

**TROPHIC RELATIONSHIPS AND FEEDING HABITS
OF FOUR DEEP-SEA SHARK SPECIES
OFF THE SOUTH COAST OF PORTUGAL**

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EXTENDED ABSTRACT ONLY- DO NOT CITE

In the present work, the feeding habits of four deep-sea shark species (*Etmopterus pusillus*, *E. spinax*, *Galeus melastomus* and *Scyliorhinus canicula*), taken as bycatch and discarded by commercial trawl fisheries, are studied also as part of some scientific projects that aim to study discards off the south coast of Portugal. Data was collected during 1997 to 1999. Stomach contents were analysed to infer trophic interactions between these four species through their diet composition. Some indices (frequency of occurrence, percentage by number, percentage by weight and index of relative importance) were used in order to express the importance of different prey in the feeding habits of these species. Multivariate analysis (Detrended Component Analysis, Principal Component Analysis, Redundancy Analysis) were applied in order to determine major patterns of variation in prey data, and to examine which variables can best account for dietary variation in these deep-sea elasmobranch species. Two more and well defined groups (*S. canicula* and *E. pusillus*) and one non-defined group (*G. melastomus* and *E. spinax*) of predators were identified. Between these two groups, distinct feeding habits are evident being the sample distributions of the

latter group highly overlapping. *Galeus melastomus* and *E. spinax* are relatively similar in their feeding habits. *Etmopterus spinax*, as well as *E. pusillus*, is the deep-sea shark species with the less diverse prey species. The diet of *Etmopterus spinax* was composed preferentially of decapods natant crustaceans, mostly *Pasiphaea sivado*, and fishes were the secondary prey items selected by this species. The velvet belly did not eat polychaets and other crustaceans, such as amphipods and isopods. *Galeus melastomus*, as well as *Scyliorhinus canicula*, is the elasmobranch species with the most diverse prey species. *Galeus melastomus* also showed food preferences for decapods natant crustaceans seeking fishes as secondary preys. Blachmouth catshark may consider polychaets in its diet although they are just accessories preys. *Etmopterus pusillus* and *S. canicula* distinguishes reasonably well among the others and these predators could have a more specific niche. *Etmopterus pusillus* was found to feed preferentially on cephalopods and secondary on fishes and natant crustaceans. Polychaets don't seem to be part of smooth lanternshark's diet. Natant crustaceans were the preferential prey items, occurring in 100% of the *S. canicula* stomachs. Polychaets and fishes were considered secondary and accessory preys items, respectively, and cephalopods were the prey item that less account for the diet of smallspotted catshark. From the analysis, *G. melastomus* and *E. spinax* seem to be generalist-feeders, and *S. canicula* and *E. pusillus* specialist-feeders. Size of prey and depth of capture don't seem to be statistically significant for the understanding of diet composition of the deep-sea elasmobranches considered.

Material & Methods

Data Source

Specimens utilised in this study were collected in accidental catches (bycatch) of crustacean and fish deepwater commercial trawlers, operating off the south coast of Portugal (Algarve). Sampling was conducted from October to June during the period 1007-1999, from depths between 96 and 644 meters, and the study area extended from Sagres to Vila Real de Santo António.

The material utilised for the analysis of the diet comprised a sub-set of 176 deep-sea shark specimens: 39 *Etmopterus pusillus* (Smooth lanternshark), 61 *Etmopterus spinax* (Velvet belly), 50 *Galeus melastomus* (Blackmouth catshark) and 26 *Scyliorhinus canicula* (Smallspotted catshark)..

The stomachs were individually preserved in 4% buffered formalin for 24 hours, stored in 70% ethanol in marked containers, and analysed over some months. Prey items in each stomach were, whenever possible, identified to species level, measured, counted and weighed on an electronic balance (precision 0.01 g).

Data Analysis

In this work the stomach contents observed in the stomachs of the four predator species are described. For every predator species we have conducted analyses of the frequency of occurrence (FO%), percentage by number (N%), percentage by weight (W%) and index of relative importance (IRI) of the main prey species, taxa or ecological groups, following methods described by Hureau (1970) and Hérran (1988).

In order to study the overlap in prey composition among the four predators and the effect of several environmental variables on a multitude of prey species, multivariate methods were required. Multivariate analysis - Detrended Correspondence Analysis (DCA), Principal Component Analysis (PCA) and Redundancy Analysis (RDA) - were performed using CANOCO (CANONical Community Ordination) (ter Braak & Šmilauer, 1998).

The importance of each prey group in any given stomach was measured in terms of wet weight in these analysis. Individual stomachs were considered as “sites” and prey taxa (category) as “species”. The species data were log-transformed, centred and standardized, and the scaling of the data was based in inter-species correlation. For statistical analysis purposes, the prey species were grouped in to higher groups or categories to avoid spurious trends brought about by sparse matrices and rare prey species. Further, the unidentifiable (digested) material was excluded from the analysis.

Results & Discussion

Diet Composition

Table I shows the prey composition of the stomach contents of the all four deep-sea shark species in study. A total of 21 prey taxa were observed in the *Etmopterus pusillus* stomachs. When considering prey species, the diet of the smooth lanternshark was composed primarily of non-identified cephalopods followed by non-identified bony fishes, occurring in 46.2% and 38.5% of the analysed stomachs and weighting 25% and 17.5%, respectively. These were considered as the most important preys due to the higher values of IRI, being classified as preferential and secondary preys, respectively. The remaining prey items found were considered as accessory prey species (percentages of IRI less than 12%). When considering prey categories, this elasmobranch was found to feed preferentially on cephalopods, not only in terms of frequency of occurrence (69.2%) but also of percentages by number and weight (45.5% and 49.19%, respectively). Although considered as accessory prey categories due to low values of IRI (less than 25%), fishes and decapods natant crustaceans and other prey species (“OthP”) (such as algae, nematodes, nemertines and non-identified preys), are the next prey categories most frequent in the diet of the smooth lanternshark (46.2% and 30.8%, respectively). Polychaets don’t seem to be part of *Etmopterus pusillus* diet.

Concerning the prey species, *E. spinax* fed on the fewest (15) prey species items (Tab. I). Their diet was dominated by non-identified decapods natant crustaceans both in frequency of occurrence (55.7%) and in percentage by number (40.7%) contributing with 21.8% by weight. These were considered

Table I – List of the prey categories identified in all four deep-sea elasmobranchs stomachs and values of frequency of occurrence (%FO), percentage by number (%N), percentage by weight (%W) and index of relative importance (IRI) for each one (n=number; --- indicates absence).

Prey Category	<i>Etmopterus pusillus</i> (21 prey species)					<i>Etmopterus spinax</i> (15 prey species)				
	n	%FO	%N	%W	IRI	n	%FO	%N	%W	IRI
Ceph	40	69.23	45.45	49.19	6552.24	13	14.75	11.02	2.68	202.08
Euph	2	5.13	2.27	0.69	15.21	16	11.48	13.56	2.87	188.55
Nata	17	33.33	19.32	7.82	904.45	64	72.13	54.24	32.93	6287.40
OCrus	3	7.69	3.41	1.91	40.92	—	—	—	—	—
OthP	1	33.33	1.14	7.64	292.67	2	39.34	1.69	15.79	687.79
Poly	—	—	—	—	—	—	—	—	—	—
Pisc	23	46.15	26.14	27.58	2479.43	20	22.95	16.95	23.12	919.66
Rept	2	5.13	2.27	1.60	19.85	3	1.64	2.54	4.96	12.30
Sedi	—	2.56	—	3.56	—	—	14.75	—	17.65	—
Total	88	202.56	100.00	100.00	10304.77	118	177.05	100.00	100.00	8297.78
Prey Category	<i>Galeus melastomus</i> (17 prey species)					<i>Scyliorhinus canicula</i> (24 prey species)				
	n	%FO	%N	%W	IRI	n	%FO	%N	%W	IRI
Ceph	11	20.00	3.79	1.76	111.12	1	3.85	0.63	0.00	2.43
Euph	56	22.00	19.31	11.52	678.20	30	15.38	18.87	3.84	349.29
Nata	137	100.00	47.24	31.12	7836.55	34	100.00	21.38	48.10	6948.14
OCrus	4	6.00	1.38	0.07	8.70	2	7.69	1.26	0.11	10.49
OthP	10	66.00	3.45	9.79	873.89	34	53.85	21.38	13.56	1881.67
Poly	4	8.00	1.38	0.06	11.53	37	115.38	23.27	17.04	4651.27
Pisc	57	68.00	19.66	28.25	3257.53	17	61.54	10.69	10.11	1279.89
Rept	11	20.00	3.79	4.61	168.08	4	15.38	2.52	7.25	150.23
Sedi	—	18.00	—	12.81	—	—	—	—	—	—
Total	290	328.00	100.00	100.00	12945.60	159	373.08	100.00	100.00	15273.41

as the most important preys (IRI=3480.6) for the velvet belly and classified as preferential preys. Bony fishes, belonging to the group of accessory preys and the second most abundant (%N=16.1) and more important (IRI=835.2%), was the prey that most accounted for percentage by weight (23.1%) occurring in 21,3% of the analysed stomachs. Non-identified prey species, although considered as accessory preys, were the second most frequent, occurring in 37.7% of the analysed stomachs, being however the less abundant (%N=0.85). Summarizing the prey into major groups, decapods natant crustaceans occurred in the majority (72.1%) of the velvet belly stomachs and were the most important (IRI=6287.4) and preferential prey category. Other prey (“OthP”), although considered as accessory, were the less abundant prey category (1.7%). Cartilaginous and bony fishes were the second most abundant (%N=17) and secondary prey category, ranking third in terms of percentage by weight overall (23.1%). Reptant crustaceans were the most unimportant (accessory) prey category present in this elasmobranch diet. Polychaets and other crustaceans (such as amphipods, isopods and other non-identified crustaceans) were not eaten by the velvet belly analysed specimens.

A total of 17 prey items were found in the stomachs of the *Galeus melastomus* (Tab. I). Analysis of the diet of this elasmobranch shows that decapods decapods natant crustaceans forms the main fraction of the diet considering either frequency of occurrence (94%) or percentage by number (46.2%), and were the most important preys (IRI=6812.5) and the only preferential preys in the diet composition of blackmouth catshark. Bony fishes, the second most important (IRI=3257.5) and accessory prey, also occurred in high percentages (68%) of the analysed stomachs being the main important preys in percentage by weight (28.3%) and the second most abundant (19.7%). When considering prey categories, blackmouth catshark was found to feed preferentially on decapods natant crustaceans and also on fishes (cartilaginous and bony) and other prey species (“OthP”) categories (%FO=100, 68, 66, respectively), being the decapods natant crustaceans the most important one (IRI=7836.6) and accounting for the highest values of percentage by number (47.2%) and by weight (31.1%). Fishes, the second most abundant prey category (%N=19.7%), were considered as secondary preys.

Scyliorhinus canicula is, of the four deep-sea shark species considered, the one that presented the most diverse prey species (24 items) (Tab. I). The diet consisted primarily of non-identified decapods natant crustaceans as preferential preys and bony fishes as secondary preys. The former was the most important one (IRI=4363.2) occurring in 80.8% of the stomachs and the most abundant

(%N=17), weighting 37% of total weight. The osteichthyes, occurring in 61.5% of the stomachs, contributed less in terms of both percentages by number (10.7%) and by weight (10.1%). Almost half (45.8%) of the smallspotted catshark's diet composition is constituted by polychaets items, of which *Nainereis laevigata* is the most important one followed by Onuphidae specimens (IRI=420.2 and 130.5, respectively), although classified as accessories preys when considered isolated. Concerning prey categories, *S. canicula* was found to feed most frequently on polychaets (115.4%) followed by decapods natant crustaceans (100%), fishes (61.5%), and other preys ("OthP") (53.9%). However, decapods natant crustaceans formed the most important prey category (IRI=6948.1) that accounted for the highest percentage by weight (48.1%), while polychaets were the most abundant ones (%N=23.3). According to category of preference, decapods natant crustaceans remains the preferential preys for the smallspotted catshark but, when considering prey categories, polychaets are now classified as secondary preys and fishes (both cartilaginous and bony) as accessory ones. No sediment was found in the stomach contents of this deep-sea shark species.

Ordination Results

Detrended Correspondence Analysis (DCA) of the data suggested relatively short gradients along the first axis (2.087 SD) leading linear ordination methods to be more appropriate to this case, Principal Component Analysis (PCA) for indirect analyses and Redundancy Analysis (RDA) for direct analyses.

The eigenvalues of the first four axes resulting from the PCA were all low, reflecting weak separation of the species scores along these axes. The percentage variance of species data explained by the first four axes were, 16.8, 14.1, 12.8 and 12.1, respectively.

Eigenvalues and percentage-explained variance of species data dropped from PCA to RDA. The first eigenvalues of RDA with all explanatory variables included is lower than that of PCA, resulting in a major fall in the percentage variance of the species data explained by this axis (10.8%) from PCA to RDA. The eigenvalue of the second, third and fourth axes decreased no much more than that of the first axis, and the loss in the explained species variation was high. This indicates that the measured environmental variables did not account for the main variation in the species data. The total of all constrained eigenvalues explained only 11.3% of the total unconstrained eigenvalues.

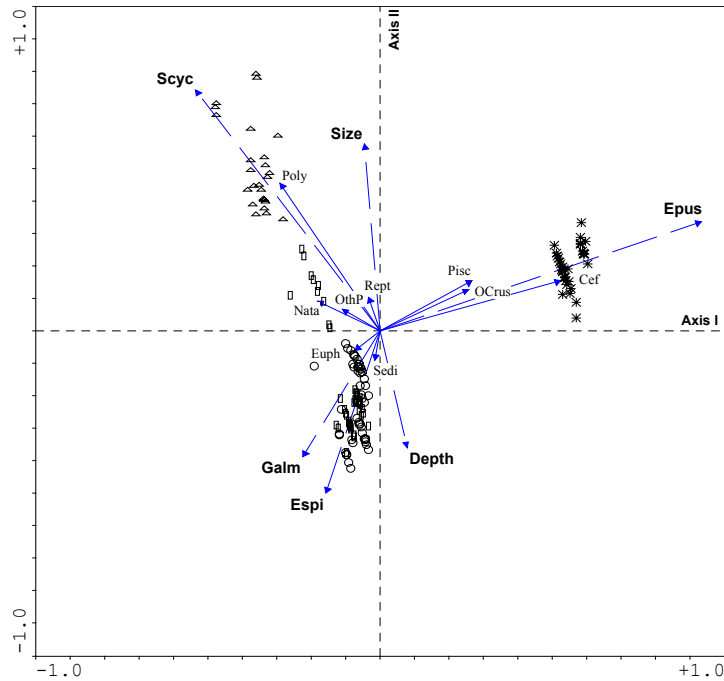


Figure 1 – RDA ordination diagram of axes 1 and 2, with environmental variables (dotted arrows), prey categories (solid arrows), individual stomachs (symbols: Δ Scyc, * Epus, \square Galm, \circ Espi) sampled off the South coast of Portugal. Both nominal (predator species) and quantitative (predator size and depth) environmental variables are illustrated as arrows.

According to the forward selection of environmental variables included in the analyses, on individual stomach a sites, we can observe a similar ranking of variables. However, the proportion of the total variation in the species data explained by the measured variables was small. The predator *Etmopterus pusillus* appears to be the “environmental” variable most responsible for the variation in the diet composition, followed by *Scyliorhinus canicula*. The “environmental variable retained by the forward selection procedure was the predator *Etmopterus spinax*. A Monte Carlo Permutation test confirmed that both *E. pusillus* and *S. canicula* variables had a significant effect ($P=0.005$) in

the variance in species data. The additional effects of the other variables are not statistically significant ($P > 0.05$) meaning that they did not significantly affect the variance in species data. However, as all explanatory variables had an extra fit (λ), given from conditional effects, much less than 5%, they were all considered as unimportant for predicting variations in the diet composition.

Considering the site scores and species scores of the RDA ordination diagram by the first two axes (Fig. 1), we can identify two more (well) defined groups (*Scyliorhinus canicula* and *Etmopterus pusillus*) and one non-defined group of predators (*Galeus melastomus* and *Etmopterus spinax*). The triplot shows that *S. canicula* and *E. pusillus* stomach contents are very different from those of *G. melastomus* and *E. spinax*, and the sample distributions of the latter's highly overlap. The first axis separates the predators *E. pusillus* from the *S. canicula* meaning that the first one has different feeding habits from the other ones. *Galeus melastomus* and *E. spinax* are relatively similar in their feeding habits (not well separated), partly because both of them seem to be generalist-feeders. *Scyliorhinus canicula* distinguishes reasonably well among the others and this predator, as for *E. pusillus*, could have a more specific niche. The second axis separates the predators *S. canicula* and *E. pusillus* from the others two, meaning that they could have feeding habits very distinct, characteristic or specific of their owns (specialist-feeders).

The predator *E. pusillus* seems to be more strongly associated with cephalopods, followed by other crustaceans and fishes. Only polychaets were strongly associated with the predator *S. canicula*. Reptant crustaceans and, to a lesser extend, other preys and decapods natant crustaceans, were weakly associated with this predator. The predators *E. spinax* and *G. melastomus* were more associated with sediment and euphausiacea, respectively. Even so, this association was not very strong.

Among the other ones, *S. canicula* was the only predator species that was more associated with the predator size ("Size") and the variable explanatory depth of capture ("Depth") is much more associated with *G. melastomus* and *E. spinax* in identical proportions. *Etmopterus pusillus* was not specially associated with any of these two explanatory variables. However, the negatively associated "size" and "Depth" explanatory variables did not captured any significant tendencies of the observations in the ordination diagram, when considering all predators together. Therefore they don't seem to be (statistically) significant for the understanding of diet composition of the deep-sea sharks considered.

To a better understanding of the feeding diet of the four deep-sea shark species studied and of the effect of these environmental variables in the category prey species, the results of the multivariate analysis were related with the diet composition results by predator size. From the analysis of the prey categories composition according to size of predators, we cannot confirm the greatest association between *S. canicula* diet composition and the variable explanatory “Size” seen in the ordination diagram. Also, the observation of the *E. pusillus*, *G. melastomus* and *E. spinax* diet compositions, lead us to point out lower or none association of the diet with the size of predator.

The variable “Depth” was then pooled against “Size” of predator in order to see if these two explanatory variables were, in fact, negatively associated as seen by the ordination diagram. Analysis shows that, for all predator species studied, smaller specimens are generally present at lowest depths within species although each group size frequents a wide range of depth. Thus, the explanatory variables “depth” and “size” are not negatively associated.

Final Considerations

The results indicate that the trophic status of these species can be assigned primarily to the carnivore guild. The general preference of the four predators relay fundamentally on four major motile prey categories: decapods natant crustaceans, fishes (osteichthyes and chondrichthyes, the latter only present in the stomachs of the genus *Etmopterus*) and cephalopods, in different ranking orders of the food composite preference according to predator. Annelids polychaets occurred only in the diets of *G. melastomus* and *S. canicula* being most important in the latest where a wide variety of preys was found.

Other prey items were present in their diets: euphausiids, decapods reptant and other non-identified preys in the stomachs of all four deep-sea shark species; isopods, reptants Galatheidae (*Munida sp.*) and algae in the stomachs of *Galeus melastomus*; amphipods and reptants brachyura in the stomachs of *Scyliorhinus canicula*; osteichthyes *Myctophidae* and euphausiids *Meganyctiphanes Norvegica* in the stomachs of *Etmopterus pusillus*. Nemertines were encountered only the stomachs of *G. melastomus* and *E. pusillus* and nematodes in the stomachs of *E. spinax* and *S. canicula*.

Two more and well defined groups (*S. canicula* and *E. pusillus*) and one non-defined group (*G. melastomus* and *E. spinax*) of predators were identified. Between these two groups, distinct feeding habits are evident being the sample distributions of the latter group highly overlapping. *Galeus melastomus* and *E.*

spinax are relatively similar in their feeding habits. *Etmopterus spinax*, as well as *E. pusillus*, is the deep-sea shark species with the less diverse prey species. *Galeus melastomus*, as well as *Scyliorhinus canicula*, is the elasmobranch species with the most diverse prey species. *Etmopterus pusillus* and *S. canicula* distinguishes reasonably well among the others and these predators could have a more specific niche. From the analysis, *G. melastomus* and *E. spinax* seem to be generalist-feeders, and *S. canicula* and *E. pusillus* specialist-feeders.

Feeding studies based on stomach contents are conditioned and influenced by a number of factors. The fishing method used may influence the quality of the stomach contents as the trawling time can take several hours and the contents may become completely digested and non-identifiable. Besides the advanced stage of digestion of many of the prey items that did not allow identification to the species level for some taxonomic groups, the differences in the diet composition of the four deep-sea sharks considered in this study, given by a spacious variety of prey found in the stomachs, could reflect some opportunistic foraging behaviour.

In fact, sharks are considered to have an opportunistic feeding nature, consuming whatever prey is encountered, caused by changes in diet with size, season and habitat. Some shark species indeed appear to be opportunistic, but the extent to which they are opportunistic or selective feeders is not well defined (Wetherbee *et al.*, 1990). Nevertheless it is difficult to make generalizations about feeding habits of any particular species, being fundamental and necessary sampling consistently during the year and during 24 hours periods. Therefore, our observations should be regarded as preliminary and additional studies of these species should be carried out.

Analysis of the size of predator and depth of capture don't seem to be statistically significant for the understanding of diet composition of the deep-sea elasmobranches considered. The main components of the diet did not vary significantly with fish length and depth related differences in diet composition of the four deep-sea shark species were not observed. Depth does not explain the feeding diet as a whole and this variable should rather be used at the individual predator level. The limited size of our data set presented, however, a more detailed analysis at the species by depth level.

Most of the prey species consumed by the four benthic predators live in benthopelagic and epibenthic environments. The ingestion of small amounts of sand and detritus can provide a clue that is also foraged near the bottom.

Therefore, it is apparent that they are not dependent on live bottom organisms for prey, since they can feed on benthopelagic and even pelagic and mesopelagic preys. This fact could allow us to admit that these deep-sea sharks can make vertical dislocations in the water column. However, the corroboration of these migrations and the definition of its periodicity, requires a sampling methodology conducted in different moments of the day and a study should be done separately.

No data are available on the abundance of the prey organisms in the southern coast of Portugal environment, and therefore it is not clear whether the prey species are dominant and the predators are selecting their prey preferentially, whether the food resources are exploited in a density-dependent manner.

This study should be regarded as a general contribution to the understanding of the trophic relationships and feeding habits of the *Etmopterus pusillus*, *Etmopterus spinax*, *Galeus melastomus* and *Scyliorhinus canicula* deep-sea shark species off the south coast of Portugal.

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