Diet of the Deep-Sea Shark *Galeus melastomus* Rafinesque, 1810, in the Mediterranean Sea: What We Know and What We Should Know

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Abstract: 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many areas of the western basin; instead, for the Tyrrhenian, Adriatic, and central Mediterranean Seas, information is outdated and fragmentary.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. Widening knowledge of *G. melastomus* feeding habits is a fundamental tool for better understand meso and bathy-pelagic ecosystems.

Keywords: conservation; shark; feeding habit; black mouth catshark

1. Introduction

Chondrichthyes, which include Elasmobranchii (sharks and batoids) and Holocephali (chimaeras), are of fundamental importance in all the ecosystems where they live. They are a relatively small group in the Mediterranean Sea, with 89 species that inhabit this geographical area, including Lessepsian, vagrant, visitors, and highly migratory species [1]. At present, around 40% of the species belonging to this group are considered critical endangered and threatened as a result of anthropogenic effects, including fishing activity, pollution, and habitat degradation [2]. Over the last few decades, decreasing trends have been shown through research on long time series of chondrichthyan catches carried out in many areas of the Mediterranean [3,4]. Furthermore, there is evidence that diversity of Chondrichthyes has declined. At present, several species such as *Dipturus batis* Linnaeus 1758 (split *D. cf. flossada* and *D. cf. intermedia*), *Pristis spp.*, and *Squatina spp.* [5] are locally extinct [6–8]. According to the International Union for Conservation of Nature (IUCN), the Mediterranean Sea is a hotspot of extinction risk for Chondrichthyes, where more than half of them (39 species out of 73, excluding Lessepsian, vagrant, visitors, and highly migratory...
species) are considered to be threatened: 20 species critically endangered, 11 endangered, and 8 vulnerable [9].

Almost half of the known chondrichthians, 575 of 1207 species [10], live in the deep sea environment (below 200 m), but their biology, ecology, and trophic habits are still little explored [11]. The abyssal plain seem to be the only border for the distribution of this taxon [12]. Abyssal habitats are inhospitable for deep water Chondrichthyes. This is probably due to the buoyancy control and its energetic limitations [13], the dietary limitation of trimethylamine N-oxide (TMAO) required in a high concentration of urea for stabilizing proteins [14], or trophic limitations [15].

The ecological habits of demersal Chondrichthyes make them especially vulnerable to trawl fishing [7], the most important fishery in terms of fishing capacity of both the fleet and catches [16]. Trawl fishing acts on a wide bathymetric range (50–800 m), exploiting different communities [17], and thus many species are involved in the catches (bony and cartilaginous fishes, decapod crustaceans, cephalopods, and other invertebrates). Chondrichthyes of deep-sea environment represents an important fraction of by-catch and discards [18–21]. In southeastern Australia, for over 20 years, the relative abundances of six species of deep-water sharks, captured as by-catch in trawl fisheries targeting teleosts, have declined by more than 95% [22]. In the Eastern Mediterranean Sea [23], researchers reported a decline in biomass of chondrichthyan species with increasing fishing effort in the last decade. There is ubiquitous evidence of sharks’ and rays’ decline in the Mediterranean in all the ocean, linked to fisheries’ activities [3,19,24–27].

In the Tyrrhenian Sea, trawl surveys in 1974–2005 indicated a strong decline for most of the sharks (e.g., Galeus melastomus Rafinque 1810, “73%” Scyliorhinus stellaris Linnaeus 1758, “99%”, Squalus acanthias Linnaeus 1758, “89%”), while batoid species and deeper-water species catch rates declined less or even increased [28]. In the Mediterranean, a century of trawl fishing has led to the loss of 16 of 31 recorded elasmobranch species, 6 of 33 species in the Adriatic Sea [29,30], and half of the elasmobranch species recorded by trawling in the Gulf of Lion since the 1950s [6,29,30]. The rebound potential for deep-water sharks has rarely been studied [31], although the capacity to recover from population declines is very low compared to shelf and pelagic species [32]. However, coastal artisanal fishery can also negatively impact elasmobranch populations [33]. Long-term trends of chondrichthians community and population have been examined in many areas of the Mediterranean [6,20,34–37], especially because Chondrichthyes are highly susceptible to fishing activities for their life history [7,38–40].

The stock health status monitoring of the various elasmobranch taxa can help to define their communities and population features. This could lead to a precise estimation of the temporal trends of demersal Chondrichthyes [41]. Marine ecology researches focused on elasmobranchs, are of fundamental importance to better comprehend top-down trophic interferences of this predators on other communities [42–44].

However, Scyliorhinidae (like G. melastomus and Scyliorhinus canicula Linnaeus 1758) can maintain their population despite the high fishing effort exerted in some areas [24,36,45–48]. This could be due to their particular biological features, which made them adapt to the most exploited areas. Scyliorhinidae have an early maturation [30], a shorter generation time, a faster population increment, and S. canicula and G. melastomus have a continuous reproductive cycle in the Mediterranean [45,49,50]. Moreover, although bottom trawl fisheries capture smaller individuals of these species, these are usually discarded and, in the best case, returned to the sea [19]. These are considered “indicator species” for the evaluation of fishing efforts, ecosystem stability [2,38,51,52], and broad scale changes caused by increasing exploitation in their ecosystem [53], detected by the changes in abundance and diets of G. melastomus and S. canicula [52].

This review aims to describe the ecological role, diet composition, and feeding habits of the Scyliorhinidae G. melastomus in Mediterranean Sea, highlighting what we know and what we should focus on for a better understanding of this species and its trophic interactions. The diet of G. melastomus can give an overview about ecological status of deep habitats of this species, due to its generalist opportunistic behavior. We focused our
attention on it for its easy availability, being in great percentage in the trawling discard, for its biological features, that make it one of the Chondrichthyes best adapted to the anthropological impacts, and for its ecological role and trophic position. All these features make this species a good indicator for: (1) The monitoring of the deep sea’s habitats and trophic chains ecological status, (2) the health of the large and small elasmobranchs, with their trophic relations, and (3) the anthropological impact of trawl fisheries in Mediterranean deep environments.

*G. melastomus*

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 [2]. 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 [54]. Their population size is linked to the abundance of bigger elasmobranchs top predators, which are the only consumers of meso predators like *G. melastomus* [55,56]. In all the demersal habitats, including the Mediterranean [28,57–61], an increase of meso predators has been reported and correlated with the large sharks’ decline.

*G. 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 [58]. However, the fishing can quickly reverse this increase, because of their high sensitivities to this activity [59].

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 [62–64].

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 [39,56,65]. 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 [62], especially for those living in deep habitats, a food limited environment [66]. 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 [67]. Stable-isotopes analysis [68] have been used as a complementary method in feeding studies. A dietary analysis is also essential to understand the feeding strategy [69] and the breadth of a predator’s diet (i.e., niche width; [70]), 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 [40]. Ubiquitous in the basin [45,46,57,58,71–74], 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 [75,76]. It also inhabits greater depths [47,77], but the higher abundance of the species has been reported from 300 to 800 m [45,47,57,78].

*G. 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 [55,63,65,79].
Available information about *G. melastomus* mainly concerns the biology, assemblages, and depth distribution; few studies deal with abundance fluctuations [78]. Most of this information comes from the central and western Mediterranean Sea, while eastern Mediterranean Sea studies are limited.

2. Methodological Approach

As shown in Table 1, a survey of the available published literature was carried out through a bibliographic study using scientific online databases (PubMed, Google Scholar, and Web of Science).

Table 1. Studies on *G. melastomus* diet in the Mediterranean Sea, broken down by year and geographical sub area.

| Mediterranean Sub Area  | References |
|-------------------------|------------|
| Adriatic Sea            | [63]       |
|                         | [80]       |
|                         | [81]       |
|                         | [82]       |
| Aegean Sea              | [68]       |
|                         | [83]       |
|                         | [84]       |
|                         | [85]       |
| Algerian coast          | [53]       |
|                         | [86]       |
| Ionian Sea              | [66]       |
|                         | [87]       |
|                         | [88]       |
| North Western Mediterranean | [63]   |
|                         | [89]       |
|                         | [90]       |
|                         | [91]       |

A combination of keywords was used as criteria (e.g., “*Galeus melastomus* diet”, “feeding habits”, “trophic position and relation”, “deep environment adaptations”, “distribution”, “ecology and biology”). All the articles found about feeding habits (17 references), biology (27 references), and distribution (9 references) of *G. melastomus* in Mediterranean areas were reviewed, with particular attention on the diet, subdividing them according to the Mediterranean region studied in each paper. No studies have been excluded for the review process. The diet of *G. melastomus* has been studied in many areas of the north-east Atlantic Ocean [51,92,93] and western Mediterranean Sea [51,63,89–91,94]. As summarized in Figure 1, there are less data about the Tyrrhenian sea, Adriatic Sea, and eastern and central Mediterranean Sea than the western macro-area. The Adriatic Sea, Tyrrhenian, strait of Sicily, and the Levantine basin are the areas where the information about feeding habits and diet of *G. melastomus* are outdated, scarce, and fragmentary. The only data recovered from the Adriatic Sea are on the trophic relationship with Cephalopoda [80–82]. Additionally, cephalopod and crustacean prey species in the elasmobranch diet have been defined in the same area [81,82,84,87].

Investigated Area

In this review, the Mediterranean Sea has been divided into three macro-areas: Western, Central, and Eastern. The western macro-area includes: The Alboran Sea, the Balearic sea, the gulf of Lion, and the Ligurian sea; the central macro-area includes the straits of Sicily, the Tyrrhenian, Ionian, and Adriatic seas; the eastern macro-area includes the Aegean Sea and the Levantine Basin. In Figure 1 available studies on *G. melastomus* diet are plotted.
3. Diet, Feeding Habit, and Trophic Position of \textit{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 [63]. 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 [63,95]. \textit{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 [51,63,66,89–91]. The individual specialization could be an adaptive strategy to the deep-sea environment, common in many sharks (called “opportunistically selective feeders”) [96]. This is, in fact, considered a food-limited environment [67], with patchy resources and an unpredictable food availability. A fish that holds a generalist niche can be adapted to an oligotrophic extreme environment [97]. 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 \textit{G. melastomus} is a benthic feeder and scavenger [53,63,95,98–100], and a demersal supra-benthic predator [101–104]. Due to its opportunistic behavior, this cartilaginous fish feeds on all available prey [66]. Some authors [51] 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 [63,66,105]; (2) environmental characteristics that can change the prey availability in different zones; and (3) the individual size class [53,89,106]. 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 [51,90].

There is evidence of ontogenic shifts in the diet of \textit{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 [94]. The ontogenic variation of the diet in G. melastomus and other deep-sea predators has been widely reported [95,107–110].

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 [53,89,106], with depth, that is correlated with the size development [51,89,90], seasonal availability, and distribution of different prey groups in each sub-area [63,66,89,108].

3.1. 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 [87]. This is due to their high energetic value [111], and their migrations along the water column that increases their availability to a wide variety of predators [103].

The diet of G. melastomus comprises a large part of crustacean decapods taxa that inhabit the demersal and benthic deep environment [66,83,86,87] as summarized in Table 2.

Table 2. 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   | [66]       |
| Central Aegean Sea          | Crustacea                           |   |           |          | [85]       |
| Western and central         | Euphausiids                         | D | <250      | Autumn   | [51]       |
| Mediterranean               | Caridea and Dendrobranchiata        | S | 251 to 450| Autumn   | [86]       |
| North-Western Mediterranean | Small Cephalopods (Abralia veranyi, Heteroteuthis dispar) D | A1 | <250 | Spring | [89] |
|                             | Large Cephalopods (Todarodes sagittatus) D | S | >500 | Spring | [89] |
| Eastern Mediterranean       | Cephalopods                         | D | 181 to 546| Summer   | [66]       |
| Aegean Sea                  | Cephalopods (Argonautidae, Chiroteuthidae, and Loliginidae) D |   | 181 to 546| Autumn   | [66]       |
| Adriatic Sea                | Cephalopods (Heteroteuthis dispar) D |   | 280 to 480| -        | [80,81,112]|
| Algerian coast              | Cephalopods (Sepiolidae spp., Abralia verany, Histioteuthis bonnellii, Histioteuthis reversa, Brachioteuthis sp., Todarodes sagittatus, and Argonauta argo) S |   | - | - | [80,81] |
|                             | Cephalopods (Octopus vulgaris, Loligo vulgaris) A | S | - | Spring | [53] |
Table 2. Cont.

| Area                       | Prey                          | F  | Dimension | Season     | References |
|----------------------------|-------------------------------|----|-----------|------------|------------|
| **Eastern Mediterranean**  | *Bony fish*                   | D  | 181 to 546| All seasons| [66]       |
|                            | *Myctophidae*                 | D  | 181 to 546| Autumn     |            |
| **Western and central**    | *Bony fish (Myctophidae, Micromesistius poulasso)* | S  | >500      | Summer     | [51], [53], [86], [90], [91] |
| Mediterranean              | *Bony fish (Myctophidae, Sternoptychidae, and Stomidae)* | A  | 251 to 450| Autumn     | [90], [94] |

D: Dominant; S: Secondary; A: Accessory; A\(^1\): Accidental.

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 [63,66,85,86].

In the Eastern Mediterranean Sea, Natantia are the dominant preys in Autumn and secondary preys in Summer [66].

According to [85], crustaceans dominate the stomach content of *G. melastomus* in the central Aegean Sea.

In the western and central Mediterranean, [51,53,79,86,90,91], investigations showed that *G. melastomus* predominantly consume crustaceans, with evidence of a bigger–deeper trend, influencing the species composition of prey [90,113]. Euphausiids (es. Meganyc-tiphanes 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, Aristaeus antennatus Risso, 1816, Plesionika sp.). The large size (below 500m) 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 [90,91,113]. 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 [90,113,114].

### 3.2. Cephalopods

Cephalopods are the main prey in the diet of *G. melastomus* for its entire life cycle (Table 2). 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 [115–118]. *G. melastomus* does not exhibit an ontogenetic shift in the diet with its size increase for this kind of prey [84]. 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 [119], becoming prey for demersal fish.

Heteroteuthis dispar Rüppel, 1844, Abralia veranyi Rüppel, 1844, Abraliopsis morisi Véray, 1839, Pyroteuthis margaritifera Rüppel, 1844, Histiotethididae, 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* [66,82–84,90].

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 [90] 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 [89], 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 [66]. 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 [80–82] 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 [80,81,112], followed by Sepiolidae spp., A. verany, Histiotethis bonnellii Férussac, 1834, Histiotethis reversa Verrill, 1880, Brachioteuthis sp., T. sagittatus, and Argonauto arg Linnaeus, 1758 [80,81]. 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 [86]. This prey category is the third in abundance in G. melastomus’ diet [54], 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 [53].

3.3. Bony Fish

This taxon is the most important in the diet of medium and large G. melastomus diet (Table 2).

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, Sternopytchidae, and Stomiidae (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) [66,94].

Fundamental in G. melastomus’ diet are also the Clupeidae (Sardina pilchardus Walbaum, 1792, Sardinella aurita Valenciennes, 1847), Engraulidae (Ingraulis encrasici Linnaeus, 1758), Gadidae (Gadilus argenteus Guichenot, 1850, Micromesistius poutassou Risso, 1827), Phycidae (Phyctis bennoides Brünnich, 1768), Chlorophthalmidae (Chlorophthalmus agassizi Bonaparte, 1840), Paralepididae, benthic fishes (i.e., Bothidae, Bythitidae, Cynoglossidae and Scorpaenidae), Macruridae (Hymenoncephalus 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 principals prey during all seasons in the Eastern Ionian Sea [66], 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 [68,83], with Macruridae and Myctophidae contribution relative higher than other groups, whereas the bony fishes are the second prey in the central Aegean Sea [85].
In the Western and Central Mediterranean, the bony fishes seem to be a secondary or accessory prey, increasing in importance in larger adult specimens [51,53,85,90,95].

The consumption of M. poutassou is most important for the adult specimen in this area [51], large quantities of these fishes consumed could come from discards. The mesopelagic fishes consumption [90], especially Myctophidae, increase with the depth and specimens growth, according also with [113] 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 [120], and the reference scientific literature.

4. Discussion and Conclusions

Galeus melastomus is an opportunistic predator and scavenger, and fishing activity can supplement their food with offal and discards [51]. It seems to resist trawling [24,36,45–48,51,121], unlike most elasmobranchs, thanks to their life history [45,49,50] and ability to adapt. As shown by the reviewed literature, G. melastomus has a broad spectrum of prey, adapting its diet to seasonal and geographical fluctuations of prey availability in each Mediterranean area.

Morphological and physiological characteristics of the eyes promote the adaptation of this species in the oligotrophic deep environment. Its well-developed eyes with a retina rich of photoreceptors [98] are fundamental for hunting their prey at the depth at which they occur. The bioluminescent preys represent a high proportion in black mouth catshark diets. Small crustaceans (M. norvegica), fishes, and small sepiolids are unselectively preyed on by smaller individuals. Bathypelagic fishes (M. punctatum, C. sloani, H. benoiti, C. maderensis, Diaphus sp.), crustaceans (Eusergestes arcticus Krøyer, 1855, Pasiphea multidentata Esmark, 1866), and cephalopods (H. dispar, A. verany) [66,80,89,91,109,118] are preyed on by adults. The ability to detect small sources of bioluminescent light produced by preys make the difference in an environment with low to absent light or visibility, making the good visual acuity and its larger lens fundamental features for survival in a difficult habitat. This visual acuity, that increase with fish growth, gives the species a better ability to detect smaller or same size prey from a greater distance. Moreover, the long rods in G. melastomus retina [98] provide a better sensitivity to distinguish an object from its background, a trait important in benthopelagic hunting. The maximum rods pigment absorption is matched to the light spectral emission emanating by several preys photophores. Maximum emission of M. norvegica and A. veranyi photophores is around 475 nm [122]. 470 nm and 474 nm are the emission for M. punctatum and H. dispar, respectively [123,124]. The overlap of these values with the spectral absorption of Galeus pigments suggests that it use the bioluminescent light sensing for prey detection. Thanks to this feature the study of its stomach content, trophic ecology, and diet is a way to discover the population dynamic of some rare species that are quite elusive of traditional sampling devices [81] and the ecological dynamic of meso- and bathy-pelagic environments, until now little know in different Mediterranean areas.

The stomach content of G. melastomus can have a wide range spectrum of deep benthic biocenosis. It is a predator that occupies a high trophic level but is also a prey for bigger cartilaginous fish (D. licha, H. griseus, C. coelolepis, and holoccephalan C. monstrosa). It may be considered in the trophic guild of “non-migratory macroplankton feeders” for its preference to exploit mesopelagic resources [90,125]. It shares the deep environment with other sympatric sharks [51,63,68,90,95,125].

Galeus melastomus has managed to carve out its own niche thanks to its adaptability to the surrounding environment. In many studies from different areas of the Mediterranean Sea it is considered a specialistic feeder. For example, in the western Mediterranean Sea and the central Aegean Sea, G. melastomus predominantly consumed crustaceans [85,91], whereas it preferred cephalopods and shrimps in the Gulf of Lion [79]. These differences may be due to the seasonal variations of preys availability and ontogenetic changes in the specimens diet [51,79]. However, other studies indicate that this species has a generalist op-
portunistic feeding strategy, because it probably prefers specific prey when food availability is higher. Moreover, *G. melastomus* is physiologically adapted to the benthopelagic hunting, thanks to its big eyes and retina features [98]. This is a fundamental aspect for the coexistence of this shark species [51,63,68,90,95,125] with other ones. It is able, in fact, to inhabit deeper environments unsuitable for other elasmobranchs. It is most explanatory with the example of resource partitioning between *G. melastomus* and Lesser-Spotted Catshark *S. canicula* in the Cantabrian Sea [51]. *S. canicula* has large developed olfactory lobes and it is a mostly benthic feeder that feeds on a greater diversity of prey than *G. melastomus*. This is due to the better vision of *G. melastomus*, which feeds more in the water column, whereas the better developed olfactory sense of *S. canicula* is an adaptation to benthic feeding. The differences in search and capture of prey of these catsharks species are the result of the morphological features of the eyes and olfactory lobes. The hunting and capture of prey that are found in the water column are favored by the better sight and poorer smell of *G. melastomus*. The better adaptation to consume benthic preys is suggested by the poorer sight and better smell of the lesser-spotted cat shark.

In conclusion, for its trophic importance, is essential to expand the knowledge about the health status of *G. melastomus* in all the Mediterranean Sea. To do this, it is important to improve the knowledge about the feeding habits and the diet of this catshark, also in relation with the other sympatric species, especially in Mediterranean sub areas, like the Tyrrhenian and Adriatic Sea, the Central Mediterranean Sea, and the Levantine basins, where this data are few and fragmentary. For example, in the Tyrrhenian sea and Central Mediterranean Sea, there is no evidence of research on *G. melastomus’* diet, while in the Adriatic sea there are some studies, dating to the 1990s, on the teutophagus Adriatic predators, that include *G. melastomus* [80–82]. Moreover, the stomach content analysis alone cannot give a full and exhaustive vision of diet and trophic relation of this species, because it gives a taxonomic description of the predatory diet that can overestimate certain prey, providing only a snapshot of the diet at the time of the specimen’s sampling [126]. Furthermore, quantitative data can be obtained only by analyzing large numbers of specimens with the risk of high occurrence of empty stomachs; also, findings of little prey items often in an advanced digestion state can alter the results. So, to improve the knowledge on trophic relation and feeding habits, we must explore new alternative ways to pair with stomach content analysis, detecting dietary changes on broad spatial and temporal scales with efficient methods [127].

This can be done with stable isotopes analysis, like in the several studies performed on *G. melastomus* from many Mediterranean areas [51,55,63,68,90,95]. The stable isotopes technique, applied to several tissues of the individuals [128], is implemented successfully in ecological trophic analysis, and it can offer information about the trophic position and diet switching of the species, in relation with the entire biocenosis, on a broad spatial and temporal scale.

Another way to improve the knowledge about diet and to broaden the prey’s spectrum, not yet applied to sharks, is the meta barcoding approach on stomach content. This technique has already implemented in Winter breeding storm petrel (*Hydrobates castro* Harcourt, 1851) and European hake (*Merluccius merluccius* Linnaeus, 1758) in the Adriatic Sea [129,130]. It allows us to expand the spectrum of prey in the stomach content analysis, filling the gap that can arise from the classic identification, for example in the case of too degraded preys.

The fatty acids profile is another innovative technique that can improve the information about diet and feeding habits of demersal sharks [127,131–133]. The diets of a lot of low order (e.g., decapods [134,135]) and high order (including: Seabirds [136]; mammals [137]; cephalopods [138]; and fish [135]) predators have been studied using the approach of the fatty acids “biomarker”. These are major biological constituents of lipids linked with key processes in the organism. In marine ecosystems, the fatty acids’ composition of organism with lower trophic position (like phytoplankton) influences [139] the composition of high order predators, because many of them are not able to produce polyunsaturated fatty acids.
Therefore, this technique, applied to several individual tissues, can result in a broader spectrum of *G. melastomus*. This could be useful for species identification, recently and less recently ingested, using a lower number of samples avoiding taxonomical errors.

From all the reviewed literature, it is clear that *G. melastomus* is a ubiquitous species of the deep environment, commonly fished in the entire Mediterranean. It is part of the by-catch and discarded in almost all the trawl fisheries [140]. Generally, it has no economic value, with the exception of some areas, like Civitavecchia near Rome, where it has a medium-low commercial value, usually being sold to the fish market. Trawl fisheries, along with predation from the larger sharks, is the only cause of death and reduction of population of this species. Using the large amount of *G. melastomus* caught accidentally, and often killed unnecessarily, for scientific purposes could be a great way to avoid unnecessary waste. In this way, we can get more scientific information about this species, but we should work on more selective fishing methods to avoid bycatch.

*G. melastomus* may be a good indicator of the deep biocenosis health status in relation to the anthropic impact, especially due to fisheries effort. The studies on its diet and changes in its feeding habits and population dynamics can bring new information about the ecological dynamic inside an overexploited deep environment [141], monitoring its state of health. For a better monitoring of the population dynamic, we must also improve the knowledge about their age. For a better understanding of the ontogenetic shift of diet and feeding ecology, a correct estimation of biological parameters and fishery stock management, the knowledge of fish age [142,143], estimation of growth, mortality, and longevity are fundamental for a full trophic ecological evaluation. Moreover, in the Mediterranean Sea, the knowledge about the age and growth of elasmobranchs is scarce, especially for demersal species. This is probably due to the complexity of age determination in cartilaginous fish [142,143], for the absence of hard structures, like otoliths and scales, and for their low level of calcification. The vertebral centra (analyzed in toto or sectioned), neural arches, spines, and dermal denticles are the biological structure suitable for age reading in this fish taxa [142,143]. The most common and used method is the preparation of thin sagittal sections of the vertebral centra [139].

The application of this techniques on *G. melastomus* populations, in addition to stomach contents, stable isotopes, fatty acid composition, and meta barcoding analysis, can give a more accurate view about the ecological dynamic, health status, trophic ecology, feeding habits, and ecology of the Mediterranean populations, that can be used as indicators for the health status of the entire deep biocenosis. This increases the knowledge and, as a consequence, the way to preserve the deep environment biocenosis, a fragile important ecosystem that supports the balance of the entire Mediterranean Sea environment and provides many human communities with their livelihood.

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