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Old Info for a New Fisheries Policy: Discard Ratios and Lengths at Discarding in EU Mediterranean Bottom Trawl Fisheries

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Discarding is considered globally among the most important issues for fisheries management. The recent reform of the Common Fisheries Policy establishes a landing obligation for the species which are subject to catch limits and, in the Mediterranean, for species which are subject to Minimum Conservation Reference Size (MCRS) as defined in Annex III to Regulation (EC) No 1967/2006. Additionally, several other initiatives aim to reduce unwanted catches of target and bycatch species, including species of conservation concern. This raises the need to study discarding patterns of (mainly) these species. In this work we collated a considerable amount of historical published information on discard ratios and lengths at discarding for species caught in EU Mediterranean bottom trawl fisheries. The main aim was to summarize the available historical records and make them more accessible for scientific and managerial needs, as well as to try identifying patterns in discarding. We show discard ratios and lengths at which 50% of the individuals were discarded (L_{50}) for 15 species (9 bony fishes, three crustacean decapods, and three elasmobranchs). Discard ratios were usually low for target species such as hake, red mullets and highly commercial shrimps and exemptions from the landing obligation under the *de minimis* rules could be sought in several cases. Discard ratios were usually higher for commercial bycatch species. Discarding is affected by a combination of factors and for a given species, especially for non-target ones, discards are likely to fluctuate within a fishery, across seasons, years, and regions. For most species considered, L_{50}s were lower than the MCRS (when in place) and length at first maturity. L_{50}s of target species, such as hake, were very small due to the existence of market demands for small sized individuals. However, for species of low demand, like horse mackerels, a higher retention size was observed, often exceeding

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MCRS. Lengths at discarding are affected by legal provisions, market demands but also by biological, population, and ecological traits. Understanding the factors that affect discarding constitutes the starting point for designing mitigation measures and management plans to reduce discards and improve the sustainability of the stocks.

Keywords: discarding behavior, multi-species fishery, trawling, unwanted catches, Minimum Conservation Reference Size, landing obligation

INTRODUCTION

Discarding, returning part of the catch back into the sea for whatever reason, is a hot topic for fisheries scientists, managers, and even the wider public (Catchpole and Gray, 2010; Bellido et al., 2011; Condie et al., 2014; Borges, 2015; Sardà et al., 2015; Veiga et al., 2016). The variety of factors (e.g., economic, legal, cultural, natural, biological, technical) affecting discarding render the issue quite complex for fisheries scientists and managers (Bellido et al., 2011; Santiago et al., 2015). Several solutions have been proposed and enforced to mitigate discards (e.g., Sigurðardóttir et al., 2015; Rijnsdorp et al., 2016), however, it is widely recognized that they need to be adapted to the local features of each fishery (Hall and Mainprize, 2005; Johnsen and Eliasen, 2011; Rochet et al., 2014; Sala et al., 2016, 2017).

The recent EU Common Fisheries Policy (CFP) (EU Reg. No 1380/2013), toward a gradual elimination of discards, imposes a landing obligation for the species with catch limits and, in the Mediterranean (where catch limits are applied only for bluefin tuna), for species with defined Minimum Conservation Reference Size (MCRS) [as mentioned in the Annex III of the Council Regulation (EC) No 1967/2006]. The landing obligation raises several issues to stakeholders and presents a wider concern, such as waste management, building port facilities, or adapting the existing ones, handling extra costs related to sorting and on board preservation of the unwanted catch, transportation to land facilities, creation of new markets and the challenge to avoid incentives to fish unwanted catches (Bellido et al., 2011, 2017; Sardà et al., 2015). However, the amounts of unwanted catches that need to be handled are not always well-estimated, especially since the ban applies to a certain number of species. In addition, the regulation states that derogations can be decided and discard plans should be set (Damalas, 2015) on the basis of specific criteria such as the *de minimis* exemption. Further to these timely policy issues, estimates of discards are also important for scientific and managerial goals such as stock assessments, ecosystem modeling, estimation of total catches (including catch reconstructions) as well as for marketing and environmental awareness, e.g., for stock certification (eco-labeling). To tackle the above and to further reduce unwanted catches, understanding of the magnitude of discards and the reasons affecting discarding behavior is essential.

In the past two decades, discards studies in the Mediterranean Sea have increased, while much attention has been placed on bottom trawling, which produces the bulk of discards (Tsagarakis et al., 2014). However, most peer-reviewed studies report discards at the fishery level and the information at the species level is more scattered. This is especially important since target species are not clearly defined in the basin and the fishers actually target a species complex (Stergiou et al., 2003; Caddy, 2009). Species specific discards may vary greatly, from zero (for some highly commercial species in some fisheries) to total discarding (for non-commercial species) (e.g., Carbonell et al., 2003; Damalas and Vassilopoulou, 2013). In addition, commercial bycatch is important in many fisheries and constitute a substantial complementary source of income for the fishers (Tsagarakis et al., 2008). Thus, discard ratios of commercial bycatch may greatly vary seasonally or geographically due to natural conditions, community, state and regulations, and market influence (Eliasen et al., 2014; Tsagarakis et al., 2014). The diversity of the Mediterranean marine environment, the multi-gear, multi-species nature of the fisheries as well as the variant cultural characteristics is expected to differentiate discarding patterns in the basin.

Other than peer-reviewed papers, there is also a great amount of information published in the gray literature which has attracted little attention so far. In the current work we present available published information (i) on species-specific discard ratios as well as (ii) on lengths at discarding for species caught in EU Mediterranean bottom trawl fisheries. The main aim is to summarize the available historical records and make them more accessible for scientific and managerial needs, as well as to try identifying possible patterns in discarding. Special focus is placed on target and main commercial bycatch species as well as on elasmobranchs caught in bottom trawling in the basin.

METHODOLOGY

We collected historical information concerning species-specific bottom trawl fisheries discards in the EU Mediterranean Sea from scientific papers and gray literature, including technical reports. All studies considered collected discards data by using observers on board. The information concerned two aspects. First, we summarized information on discard ratios for species caught in bottom trawl fisheries. Discard ratio was defined as the discarded fraction (in weight) in relation to total catch of a species. In few cases where the discard to marketable ratio (discards/retained catch) was reported, we transformed it to discard ratio (as defined above) for comparative purposes. Along with the discard ratio, additional information regarding the sampling (season, time period), and the fisheries (region, depth stratum, mesh configuration) was noted, where possible. In the Mediterranean Sea, bottom trawl fisheries are officially defined by GSA and by target species (or target assemblages). In addition, in some GSAs, only one bottom trawl fishery is defined. Although—due to data limitations—we did not address specific fisheries, we analyzed

the data at the GSA level, which is the best approximation of the fishery that we were able to achieve.

The information derived from 24 sources (six papers in international scientific peer-reviewed journals, three papers in national scientific peer-reviewed journals, three papers in conference proceedings and 12 reports) and concerned 847 records of discard ratios for 71 taxa at the genus or species level in 12 GFCM Geographical Sub-Areas (**Figure 1**) (GSAs 1, 5, 6, 7, 9, 10, 11, 16, 17, 18, 19, 22) during the period 1995–2014. The vast majority of the information came from Spain (663 records) followed by Italy (126 records), Greece (50 records), and Croatia (8 records). Spanish GSA 6 was divided to Northern and Southern parts because the differences in geomorphology and substratum determine the fishing métiers in each zone. Specifically the Southern part (Spanish Levantine coast) is characterized by a large continental shelf of sandy and muddy bottoms, while the Northern area (Catalan coast) includes more abrupt geomorphological structures like canyons and narrow continental shelf. Furthermore, in some studies (STECF, 2006, 2007; Bellido et al., 2014) discard ratios were reported for the entire Spanish Mediterranean and not per GSA. Discard ratios were more frequently reported for bony fish; for crustaceans they were mainly reported for the most important commercial species while the information was scarce for other invertebrates. Several elasmobranch species were covered, obviously because they are of interest for conservation; however, very few records per species were usually available.

For the species with the largest amount of records we present box-plots of all the records of discard ratios in the EU Mediterranean. In addition, we present this information at the GSA level aiming to identify patterns and factors affecting discards. It should be noted here that the different horse mackerel species (*Trachurus* spp.) were pooled together for the purpose of this presentation since (i) they are often reported at the genus level, (ii) their identification at the species level may be spurious and (iii) they are often marketed together.

We did not try to estimate mean values of ratios because (i) of the variability of the data (different gears, time periods, and sampling designs) and (ii) in order to do this correctly discard ratios should be weighted with landings of the species in each record (an information which was not available). Furthermore, we did not explore the interranual progress of discard ratios since the level of aggregation of the discard ratios reported in the original sources differed; some papers/reports reported values averaged over several years, while others mentioned values for a single sampling season.

Second, we collected information on lengths at discarding. These studies are scarcer and may report different kinds of information, i.e., length range or L_{50} (the length at which 50% of the individuals are discarded after sorting on board). Thus, we focused only on L_{50}s of species discarded and, again, additional information on the sampling and the fisheries was collected. In total, we collected 174 records of L_{50} for 30 species in 8 GSAs, derived from five studies (four papers in international or national scientific peer-reviewed journals and one report). Only records from Spain (18 records), Italy (54 records), and Greece (102 records) were available.

For selected species we graphically represent box-plots of L_{50}s in comparison with MCRS (where applicable) and Length at First Maturity (LFM). The graphical representations enable to instantaneously evaluate if fishermen were discarding mature or immature individuals as well as below or above MCRS. Despite that some differences in LFM may have been reported across the basin for a given species, we assumed the same LFM value for each species independent of the GSA. Specifically the median LFM for each species was calculated based on the data reported in Tsikliras and Stergiou (2014) (**Table 1**). For crustacean species not reported in Tsikliras and Stergiou (2014) LFM was calculated by reviewing other available scientific literature (Supplementary

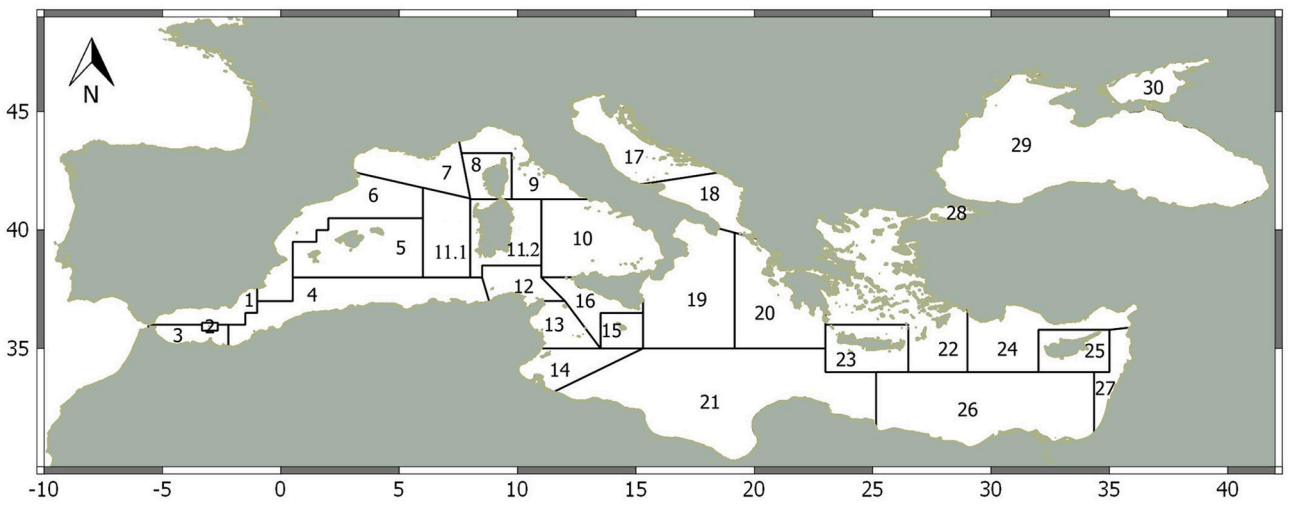

FIGURE 1 | Geographical Sub-Areas (GSA) according to GFCM division.

TABLE 1 | List of species and their code names presented in the Figures.

Scientific name	Common name	Code	LFM (mm)
BONY FISHES			
Boops boops	Bogue	BOG	139.5
Lepidorhombus boscii	Four-spot megrim	LDB	138
Merluccius merluccius[a]	Hake	HKE	305
Micromessistius poutassou	Blue whiting	WHB	210
Mullus barbatus[a]	Red mullet	MUT	129
Mullus surmuletus[a]	Striped red mullet	MUR	155
Pagelllus erythrinus[a]	Red pandora	PAC	164
Phycis blennoides	Greater forkbeard	GFB	200
Trachurus sp.[a]	Horse mackerels	JAX	191
ELASMOBRANCHS			
Etmopterus spinax[b]	Velvet belly lanternshark	ETX	–
Galeus melastomus	Blackmouth catshark	SHO	489
Scyliorhinus canicula	Lesser spotted dogfish	SYC	420
DECAPODS			
Aristeus antenattus	Red shrimp	ARA	27.8
Nephrops norvegicus[a,b]	Norway lobster	NEP	–
Parapenaeus longirostris[a]	Deep water pink shrimp	DPS	24.3

The Lengths at First Maturity (LFM) in mm (from Tsikliras and Stergiou, 2014 and references listed in Table S1 of the Supplementary Materials) are indicated. Lengths are Total Length for fish and Carapace Length for decapod ctustaceans.
[a]Species with MCRS; [b]Species with no information on L_{50}.

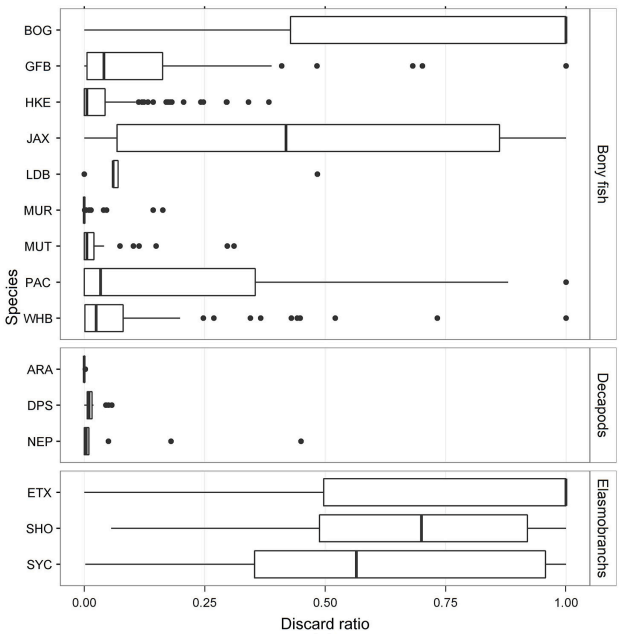

FIGURE 2 | Box-plots of discard ratios (discards/total species catch) in EU Mediterranean bottom trawl fisheries for selected bony fish, elasmobranch, and decapod species. See **Table 1** for species codes.

Materials, Table S1). The median values were used instead of mean, because they are not influenced by the outliers in the dataset (Zar, 1996). If LFM differed between genders, the more conservative (larger) median value was used.

For the sake of simplicity, in the presentation of the results we show (a) the most commercial species, (b) some common bycatch species with commercial interest, and (c) some common elasmobranch species in the bottom trawl fisheries. Nevertheless, full records that we collected are listed in the Supplementary Materials accompanying this paper.

RESULTS

Discards Ratios

All species specific discard ratios that derived from the literature review as concerns the EU Mediterranean bottom trawl fisheries are listed in Table S2 of the Supplementary Materials. **Figure 2** summarizes the compiled published information on discard ratios for the most frequent species found in our database, for the whole Mediterranean. These include nine bony fish, three elasmobranch, and three decapod species. Both target species, such as *Merluccius merluccius* (hake), *Mullus barbatus* (red mullet), *Aristeus antennatus* (red shrimp), and some abundant commercial bycatch species such as *Boops boops* (bogue), *Trachurus* sp. (horse mackerels), *Phycis blennoides* (greater forkbeard), and *Micromessistius poutassou* (blue whiting) were included in this analysis (**Figure 2**, **Table 1**). The box-plots highlight the highly fluctuating discard ratios as a characteristic of these fisheries; great range in discarding was observed among and within species, in different areas from the western to the eastern Mediterranean as well as for target and commercial bycatch species (**Figure 2**). Part of this variation is also due to the disaggregation of discard ratios by season, year, location, gear characteristics, depth stratum, and/or other (Supplementary Materials, Table S2), as each record in the data set was treated as a different entry in the data analysis. In addition, the large number of outliers (**Figure 2**) is probably in close relation to the latter, as some outliers of high discard ratio can be attributed to low captures or small sizes of a species in a given season, depth stratum, etc.

Discard ratios for target species such as hake, red mullet, stripped red mullet, red shrimp, *Nephrops norvegicus* (Norway lobster), and *Parapenaeus longirostris* (deep water pink shrimp) are very low (<10% and often <2% of the total species catch; **Figure 2**, Supplementary Materials, Table S2). In contrast, discarding for bogue and horse mackerels exceeded 40% in the majority of records (**Figure 2** and Supplementary Materials, Table S2). Discard ratios were also very high (usually >65%) for the elasmobranchs considered.

The above information is also analyzed by country and GSA in **Figure 3** (bony fish) and **Figure 4** (decapods and elasmobranchs). High variability in discarding is observed among countries and GSAs. Even though discard ratios for some species were similar and almost always negligible across the basin, regional variations were observed for others (**Figures 3**, **4**). Hake, the main target species for the shelf and shelf-break demersal fisheries, showed low discard ratios (usually 0–5%) for almost all areas studied, with some exceptions in certain

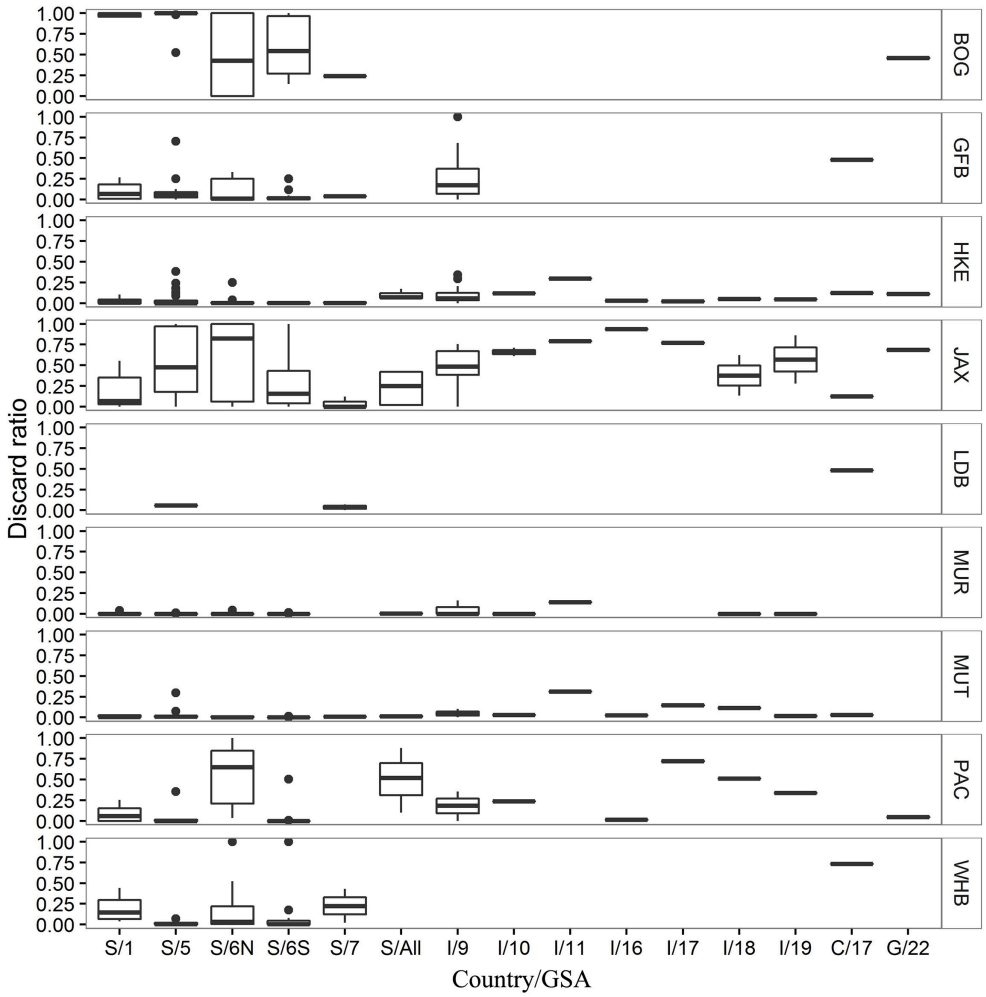

FIGURE 3 | Box-plots of discard ratios for main target and commercial bycatch bony fish species, per country/GSA. C, Croatia; G, Greece; I, Italy; S, Spain. See **Table 1** for species codes.

areas (e.g., GSAs 5, 9, and 11) where few records of higher discards that exceeded 20% were observed (**Figure 3**). Red mullet and stripped red mullet can be considered as species with negligible discards throughout the basin (**Figure 3**) except GSA 11 where the discarded fractions exceeded 10%. Bogue, a coastal species, is a special case in the Mediterranean, since it was almost completely discarded in the west (Spain) but showed commercial importance in the east (Greece). The other coastal species, *Pagellus erythrinus* (red pandora), also showed different discard ratios depending on the areas, i.e., lower discard ratios in most Spanish GSAs, Italy and Greece compared to Spanish GSA 6N, the entire Spanish Mediterranean and Italian GSAs 17, 18, and 19 (**Figure 3**). Horse mackerels were probably the species with the higher fluctuations; they seemed to have lower discards in Croatia (GSA 17), and some Spanish GSAs (GSAs 1, 5, 6S, 7) compared to Greece (GSA 22), most Italian GSAs and Spanish GSA 6N. The discard ratios of greater forkbeard, blue whiting, and *Lepidorhombus boscii* (four-spot megrim) were quite homogeneous in the western and eastern areas with the exception of Croatia where the ratios were generally higher (**Figure 3**).

For crustaceans, the main targets of the shelf-break to middle slope trawl fisheries, discards were almost null for red shrimp and deep water pink shrimp in the Western and Eastern areas respectively, and very low for Norway lobster in almost all areas (**Figure 4**). As for the three most common elasmobranchs presented, *Galeus melastomus* (blackmouth catshark), *Scyliorhinus canicula* (lesser spotted dogfish), and *Etmopterus spinax* (velvet belly lanternshark) a wide range in discard ratio was observed but they were usually discarded by 40–100% (**Figure 4**).

Seasonal discard ratios were mainly available for Spanish GSAs and Italian GSA 9 and are illustrated only for bony fishes in Figure S1 of the Supplementary Materials. However, taking into account the data available, no clear seasonal patterns were observed.

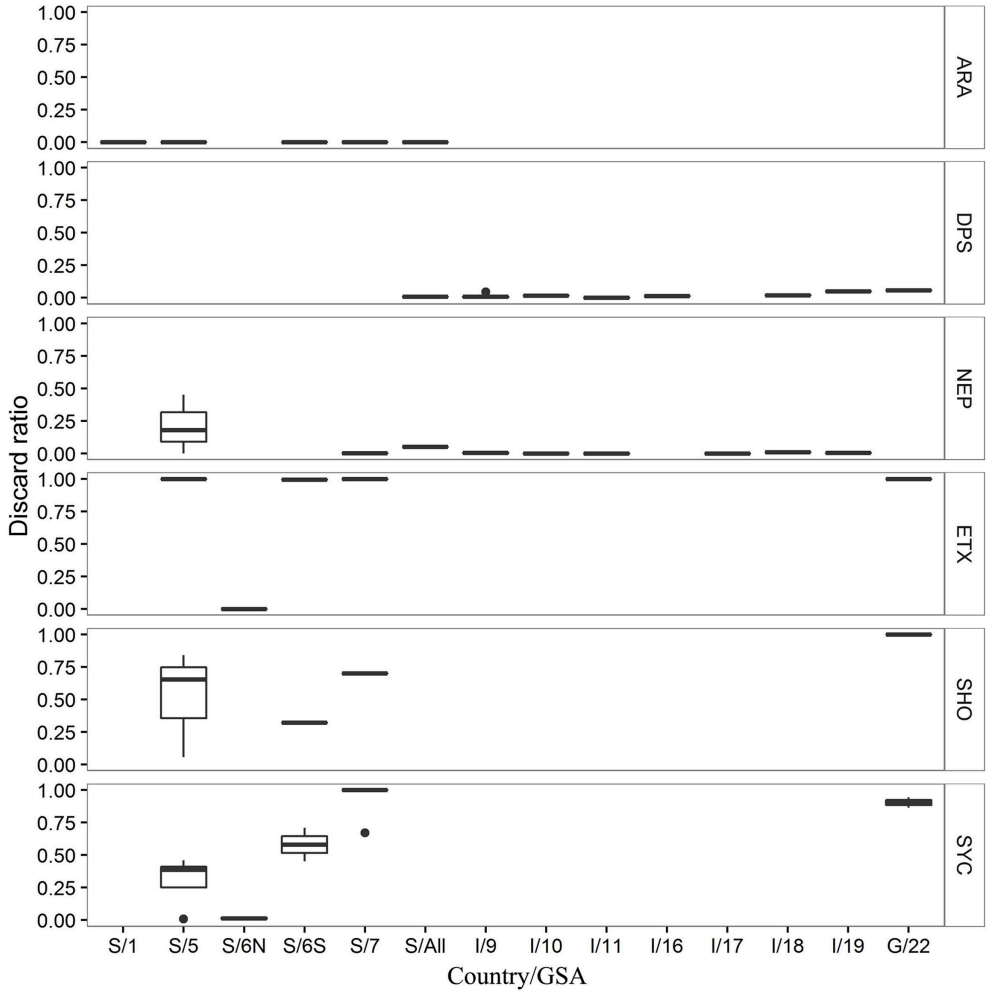

FIGURE 4 | Box-plots of discard ratios for main decapod (ARA, DPS, NEP) and elasmobranch (ETX, SHO, SYC) species per country/GSA. G, Greece; I, Italy; S, Spain. See **Table 1** for species codes.

Lengths at Discarding

The data from the literature review on L_{50}s are listed in Table S3 of the Supplementary Materials. **Figure 5** summarizes the L_{50}s for each country and GSA for the same species presented earlier, with the exception of Norway lobster and velvet belly lantern shark for which no records of lengths at discarding were retrieved. Together with the L_{50} values, the MCRS (where applicable) and LFM are plotted (**Figure 5**), which helps to evaluate if fishermen in a certain country were discarding mature or immature individuals, below or above MCRS. Within species geographical differences in the lengths of discards were observed; however they were usually not as pronounced as the differences in discard ratios. All species were retained at sizes below the LFM with the exception of four-spot megrim in Greece and Italy, greater forkbeard in GSA 22, horse mackerels in GSAs 19 and 22 as well as blue whiting in GSA 19 (**Figure 5**). All species with MCRS defined in Council Regulation (EC) No 1967/2006 were also retained at sizes smaller than the legal, with the exception of horse mackerels (**Figure 5**). Hake L_{50} was closer to MCRS in GSAs 22 and 19 than in other areas, while red pandora in Italian GSA 19 and red mullet in Greek GSA 20 were retained very close to MCRS. In addition, differences were observed also within the same country; for example in Spain, hake L_{50} was larger in GSAs 1 and 5 compared to GSA 6N (**Figure 5**). Another interesting outcome of the graphs is that the retention sizes of the target species were very small compared to bycatch species even if they concerned larger species (with larger maximum length). For example, the median L_{50} for hake is 10–17 cm (depending on the country) and the median L_{50} for horse mackerels is 18–21 cm (**Figure 5**, Supplementary Materials Table S3), despite that hake and horse mackerels LFM (Lmax) are 30.5 (140) and 19.1 (70) cm respectively (**Table 1**; Froese and Pauly, 2016).

DISCUSSION

Bottom trawling produces the bulk of discards in the Mediterranean fisheries (Tsagarakis et al., 2014). Thus, it is not surprising that there is a large amount of information

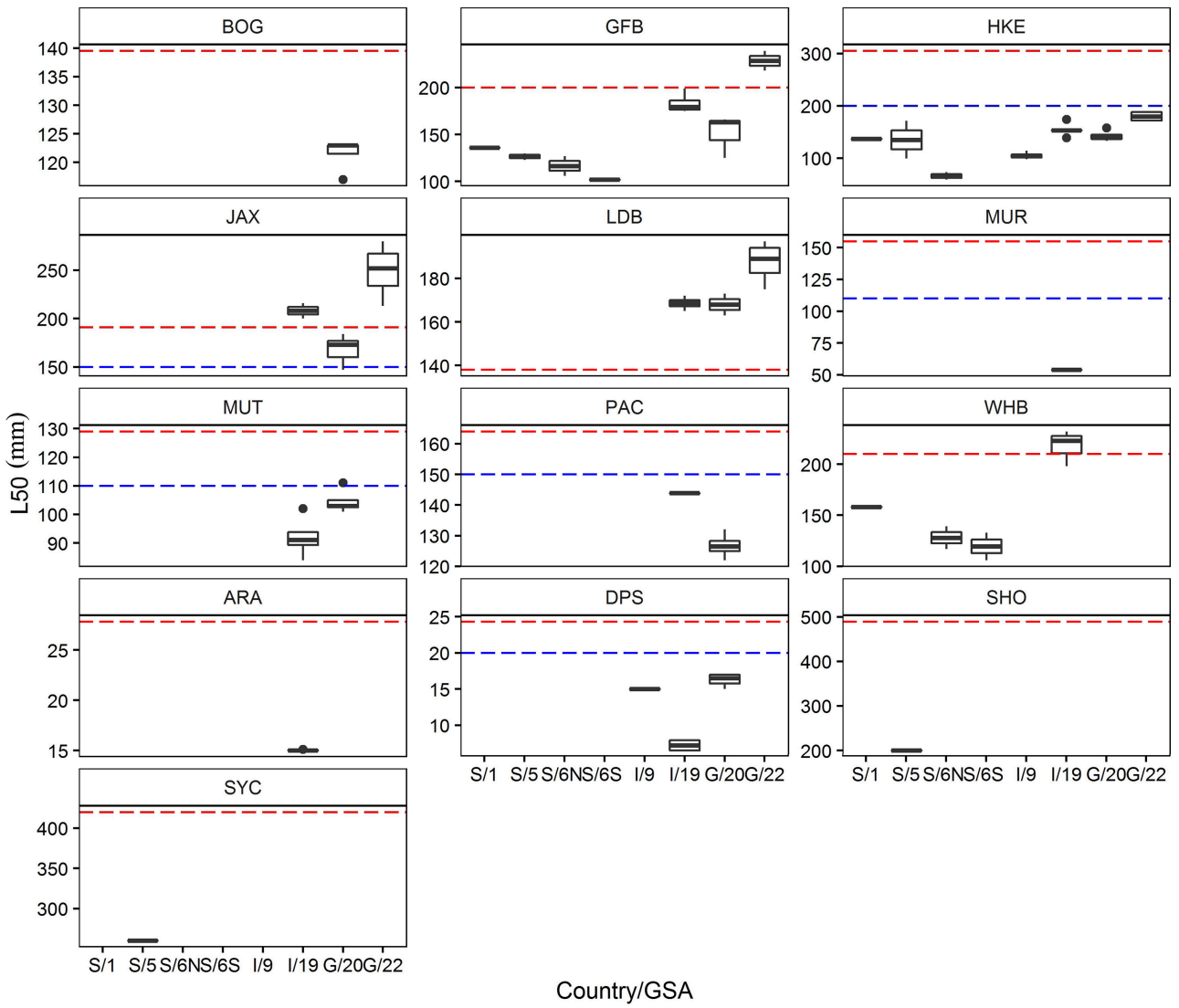

FIGURE 5 | Box-plots of L_{50} (lengths at which 50% of individuals are discarded; in mm) for main bony fish, elasmobranch, and decapod species caught in bottom trawls per country/GSA (G, Greece; I, Italy; S, Spain). MCRS (blue horizontal lines) and lengths at first maturity (red horizontal lines) are also indicated. Lengths for crustaceans (DPS, ARA) refer to carapace length while for fish to total length. See **Table 1** for species codes.

across the basin as concerns discards of the bottom trawl fisheries. Because of the nature of discard research, there are many interesting discard studies as gray literature (reports, working documents, national reports to authorities, etc.), which remain quite often unavailable to the scientific community. This paper makes available some of this information in a synthetic approach, which is quite important for future research and management, e.g., for use in stock assessment and ecosystem models, for the characterization of specific bottom trawl fisheries and for decision making including the implementation of the CFP. As expected, the information was more frequent for the commercially most valuable and most abundant species in the bottom trawl fisheries, thus, inevitably, we chose to focus our presentation on these. Discards studies in general consider and focus their estimations on valuable commercial species; however, the multi-species nature of catches in the Mediterranean, driven by the diversity of assemblages and bottom substrata (de Juan et al., 2013), sets necessary to include additional species in the future studies. This is important for the sustainable exploitation of the resources in the context of the Ecosystem Approach to Fisheries, including Integrated Ecosystem Assessments (e.g., ICES, 2016), and for the goal to reduce the quantities of unwanted catches.

The information that we managed to retrieve was not equally distributed among EU countries, with Spain having more detailed information at temporal and spatial scale, followed by Italy and Greece, while only few records were available for Croatia and none for other EU countries. Most of the information derived

from research and monitoring projects related to discards in the period 1995–2000 (e.g., West Mediterranean: Carbonell et al., 1997; Central and East Mediterranean: Tsimenides et al., 1997), thus this period is highly represented in the database that we built following the literature review (Supplementary material, Tables S2, S3). It seems that the first monitoring projects quantified discards in much detail and described an issue which had attracted little attention up to then. In the following period the interest in publishing on this field faded and/or the next projects and analyses focused less on the description of the issue itself and more on the factors affecting discards. Undoubtedly, more historical data on discards exist in databases and technical reports that are not publicly available and were not accessible to us. The inclusion of this information could complete the gaps in order to shed light on the evolution of trawl discards in the Mediterranean in terms of discard ratios, diversity and size structure of discards. These questions are important not only for the design and application of the CFP but also for the Marine Strategy Framework Directive (EU Directive 2008/56/EC), for the Ecosystem Approach to Fisheries and for the evaluation of policies such as technical measures (e.g., mesh configuration) and spatial restrictions included in the Mediterranean Regulation [Council Regulation (EC) No 1967/2006]. However, given that the general patterns reported in the literature, highlighted in our analysis and discussed below (i.e., low discarding of valuable species and large fluctuations of commercial bycatch) are common across the basin, the inclusion of additional data is not expected to significantly alter the picture presented here. In any case, improving access to such data would favor fisheries research needs and management in the Mediterranean. Furthermore, the use of raw data collected under the EU Data Collection Framework could help tracking the progress of the discards issue from the onset of the first monitoring programs until present, across the basin.

Our review showed that discard ratios highly fluctuated within and among species. Several characteristics of the fisheries in the Mediterranean Sea affect discarding patterns: (i) trawl fishing is essentially multispecies and targets a species complex rather than one or two species (Caddy, 2009), (ii) there is a great diversity of species in the catch including, aside from the so-called "target" high-commercial species, the fraction of bycatch that consists of species which are not marketable and of species which may constitute an important commercial fraction and are partly retained, and (iii) there are no overquota discards and MCRS seems the only management measure directly affecting discarding behavior. As a result of the above, the discarded fractions of the so considered target species were usually very low or even negligible and comprised damaged or undersized specimens (Carbonell et al., 2003; D'Onghia et al., 2003; Sartor et al., 2003; STECF, 2006). This was obvious across the basin for all the main commercial species (hake, red mullet, stripped red mullet, Norway lobster, deep sea pink shrimp, red shrimp) of the bottom trawl fisheries considered in our analysis. Only few exceptions were evident in which high discard percentages generally coincided with zones in which MCRS are more respected; this was, for example, the case for the Balearic Islands (GSA5) where some outliers of high discard ratios of hake and a discards percentage of Norway lobster higher than in other Mediterranean regions (around 20%) were observed. In this area discards seem to be more associated with undersized discards and local compliance with MCRS regulations. In contrast, in other areas (such as GSA 9 and 11 for hake and GSA 11 for red mullets) the high discard ratios reflected the concentration of the fishery on nursery areas and in the recruitment periods. Especially in GSA 11 the large discard ratios of hake, red mullet and stripped red mullet are partly attributed (i) to the extended presence of nurseries of these species (Colloca et al., 2015) which leads to relatively large catches of juvenile fish that are discarded, as well as (ii) to the targets of the bottom trawl fishery in Sardinia. Specifically, the majority of vessels off Sardinia exploit the deep part of the continental shelf (nursery of hake) as well as the slope, where the main targets are deep water pink shrimp, Norway lobster, red shrimp and giant red shrimp, *Aristeomporpha foliacea* (Follesa et al., 2012); therefore, species like hake and red mullets are considered as by catch and only the bigger specimens are retained. However, due to the inclusion in the analyses of discard ratios estimated only based on weight of catches, the ratios may not always reflect high discarding of juveniles in nursery areas (e.g., for hake in Gulf of Lions—GSA7). Apart from these scarce exceptions, low ratios were the rule for target species across the basin, which additionally seemed to be sustained throughout the years. Therefore, exemptions from the landing obligation according to the *de minimis* rule (Article 15 of the EU Regulation 1380/2013) may be sought for several species in various trawl fisheries in the frame of discard plans, in line with the reformed CFP.

However, most studies in the Mediterranean report relatively low proportion of key commercial (i.e., target) species in the catch, even in cases that target species are clearly defined (e.g., Carbonell et al., 2003; Atar and Malal, 2010). Nevertheless, it is reported that a great amount of the bycatch is commercialized since numerous bycatch species are occasionally landed, reducing the discarded quantities to lower levels. For example, in the strait of Sicily, for 1 kg of targeted shrimps 9.6 kg of bycatch was produced but 4.4 kg of this was commercialized (Castriota et al., 2001) with an estimated crustacean (*P. longirostris*, *N. norvegicus* and *A. foliacea*) discard rate of 21.7% in spring 2001 (Vitale et al., 2006). Despite the commercialization of several non-target species, a large number of species that are always totally discarded are included in the catch (e.g., Machias et al., 2001: 142 species in the Aegean and Ionian; Sánchez et al., 2007: 49 species in the Adriatic, 35 species in the Catalan; Tsagarakis et al., 2008: 47 fish species in the Ionian; Bellido et al., 2014: Up to 60% of species in Mediterranean bottom trawl fisheries).

The species belonging to the commercial bycatch were usually characterized by higher discard ratios than the most valuable species and exhibited higher fluctuations geographically (e.g., Machias et al., 2001) and seasonally (Tsagarakis et al., 2008; Pennino et al., 2014), ranging from zero to almost full discarding in some sampling periods. The range of the fluctuations also depended on the species, since a species which is marketed in one country (or even GSA) may not be marketed in the others. Horse mackerels exhibited great differences in discarding within and among GSAs since they were subject to high grading regardless

their sizes in Greece and most Spanish and Italian GSAs, but the discard ratios were lower in Croatia, and Spanish GSAs 1, 6S, and 7. On the other hand, bogue, a coastal species, was more appreciated in Greece than in Spain as demonstrated by the lower discard ratio in the former; commercialization in the eastern Mediterranean is mainly oriented to human consumption while in the western part it is related with use in aquaculture. Regional differences in the discard ratios of red pandora, which is also a coastal species, can be due to different market preferences for this species or for specific sizes. Greater forkbeard is mainly a bycatch of the deep demersal fishery, usually caught in small to intermediate biomasses and abundances and quite homogeneous discard ratios were observed in the western and eastern areas. Regarding blue whiting, an important bycatch species without MCRS at EU level and for which discarding is due to market preferences, a quite homogeneous percentage of discards was noted, at least for the western GSAs where most of the information derived from. The three species of sharks, which are the most studied in the discards literature and the most abundant in demersal fisheries, represented a different percentage of discards, always related with small sizes. Specifically, in the Balearics (Spain), 60% by weight of the lesser spotted dogfish and 35% of the blackmouth catshark were landed (Carbonell et al., 2003) while much less was commercialized in the central Aegean (Greece) (Damalas and Vassilopoulou, 2011). The velvet belly lanternshark was almost always discarded across the basin but is now partially commercialized, at least in the Balearic area (A. Carbonell, unpublished data).

Regional and seasonal environmental differences (e.g., depth, substrate types, productivity), as well as ecological and biological factors crucially affect catch and discards (Carbonell et al., 2003; Damalas and Vassilopoulou, 2011; Carbonell and Mallol, 2012). The synergistic effect of such factors determines (among others) the size distribution (e.g., mean length) of the populations which, in turn, is largely responsible for regional and/or bathymetric differences in discard ratios. As a result, nursery grounds are often characterized by high discard ratios (e.g., Paradinas et al., 2015). Further to the above, legal measures (e.g., area closures), fishers' behavior, gear characteristics as well as overexploitation leading to decreased abundance may further affect the bycatch and discarding of species (Aldebert, 1997; Damalas and Vassilopoulou, 2011; Eigaard et al., 2016, 2017). Nevertheless, discarding in the Mediterranean is mainly market driven and is further affected by socio-cultural traits which eventually affect market demands (Tsagarakis et al., 2014). At the haul level, discards of bycatch species may be high when their catch is too low to be sold or when the catches of the target species are adequate enough to provide a high income to the fisher (Tsagarakis et al., 2008). At the end, the decision to discard or not is affected by a combination of factors which is not always easy to disentangle. For example, in Spanish GSAs, large differences in within-species ranges of discards were observed (e.g., for horse mackerel and blue whiting) which could be mainly attributed either to natural conditions and population structure in different regions, or to differences in sociocultural characteristics and gastronomic habits along the Spanish Mediterranean coast.

Further to the above, although no consistent seasonal patterns were identified, discard ratios of several species were found to differ with season. This could be due to seasonal recruitment and/or migrations of species to more coastal zones for spawning or recruitment, during which increased trawl catches are observed leading to higher discards. Carbonell and Mallol (2012) found seasonal influence on discard rates, but different seasons had higher discards depending on the areas, i.e., spring-summer in the Gulf of Lions and winter in the Balearic Sea. In their study, the highest discard rates in the Gulf of Lions continental shelf were linked to pulses of productivity, during which recruitment of some target species, like hake, takes place in the area, and at the same time planktivorous species, like sardine, concentrate on the shelf for spawning and are massively caught in the trawl fishery (Carbonell and Mallol, 2012). These planktivorous fish are largely discarded due to a French regulation that only allows to retain 10% of the trawl catches of pelagic species. In the case of the Balearic area, the increased discarding in winter was also related with pulses of higher productivity in this zone, after the exhaustion of resources and food in summer (Carbonell and Mallol, 2012).

Fishers' behavior may also influence seasonal discarding either by changing fishing locations in order to target different assemblages (Carbonell and Mallol, 2012) or by changing their discarding behavior. Tsagarakis et al. (2008) also described a transfer of species from the discarded to the marketable fraction toward the end of the fishing period in the Ionian Sea, which was attributed to the reduction of target species in the catch which stimulated a change in fishers' discarding behavior toward increased commercialization of bycatch. In addition, as in the case of the velvet belly lanternshark in the Balearics mentioned above, there may be a tendency for a reduction of discards of some species through time (from the first studies to now). Whether this tendency is true remains to be further explored, however it is expected to occur due to (i) the familiarization of the consumer with certain species, (ii) the overexploitation in the Mediterranean fisheries that sets some target species less abundant and which forces to introduce additional species in the commercial fraction, (iii) the increased abundance of invasive species (e.g., Edelist et al., 2011) and, of course, (iv) the fishers' need to sustain or even increase their revenues. These reasons show that discarding could be more considered a behavioral issue of the fishery than a biologically induced cause.

A recent study reports that the level of discarding of MCRS-regulated species in Mediterranean bottom trawl fisheries is lower in relation to other EU regions, and landing rates largely exceeded those of discards, with some exceptions (Uhlmann et al., 2014). This can be partly attributed to the smaller MCRS applied in the Mediterranean, a lack of MCRS-compliance (Damalas and Vassilopoulou, 2013), and the absence of over-quota discards in the quota-independent management system of Mediterranean demersal trawl fisheries (Catchpole et al., 2014). On the other hand, criteria to make use of some fish products and reject some others should be found in the cultural and social heritage in different areas, which finally result in the existence or absence of a market for those products. Unfortunately, there is still a black market of specimens under the legal MCRS in some

Mediterranean areas where there is a tradition of consuming them although awareness against the consumption of juveniles is progressively increasing (Bellido et al., 2017).

Indeed, our findings showed that the lengths at discarding in the Mediterranean bottom trawl fisheries were generally small and only in few—usually bycatch—species L_{50} exceeded 20 cm. Tsagarakis et al. (2008) estimated the fish community-wide (independent of species and seasons) L_{50} to 13.6 cm in the Ionian Sea trawl fishery. This is due to the predominance of small sized species in the Mediterranean fished community (Edelist et al., 2014), to the massive catches of juveniles of certain species throughout the years (Farrugio et al., 1991), to the existence of market demands for small individuals as well as to the continuous overexploitation of resources that leads to a predominance of small sized populations. In addition, trawl selectivity in the multi-species Mediterranean fisheries does not always succeed to substantially reduce catches of juveniles of most species without reducing the targeted catch of other species (Sala et al., 2015).

Within species, variations were also observed as concerns the sizes at discarding. The sizes at discarding are influenced by a combination of factors such as MCRS, gear selectivity, catch composition, market demands and recruitment period, while even weather conditions may affect sorting by the crew (Machias et al., 2004; Damalas and Vassilopoulou, 2013; Sartor et al., 2016). Environmental parameters such as substrate type, depth and season have been shown to widely affect population structure and species composition, which largely determine what is discarded. Nursery grounds of several species in the Mediterranean Sea are located in the continental shelf and/or on the shelf-break (e.g., Carbonell and Mallol, 2012; Colloca et al., 2015; Paradinas et al., 2015) and can therefore be associated with small retention sizes, at least in certain seasons.

Above all, the effect of market drivers is crucial in determining discarding practices, especially since fishers' responses to market demands may be more important than legal provisions particularly in the Mediterranean, where EU countries appear to invest little in regulation enforcement as compared to other EU regions (Wallis and Flaaten, 2000). This cannot be contested given that L_{50} of most regulated species were found to be smaller than MCRS. Given the existence of black market for undersized individuals, it is doubtful whether the landing obligation in the Mediterranean quota-free management system is meaningful; in contrast, it is possible to lead to even higher (illegal) commercialization of undersized catches since they will be then legally brought to land (Bellido et al., 2017). The importance of market drivers is also reflected in the between-species differences in sizes of discards, with species of higher commercial value having lower retention sizes than species of lower commercial value, despite the fact that they may have larger MCRS and maximum length. This was clear in the retention sizes of e.g., hake and red shrimp which were often similar to or smaller than those of horse mackerels and deep water pink shrimp respectively, despite the fact that the latter ones are species with generally smaller specimens, smaller maximum size, LFM, and MCRS. Obviously, as already highlighted in other studies, discards of species with low commercial value include both undersized individuals and specimens larger than the MCRS (if applicable) (Sartor et al., 2016).

The L_{50}s were also much smaller than LFM, showing that juvenile fish are caught and marketed in the bottom trawl fishery, legally or illegally, depending on whether individuals are larger or smaller than the MCRS respectively. The discrepancy between retention sizes and LFM is expected to impede the sustainability of the stocks (Colloca et al., 2013). On the other hand, the probable revision of MCRS (in order to approximate LFM) seems unrealistic (at least for some species) and unlikely to deliver the desired results. Specifically, it is doubtful if it would drive fishers to avoid catches of juveniles and it would possibly lead to a further bloom of the black market for undersized individuals (Bellido et al., 2017). In any case, it is widely accepted that alternatives to the current management tools are needed in the Mediterranean regarding technical (e.g., Sala et al., 2015) as well as other policy measures (e.g., Bellido et al., 2015; Damalas, 2015).

According to (Sala et al., 2013) there are three main bottom trawl typologies in the Mediterranean: (i) two-panel trawls which have low vertical opening (1–2 m) and are usually used to target mixed demersal species, (ii) four-panel trawls with increased vertical opening (2–4 m) which are generally used to target crustaceans, and (iii) the least common beam trawls which are generally used in shallow waters for specific targets. Alongside the coast of the Mediterranean EU countries there are many sub groups of these trawl typologies but since the enforcement of Council Regulation (EC) No 1967/2006 all of them have either 40 mm square mesh codend or 50 mm diamond mesh codends. The only exception is Croatia which adopted these measures after joining the EU in 2013. This is important to emphasize because underwater observations showed that the majority of fish escape through the codend meshes during the tow (Wileman et al., 1996). Since the gear size selection with the above mentioned codends is relatively poor (Sala et al., 2015), and was even lower in the past, the variation in L_{50} values reported in this paper depend solely on the fishermen selection.

Trawling gears could be made more selective by using larger mesh sizes or incorporating special excluding devices, such as those based on rigid grids or juvenile excluder devices. Notwithstanding, these solutions may be challenging to apply in Mediterranean for social reasons, but their compulsory use for increasing selectivity deserve attention. The history of technical measures applying in European fisheries legislation within the framework of the Common Fisheries Policy (CFP) is one of numerous regulations, amendments, implementing rules and temporary technical measures introduced as stop-gaps to resolve emerging problems. The regulatory structure for technical measures has become highly complex and somewhat disjointed. A recent EU proposal [COM (2016)134] defines baseline technical measures to establish core selectivity standards for each regional sea basin. These baseline measures set minimum mesh sizes for towed and static nets, closed areas and minimum conservation sizes. The proposal envisages that regional groups of Member States would be able to introduce alternative technical measures to these baselines on the basis that it can be demonstrated that these measures deliver similar conservation benefits in terms of exploitation patterns and level of protection

for sensitive species and habitats to those they are intended to replace. The repeated failures to reach agreement on a new technical measures regulation clearly highlight the need for a new approach. This should be based on: Simplification, adaptation of decision-making to the Lisbon Treaty, strengthening the long-term approach to conservation and resource management including tackling the discards problem, regionalization, further stakeholder involvement and more industry responsibility (i.e., a culture of compliance).

The current review concerns studies that took place before the recent reform of the CFP and of course before the onset of the landing obligation, which is designed to be gradually implemented starting from 2017 in Mediterranean bottom trawl fisheries. As a consequence, with some exceptions (e.g., Damalas and Vassilopoulou, 2013; Sartor et al., 2016), the studies were not designed to meet the needs of the CFP as concerns discards, i.e., to quantify the unwanted catches of regulated species (subject to MCRS). In the spirit of the CFP, unwanted catches include both discards and undersized individuals that may be (illegally) marketed. Therefore, the two terms (unwanted catches and discards) are not identical and the results of historical studies cannot be directly applied to justify that a *de minimis* exemption should be granted. Nevertheless, the fact that the L_{50}s of most regulated species were found below MCRS does not provide information on the contribution of the undersized fraction to landings, which may be relatively low. Thus, future studies on discards should also include the estimation of unwanted catches as priority in order to meet management and policy needs.

AUTHOR CONTRIBUTIONS

VV, KT, JB, AC, AS, JMB, AE, and AM designed the study. KT, AC, and JB analyzed the data and wrote the first draft. All authors performed a literature review and/or contributed with data, interpreted the results and critically revised and approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fmars.2017.00099/full#supplementary-material

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