Original Article

Feeding habits of Bigeye Houndshark, *Iago omanensis* (Elasmobranchii; Triakidae); a typical deep water shark from the Gulf of Oman

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Abstract: In this study, the feeding habits of Bigeye Houndshark, *Iago omanensis*, a typical deep water shark, were examined in the Gulf of Oman by analyzing of stomach contents. In addition, the effects of sex and seasons (spring and summer) on its feeding habits were evaluated. Bigeye Houndshark diet consists of mostly teleost fishes, and to a lower extent on crustaneans, molluscs and sea snakes. The great importance of teleost in the diet of Bigeye Houndshark may be due to the fact that teleosts are the dominant in terms of biomass and abundance in the area where Bigeye Houndshark exist, allowing them to exploit food resources available in the environment. No significant differences were found between sexes and seasons. This species occupy high trophic position within the food webs. These results present new data that will allow us to understand the role of Bigeye Houndshark in the deep water of Gulf of Oman to effect of fishing activity on its population dynamics in the future.

Introduction

Marine predators have remarkable effects on the food web and are interesting case in understanding the factors that control their ecological role within the aquatic ecosystem (Navarro et al., 2013). Sharks classified as those predators which have wide effects on various potential prey within food web. Teleost fishes, sea turtles, sea snakes, sea birds, crustaceans, other elasmobranchs, cephalopods and marine mammals have reported as potential prey groups for sharks (Simpfendorfer et al., 2001). Beside the vast range of favorite prey, the degree of foraging specialization in sharks is an important aspect which shows that they utilize only a subset of prey in their environment (Davies et al., 2012; Navarro et al., 2013) or they select a wider range of trophic resources (Davies et al., 2012). This trait can be changed between different groups of population for example between sex (O'Shea et al., 2013), maturity stages or/and size classes (Simpfendorfer et al., 2001;

Rastgoo et al., 2018a) and also geographic location (Simpfendorfer et al., 2001). Knowledge of top predators' diet is important for understanding ecosystem dynamics (Baremore et al., 2010), providing the foundation for ecosystem-based management and a multi-species approach to fisheries management (Brodziak et al., 2004) and for understanding food web dynamics (Espinoza et al., 2015).

Stomach content analysis is traditionally a standard method for determining the diet and trophic ecology of sharks (Cortés, 1997; Hyslop, 1980). Analysis of diet can represent many factors of ecological interactions, including the feeding competition (O'Shea et al., 2013; Rastgoo et al., 2018b), prey preference (Baremore et al., 2008), movement of predators and preys, and also reveal that how an animal might respond to changes in its ecosystem and prey assemblage (Hambright, 1994; Juanes et al., 2001), even the role in effects on commercially

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important species (Navia et al., 2007). Furthermore, quantification of diet through stomach content analysis (to determine the food habits and feeding behavior) is essential for recognizing the roles of predators in an ecosystem (Baremore et al., 2010) and providing high taxonomic details on the diet specially for what species has recently consumed (Hussey et al., 2011). It is also pivotal in the management of shark fisheries from both natural processes as well as anthropogenic influences (Wetherbee and Cortés, 2004; Jabado et al., 2015).

Despite many studies defined the relation between ontogeny of sharks and differences in selected prey and size of species consumed (see Cortés, 1997; Ebert, Bizzarro, 2007; Hyslop, 1980), the number of studies in the Gulf of Oman and related regions are very rare (e.g. Jabado et al., 2015). Gulf of Oman is related to Arabian Sea on southward and the Persian Gulf on westward. It is environmentally unique with an unusual faunal assemblage (Valinassab et al., 2006). Every year, thousands tons of various fishes are caught in this area, which sharks are the remarkable portion of total catch quantity. According to increase in commercial fishing efforts, sharks are also over exploited next to other fishes.

The Bigeye Houndshark, *Iago omanensis* (Norman, 1939) is found on continental shelves and slopes at depths of 110-1000 m, and possibly to as deep as 2.195 m (Eagderi et al., 2019). Jabado et al. (2017) recorded this species in the Red Sea and along the coast from Oman to India with the exception of the Persian Gulf. Total biomass of *I. omanensis*, in one of the annual stock assessment survey through Iranian related waters in the Gulf of Oman, has estimated around 59 tons (Unpublished data). Sharks as agile predators can form the marine ecosystems especially in deep waters. In this study, we aimed to analyze food content consumed by *I. omanensis* in the Gulf of Oman, where there is a lack of data, to answer how this species connect to ecosystem through food webs.

Materials and Methods
Study area and sampling procedure: The study area was the northern part of Oman Gulf, with coordinates of 24°26′ and 58°55′ West and 24°13′ and 61°25′ East. The Gulf of Oman is a marginal sea with a narrow continental shelf that 3/4 of its body is deeper than 1,000 m (Reynolds, 1993). It has a rapid floristic turnover, which could be one of the sharpest biotic transition represented in marine biogeography (Schils and Wilson, 2006). The distinct partitions from the Persian Gulf and Gulf of Oman have significant differentiations from those of the Arabian Sea based on their species richness, species composition, average distribution range per species, general temperature, affinity of the composing species, and seasonal temperature data of the coastal waters (Schils and Wilson, 2006) and remarkable faunal assemblages (Valinassab et al., 2006). The main atmospheric phenomenon in the area is Indian monsoon, which makes important upwelling systems in this area and affects the structure of ecosystem communities (Schils and Wilson, 2006).

Specimens were collected as by-catch from commercial bottom trawlers during two cruises with the R/V Ferdows-1 between May and July 2017. The mesh size of cod end net was 80 mm and the headline net mesh was 72 mm. Specimens were collected at bottom depths between 50 and 110 m from 27 hauls. The duration of each haul varied from 150 to 180 min, depending on the sampling station. Specimens were identified on board and the sex, body weight (to the nearest 10 g), and the total body length for each individual were recorded.

Stomach content analyses: We weighed the stomachs of the *I. omanensis,* and then recovered the stomach contents during dissections in the laboratory. All prey parts recovered were separated, identified to the lowest possible taxon, counted, and weighed to the nearest 0.1 g. The number of individuals of each prey was determined as the least number that these fragments could have originated from to avoid overestimation of the occurrence of a particular prey item. We combined the data from the stomach contents into four functional groups (teleosts, crustaceans, mollusca, chordata).

In order to examine effect of sample size in estimating the diet of species, we constructed

cumulative prey curves (Cortés, 1997) using the Shannon-Weiner method to evaluate if the number of sampled stomachs was enough to describe the diversity of the diet of each group of the species or not. It was randomized the samples 50 times with the computer routine "sample-based rarefaction" using EstimateS 9.1 software (Colwell, 2005; Bornatowski et al., 2014). The sample size was considered to be sufficient if the curves visually reached an asymptote (Magurran, 2013). A combined Index of Relative Importance (Pinkas et al., 1971) used to estimate the relative importance of each prey group in the diet of each group as:

$$IRI_i = (N_i + W_i) \cdot FO_i \text{ (Eq. 1)}$$

Where FO_i is the frequency of occurrence of a particular functional prey group (*i*) in relation to the total number of stomachs, N_i is the contribution by number of a type of prey group (*i*) in relation to the whole content of the stomach, and W_i is the weight of a prey group (*i*) in relation to the whole content of the stomach. All calculations were based on the number of non-empty stomachs. IRI values were expressed as a percentage to allow comparisons between prey groups (Cortés, 1997):

$$\%IRI_i = 100 \cdot IRI_i / \sum_{i=1}^{n} IRI_i \text{ (Eq. 2)}$$

The diet diversity for each group of the species were estimated with using of Shannon-Weiner diversity index (*H*) (Ludwig and Reynolds, 1988) as:

$$H = -\sum_{i=1}^{n} pi \log p_i \text{ (Eq. 3)}$$

Where p_i is the proportion of the *i* prey group in the diet. The Pielou's index (J) was also used to estimate evenness of the prey distribution in the stomach contents of predator as:

$$J' = \frac{H'}{Log\,S} \text{ (Eq. 4)}$$

Where J' is the Pielou's index, *H'* is the Shannon Wiener index and S is the number of species in the diet of predator. Margalef's index also was estimated to calculate the species richness of different prey taxa in the diet of predator as:

$$d = \frac{S-1}{Log\,N} \text{ (Eq. 5)}$$

Where S is the number of species recorded in the diet and N is the total of individuals present in the diet. We also categorically estimated the trophic level

(Routley et al., 2002) that the Bigeye Houndshark preyed at using the W% with the TrophLab software (Pauly et al., 2000). TrophLab estimates TL considering the diet composition and the trophic level of the different prey present in the diet, according to W% (Pauly et al., 2000) as:

$$TL_i = 1 + \sum_{j=1}^{G} DC_{ij} * TL_j \text{ (Eq. 6)}$$

Where DC_{ij} is the fraction of prey (j) in the diet of consumer i, TLj is the trophic level of prey (j), and G is the number of prey categories. The trophic level of each prey category was extracted from the FishBase dataset (Froese and Pauly, 2000).

Statistical analysis: We tested for differences among the sex and seasons (spring and summer) in their stomach contents (based on %W) with the semi-parametric permutation multivariate analyses of variance tests (PERMANOVA test) on the Bray-Curtis distance matrix. PERMANOVA allows for the analysis of complex designs (multiple factors and their interactions) without the constraints of multivariate normality, homoscedasticity, and when there are a greater number of variables than in traditional ANOVA tests. The method calculates a pseudo-F statistic analogous to the traditional F-statistic for multifactorial univariate ANOVA models, using permutation procedures to obtain *P*-values for each term in the model. When results were significant, we then conducted pair-wise tests. We evaluated similarities in diets using the Bray–Curtis similarity coefficient and then we applied non-metric multidimensional scaling analysis (nMDS). All statistical tests were performed using PRIMER v.6 software (Clarke and Gorley, 2006).

Results
A total of 63 specimens were collected and examined. The sample was composed of 40 females and 23 males ranging 35 to 66 cm. All individuals categorized among 8 separated length class. The less length classes were belonged to 30-35, 35-40 and 65-70, whereas the highest collected specimens was categorized in 50-55 and 55-60 length classes (Fig. 1). Specimens were collected in spring (29 individuals)

Table 1. Diet composition of *Iago omanensis* from the Gulf of Oman expressed as percentages number (%N), percentage by weight (%W), frequency of occurrence (%FO), and index of relative importance (%IRI) of prey items

Food items	%N	%W	%FO	%IRI
Teleosts	67.45	87.98	90.16	89.94
Trichiuridae				
Trichiurus lepturus	3.30	6.70	9.83	1.82
Nemipteridae				
Nemipterus japonicus	1.88	9.82	4.91	1.06
Acropomatidae				
Acropoma sp.	26.88	3.39	37.70	21.13
Synodontidae				
Saurida tumbil	3.30	6.18	8.19	1.43
Platycephalidae				
Grammoplites suppositus	0.94	2.14	3.27	0.18
Carangidae				
Selar crumenophthalmus	0.47	4.34	1.63	0.14
Other carangids	1.88	4.92	4.91	0.61
Mullidae				
Upeneus sulphureus	2.35	8.2	6.55	1.28
Sphyraenidae				
Sphyraena putnamae	0.94	9.05	3.27	0.60
Unidentified fishes	25.47	33.16	54.09	58.73
Crustaceans	**28.30**	**4.12**	**44.26**	**9.21**
Penaeidae	2.35	0.93	6.55	0.39
Squillidae	6.60	0.81	14.75	2.02
Portunidae	0.94	0.96	3.27	0.11
Isopod	4.24	0.11	8.19	0.66
Amphipod	1.41	0.03	3.27	0.08
Unidentified Crustaceans	12.73	1.26	27.86	7.22
Mollusca	**3.77**	**7.57**	**11.4**	**0.83**
Sepiidae				
Sepia sp.	3.77	7.57	11.47	2.41
Chordata	**0.47**	**0.31**	**1.63**	**0.00**
Hydrophiidae				
Hydrophis sp.	0.47	0.31	1.63	0.02
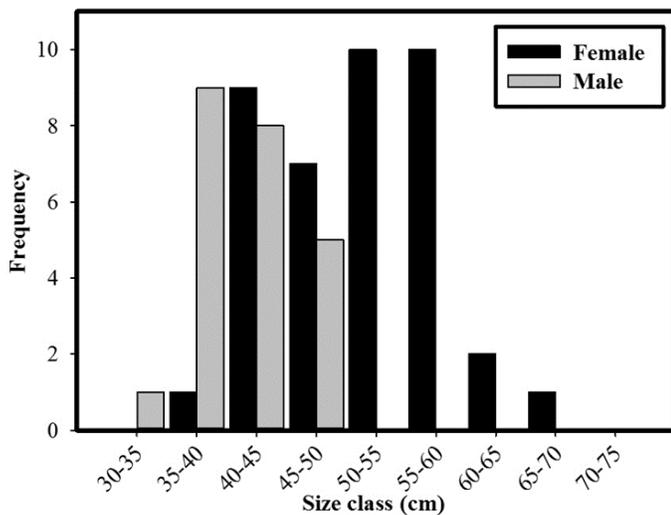
Figure 1. Size distribution of Iago *omanensis* sampled for stomach content analyses

and summer (34 individuals). In the examined specimens, 61 individuals (96%) contained food in their stomachs. The cumulative prey curves based on the diversity of prey for each group indicated that sample sizes were adequate to suggest their feeding habits (Fig. 2).

Diet composition including percentages number (%N), percentage by weight (%W), frequency of occurrence (%FO), and index of relative importance (%IRI) of prey items are shown in Table 1. In terms of importance of prey in the overall diet (%IRI), the Bigeye Houndshark mainly fed on teleosts ($\%IRI_{teleosts} = 89.94$ %), followed by crustaceans ($\%IRI_{crustaceans} = 9.21$ %), mollusca ($\%IRI_{Mollusca} = 0.83$ %) and chordata ($\%IRI_{chordate} \sim 0.01$ %) (Table 2).

The overall biodiversity indices, including Shannon-Wiener index, Pielou's index and Margalef

Table 2. Percentage of the index of relative importance (%IRI) of the main taxonomic groups in the diet of *Iago omanensis* in function of a) the sex (females and males) and b) the season (spring and summer). Number of individuals is indicated between branches.

	Teleosts	Crustaceans	Mollusca	Chordata
a) Sex				
Female (40)	94.23	4.88	0.85	0.02
Male (23)	79.48	19.15	1.36	0.00
b) Season				
Spring (29)	93.68	6.58	0.73	0.00
Summer (34)	86.89	12.14	0.92	0.03

Table 3. Biodiversity indices for the prey items of *Iago omanensis* in the Gulf of Oman.

	N	S	H′	J′	D
a) Sex					
Female	40	54	3.80	0.95	11.28
Male	23	36	3.32	0.92	7.56
b) Season					
Spring	29	36	3.35	0.93	7.70
Summer	34	49	3.66	0.94	10.23

S: total species; N: total individuals; H′: Shannon Wiener index; J′: Pielou's index of evenness and *D*: Margalef's index of richness
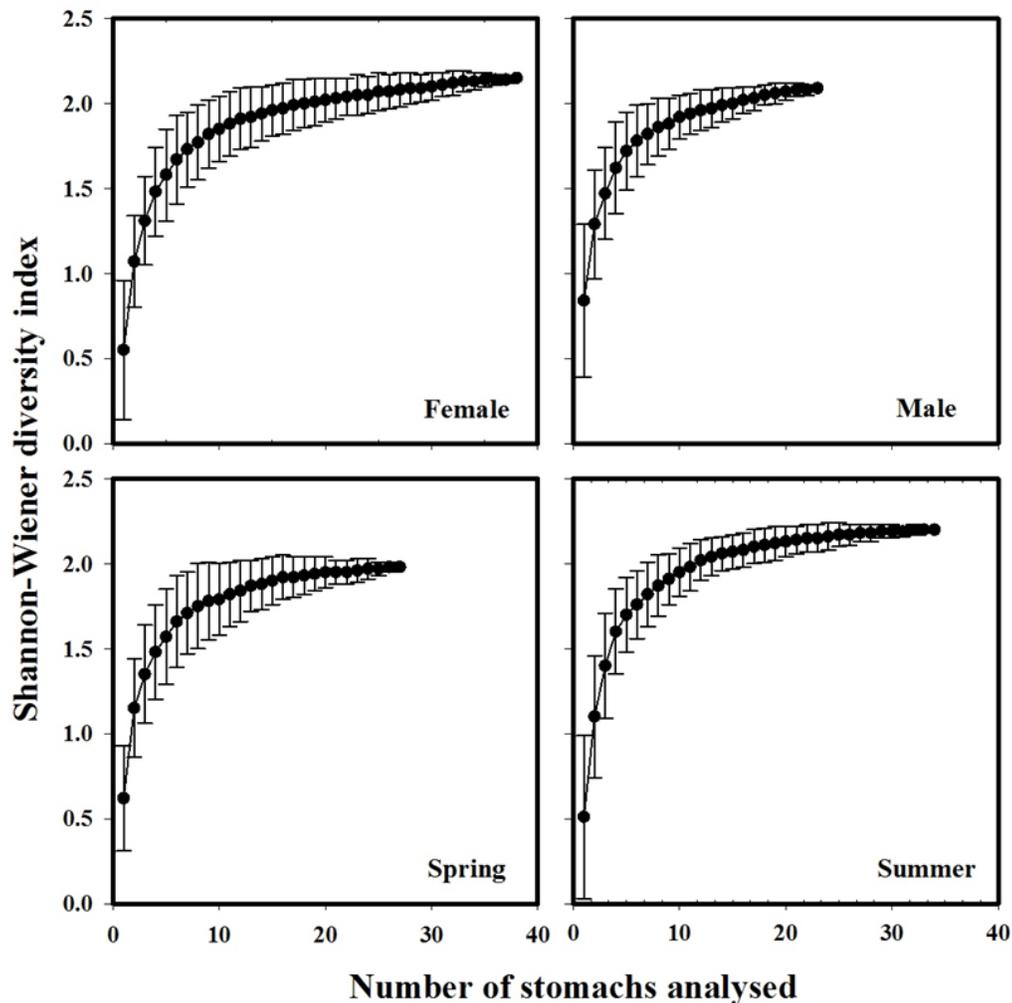

Figure 2. Cumulative average and standard deviation of Shannon–Wiener diversity index for *Iago omanensis*.
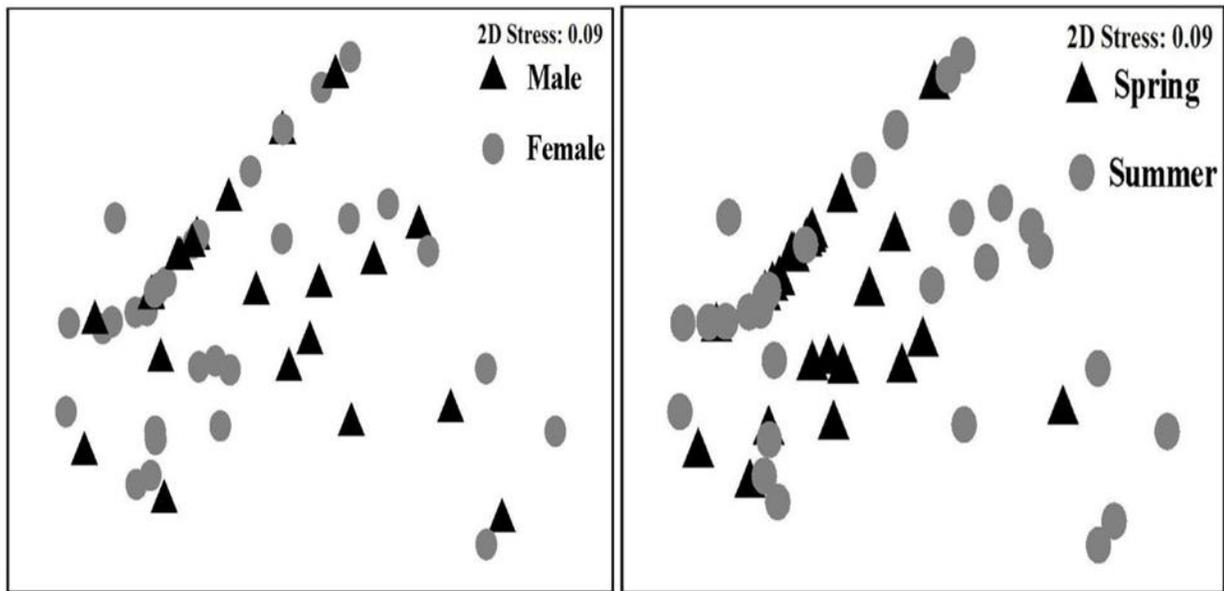
Figure 3. nMDS scaling of the stomach content of *Iago omanensis* sampled from the Gulf of Oman.

index for each group are shown in Table 3. However, except the Margalef's index of richness, no variation of indices was observed for prey items among groups.

Diet differences, based on %W were not found between males and females or between seasons (sex comparisons, $F =0.41$, df $=1$, P-value = 0.91 and seasons differences, $F=0.30$, df=1, P-value=0.97). In addition, nMDS confirmed an overlap between groups (Fig. 3). Overall, the Bigeye Houndshark has occupied a high trophic level (TL = 4.40), placing this species in top predator levels.

Discussions

Current study revealed new information on the diet of *I. omanensis*, a deep water shark, in the northern Gulf of Oman. Although the stomach contents analyses have restricted to consumed preys within a few days before (Rastgoo et al., 2018b), but it can provide fundamental information for rare species, like *I. omanensis* that occur in the deeper water. Previous studies on bottom-dwelling sharks and skates revealed that the proportion of empty stomachs is generally low (Kamura and Hashimoto, 2004; Scenna et al., 2006; Yick et al., 2011), as we observed in this study that 96% of stomachs of *I. omanensis* were full.

Based on the results, teleosts were the most preferred preys of *I. omanensis*. In addition,

crustaceans, cephalopods and sea snakes were recorded in several stomachs. Nair and Appukkuttan (1973) reported the similar diet for this species at the southeast coasts of India. Furthermore, Waller and Baranes (1994) pointed out that deep water cephalopods and benthopelagic fishes are important prey group in the diet of *I. omanensis* in the Red Sea. The importance of teleosts and cephalopods in the diet of triakids has been recorded in Costa Rica (Espinoza et al., 2015). Also, Cortés (1999) mentioned that teleosts, crustaceans and cephalopods are the most important food for several species of *Mustelus* (more than 70%). Mesopelagic aquatics such as teleosts and cephalopods are able to form an important dietary contribution to the deep sea ecosystem (Valls et al., 2014). Crustaceans also have been documented as preferred prey group in *Mustelus* sp. in north-east Atlantic (Ellis et al., 1996) and coastal waters of Colombia (Navia et al., 2007). Therefore, *I. omanensis* shows a similar diet like other members of the family Triakidae.

Focusing on possible variations based on sex to found any ontogenetic shifts in diets as well as what occurs based on habitat variation, should be studied (Jabado et al., 2015). In the present study, there was no markedly dietary preference seen by males or females of *I. omanensis*, indicating that the foraging

habitats and dietary requirements are similar for both sexes, which caused a high degree of dietary overlap (Simpfendorfer et al., 2001). But, based on the results, the prey diversity was slightly higher in female (*H'*:3.80) than male (*H'*:3.32), while the richness of prey items had significant differences in female (*d*:11.28) than male (*d*:7.56). The most proportion of diet in both sexes was teleosts which followed by crustaceans. But there was a clear difference between the volumes of consumed crustaceans in male (19.15) compare with female (4.88), which revealed that the crustaceans are more noteworthy by males of *I. omanensis*. These differences can be explained with the fact that females reach to a greater size than males, where maximum size for female and male are 84 and 54 cm from Oman (Henderson et al., 2009), 67 and 43 cm from Red Sea (Waller and Baranes, 1994), 83 and 59 cm in India (Barnes et al., 2018), respectively.

The results also indicate that *I. omanensis* is probably an important predator of teleosts and crustaceans along the deep waters of the Gulf of Oman. Interestingly, in one hand the dominated diet by teleosts shows the role of agility of this predator, followed by crustaceans which need bottom-dwelling behavior, on the other hand. The high trophic level of Bigeye Houndshark (more than TL = 4) indicates that this species occupied high trophic level, a position shared by other sharks and some batoids (Rastgoo and Navarro, 2017) and more than other genera in this family, such as *Mustelus* (Cortés, 1999). However, this species have an important potentially predator in the deep water food web of the Gulf of Oman (Rastgoo and Navarro, 2017). Due to the likely current abundance of Bigeye Houndshark in the Gulf of Oman's ecosystem, its ecological role may be potentially high and effective.

In conclusion, here we presented new information on feeding habits of Bigeye Houndshark in the northern part of Gulf of Oman. Although, the sampling period did not cover through the year, we reported first evidence of the diets of *I. omanensis* in this area. However, increasing the fleets and fishing effort maintain intensive pressure on the Gulf of Oman marine resources (Valinassab et al., 2006). Indeed, the

outspread of fishing technology to exploitation of deep sea resources is similar with the depth that this species exists. It can be predicted that in the future, the stocks or habitat of this species may be seriously damaged. Thus, our results present important data that will allow an exploration of the role of Bigeye Houndshark in the Gulf of Oman and how to connect to the food web.

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