Galeus melastomus

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We reviewed literature on the diet of the Galeus melastomus Rafinesque, 1810, from the Mediterranean Sea. Specific keywords ("Galeus melastomus diet", "feeding habits", "trophic position", "biology", "deep environment adaptation") in the principal data sources, such as Web of Science, PubMed, and Google Scholar were used. Seventeen studies conducted on the diet and trophic position of G. melastomus have been considered for Mediterranean Sea regions. The feeding habits have been analyzed in many areas of the western basin; instead, for the Tyrrhenian, Adriatic, and central Mediterranean Seas, information is outdated and fragmentary. In all investigated sub areas, the data showed that G. melastomus is an opportunistic demersal supra benthic predator, benthic feeder, and scavenger, that adapts its diet to the seasonal and geographical fluctuations of the prey availability. It occupies a generalist niche showing individual specialization. In all reviewed Mediterranean sub areas, the most important prey groups were crustaceans, cephalopods, and teleost fishes. Taxa percentage in its diet composition can vary depending on different habitats with ontogenetic development of individuals, depth (that is correlated with the ontogenetic development), seasonal availability, and distribution of different prey groups.

Keywords: Galeus melastomus ; Sharks ; Conservation ; Feeding ; Mediterranean Sea

1. Introduction

The black mouth cat shark *G. melastomus* is a demersal bottom dwelling species, inhabiting benthic environments, continental shelf breaks, and slope habitats. It is a meso predator (typically < 1.5 m total length), which plays a key role in the deep water's food network. It occupies a trophic position of generalist opportunist that is preyed on by larger sharks [1]. This is the only cause of death for this species, along with trawling bycatch. It is the connecting link between the upper and lower trophic strata and explains the high connectivity of sharks seen in food web models [2]. Their population size is linked to the abundance of bigger elasmobranchs top predators, which are the only consumers of meso predators like *G. melastomus* [3][4]. In all the demersal habitats, including the Mediterranean [5][6][7][8][9][10], an increase of meso predators has been reported and correlated with the large sharks' decline.

Galeus melastomus is among the most abundant Mediterranean Sea Selacii species. This species has a stable size structure from trawl fishing catches that might also be related to their distribution at depths that are less exploited by trawling, thus making them less vulnerable to fishing [7]. However, the fishing can quickly reverse this increase, because of their high sensitivities to this activity [8].

To obtain key information about their ecology is an important step in the monitoring, conservation, and management of shark populations and the entire deep biocoenosis, which can be done by studying their feeding habits and trophic ecology [11][12][13].

The trophic position, based on their feeding habits, of sharks and batoids in the marine food web is high, although the feeding strategies of elasmobranchs species are different [14][4][15]. However, the information about trophic relationship for most of them, especially for demersal species like *G. melastomus*, are scarce. The basic ecological knowledge, the feeding ecology, and the trophic preferences of these marine predators should be improved [11], especially for those living in deep habitats, a food limited environment [16]. The intrinsic oligotrophy of deep environments can increase the vulnerability of species inhabiting these habitats.

Ecological studies are based on the analysis of stomach contents of collected specimens; in fact, direct methods are usually difficult or even impossible due to the high depth of these environments [17]. Stable-isotopes analysis [18] have been used as a complementary method in feeding studies. A dietary analysis is also essential to understand the feeding strategy [19] and the breadth of a predator's diet (i.e., niche width; [20]), which identifies its functional role in an ecosystem.

The black mouth catshark *G. melastomus* is a small shark distributed in the eastern Atlantic and Mediterranean Sea basin [21]. Ubiquitous in the basin [22][23][6][7][24][25][26][27], it shows a wide bathymetric range throughout the Mediterranean Sea, where it lives in both the outer shelf edge (c. 150 m) and boundaries between the middle (800–1400 m) and lower (>1400 m) slope bottoms [28][29]. It also inhabits greater depths [30][31], but the higher abundance of the species has been reported from 300 to 800 m [22][30][6][32].

Galeus melastomus' trophic position is low, close to skates and rays. It is considered an opportunistic generalist. It is a prey (with *S. canicula* and other smaller cartilaginous fish) of bigger sharks (*Dalatias licha* Bonnaterre 1788, *Hexanchus griseus* Bonnaterre 1788, *Centroscymnus coelolepis* Barbosa du Bocage and de Brito Capello 1864 and holocephalan *Chimaera monstrosa* Linnaeus 1758) in the deep-sea environment [3][12][15][33].

Available information about *G. melastomus* mainly concerns the biology, assemblages, and depth distribution; few studies deal with abundance fluctuations [32]. Most of this information comes from the central and western Mediterranean Sea, while eastern Mediterranean Sea studies are limited.

2. Diet, Feeding Habit, and Trophic Position of *G. melastomus*

In the literature, two different methods have been reported to investigate the diet and the consequential trophic position of this cartilaginous fish: (i) The "traditional" stomach content analysis (13 references) and (ii) the stable isotopes approach (4 references). In many studies, the combination of these two methods have been used to examine the consistency of the feeding ecology at different temporal, trophic positions in the food chain and the trophic relationship with other sympatric species [12]. The data showed that in all the studied areas, this species has a generalist niche, with an individual specialization on food items of high specific abundance and low occurrence [12][34]. *Galeus melastomus* is an active predator of mid-water depths, with activity in the benthic area and in the layer near the bottom. For its ecological features, this species plays a strategical role in the energy transfer between pelagic and benthic environments and vice versa. It consumes prey from the benthic boundary layer, which constitute an active transport between the primary surface production and the end of trophic chains, as mentioned from different geographic areas [35][12][16][36][37][38]. The individual specialization could be an adaptive strategy to the deep-sea environment, common in many sharks (called "opportunistically selective feeders") [39]. This is, in fact, considered a food-limited environment [17], with patchy resources and an unpredictable food availability. A fish that holds a generalist niche can be adapted to an oligotrophic extreme environment [40]. With the individual specialization on a resource or prey category, an individual becomes more effective at feeding in that niche, avoiding intra-specific competition.

The diversity of prey composition showed that *G. melastomus* is a benthic feeder and scavenger [41][12][34][42][43][44], and a demersal supra-benthic predator [45][46][47][48]. Due to its opportunistic behavior, this cartilaginous fish feeds on all available prey [16]. Some authors [35] argued that it has an advantage in environments with disturbed sediment and organic matter produced by trawls and discards such as fishes.

The factors that influence the local diet and prey composition of this species are: (1) Seasonality [12][16][49]; (2) environmental characteristics that can change the prey availability in different zones; and (3) the individual size class [41] [36][50]. During their growth, like other catsharks, they change the depth and consequently their habits and prey composition, with an increase of fish and crustaceans in the diet [35][37].

There is evidence of ontogenic shifts in the diet of *G. melastomus* determined by stable isotope. Analysis has proven that juvenile and adult elasmobranchs are isotopically segregated, despite displaying the same feeding strategy, indicating that different size classes of the same prey would be consumed by both size groups [51]. The ontogenic variation of the diet in *G. melastomus* and other deep-sea predators has been widely reported [52][53][54][55][56].

In all studied areas, the most important prey groups in *G. melastomus* diet were Crustaceans, Cephalopods, and Teleost fishes. According with the bibliography obtained from different Mediterranean areas, the percentage of different taxa in the diet of this shark changed in relation with the individual ontogenetically development [41][36][50], with depth, that is correlated with the size development [35][36][37], seasonal availability, and distribution of different prey groups in each sub-area [12][16][36][54].

2.1. Crustacean Decapoda

According to the bibliography obtained from different Mediterranean areas, the percentage of different taxa in the diet of this shark changed. This taxon has a great importance in the diet of the most studied species in benthic and demersal-

supra benthic deep-sea environments [57]. This is due to their high energetic value [58], and their migrations along the water column that increases their availability to a wide variety of predators [47].

The diet of *G. melastomus* comprises a large part of crustacean decapods taxa that inhabit the demersal and benthic deep environment [16][59][60][57] as summarized in Table 1.

Table 1. Studies on *G. melastomus* diet in the Mediterranean Sea. Results are summarized for prey, frequency (F) of these in relation to season, and black mouth catshark dimension (expressed in millimeters).

Area	Prey	F	Dimension	Season	References
Eastern Mediterranean	*Natantia*	D	181 to 546	Autumn	[16]
	Natantia	S	181 to 546	Summer	
Central Aegean Sea	*Crustacea*	-	-	Autumn Summer	[61]
Western and central Mediterranean	*Euphausiids*	D	<250	Autumn Summer	[35] [41] [33]
	Caridea and Dendrobranchiata	S	251 to 450	Autumn Summer	[60] [37]
	Brachyura and Anomura	D	>500	-	[38]
North-Western Mediterranean	*Small Cephalopods (Abralia veranyi, Heteroteuthis dispar)*	D A[1]	<250	Spring	[36] [37]
	Large Cephalopods (Todarodes saggitatus)	D S	>500	Spring	[36] [37]
Eastern Mediterranean	*Cephalopods*	D	181 to 546	Summer	[16]
		S	181 to 546	Autumn	
Aegean Sea	*Cephalopods (Argonautidae, Chiroteuthidae, and Loliginidae)*	D	181 to 546	Autumn	[16]
	Cephalopods (Octopoteuthidae)	D	181 to 546	Summer	
Adriatic Sea	*Cephalopds (Heteroteutis dispar)*	D	280 to 480	-	[62][63][64]
	Cephalopods (Sepiolidae spp., Abralia verany, Histioteuthis bonnellii, Histioteuthis reversa, Brachioteuthis sp., Todarodes sagittatus, and Argonauta argo)	S	-	-	[62][63]
Algerian coast	*Cephalopods*	S	-	-	[60]
	Cephalopods (Octopus vulgaris, Loligo vulgaris)	A	-	Spring	[41]
Eastern Mediterranean	*Bony fish*	D	181 to 546	All seasons	[16]
	Myctophidae	D	181 to 546	Autumn	
Western and central Mediterranean	*Bony fish (Myctophidae, Micromesistius poutasso)*	S	>500	Summer	[35] [41] [60]
	Bony fish (Myctophidae, Sternoptychidae, and Stomidae)	A	251 to 450	Autu	[37] [51]

From the reviewed studies about different areas Natantia Dendrobranchiata and Caridea (together called “Natantia”) are among the most important prey categories found in stomach content [12][16][61][60].

In the Eastern Mediterranean Sea, Natantia are the dominant preys in Autumn and secondary preys in Summer [16].

According to [61], crustaceans dominate the stomach content of *G. melastomus* in the central Aegean Sea.

In the western and central Mediterranean, [35][41][33][60][37][38], investigations showed that *G. melastomus* predominantly consume crustaceans, with evidence of a bigger–deeper trend, influencing the species composition of prey [37][65]. Euphausiids (es. *Meganyctiphanes norvegica* M. Sars, 1857) were preyed on by smaller *G. melastomus* specimens (up to 250 mm). Medium size individuals (251 to 450 mm) preyed mostly on Caridea and Dendrobranchiata (*Robustosergia robusta* Smith, 1882, Sergestidae, Pasiphaeidae, *Aristeus antennatus* Risso, 1816, *Plesionika* sp.). The large size (below 500 m) individuals also preyed on Brachyura (Geryon longipes A. Milne-Edwards, 1882, *Macropipus tuberculatus* P. Roux, 1830) and Anomura (*Pagurus alatus* J.C. Fabricius, 1775).

This behavior confirmed the ontogenetic changes in diet and feeding ecology of this species [37][38][65]. The small and juvenile specimens inhabit and feed mesopelagic and demersal environments (up to 500 m). With the increasing of the total length, the animals feed on more deep strata, showing in the adult a more benthic behavior, confirmed by the presence of benthic preys and anthropogenic remains [37][65][66].

2.2. Cephalopods

Cephalopods are the main prey in the diet of *G. melastomus* for its entire life cycle (Table 1). It is considered a teuthophagous predator that feeds on cephalopods all year round, with seasonal fluctuations and changing on prey frequency, relative importance, and relative abundance in relation with the ecological temporal dynamic of each area. The discovery and identification of the beaks are essential to evaluate the grade of importance of the cephalopods contributing to *G. melastomus*' diet composition. These chitinous hard structures are capable of preserving in the predators stomach and could be identified up to the species level in certain occasions [67][68][69][70]. *G. melastomus* does not exhibit an ontogenetic shift in the diet with its size increase for this kind of prey [71]. Although this shark is a demersal species, in its diet it is common to also find mesopelagic cephalopods (e.g., *Todarodes sagittatus* Lamarck, 1798). This is due to their daily migration. Some of them live near the bottom during the daytime [72], becoming prey for demersal fish.

Heteroteutis dispar Rüppel, 1844, *Abralia veranyi* Rüppel, 1844, *Abraliopsis morisii* Vérany, 1839, *Pyroteuthis margaritifera* Rüppel, 1844, Histioteuthidae, and Onychoteuthidae families are the most preyed on taxa in most of the Mediterranean reviewed sub-areas. The bigger *G. melastomus* preyed on larger cephalopods too, such as *T. sagittatus* [16][73][59][71][37].

In the northwestern Mediterranean Sea, there is more evidence of the importance of cephalopods in *G. melastomus*' diet. In a study conducted during the Spring [37] in an area from the Alboran Sea to the Gulf of Lion and between 400 and 790 m depth, an ontogenetic change in the diet of this species, correlated mainly with depth changes (bigger–deeper trend) was found. Up to 500 m depth, where the population is mainly composed of small catshark specimens, smaller young individuals mainly preyed on small cephalopods (*A. veranyi*, *H. dispar*), exhibiting a more pelagic behavior. However, below 600 m, bigger adult specimens preyed on large cephalopods (e.g., *T. sagittatus*). A change in diet in correlation with bathymetric levels has also been found [36], with cephalopods that became an accidental prey in upper slope, while in middle slope, inhabited by large catsharks' specimens, *T. sagittatus* became one of the main prey.

In the east Mediterranean Sea, this taxon became the main prey during the Summer and the second prey for frequency in Autumn [16]. In the Aegean Sea, cephalopod families, such as Argonautidae, Chiroteuthidae, and Loliginidae, have been identified in the stomachs of individuals caught in Autumn, whereas the Octopoteuthidae family has been found in Summer.

For the Adriatic Sea, there are some data [62][63][73] related to the importance of cephalopods in *G. melastomus*' diet. In these studies, the stomach content analysis of all teuthophagous predators have been used to reconstruct the Adriatic cephalopod assemblage. *H. dispar* is by far the most preyed upon cephalopod, for *G. melastomus* [62][63][64], followed by *Sepiolidae* spp., A. verany, *Histioteuthis bonnellii* Férussac, 1834, *Histioteuthis reversa* Verrill, 1880, *Brachioteuthis* sp., *T. sagittatus*, and *Argonauta argo* Linnaeus, 1758 [62][63]. There is no data about the seasonality of prey composition and the relation with other prey frequency in stomach content.

In the western Algerian coast, Cephalopods are the secondary prey for frequency of ingestion [60]. This prey category is the third in abundance in *G. melastomus*' diet [2], but this can be explained with the sampling period of this study, from January to June, with lower cephalopods' abundance. These data prove a seasonality of cephalopods frequency in stomach content of *G. melastomus* in this area, with an increase of this taxon in the stomach content of specimens taken in Autumn and Winter. Among preys, *Octopus vulgaris* Cuvier, 1797, and *Loligo vulgaris* Lamarck, 1798, seem to be the most abundant among cephalopods in this area [41].

2.3. Bony Fish

This taxon is the most important in the diet of medium and large *G. melastomus* diet (Table 1).

All the demersal bony fish species are preyed on from this cartilaginous fish, but most important were the presence of bathypelagic bioluminescent preys such as Myctophidae, Sternoptychidae, and Stomidae (*Hygophum benoiti* Cocco, 1838, *Ceratoscopelus maderensis* Lowe, 1839, *Diaphus* sp., *Chauliodus sloani* Bloch & Schneider, 1801, *Stomias boa* Risso, 1810, *Myctophum punctatum* Rafinesque, 1810, *Maurolicus muelleri* Gmelin, 1789, *Lampanyctus crocodilus* Risso, 1810) [16][51].

Fundamental in *G. melastomus*' diet are also the Clupeidae (*Sardina pilchardus* Walbaum, 1792, *Sardinella aurita* Valenciennes, 1847), Engraulidae (*Engraulis encrasicolus* Linnaeus, 1758), Gadidae (*Gadiculus argenteus* Guichenot, 1850, *Micromesistius poutassou* Risso, 1827), Phycidae (*Phycis blennoides* Brünnich, 1768), Chlorophthalmidae (*Chlorophthalmus agassizi* Bonaparte, 1840), Paralepididae, benthic fishes (i.e., Bothidae, Bythitidae, Cynoglossidae and Scorpaenidae), Macruridae (*Hymenocephalus italicus* Giglioli, 1884), and all the other families that inhabit the mesopelagic environment and the benthic boundary layer about 50 m above the bottom in all the Mediterranean areas.

Fish are the principal prey during all seasons in the Eastern Ionian Sea [16], and Myctophidae characterizes the diet of this shark during Autumn, when it exploits a broader range of prey.

In the Aegean Sea, Teleost fishes are identified as the most important prey group [18][59], with Macruridae and Myctophidae contribution relative higher than other groups, whereas the bony fishes are the second prey in the central Aegean Sea [61].

In the Western and Central Mediterranean, the bony fishes seem to be a secondary or accessory prey, increasing in importance in larger adult specimens [35][41][61][37][34].

The consumption of *M. poutassou* is most important for the adult specimen in this area [35], large quantities of these fishes consumed could come from discards. The mesopelagic fishes consumption [37], especially Myctophidae, increase with the depth and specimens growth, according also with [65] for the Tyrrhenian Sea.

Like cephalopods' beaks, the otolith sagittae can be preserved in the predator stomach and can be identified up to the species level in certain instances with the aid of online libraries, like AFORO [74], and the reference scientific literature.

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