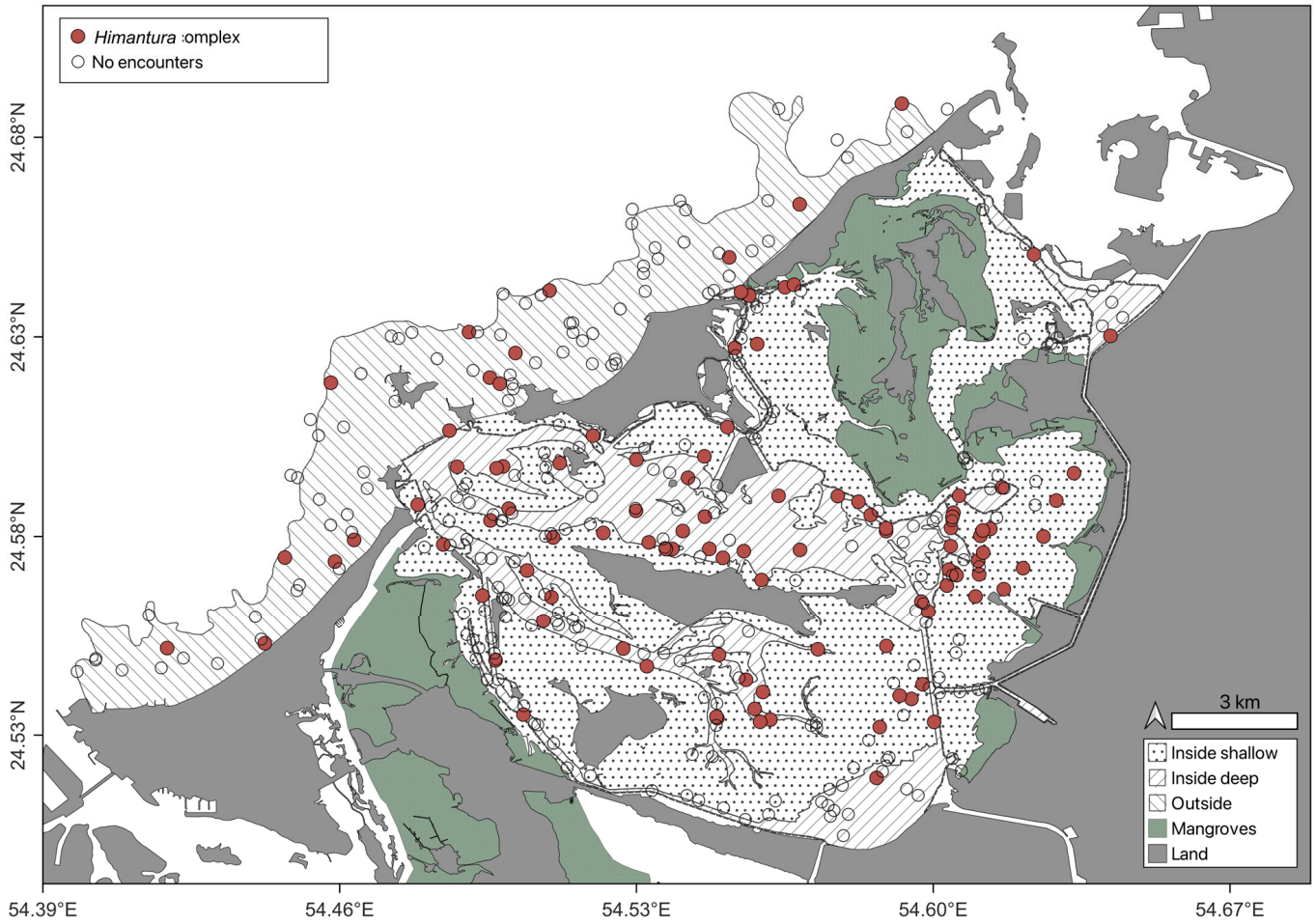


Figure 4. *Himantura* spp. encountered on Stereo-BRUVS deployed in the Khor Faridah region of Abu Dhabi. Sampling strata are illustrated according to pattern, and deployments with an encounter highlighted by colour red.

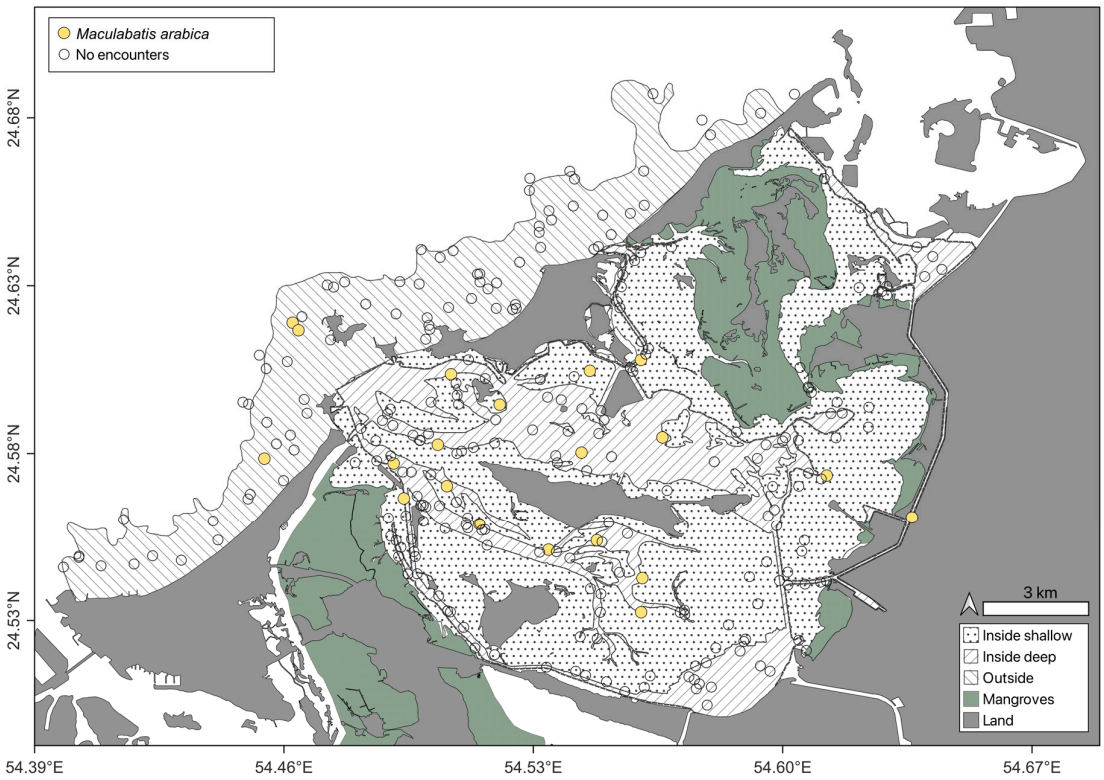


Figure 5. *Maculabatis arabica* encountered on Stereo-BRUVS deployed in the Khor Faridah region of Abu Dhabi. Sampling strata are illustrated according to pattern, and deployments with an encounter highlighted by colour yellow.

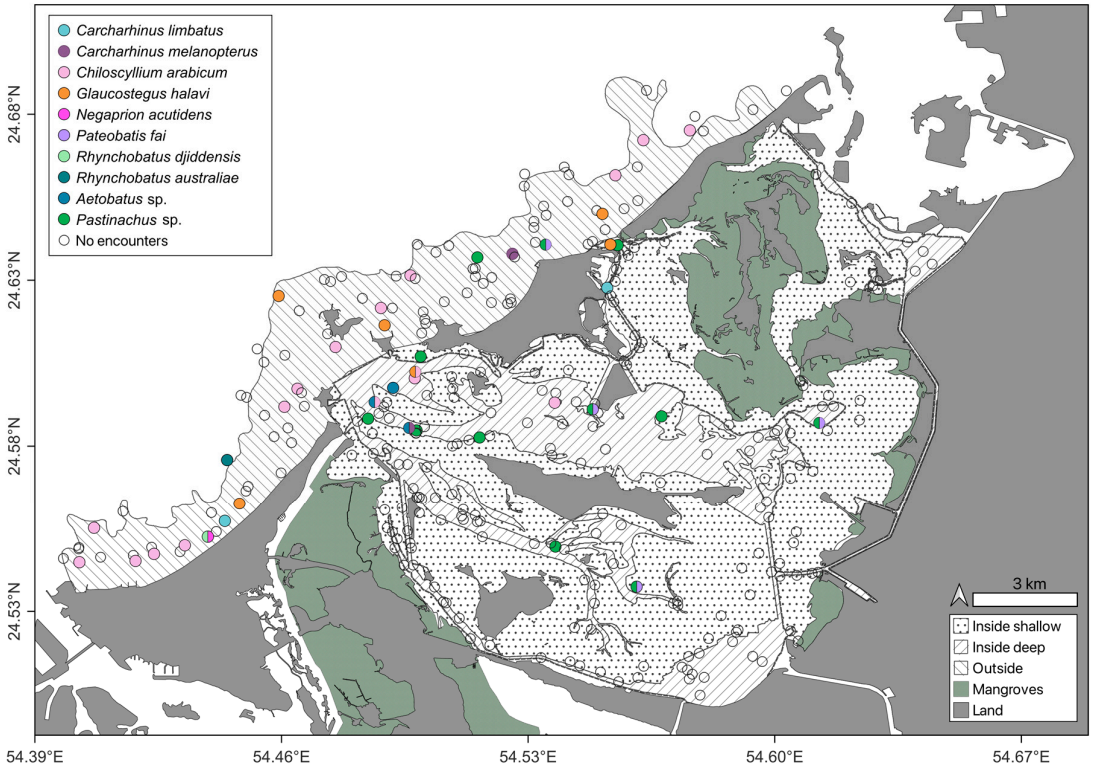


Figure 6. Infrequently encountered elasmobranch species on Stereo-BRUVS deployed in the Khor Faridah region of Abu Dhabi. Sampling strata are illustrated according to pattern, and species are differentiated by colour.

Table 3. Sex ratio, size, represented as disc width (W_D) or total length (L_T), and depth range for less abundant species within the Khor Faridah region of Abu Dhabi, United Arab Emirates.

Species	Depth (m)			Total Observations			Size L_T/W_D (cm)		
	Min	Max	Median	Female	Male	Unknown	Female	Male	Unknown
Chiloscyllium arabicum	1.6	5.9	3.9	13	10	0	median = 62.8	median = 60.8	---
Glaucostegus halavi	1.1	4.4	1.7	4	1	3	median = 89.5	99.7	59.6
Pateobatis fai	0.7	1.8	1.25	2	2	0	64.5; 62.0	52.3; 50.1	---
Pastinachus sp.	0.8	8.6	2.9	2	1	5	49.6	---	43.5
Aetobatus ocellatus	3.9	8.7	4.5	1	0	3	---	---	---
Carcharhinus limbatus	1.2	1.2	1.2	1	0	0	71.5	---	---
Carcharhinus melanopterus	2.2	8.7	5.45	1	0	1	73.0	---	---
Negaprion acutidens	5.5	5.5	5.5	1	0	0	139.7	---	---
Rhynchobatus djiddensis	5.5	5.5	5.5	1	0	0	173.2	---	---
Rhynchobatus spp.	6.5	6.5	6.5	0	0	1	155.0	---	---

The species accumulation curve increased rapidly during early deployments and then approached an asymptote, indicating diminishing returns in additional taxa with increasing effort. Across the full dataset a total of 13 taxa were detected. All taxa had been encountered by approximately deployment 227 (≈55% of deployments), after which the curve remained flat, consistent with most taxa being detected relatively early and a small number of rare taxa requiring additional sampling to encounter (Figure 7).

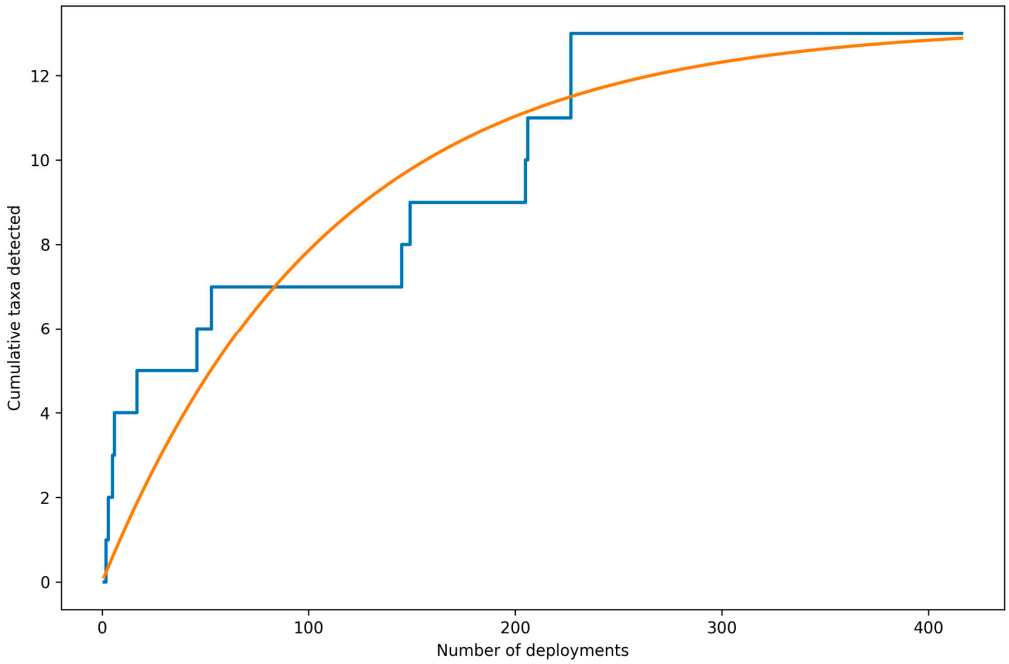


Figure 7. Species accumulation curve based on the observed sampling order of stereo-BRUVS deployments across the Khor Faridah region of Abu Dhabi. The step curve shows the cumulative number of unique taxa detected as deployments are added sequentially. A nonlinear saturating trend line is overlaid displaying the approach to an asymptote. Across 416 deployments, 13 taxa were detected, with all taxa first observed by approximately deployment 227.

Of the 250 *Himantura* encounters, it was possible to estimate the size of 225 individuals and determine the sex of 167 individuals. Because *H. uarnak* and *H. leoparda* could not be reliably distinguished, all sex- and size-based results are reported for a combined *Himantura* species complex and should be interpreted cautiously This provided a sex ratio of 1:6 (male:female). Overall, size ranged from 40.22 cm to 134.91 cm W_D, and although females displayed a greater size range than males, the latter tended to be larger (Mann–

Whitney U-test, $n = 167$, $p < 0.01$) (Figure 8). A Kruskal–Wallis test determined that the median size differed between strata ($n = 225$, $p < 0.01$), but the difference was limited to between the IS and OU strata (Dwass-Steel-Critchlow-Flinger, $n = 182$, $p < 0.01$). Moreover, a positive correlation was found between size and depth (Spearman rank correlation, $n = 225$, $p < 0.05$), with larger individuals occurring in deeper water. Of the 64 *M. arabica* individuals encountered, it was possible to estimate the size of 54 individuals and assign sex to 45 individuals. This provided a sex ratio of 14:1 in favour of females. The three males were 51 cm, 48 cm, 41 cm W_D, while females ranged from 27 cm to 75 cm W_D with a median size of 46.30 cm (IQR = 11.0) (Figure 9).

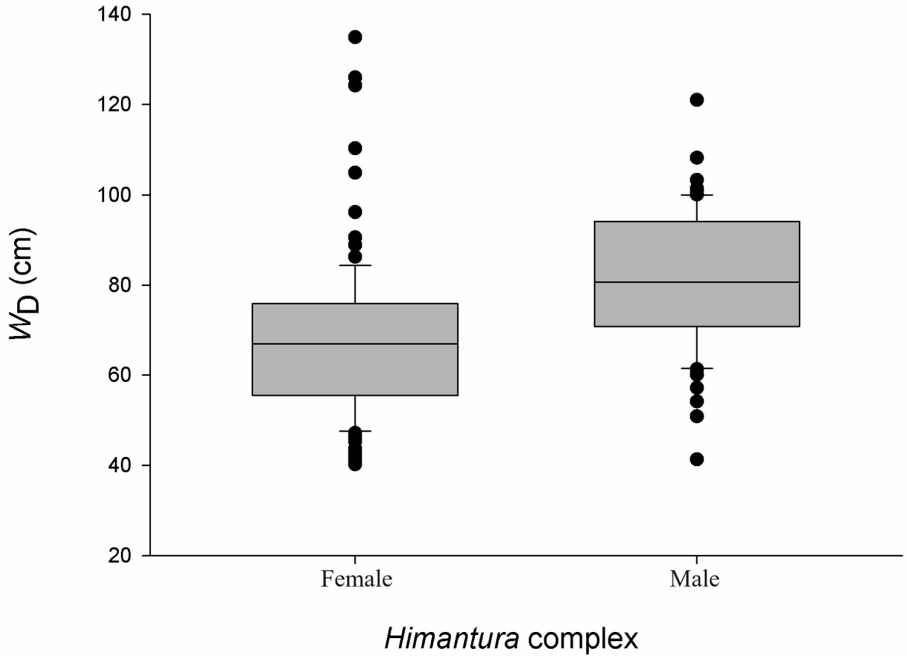


Figure 8. Size distribution of *Himantura* spp. observed in the Khor Faridah region of Abu Dhabi. Size is reported as disc width (W_D), and boxplots illustrate median, interquartiles and outliers. For males $n = 60$ and for females $n = 96$.

Both, the *Himantura* species complex and *M. arabica* showed a distinct habitat association (Table 4). The *Himantura species* complex was recorded most frequently in Seagrass habitats (0.89 encounter per deployment), but also showed notable occurrence on sand (0.42) and Rocky Reef (0.30). In contrast, *M. arabica* was more restricted, with its highest relative occurrence in Seagrass (0.21 encounter per deployment) and much lower values across other habitats ($\leq$0.15). A Chi-square test of independence confirmed that habitat use differed significantly among habitats for both species (*Himantura* species complex: $\chi^2 = 187.4$, df = 4, $p < 0.001$; *M. arabica*: $\chi^2 = 41.6$, df = 4, $p < 0.001$), indicating non-random distributions and a strong association with Seagrass habitats. Further analysis on their spatial ecology using Kernel density analysis revealed that both taxa show clear habitat preference. Rays of the *Himantura* species complex were broadly distributed across the study area, with high densities in inshore channels and seagrass beds but extending into sandflats and outer lagoon habitats (Figure 10). Although both mature male and female *Himantura* were observed, the number of individuals was insufficient to conduct robust statistical tests of sexual segregation. In contrast, *M. arabica* was more restricted, with core areas concentrated in shallow channels and mangrove-fringed seagrass, and little use of open sand (Figure 11). Interestingly, *Himantura* are found more in shallow areas inside, whereas the individuals of *M. arabica*, tend to be on seagrass habitats but in vicinity of

deeper channels throughout the study area. Other species were encountered to less in number to interfere any trends of their spatial distribution and habitat preference (Table 4).

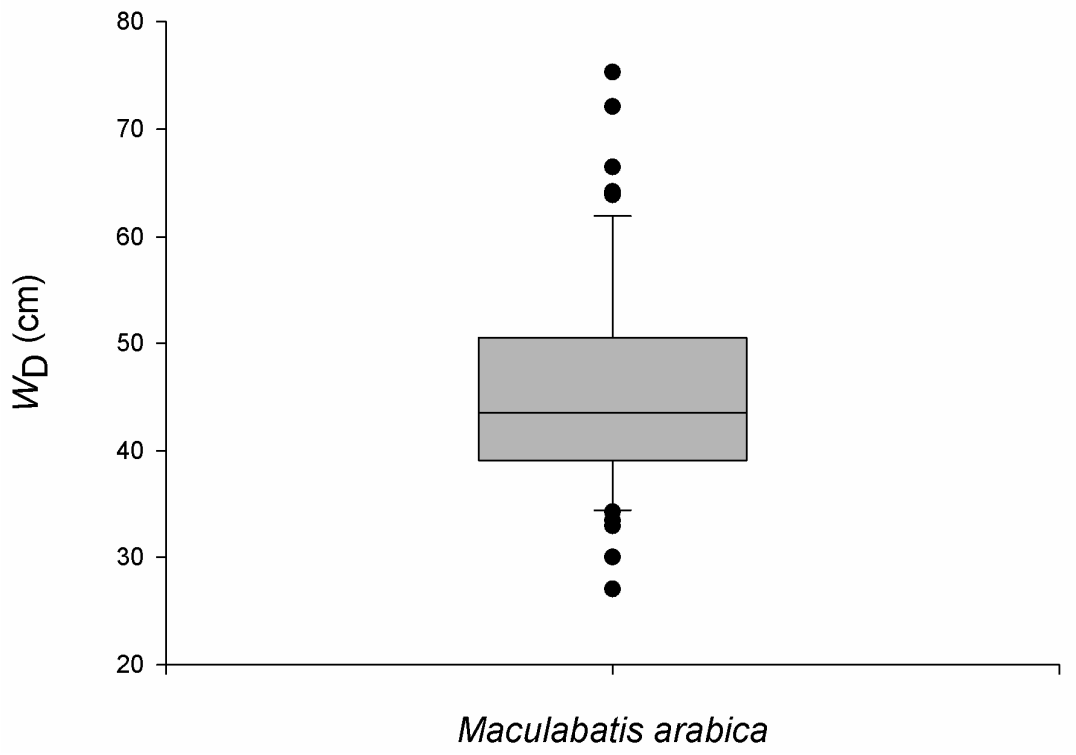


Figure 9. Size distribution of *Maculabatis arabica* observed in the Khor Faridah region of Abu Dhabi. Size is reported as disc width (W_D), and boxplots illustrate median, interquartiles and outliers. Sexes are not presented separately as only three males were encountered during the study. Sexes combined, $n = 54$.

Table 4. Encounters per deployment for each different habitat type, by species recorded during a Stereo-BRUVS survey in the Khor Faridah region, Abu Dhabi, United Arab Emirates.

Species	Encounter per Deployment				
	Seagrass	**Mud Flat**	**Patch Reef**	**Rocky Reef**	**Sand**
Aetobatus sp.	0	0	0.143	0.03	0.005
Carcharhinus limbatus	0	0	0	0.03	0.005
Carcharhinus melanopterus	0	0	0.286	0	0
Chiloscyllium arabicum	0.039	0	0	0.182	0.055
Glaucostegus halavi	0	0	0	0.061	0.033
Himanutra species complex	0.889	0.231	0.143	0.303	0.418
Maculabatis arabica	0.211	0.154	0	0.121	0.11
Negaprion acutidens	0	0	0	0	0.005
Pastinachus sp.	0.022	0	0	0.061	0.011
Pateobatis fai	0.006	0	0	0.03	0.011
Rhynchobatus australiae	0	0	0	0	0.005
Rhynchobatus djiddensis	0	0	0	0	0.005
Unidentifiable sp.	0.028	0.077	0	0	0.055

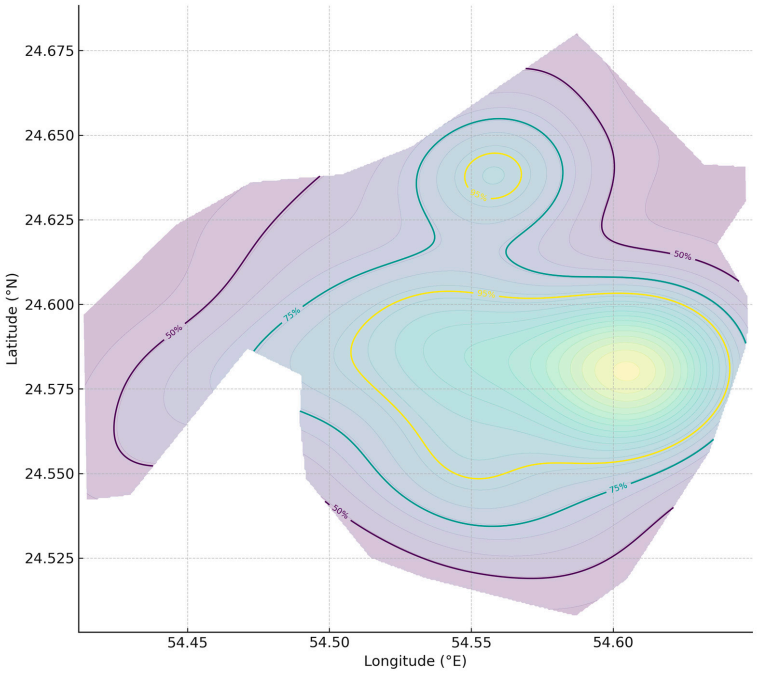


Figure 10. *Himantura* species complex utilization distribution (UD). Kernel density estimate (KDE) of OPUE (individuals per hour) for *Himantura* species complex across the Khor Faridah, Abu Dhabi, United Arab Emirates, shown as 50%, 75%, and 95% utilization isopleths. Density reflects relative encounter intensity, not absolute counts.

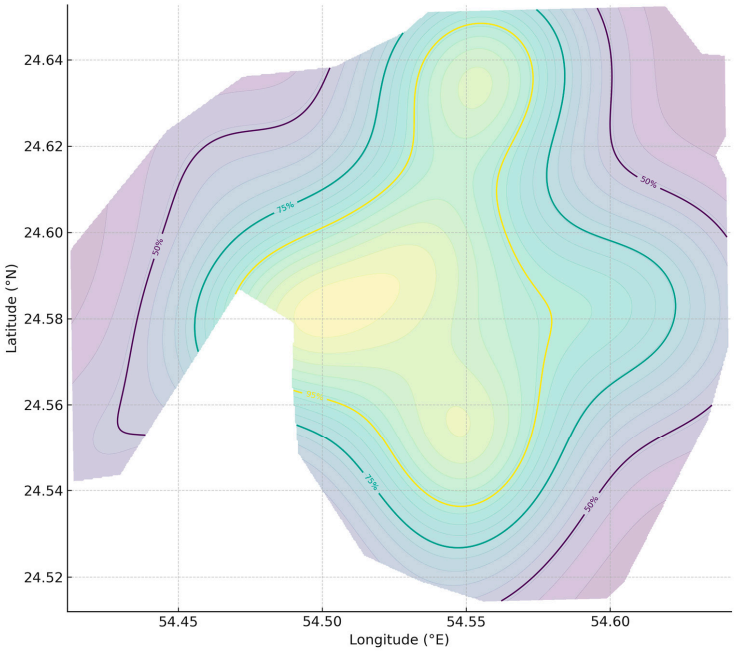


Figure 11. *Maculabatis arabica* utilization distribution (UD). Kernel density estimate (KDE) of OPUE for *Maculabatis* arabica across the Khor Faridah, Abu Dhabi, United Arab Emirates, shown as 50%, 75%, and 95% utilization isopleths. Density reflects relative encounter intensity, not absolute counts.

All 23 *C. arabicum* were successfully sexed and measured. The species had a mean L_T of 62.41 cm (SD = 5.82 cm) and a sex ratio of 1.3:1 (Female:Male). The remaining species encountered in the survey were fewer in number (Table 3). The three Myliobatiformes, *Aetobatus ocellatus* (Kuhl, 1823), *Pastinachus* sp., and *Pateobatis fai* (Jordan & Seale, 1906), were observed infrequently, with three, eight, and four encounters, respectively (Table 3). Similarly, the other three shark species *Negaprion acutidens* (Rüppell 1837), *Carcharhinus*

limbatus (Müller & Henle, 1839), and *C. melanopterus* were observed in small numbers; one, one and two individuals, respectively. Of the total encounters, 12.9% could not be measured successfully; this was the case when encounters were only made on the back camera, or when one of the front cameras did not operate correctly.

4. Discussion

All of the elasmobranch species encountered in this study are known to occur in the Arabian Gulf and have been previously reported in U.A.E. waters [11,16,29,39].

The study area was dominated by batoid species, with few small-bodied carcharhinid shark encounters. This contrasts with local ecological knowledge from a retired fisherman active in the region during the 1970s/1980s (J. Al Romaithi, pers. com., 2022), who reported regular encounters with a broader assemblage, including sicklefin lemon shark *Negaprion acutidens* (Rüppell, 1837), Arabian carpetshark *Chiloscyllium arabicum* Gubanov, 1980, spot-tail shark *Carcharhinus sorrah* (Valenciennes, 1839), halavi guitarfish *Glaucostegus halavi* (Fabricius, 1775), wedgefish *Rhynchobatus* spp., leopard-patterned whiprays *Himantura* spp., cowtail rays *Pastinachus* spp., and green sawfish *Pristis zijsron* Bleeker, 1851. Moreover, the account described the presence of multiple size classes across rays, guitarfish and sharks, consistent with a range of life stages, whereas bull/pigeye sharks *Carcharhinus leucas* (Valenciennes, 1839) and *C. amboinensis* (Müller & Henle, 1839) were mentioned only as juveniles. However, apart from two wedgefish individuals, no large-bodied elasmobranchs were encountered in this study.

The diversity indices calculated in this study reflect these patterns, with moderate species richness but relatively low evenness, as assemblages were dominated by a few common batoid taxa. This skewed community structure is consistent with other reports from the Arabian Gulf, where elasmobranch assemblages are increasingly characterised by rays rather than sharks [9,40]. The absence of large-bodied sharks and shark-like rays in our records, despite their historical presence, highlights how decades of intense and largely unmanaged fishing pressure have reshaped community composition, leading to present-day diversity deficits that are masked by the relative abundance of smaller, more resilient species.

Although the U.A.E. developed a national plan of action for sharks in 2018 [41] and implemented some fishery management measures, fisheries in the preceding decades were largely unregulated [12,42]. Large-bodied sharks and shark-like rays are especially targeted because of the high commercial value of their fins in the export market [13,16,43]. Indeed, the U.A.E. ranked fifth globally in total reported fin exports to Hong Kong in 2010 [1], with this trade consisting of both locally sourced and reexported fins. Additionally, there has been considerable coastal development in the U.A.E. over the past five decades, resulting in large alterations in coastal habitats [44]. It is possible that the assemblage of species altered over time and large bodied elasmobranchs declined in the area.

The most commonly encountered taxon during this study was *Himantura* but, unfortunately, it was not possible to identify these individuals to species. Previous surveys within the study area have confirmed the presence of both *H. leoparda* and *H. uarnak* [29]; therefore, it is highly likely that the observations included these two species. Further dedicated studies are needed to investigate the relative abundance of *H. leoparda* and *H. uarnak* in U.A.E. waters. However, it is essential that any such efforts include molecular data, as colour patterns are not a reliable differentiator of these species [35,37].

Bearing this in mind, it is difficult to assign any importance to the sex ratio observed during the present study, as either species may have been represented by a single sex or a combination of sexes. Nevertheless, *Himantura leoparda* and *Himantura uarnak* reach sexual maturity at broadly similar sizes, i.e., 75 and 83 cm W_D, respectively [45–47], indicating

that the *Himantura* observed during the present study were a mix of mature and immature individuals. Indeed, a large proportion of females, in particular, were likely immature. That being said, numerous individuals were encountered during this study that were consistent with the maximum sizes reported for *H. leoparda* and *H. uarnak* [16,46]. Taken together, these observations suggest that the Khor Faridah region is utilised by all life stages of this taxon.

M. arabica, but little is known about its biology and ecology. Although its geographic range was initially reported to be limited to the west coast of India [35], the species has since been confirmed within the Arabian Gulf [29,48]. Of particular note is the fact that the species grows larger than previously thought, and it exhibits pronounced sexual segregation, with females dominating the nearshore environment. It is worth noting that Al Hameli et al. [29] recorded a higher relative abundance of *Glaucostegus halavi* (Fabricius, 1775) in the study area than in the present Stereo-BRUVS survey. This discrepancy between the two studies requires further attention but suggests that the use of a multiple-survey-technique approach can be advantageous when investigating relative abundance or species diversity.

The size at which sexual maturity is attained in *M. arabica* remains unknown. However, a very broad size range was observed here and by Al Hameli et al. [29] suggesting the presence of mature and immature females in the area. Females with notably distended abdomens during the summer months, including some with well-developed and fully pigmented tails protruding from the cloaca (S. Bruns pers. obs., 2022) confirmed the presence of pregnant females in the study area and suggested that parturition may occur at this time of the year. Future studies should aim to survey a wider geographic area that extends further from the shore and incorporate deeper waters to elucidate the demographics of male *M. arabica*.

The only other species encountered during the present study in sufficient numbers to provide any information about sexual demographics was *C. arabicum*, in which both sexes were equally represented. The size range in both sexes during this study and published records on size at maturity indicate that a mix of mature and immature individuals was present [49]. Data from previous studies elsewhere suggest that most of the *G. halavi*, *Rhynchobatus djiddensis* (Forsskål, 1775), and *Rhynchobatus* sp. individuals encountered here were also sexually mature [35,50,51], whereas *C. melanopterus*, *C. limbatus*, *N. acutidens*, *Pastinachus* sp., and *P. fai* were more likely to be immature [47,52–54]. While comparisons with other regions are limited due to the unique environmental conditions of the Gulf, this study provides baseline data critical for understanding regional diversity patterns. For instance, the diversity observed here contrasts with the lower abundance of elasmobranchs recorded in open waters of the Gulf [28], and highlights the importance of shallow coastal habitats.

Coastal inshore areas play a critical role in the ecology and biology of various elasmobranch species [27]. However, rapid coastal development and extreme environmental conditions around the Gulf has introduced numerous anthropogenic stressors coupled with rapid coastal development in Abu Dhabi, significantly impact habitat quality and elasmobranch populations. Previous studies [18,44] have demonstrated that such anthropogenic pressures contribute to habitat fragmentation and biodiversity loss, underscoring the importance of conserving areas that appear to provide juvenile habitat consistent with nursery function like the Khor Faridah region. Moreover, such activities have been shown to adversely affect elasmobranch biology and ecology, particularly their reproductive processes elsewhere [55–57]. This stresses the concern that future coastal development in the study area will have severe implications for the elasmobranch communities present.

Studies from elsewhere have shown that reduced shark populations can benefit ray population growth due to a release from predation pressure [58–60]. This may help to

explain the relatively high abundances of rays during this study, although their low commercial value and the lack of a targeted fishery is also important to consider. Similarly, the low commercial value of *C. arabicum* is likely to have contributed to its abundance in the study area and throughout the Gulf [28,39].

The spatial characteristics of species occurrence and abundance did not follow any clear trends for the majority of the encountered taxa. Although some species were limited to certain areas, habitat types and depths, this is likely a reflection of their low abundance during the present study. Interestingly, despite the relatively high-water temperatures recorded during the study, no significant decline in species abundance was detected. This suggests that even under elevated thermal conditions, inshore habitats continued to be actively used by a range of species encountered during this study. Species that were sufficiently represented to investigate spatial dynamics, that is, *Himantura* and *M. arabica*, were encountered in all strata. However, both species displayed their greatest abundance in the IS, followed by the ID and OU, highlighting the importance of the sheltered inshore area of the Khor Faridah region for both species. The 95% utilization distributions highlight the habitats that function as the main activity areas for both taxa within the lagoon. These broad areas represent the extent of space used beyond the core hotspots and are ecologically important because they encompass the channels, sandflats, and seagrass beds that likely provide access to foraging resources, refuge, and movement corridors. Protecting these wider areas of use is critical, as management that focuses only on the densest core areas may overlook the habitats that support connectivity and daily movements. The apparent overlap in 95% UDs between *Himantura* and *M. arabica* further suggests that shared inshore habitats are key to sustaining both species, even though they differ in how intensively they use them. Here, especially seagrass meadows are essential to a range of batoid life stages, such, ongoing coastal development across the Gulf is a major threat to seagrass meadow loss and the inherent loss of suitable nursery habitats [61,62].

Even though seasonal fluctuations in abundance were not further analysed in this study due to the limited duration of one year, a previous study conducted by Al Hameli et al. [29] recorded the highest abundance of *M. arabica* during the summer and the lowest during the winter. If parturition indeed takes place during the summer, the higher abundance during this season may reflect an inshore migration of gravid females. Further studies are required to investigate this possibility and to better understand the seasonal dynamics and reproductive behaviours of this species.

In conclusion, this survey of the Khor Faridah region revealed a moderate diversity and abundance of batoid species, three of which are categorised as critically endangered by the IUCN, namely *G. halavi*, *M. arabica* and *R. djiddensis* [63–65]. The high abundance of *M. arabica* in this area is of particular note given the lack of knowledge about the species and its current extinction risk [63]. Coastal development in this area is ongoing, and a conservation strategy is needed to avoid detrimental changes to the elasmobranch fauna inhabiting the region. From a management perspective, these findings support prioritising the protection of shallow mangrove and seagrass habitats, as well as channel corridors that likely underpin juvenile habitat use. Particularly, actions that limit dredging and/or reclamation activities in shallow flats and channels.

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Data Availability Statement: All data are available from the corresponding author upon request.

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