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Food and feeding strategy of four fish species from the continental Moroccan Atlantic slope -Eastern Atlantic.

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ABSTRACT

In the North Moroccan Atlantic, the four species of fish: *Hoplostethus mediterraneus mediterraneus, Galeus melastomus*, *Helicolenus dactylopterus* and *Coelorinchus caelorhincus* are sympatric and co-occur in the continental slope. In order to describe their feeding habits in this area, the diets of these species were studied. The stomach contents of the four species caught during the trawl survey in the summer of 2010 at depths between 300 and 720 m, were analyzed. The diet composition of *Hoplostethus mediterraneus mediterraneus* showed that Mysida and Euphausiidae were the most important prey groups. *Galeus melastomus* preferred to eat Actinopteri. For *Coelorinchus caelorhincus,* the main items in the diet was Polychaeta. *Helicolenus dactylopterus* mostly preyed on invertebrates, especially, Dendrobranchiata and Brachyura. Only for the last species, the diet was influenced by size fish and sexual maturity. In addition, the diet of the four species was characterized by a clear difference in the feeding strategy, showing different situations ranging from individual specialization to a generalized feeding strategy. The dietary overlap was low among all species. These differences in feeding patterns would reduce competition for prey between the four species, allowing co-existence in the same area.

Keywords: Slope fish, stomach analysis, feeding strategy, overlap, Moroccan Atlantic

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INTRODUCTION

Studies on the diet of fish species have been given increased attention over the last few decades. They are the basis for the interpretation of species interaction in multispecies trophic models, which are essential in developing ecosystem-based fisheries management [1]. Most of the available studies describe the dietary composition, temporal, ontogenetic and depth-related changes, daily rations and/or try to establish energetic balances mainly of commercial fish [2-10]. This information is important for understanding foraging behavior, but is insufficient to define the ecological role of species or population. One of the classical approaches used to understand this role involves describing the trophic niche that indicates whether the population is specialist or generalist [11]. However, it is important to distinguish between the niches of the individuals and that of the entire population [12, 13]. This information on trophic behavior can be obtained through the study of feeding strategy. Studies that describe the diet of marine fish from the continental slope have been less detailed in different areas around the world [2, 4, 14-19] and the description of trophic niches and feeding strategy has been rarely contrasted and is relatively unknown.

In the Moroccan Atlantic Sea, the Blackmouth Catshark *Galeus melastomus* (Rafinesque, 1810), the Mediterranean Slimehead *Hoplostethus mediterraneus mediterraneus* (Cuvier, 1829), the Hollowsnout Grenadier *Coelorinchus caelorhincus* (Risso, 1810) and the Blackbelly Rosefish *Helicolenus dactylopterus* (Delaroche, 1809) cohabit in the continental slope [20]. The four species are commonly taken as by-catch in the trawl fishery for crustacean and fish in the Atlantic and Mediterranean Sea of Morocco. In spite of their wide distribution and co-occurrence, very little information is available on the biology and the ecology of these species. The existing research in Moroccan area have only included taxonomic and distribution studies [21, 22]. No research has addressed the trophic ecology of one of these four species. The aim of this study is to determine diet composition and feeding strategy and to analyze the dietary overlap between them in the continental Moroccan north Atlantic slope.

MATERIAL AND METHODS

All specimens were occasionally collected from the north Atlantic of Morocco during research cruises in July 2010 using the research vessel "R/V Charif Al Idrissi" of the National Institute of Fisheries research. This trawl survey was designed for the assessment of demersal species stocks, especially European Hake (*Merluccius Merluccius*) and rose shrimp (*Parapenaeus longirostris*) in the Sea area on the bottoms ranging from 20 to 800 m. The fishing gear used was a locally designed bottom trawl with the vertical opening of 1.5 to 3 m, the horizontal opening of 18 to 22 m and the stretched mesh sizes of 40 mm. During this survey, depth and substrate type (mud, sand, hard) were noted.

150 specimens (47 *H. mediterraneus mediterraneus*, 41 *G. melastomus,* 28 *C. caelorhincus* and 34 *H. dactylopterus*) were collected on the continental slope between 30°N and 34°96'N (Figure 1). For each species, total lengths (*TL*) of sampled specimens were measured to the nearest 1 mm and sexual maturity was determined by macroscopic examination of gonads. Stomachs were removed, frozen at -18°C and analyzed ashore. At the laboratory, stomachs were emptied of their contents, and examined using a binocular magnifier (Motic® SMZ-168). Prey items found in the stomach contents were identified to the lowest taxonomic level possible, counted and wet-weighed to the nearest 0.001 g.

To evaluate the prey's importance, the relative importance index (*IRI*) of Pinkas *et al*. [23] as modified by [24] was used:

$$[IRI = (N + W) \text{ x } F] \qquad \text{And} \qquad [\%IRI = (IRI \,/\, \sum IRI) \times 100]$$

Where *F* is the frequency of occurrence of the prey *i*,
N is the percentage of number of the prey *i*,
W is the percentage of weight of the prey *i*.

According to their contribution to the cumulative percentage of IRI, prey items were classified into three categories: preferential, secondary and accidentally food. In this order, prey were sorted in decreasing order of their *%IRI* contribution, then the *%IRI* of first prey are gradually added until to obtain 50% or more, these items are preferential food. This calculation is pursued until it has 75% or more, these items are called secondary prey. The other items are accidental [25].

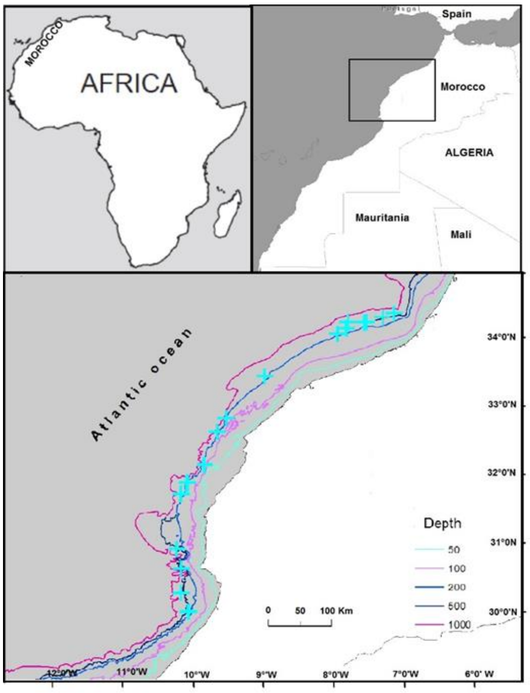

Figure 1: Map of geographical location of the study area in the north Atlantic of Morocco, showing sampling stations where fish species were caught.

To calculate the trophic niche breadth, the Levins standardized index (*Bi*) was used [26]. This index ranges between 0 and 1. The *Bi* value less than 0.6 was chosen to represent a specialized diet and over 0.6 was chosen to represent a generalized diet [27].

$$[Bi = (1/n - 1) * (1/\sum jP^2ij - 1)]$$

Where, B_i is the Levins index for predator *i,*
Pij is the proportion of the diet of predator *i* given by prey *j*,
n is the number of prey categories.

To measure the diet overlap between species, the Schoener index *Cxy* [28] was calculated using each pair of species. This index takes values from 0 when no food is shared to 1 when there are the same food resources [29]. Values exceeding 0.6 are considered indicative of a biologically significant overlap.

$$Cxy = 1 - 0.5 \sum_{i=1}^{n} (|Pxi - Pyi|)$$

Where *Pxi* and Py_i are the proportion of food category *i* in the diet of species *x* and *y*.
n is the total number of prey.

To assess the feeding strategy, the modified Costello [30] graphical method [13] was used. The diagram is based on a two-dimensional representation, where the prey-specific abundance (*Pi*) (y- axis) was plotted against the frequency of occurrence (*F*) (x- axis); the prey-specific abundance was calculated according to the following formula:

$$[Pi = (\sum Si / \sum Sti) * 100]$$

Where: *Si* is the number of prey *i*,
Sti is the total number of prey in only stomachs containing prey *i*.

Information about prey importance and the feeding strategy of each predator can be obtained by analyzing the distribution of points along the diagonals and the axes of the diagram [13]. Prey items with low specific abundance and moderate to high occurrence show a generalist population, while prey items with high specific abundance and high occurrence indicate specialized population and prey items with high specific abundance and low occurrence indicate specialization by individuals. Amundsen *et al*. [13] give a more detailed description of the method.

In order to detect sources of variability in the diet of each species separately, non-parametric multivariate analysis of variance (NP-MANOVA) was performed on feed composition after testing homogeneity of covariance using the Shapiro-Wilk test of multiple normality. NP-MANOVA was applied on four factors: bottom depths (depth strata) and substrate type (muddy, sandy, hard), fish size and sexual maturity (juveniles/adults) to identify variables that influence diet for each species. This analysis was performed using the 'Adonis' procedure of the 'Vegan' library under R software [31].

RESULTS AND DISCUSSION

Bathymetric distribution

The four studied species occurred in deep water on the continental slope. *C. caelorhincus* and *H. mediterraneus* were found at similar depths between 300 and 720 m (Figure 2). *G. melastomus* occupied depths ranging from 336 to 720 m. *H. dactylopterus* inhabited shallower waters within the depth range 300–570 m. However, the four species mainly occurred between 350 and 600 m depths.

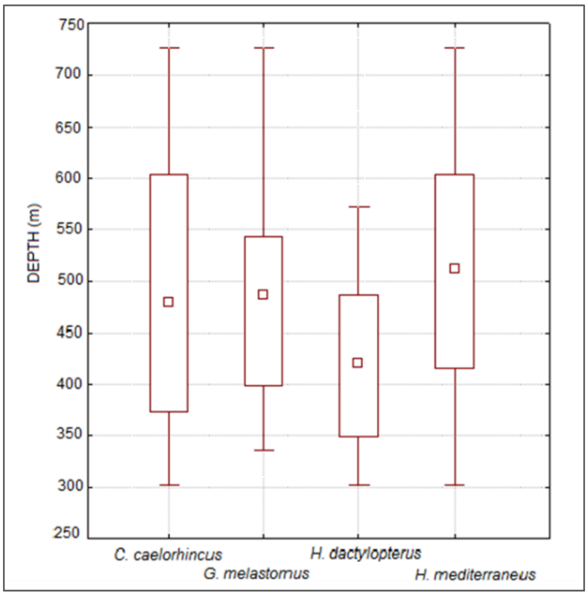

Figure 2: Boxplot of the bathymetric distribution of the studied species.

Food composition

The sampled specimens of *H. mediterraneus mediterraneus* ranged in size from 5.5 to 17 cm TL, with a mean value (± SD) of 10.7 cm (± 3.1). The prey items identified in stomach contents of this species belonged to three major zoological groups: Crustacea, Mollusca and Annelida (Table 1). Among Crustacea, Euphausiidae and Mysida seemed to be the most important and became the preferential prey item with %IRI= 85. The contribution of Dendrobranchiata was minor (%IRI= 14.4). The other taxa of prey (Bivalvia, Cephalopoda, Isopoda, Polychaeta and unidentified Crustacea) were negligible and therefore, they were an accidental dietary component. The importance of Crustacea prey has been found in previous studies in different areas. In the North Atlantic, this species mainly fed on moving prey; Mysida and Pasiphaea were the dominant food [14] and in the

Mediterranean Sea, Madurell and Cartes [16] and Sever *et al*. [32] reported that *H. mediterraneus mediterraneus* actively fed on benthopelagic natantian Decapods. In Portuguese waters, Euphausiidae and Isopoda were considered the main prey groups [33]. It seems likely that these differences would be due to geographical changes in prey availability. According to Sever *et al*. [34], in a thermally stable environment such as deep waters, food availability probably constitutes the main factor influencing food consumption of this species. Added to this, *H. mediterraneus mediterraneus* is a non-migratory species [35].

The specimens of *C. caelorhincus* ranged in size from 17.8 to 41 cm TL, with a mean value (± SD) of 27.4 cm (± 6.0). Small invertebrates dominated the diet, particularly benthic infauna (Table 1). Polychaeta were found to be the main prey groups (%IRI= 71.8) and isopoda were classified as secondary food (%IRI= 21.9). The other prey (Tanaidacea, Nephropidae, Brachyura, Dendrobranchiata, unidentified Crustacea and Gastropoda) were considered accidentally prey. In earlier studies, the general impression concerning the diet of *C. caelorhincus* is consistent with our findings. In the western Mediterranean Sea, Macpherson [36] underlined that this species predominantly consumes Polychaeta and benthic Crustacea. Madurell and Cartes [16] reported that the dietary composition, in the eastern Mediterranean, consisted largely of Polychaeta and secondarily of Amphipods and Copepods. In addition, Sever *et al*. [34] pointed out that the *C. caelorhincus* mouth shape seems to affect its feeding behavior. It has a long rostrum and a subterminal mouth and tends to probe the sediment to feed on epifauna and infauna with the snout oriented towards the substrate [37, 17]. This is the case for Polychaeta, which were common dietary items for this species in our area.

The diet of *G. melastomus* was investigated from specimens ranging between 20.5 and 65 cm TL, with a mean value (± SD) of 36.3 cm (± 10.9). The examined stomachs contained remarkable amounts of fish (Table 1). The Actinopteri prey had the highest alimentary indexes and was the preferred prey-group (%IRI = 80.7). The contribution of the remaining prey (Crustacea and Sepiida) was minor; they are therefore an accidental dietary component**.** The three groups of prey (Fish, Crustacea and Cephalopoda), chosen by *G. melastomus* in our region, were found in other areas but in different proportions. In the Cantabrian Sea, fish and Crustacea were the main prey, but Cephalopoda were the minor prey [38]. Whereas Cephalopoda and fishes were the principal prey, shrimps were secondary food in the eastern Ionian Sea [39]. In the Spanish Mediterranean, *G. melastomus* fed mostly on Natantian Decapods and secondarily on Cephalopoda, Euphausiidae and fish [6]. It has been suggested that morphological characteristics of the eyes and olfactory lobes of *G. melastomus* have an effect on its feeding habits. This shark has large eyes, which enables better vision that favors the hunting and capture of moving prey in the water column [38].

The TL specimens of *H. dactylopterus* ranged from 12.3 to 29 cm TL*,* with a mean value (± SD) of 21 cm (± 4.1). Four groups of prey (Crustacea, Polychaeta, Actinopteri, and Mollusca) composed its feed (Table 1), but Crustacea were the most important group. According to the percentage index of relative importance (%IRI), the preferential prey was Brachyura (%IRI= 38.3) with Dendrobranchiata (%IRI= 33.2) followed by unidentified Crusaceans (%IRI= 18) and as secondary food. The other taxa of prey: Isopoda, Nephropida, Gastropoda, Polychaeta and fish were of minor dietary importance. It has been noted that *H. dactylopterus* may be a sit-and-wait predator, occurring almost exclusively attached to the bottom, and may attack its prey (mainly benthic crustaceans) as they swim at rather short distances and close to the bottom [40]. *H. dactylopterus* feed on different prey depending on the region, but its diet is mainly based on Crustacea. In central Mediterranean Sea, this species is considered a carnivorous species, showing preference for benthic crustaceans (mainly *Goneplax rhomboides* and *Lophogaster typicus*) [41], while in the Portuguese coast, Neves *et al.* [42] reported that this predator has a diverse diet focused on small crustaceans such as-Mysida, shrimp and fish. The most important prey of *H. dactylopterus* taken from the Cape south of South Africa were Mysida, Euphausiidae, Brachyura and Teleostei [37].

Statistical analysis did not show a dietary shift in relation to sampling depth, nature of the substrate, fish size and maturity for three species: *G. melastomus*, *H. mediterraneus mediterraneus*, and *C. caelorhincus*. Therefore, during this study's period, the effects of these variables were not statistically significant ($p > 0.05$) meaning that individuals from each one of the three species ate the same prey taxa at the study site. However, NP-MANOVA analysis revealed that size fish (p=0.001) and sexual maturity (p=0.002) were the statistically significant factors, affecting the diet of *H. dactylopterus.* The juveniles individuals and then the smallest (TL < 25.2 cm) had a diverse diet, focused mainly on Dendrobranchiata %IRI= 51.5% (Figure 3). In contrast, adults specimens (TL > 25.2 cm) had a narrower food spectrum based mostely on Brachuyura (%IRI= 49%). The ontogenetic diet changes have been also observed in others area. For example in the Mediterranean, Macpherson (1979) reported that the diet of individuals from 4 to 9 cm was focused on fish (51.9%) and as specimens grow (20–29 cm in length) decapod crustacean *Goneplax rhomboides* become more consumed (49.4%). In the Portuguese coast, Neves *et al*. [42] also found that smaller *H. dactylopterus* had a generalized diet, feeding mainly on Mysida changing their diet above 20 cm, where a major consumption of Natantia was found, with larger specimens (>28 cm) the diet is focused on fishes. Rodríguez-Mendoza *et al*. [43] reported that the observed changes in mouth shape and position during the growth are very likely to be related to ontogenetic changes in the diet of *H. dactylopterus*. Functionally, mouth shape changes plays an essential role in determining the type of prey consumed, and morphological variations can lead to changes in foraging/predation ability and subsequently differential exploitation of food resources [44].

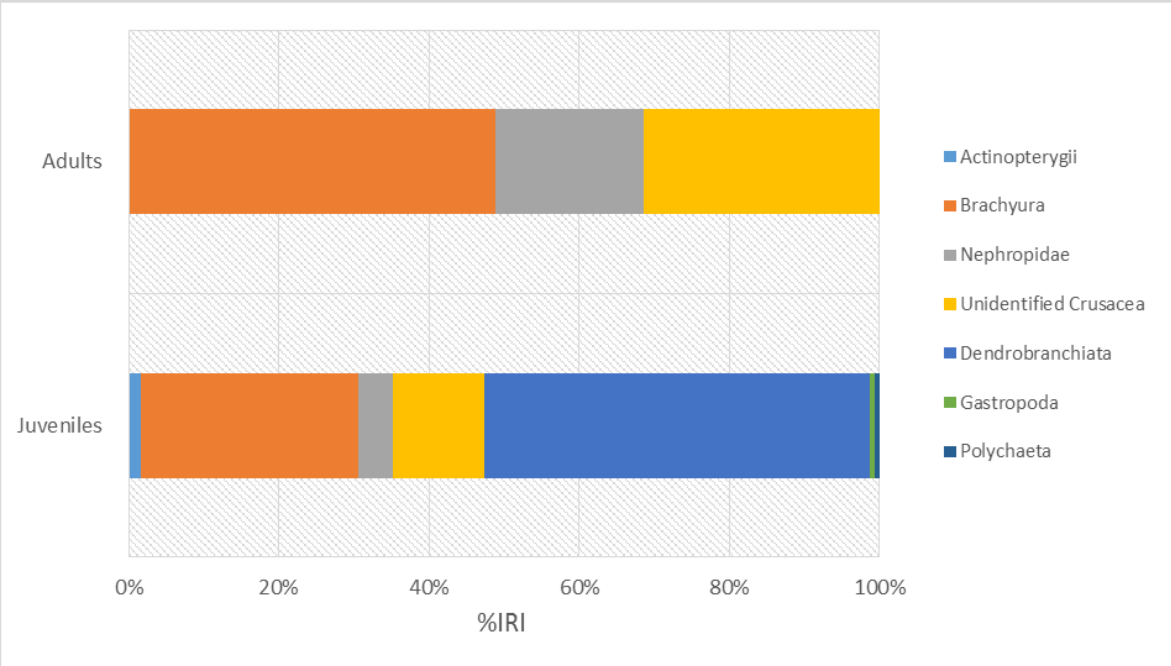

Figure 3: Diet composition by two groups (juveniles and adults) of *H. dactylopterus* represented as percentages of relative importance index (% IRI).

Interspecific overlap

The Schoener index calculated for the four studied species was always under the significant threshold of 0.60 (Table 2). The minimal value (Cxy = 0.03), which indicates no trophic overlap, was obtained between *H. mediterraneus mediterraneus* and *C. caelorhincus*. The highest value (Cxy = 0.5) was found between *G. melastomus* and *H. dactylopterus,* suggesting a low overlap between them.

Feeding strategy and trophic niche breadth

The findings obtained with feeding strategy showed different situations where the resource use patterns varied according to species. The first example of *C. caelorhincus* (Figure 4a) showed most prey with lower value of specific abundance, displaying a generalized strategy with wide trophic niche (*Bi* = 0.7).

In contrast, a clear tendency to specialize on Euphausiidae and Mysida (positioned in the upper right quadrant) is observed for *H. mediterraneus mediterraneus* (Figure 4b), although other food categories were occasionally eaten by some individuals. This was consistent with the findings obtained with the Levin's index, which indicated that the trophic niche width was narrow (*Bi*= 0.1) and showed a diet dominated by fewer prey.

H. dactylopterus presented situation with strong individual specialization (most prey have high P*i* and low F (Figure 4c). The Levins standardized index (*Bi*= 0.7) was more than the biologically significant value (0.6). The findings indicated that *H. dactylopterus* holds a generalist niche at the population with a specialization at the individual level.

The last example of *G. melastomus* (Figure 4d) showed a mixed feeding strategy with varying degrees of specialization and generalization on different prey types. In fact, the graph indicated a specialization towards Actinopteri, particularly consumed by more than half the specimens (*F* = 56%) and with higher contribution in specific abundance (*Pi* = 59%). Nevertheless, other preys (Sepiida, Brachyura and Dendrobranchiata) have a low value of Pi and low to moderate value of F, revealing a generalist feeding strategy. The trophic niche had a value close to significance (*Bi = 0.55*).

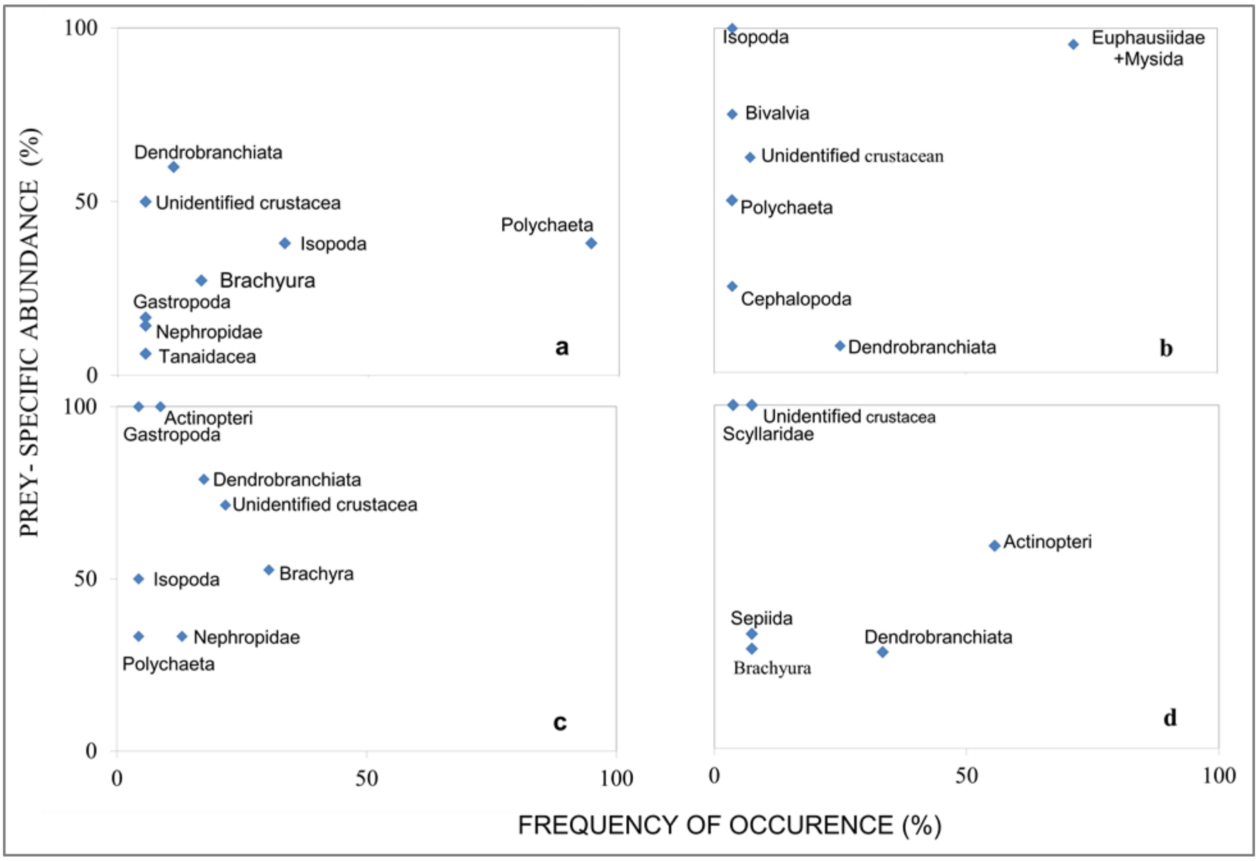

Figure 4: Feeding strategy diagram for four fish species from the North Atlantic of Morocco. (a) *C. caelorhincus*, (b) *H. mediterraneus mediterraneus*, (c) *H. dactylopterus* and (d) *G. melastomus.*

The low dietary overlap between *H. dactylopterus, G. melastomus* and *C. caelorhincus* suggests low resource sharing between these species in their similar geographical area. This is partly minimized by differences in resources used and probably has been related to different feeding strategies developed by each of them in the Moroccan North Atlantic. In addition, non-overlapping trophic niches reflect non-possible competition between *H. mediterraneus mediterraneus* and the three other species of predators. This may be attributed to the specialized feeding strategy developed by *H.mediterraneus mediterraneus*, which mostly fed on Euphausiidae and Mysida. In the same case, Carrassón *et al.* [45] also claimed that the low trophic overlap between two bathyal sharks was mainly attributed to the dietary specialization of one of them.

CONCLUSION

When the four fish species: *H. mediterraneus mediterraneus*, *C. caelorhincus, H. dactylopterus* and *G. melastomus* are sympatric, they do not use the same food with the same feeding strategy. This probably allows the coexistence and reduces the interspecific competition in the continental Moroccan Atlantic slope. Studies on food resources availability are needed in this area to provide detailed information on the abundance of prey. This will clarify whether the prey species are abundant and the predators are selecting preferentially their prey, whether the resources are exploited according on their level of abundance.

Table 1: Values for frequency of occurrence (F), percentage of number (N), percentage of weight (W) and index of relative importance (IRI and %IRI) for prey items observed in stomachs of *H. mediterraneus mediterraneus*, *C. caelorhincus, H. dactylopterus* and *G. melastomus* caught of continental slope in the North Atlantic of Morocco.

		H. mediterraneus mediterraneus					*C. caelorhincus*					*G. melastomus*					*H. dactylopterus*				
	Prey taxa	**F**	**N**	**W**	**IRI**	**% IRI**	**F**	**N**	**W**	**IRI**	**% IRI**	**F**	**N**	**W**	**IRI**	**% IRI**	**F**	**N**	**W**	**IRI**	**% IRI**
Crustacea	Unidentified Crusacea	7.1	1.3	4.7	43.0	0.4	5.6	2.2	1.9	22.6	0.3	7.4	10.9	1.3	89.8	2.5	21.7	22.2	9.0	678.3	18.1
	Isopoda	3.6	0.3	1.6	6.6	0.1	33.3	30.4	19.4	1661.7	21.9						4.3	2.2	0.7	12.8	0,3
	Dendrobranchiata	25.0	2.6	58.8	1534.9	14.4	11.1	6.5	2.9	105.0	1.4						17.4	33.3	38.6	1250.3	33.2
	Parapenaus longirostris											3.7	2.2	1.7	14.4	0.4					
	Unidentified shrimps											14.8	10.9	6.4	256.3	7.1					
	Pasiphaea multidentata											3.7	8.7	1.8	39.0	1.1					
	Pandalidae											11.1	6.5	9.7	180.0	5.0					
	Scyllaridae											3.7	2.2	0.2	8.9	0.2					
	Euphausiidae+Mysida	71.4	94.5	32.3	9059.6	85.0															
	Brachyura						16.7	13.0	4.3	289.2	3.8										
	Goneplax rhomboides											7.4	4.3	3.1	55.3	1.5	4.3	4.5	8.8	57.4	1.5
	Unidentified crabs																30.4	22.2	23.2	1383.2	36.8
	Nephropidae						5.6	2.2	2.8	27.8	0.4						13.0	6.7	16.8	306.2	8.1
	Tanaidacea						5.6	2.2	0.3	13.6	0.2										
Mollusca	Bivalvia	3.6	0.7	0.2	3.6	0.03															
	Cephalopoda	3.6	0.3	0.2	1.6	0.02															
	Sepiida											7.4	4.3	3.4	57.1	1.5					
	Gastropoda						5.6	2.2	0.5	15.0	0.2						4.3	2.2	1.5	16.4	0.5
Annelida	Polychaeta	3.6	0.3	2.2	8.8	0.1											4.3	2.2	1.0	14.0	0.4
	Nereis sp						33.3	15.2	29.2	1476.8	19.5										
	Unidentified polychaeta						61.1	26.1	38.7	3961.3	52.3										
Actinopteri	*Solea vulgaris*											3.7	2.2	12.1	52.9	1.5					
	Myctophidae											7.4	6.5	5.7	90.4	2.5					
	Merluccius merluccius											7.4	4.3	21.6	192.6	5.3					
	Unidentified fish											37.0	37.0	33	2588.4	71.4	8.7	4.5	0.4	42.1	1.1

Table 2: Schoener's diet overlap index for four species of fish from North Atlantic of Morocco.

	G. melastomus	*C. caelorhincus*	*H. dactylopterus*	*H. mediterraneus*
G. melastomus	1.0			
C. caelorhincus	0.1	1.0		
H. dactylopterus	0.5	0.3	1.0	
H. mediterraneus	0.04	0.03	0.04	1.0

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