ICES Journal of Marine Science

ICES Journal of Marine Science (2014), 71(5), 1219–1234. doi:10.1093/icesjms/fst074

Contribution to the Themed Section: 'Bycatch and discards: from improved knowledge to mitigation programmes'

Review

Mediterranean fishery discards: review of the existing knowledge

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Tsagarakis, K., Palialexis, A., and Vassilopoulou, V. 2014. Mediterranean fishery discards: review of the existing knowledge. – ICES Journal of Marine Science, 71: 1219 – 1234.

Received 26 December 2012; accepted 22 April 2013; advance access publication 5 June 2013.

A considerable amount of the existing knowledge of discards in the Mediterranean Sea is presented. Discarding highly varies along the basin both geographically and among the different fishing gears with bottom trawls being responsible for the bulk of discards, since they are characterized by high discards ratios. Midwater trawls, purse-seines, and small-scale fisheries, despite their less proportion of discards *per se*, produce overall high discards quantities, since they are responsible for the majority of the landings. Based on the collected information, a rough Mediterranean-wide estimate of discards around 230 000 t or 18.6% (13.3 – 26.8%) of the catch is produced. Discarding in the Mediterranean is regulated by market demands rather than by legal constraints, and marketable bycatch may constitute an important supplemental source of income. A pattern in resource use related to socio-cultural characteristics is apparent, with welfare communities discarding more in terms of percentages. Natural conditions (e.g. environmental gradients) and fishers' strategies also substantially affect discarding. Mitigation tools mainly comprise selectivity improvement and spatio-temporal closures. Despite the progress in studying discards, needs are evident to expand monitoring schemes, apply analytical techniques, and establish objectives of the discards issue under the framework of ecosystem approach to fisheries.

Keywords: bycatch, discards, ecosystem effects, fishers' behaviour, fishing fleets, Mediterranean Sea, mitigation measures.

Introduction

Several definitions of the terms "bycatch" and "discards" have been employed (e.g. Alverson *et al.*, 1994; Hall *et al.*, 2000), with the geographical origin of the reporting author(s) playing, among others, an influential role in the adoption of definitions (Kelleher, 2005). To this work, we use the definition more usually adopted in Mediterranean Sea studies, i.e. discards is the part of the total catch brought on board but then returned to the sea dead or alive for whatever reason (Alverson *et al.*, 1994). Bycatch is considered as the incidental capture of non-target organisms (species and sizes). Discarding has been acknowledged globally among the most important issues for fisheries management, since it is considered a waste of resources, a source of uncertainty for fisheries scientists and decision-makers, as well as a factor affecting biodiversity and community structure (Hall *et al.*, 2000; Hall and Mainprize, 2005; Bellido *et al.*, 2011). Moreover, it is far from being an easy issue to solve, as it involves economic, legal, and biological considerations taking place during fishing operations (Bellido *et al.*, 2011).

Not surprisingly, research on discards has drawn much attention in the recent years. Much focus has been placed on sampling methodologies and raising techniques to provide reliable estimates of discards (e.g. Allen *et al.*, 2001; ICES WKDRP, 2007). Furthermore, understanding reasons for and factors affecting discarding (e.g. Rochet and Trenkel, 2005; Feekings *et al.*, 2012), as well as adopting indices useful for the monitoring of discards (Catchpole *et al.*, 2011), are important steps towards the management of the discards issue.

Currently, the mitigation of discards is a major concern to conservation bodies and the wider public (Catchpole and Gray, 2010). Many EU fisheries have put in place measures such as minimum mesh sizes, effort regulations including spatio-temporal fishery closures, days at sea quotas, daily hour restrictions, and landing quotas (STECF, 2008), in an effort to mitigate the capture of unwanted species/sizes. Certain countries (e.g. Iceland, Norway) have addressed the discards issue by banning discarding, which is also currently considered under the reform of the European Union Common

Fisheries Policy (EC, 2011). However, solutions to bycatch/discards need to be designed for specific fisheries and may differ between regions of the world (Hall and Mainprize, 2005; Johnsen and Eliasen, 2011), especially given the varying incentives for discarding.

Kelleher (2005) notes that studies on discards cover only a small proportion of the total fishing activity in the Mediterranean Sea, indicating a shortage of information. This issue has been acknowledged, among others, as an important constraint for performing reliable stock assessments (Caddy, 2009). Studies on discards were scarce before the 2000s but much progress has been made in recent years after (i) the establishment of the ecosystem approach to fisheries (EAF) as an integrated management approach that considers the entire ecosystem, as well as (ii) the implementation of the EU Data Collection Regulation [Commission Regulation (EC) No 1639/2001; currently, Data Collection Framework, Council Regulation (EC) no 199/2008] and other, rather sporadic and fragmented national projects for non-EU countries. Despite this progress, gaps of knowledge are evident and along with the fact that several stocks are shared among countries (Lleonart and Maynou, 2003), they highlight the need to expand discards surveys and standardize practices to compare among fisheries, explore trends, and test potential methods and tools aiming to mitigate discards. However, the diversification of the Mediterranean marine environment and fisheries places several constraints towards this direction. In particular, the multispecies/multigear nature of the Mediterranean fisheries result in highly varying fisheries geographically and among the different fishing gears in terms of catches, target species, sorting practices, and composition of discards (STECF/SGRN, 2006). Differences in environmental factors such as productivity, seabed characteristics and depth, as well as differences in fishing intensity affect community composition and eventually landings and discards (e.g. Carbonell *et al.*, 2003a; Sánchez *et al.*, 2007). In addition, the use of marine resources highly depends on economic and cultural characteristics which regulate needs, demands, and species prices (Rochet and Trenkel, 2005).

In the present work, we collected a considerable amount of the existing knowledge of discards in the Mediterranean Sea. Area- and gear-specific discards ratios are reviewed and are further used to derive a rough estimate of discarded quantities for the whole basin. Reasons for discarding and factors affecting discards quantities are summarized aiming to identify common and contrasting patterns related to geographic resource allocation, economic, and socio-cultural factors. Furthermore, mitigation tools applied in the basin are presented and documented ecosystem effects of discarding in the Mediterranean Sea are discussed. Finally, gaps of knowledge in relation to regional specificities of fisheries as well as possible further requirements towards a coordinated approach for an effective management of the discards issue are highlighted.

Methods and outline of the review

Fisheries in the Mediterranean Sea can be divided into small-scale and semi-industrial fisheries, the latter category mainly including trawlers and purse-seines (Papaconstantinou and Farrugio, 2000). Small-scale fishing boats use a great variety of fishing gears, often switching among them during a trip. Most of the fisheries are multispecies in nature. Thus, the definition of target species in the Mediterranean fisheries is usually not a straightforward approach, also due to the lack of legal framework such as species-specific quotas. In this work, we follow an expert-based knowledge approach and we thus refer to target species when the authors of the original sources of information considered have used this term.

To this work, we collected quantitative information concerning fisheries discards in the Mediterranean Sea, mainly from scientific papers but some technical reports were also considered. We focused on studies that examined discards ratios (discards/total catch; total catch includes retained plus discarded catch) for the whole community, not species-specific information. In few cases that the discards on the marketable ratio (discards/retained catch) was reported in the initial sources, we transformed this to the discards ratio (as defined above) to be used in the quantitative analysis. We present these ratios categorized per fishery type [(i) bottom trawls, (ii) purse-seines and pelagic trawls, and (iii) small-scale fisheries] in the following sections as well as in Tables 1–3, where we also report additional information for each fishery, when possible. Overall, we report ratios for (i) 32 bottom-trawl fisheries based on 22 sources of information (Table 1), (ii) one pelagic trawl and three purse-seine fisheries based on three sources of information (Table 2), and (iii) 20 small-scale fisheries (nine nets, one longlines, two traps, two boat seines, one hydraulic dredge, one beach-seine, and four mixed fisheries) based on 15 sources of information (Table 3). Most of this information comes from Spain (13 fisheries), Italy (13 fisheries), Greece (12 fisheries), and Turkey (5 fisheries), whereas six more countries (Croatia, Egypt, Israel, Lebanon, Syria, and Tunisia) are represented with <4 fisheries. Based on this information, we try to identify patterns in discarding and infer robust conclusions, where possible. In parallel, in an effort to better identify these patterns, we present supplemental information from several works that have reported species-specific discards ratios or other discards related issues.

Furthermore, we attempted a rough estimation of discards in the Mediterranean Sea based on (i) the collected information and (ii) total landings per fishing gear at the Mediterranean level, as estimated by the Sea Around Us Project (SAUP) (2012). Specifically, following the fishing gear categorization of SAUP landings data, we estimated a gear-specific discards ratio (discards/discards + landings) averaged for the whole basin, i.e. the average value of all reported ratios for each gear. Subsequently, we used total landings per fishing gear to estimate total discards quantities. Due to lack of adequate data for some gears (i) we slightly modified the SAUP gear categorization by grouping "purse-seine", "lampara", and other "seining nets" in one category and (ii) for the "Other gears" category, we used a constant arbitrary value of 10% discards ratio, as a typical ratio for small-scale fisheries. In addition, the rapido trawl was categorized as a dredging gear.

In a next section, we identified reasons for discarding and factors affecting discards mainly based on the previously presented information. Factors discussed are thus the ones identified in the Mediterranean Sea but placed in a broader context. The collected information showed that there are clear geographical patterns in discarding, with eastern and southern countries presenting lower discards ratios. It is probable that this is due to differences in resource use related to socio-cultural and economic characteristics of the Mediterranean countries. To test this hypothesis, we performed a meta-analysis of the information we collected. Specifically, we related per capita Gross Domestic Product (per capita GDP: country's GDP divided by midyear population) with trawl fishery discards ratios collected from studies conducted in several countries along the Mediterranean. We used values of per capita GDP (in US dollars averaged over the period 2000–2010) accessed from the World Bank (2012) website. Trawl fishery was chosen as the one with the largest amount of information available. To minimize error produced by gear-specific discarding ratios, we

Table 1. Discards ratio (discards/total catch by weight) for trawl fisheries in the Mediterranean Sea (including Marmara Sea).

Country	Region	GSA	discards (%)	Depth stratum	Main target category	Reference
Bottom trawl						
Spain	Medit. coast	1,5,6	30.0	Deep	Shrimps	Carbonell *et al.* (2003b)
Spain	Balearic islands	5	42.0	Deep	Shrimps	Moranta *et al.* (2000)
Spain	Balearic islands	5	59.3	Shallow (50–150 m)	Fish	Carbonell *et al.* (2003a)
Spain	Balearic islands	5	45.3	Intermediate (150–350 m)	Fish	Carbonell *et al.* (2003a)
Spain	Balearic islands	5	33.3	Deep (400–800 m)	Shrimps	Carbonell *et al.* (2003a)
Spain	Alicante	6	39.3	Shallow	Fish	Martínez-Abraín *et al.* (2002)
Spain	Catalan	6	64.5[a]	Coastal (14–35 m)	Fish and octopus	Sánchez *et al.* (2004)
Spain	Catalan	6	51.3[a]	Shallow (35–78 m)	Fish	Sánchez *et al.* (2004)
Spain	Catalan	6	19.4[a]	Intermediate (119–391 m)	Fish	Sánchez *et al.* (2004)
Spain	Catalan	6	19.5[a]	Deep (405–773 m)	Shrimps	Sánchez *et al.* (2004)
Spain	Catalan	6	43.2	Shallow	Fish	Sánchez *et al.* (2007)
Italy	N. Tyrrhenian	9	20.0	Deep	Norway lobster/shrimps	Sartor *et al.* (2003)
Italy	Strait of Sicily	16	49.0	Deep (300–585 m)	Shrimps	Castriota *et al.* (2001)
Italy	Adriatic	17	43.5	Shallow	Fish/shrimps	Sánchez *et al.* (2007)
Italy	W. Ionian	19	34.0	Deep (250–750 m)	Shrimps	D'Onghia *et al.* (2003)
Greece	E. Ionian	20	38.0	All	Fish	Tsagarakis *et al.* (2008)
Greece	E. Ionian and Aegean	20, 22	44.0	All	Fish	Machias *et al.* (2001)
Greece	E. Ionian and Aegean	20, 22	45.0	All	Fish	Stergiou *et al.* (1998)
Turkey	Mersin Bay	24	70.3[b]	Coastal	Shrimps	Duruer *et al.* (2008)
Turkey	Mersin Bay	24	9.6	Shallow (<94 m)	Shrimps/fish	Atar and Malal (2010)
Egypt	Medit. coast	26	14.7	Shallow - Intermediate (30–225 m)	Shrimps/fish	Alsayes *et al.* (2009)
Egypt	Medit. coast	26	15.3	Not specified[d]	Not specified[d]	Faltas *et al.*, (1998)
Egypt	Medit. coast	26	26.6	Not specified[d]	Not specified[d]	Rizkalla (1995)
Egypt	Medit. coast	26	14.9	Not specified[d]	Not specified[d]	El-Mor *et al.*, (2002)
Syria	Medit. coast	27	~0	Not specified	Not specified	Kelleher (2005)
Israel	Medit. coast	27	23.3[c]	Deep (>83 m)	Shrimps/fish	Edelist *et al.* (2011)
Israel	Medit. coast	27	26.7[c]	Shallow (37–83 m)	Fish	Edelist *et al.*, (2011)
Israel	Medit. coast	27	40.1[c]	Coastal (<37 m)	Shrimps	Edelist *et al.* (2011)
Turkey	Marmara	28	16.0	Shallow	Shrimps	Zengin and Akyol (2009)
Rapido trawl						
Italy	Adriatic Sea	17	69.4	Shallow	Flatfish	(Pranovi *et al.*, 2001)
Italy	Adriatic Sea	17	13.0	Shallow	Queen scallop	(Pranovi *et al.*, 2001)
Italy	Adriatic Sea	17	90.4	Shallow	Scallop	(Pranovi *et al.*, 2001)

In cases that discards on landings ratios were reported in the original source, the discards on the total catch ratio was estimated. GSA, Geographical Subarea according to GFCM division (Figure 1); Medit, Mediterranean Sea.
[a]Average of study taking into account all depth strata: 33%.
[b]This study examines a shrimp trawl fishery which uses different gear than bottom-trawl fishery.
[c]Average of study taking into account all depth strata: 28.3%.
[d]Based on the abstract only.

excluded the rapido trawl fishery (Pranovi *et al.*, 2001), as well as the discrete shrimp trawling gear operating in Mersin Bay (Duruer *et al.*, 2008) which constitute separate categories and are not exerted in all countries. For studies that discards ratios were available for different depth strata (Sánchez *et al.*, 2004; Edelist *et al.*, 2011), the mean value of the fishery, also reported by the authors, was used since the scope was to analyse socio-economic effects leaving aside depth-related patterns. We applied a Generalized Additive Model (GAM) of the form:

$$E(\text{discards ratio}) = s(\text{per capita GDP}),$$

where s is a smooth function. A Gaussian distribution was assumed and the natural cubic spline smoother was used. The "mgcv" library in the R statistical software (v. R2.13.1; R Development Core Team, 2011) was used for the application of GAMs (Wood, 2006).

Our review of the discards issue further summarizes mitigation tools and management measures aiming at the avoidance of unwanted catches, which are applied in the Mediterranean Sea. Placing discards in an ecological context, in line with the EAF, we additionally present discards-related trophic interactions that have been shown in the Mediterranean Sea. Finally, we synthesize the presented information by identifying gaps of knowledge and future requirements for scientific research and management of the discards issue.

Overview of fishery discards per fleet in the Mediterranean

Bottom-trawl fishery

Most of the effort concerning discards studies in the Mediterranean Sea has been placed on bottom trawls. The reason is that trawling is usually characterized by high discarding (Hall *et al.*, 2000) which seems also valid for the Mediterranean. Information on discards ratios (discards on total catch) from several Mediterranean bottom-trawl fisheries was collected and is presented in Table 1 ordered by Geographical Subareas (GSA; Figure 1), along with information concerning the operating depth and target group, where possible. The majority of these studies concern otter trawls, which is the

Table 2. Discards ratio (discards/total catch by weight) for purse-seines and midwater trawls in the Mediterranean Sea

Country	Region	GSA	Fishing gear	discards (%)	Reference
Italy	Adriatic	17	Purse-seines and midwater trawlers	2.0–15.0	Santojanni *et al.* (2005)
Greece	E. Ionian	20	Purse-seines	2.2	Tsagarakis *et al.* (2012)
Greece	Aegean	22	Purse-seines	4.6	Tsagarakis *et al.* (2012)
Lebanon	Mediterranean coast	27	Purse-seines	~0	Bariche *et al.* (2006)

Table 3. Discards ratios (by weight) for small-scale fisheries and other fleets in the GFCM areas.

Country	Region	GSA	Fishing gear/métiers	discards (%)	Reference
Nets					
Spain	Balearic and Columbretes islands	5	Trammel-nets for spiny lobster	42.1	Quetglas *et al.* (2004)
Tunisia	La Galite islands and Esquerquis Bank	12	Trammel-nets for spiny lobster	32.1	Quetglas *et al.* (2004)
Italy	C. Adriatic	17	Gillnets	19.0	Fabi and Grati (2005)
Italy	C. Adriatic	17	Trammel-nets	19.0	Fabi and Grati (2005)
Greece	E. Ionian	20	Trammel-nets	12.9	Vassilopoulou *et al.* (2007)
Greece	C. Aegean	22	Gillnets	5.1	Stergiou *et al.* (2002)
Greece	Aegean	22	Trammel-nets	10.6	Vassilopoulou *et al.* (2007)
Greece	C. Aegean	22	Trammel-nets	14.7[a]	Gonçalves *et al.* (2007)
Turkey	Aegean	22	Trammel-nets	43.5	Gökçe and Metin (2007)
Longlines					
Greece	C. Aegean	22	Longlines	3.2	Stergiou *et al.* (2002)
Traps					
Italy	S. Tyrrhenian Sea	10	Traps	1.6	Castriota *et al.* (2004)
Italy	C. Adriatic	17	Traps for cuttlefish	9.0	Fabi and Grati (2005)
Boat seines					
Croatia	E. Adriatic	17	Boat seine	28.5	Cetinić *et al.* (2011)
Greece	Aegean and Ionian	20, 22	Boat seine	10.0	Petrakis *et al.* (2009)
Other gears					
Italy	Adriatic	17	Hydraulic dredge for clam	~50.0	Morello *et al.* (2005)
Turkey	Aegean	22	Beach-seine	21.0	Akyol (2003)
Mixed fisheries					
Spain	Tabarca Marine Reserve	6	Trammel-nets, gillnets, trolling lines, handlines, traps, pots	4.1	Forcada *et al.* (2010)
Croatia	C. Adriatic	17	Trammel-nets, gillnets, bottom longlines, traps	~0	Matić-Skoko *et al.* (2011)
Greece	Patraikos gulf	20	Trammel-nets, gillnets, longlines	10.0	Tzanatos *et al.* (2007)
Syria	Medit. coast	27	Artisanal fishery gears	~0	Kelleher (2005)

When ranges instead of mean values are reported in original source, we used median values of these ranges. Medit, Mediterranean Sea.
[a]In numbers.

most common bottom trawling gear operating in the Mediterranean, while few concern beam and rapido trawls which also operate in certain regions.

Regarding otter trawls, several studies from Egypt (Faltas *et al.*, 1998; El-Mor *et al.*, 2002), Syria (Kelleher, 2005), Turkey (Marmara Sea, Zengin and Akyol, 2009; Mersin Bay, Atar and Malal, 2010), and Italy (north Tyrrhenian Sea, Sartor *et al.*, 2003) report discards on total catch ratios no more than 20%. These values are quite high in relation to other fishing gears (Tables 2 and 3) but are lower compared with trawl fisheries from Greece (38–49%; Stergiou *et al.*, 1998; Machias *et al.*, 2001; Tsagarakis *et al.*, 2008), Spain (26.7–64.5%; Moranta *et al.*, 2000; Carbonell *et al.*, 2003a, b; Sánchez *et al.*, 2004, 2007), the Adriatic (39.1–47.8%; Sánchez *et al.*, 2007), and the Straits of Sicily (49%; Castriota *et al.*, 2001) (Table 1). Obviously, there is a high range of discards ratios, and the aforementioned fisheries could be categorized according to their discards generation, i.e. low and high discards. These values also show that there are large-scale geographic and regional differences in discarding practices. These differences are observed due to environmental characteristics such as substrate type, depth, and productivity, which affect the species composition of the communities, as well as due to fishing practices (gear type and target species) and commercial preferences. Overall, discards ratios in the Mediterranean (Table 1) are similar to values from European Atlantic trawl fisheries (e.g. Borges *et al.*, 2001: 62% in Algarve, Portugal; Enever *et al.*, 2009: 25% in the North Sea; Rochet *et al.*, 2002: 32% in the Celtic Sea) where high differences have been also reported among areas and operations (EC, 2011).

In addition, fishing operations and discarding practices can be categorized based on the target species/group. In a multispecies fishery like demersal trawling in the Mediterranean, the definition of target species is not a straightforward process and fishers target a catch complex rather than one or two species (Stergiou *et al.*, 2003; Caddy, 2009). Several trawl fisheries targeting shrimps operate throughout the Mediterranean with varying generation of discards according to the species targeted and the depth stratum that they operate. An important trawl fishery mainly targeting the alien prawn *Marsupenaeus japonicus* and other shrimp species takes places at shallow waters in the southeastern Mediterranean (Israel, Egypt, Turkey) with discarded catch estimated at 40% in

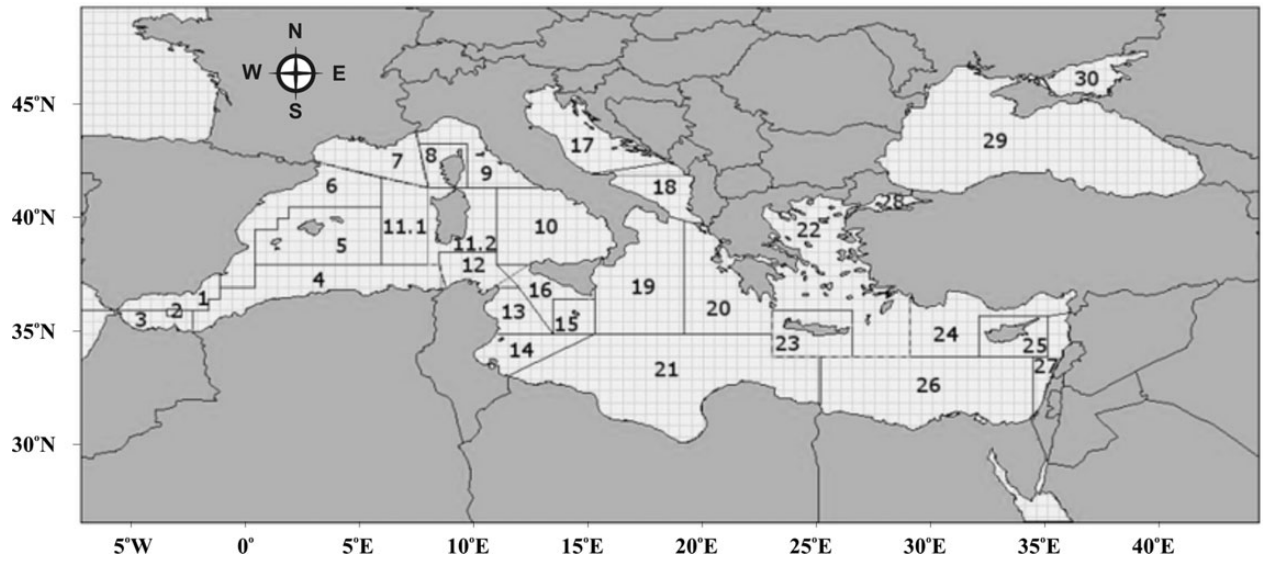

Figure 1. GFCM GSAs. 1–28, Mediterranean Sea (1, Northern Alboran Sea; 2, Alboran Island; 3, Southern Alboran Sea; 4, Algeria; 5, Balearic Island; 6, Northern Spain; 7, Gulf of Lions; 8, Corsica Island; 9, Ligurian and North Tyrrhenian Sea; 10, South Tyrrhenian Sea; 11.1, Sardinia (west); 11.2, Sardinia (east); 12, Northern Tunisia; 13, Gulf of Hammamet; 14, Gulf of Gabes; 15, Malta Island; 16, South of Sicily; 17, Northern Adriatic; 18, Southern Adriatic Sea; 19, Western Ionian Sea; 20, Eastern Ionian Sea; 21, Southern Ionian Sea; 22, Aegean Sea; 23, Crete Island; 24, North Levant; 25, Cyprus Island; 26, South Levant; 27, Levant; 28, Marmara Sea); 29, Black Sea; 30, Azov Sea.

the Israeli coast (Edelist *et al.*, 2011). In deeper waters, shrimp trawl fishery has been found to generate high quantities of discards in the Balearics (42%; Moranta *et al.*, 2000), the western Ionian Sea (up to 50%; D'Onghia *et al.*, 2003), and the straits of Sicily (49%; Castriota *et al.*, 2001). In the western Ionian Sea, the discards ratio increased with depth (D'Onghia *et al.*, 2003). In contrast, in the Balearics, these high ratios were mostly associated with fishing for rose shrimp *Parapenaeus longirostris* and Norwegian lobster *Nephrops norvegicus* at the upper slope, with discards being lower in deeper waters where red shrimp *Aristeus antennatus* is the main target (Moranta *et al.*, 2000). Moreover, there are some deep shrimp fisheries where discards represent <20% of the catch, like the Catalan fleet targeting red shrimp at depths >400 m (Sánchez *et al.*, 2004) and the deep sea trawl fishery in the Tyrrhenian Sea (Sartor *et al.*, 2003). Overall, deep sea shrimp trawl fisheries do not seem to generate higher discards compared with the rest trawling practices in the Mediterranean. Shallow water fisheries targeting stripped red mullets *Mullus surmuletus* and red mullets *M. barbatus* in the Balearic Islands and the Catalan coast as well as intermediate water fisheries targeting hake *Merluccius merluccius* presented higher discards ratios compared with deep fisheries in the same areas (Carbonell *et al.*, 2003a; Sánchez *et al.*, 2004). Red mullets and hake are the most common target species in shelf trawl fisheries in several Mediterranean regions with discards from these fisheries being roughly around 40% (Martínez-Abraín *et al.*, 2002; Sánchez *et al.*, 2007; Tsagarakis *et al.*, 2008; Edelist *et al.*, 2011). Often, these are accompanied by additional target species such as anglerfish *Lophius* spp. and cephalopods, depending on the region. Finally, blue whiting *Micromesistius poutassou* is targeted in certain depth strata in the Catalan Sea and south Turkey with these fisheries presenting <20% discards (Sánchez *et al.*, 2004; Atar and Malal, 2010).

Furthermore, different gears may present quite different discard rates. In Mersin Bay (south Turkey), a shrimp trawl fishery takes place, using a gear different from the bottom trawls also operating in the area, with discards estimated at 70.3% of total catch in a short period study (Duruer *et al.*, 2008). A coastal beam trawl shrimp fishery, though not a common practice in the Mediterranean, is exerted in the Sea of Marmara, where bycatch represented 29% of which 45% was utilized (i.e. 16% discards; Zengin and Akyol, 2009). Moreover, rapido trawl, a modified beam trawl, targeting either flatfish or scallops in the Adriatic, is a separate trawl category and produces extremely high discards quantities, i.e. 69.4 and 90.4% of the total catch, respectively (Table 1), mostly consisting of benthic invertebrates (Pranovi *et al.*, 2001). However, discards in this fishery are low (13%) when targeting queen scallops (Pranovi *et al.*, 2001).

Concerning species-specific discarding, great differences are observed among species and regions. In general, discarded fractions of the so-considered target species (e.g. hake, red mullet, red shrimps) are usually very low or even negligible (e.g. Carbonell *et al.*, 2003a; D'Onghia *et al.*, 2003; Sartor *et al.*, 2003; STECF/SGRN, 2006) and comprise damaged or undersized specimens. However, most studies report relatively small proportion of target species in the catch even in cases that target species are clearly defined (e.g. Carbonell *et al.*, 2003a; Atar and Malal, 2010). Nevertheless, a great amount of the bycatch is commercialized since many 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 were produced but 4.4 kg of these were commercialized (Castriota *et al.*, 2001). Species-specific discard ratios for commercial bycatch species may fluctuate locally (Machias *et al.*, 2001) and seasonally (Tsagarakis *et al.*, 2008), since they depend on seasonal abundance and length distribution (Carbonell *et al.*, 2003a), market demands, and the rest of the catch. As an example, concerning elasmobranchs, which present a special interest for conservation, 60% by weight of the spotted dogfish (*Scyliorhinus canicula*) and 35% of the blackmouth catshark (*Galeus melastomus*) were landed in the Balearics (Carbonell *et al.*, 2003a), while much less was commercialized in the central Aegean (Damalas and Vassilopoulou, 2011). Regional

environmental differences (e.g. substrate types, productivity), seasonal patterns in their abundance (Carbonell *et al.*, 2003a; Damalas and Vassilopoulou, 2011), as well as overexploitation leading to decreased abundance may further affect the bycatch and discarding of sharks and rays (Aldebert, 1997; Damalas and Vassilopoulou, 2011). Still, despite the commercialization of several non-target species, a large number of species that are always totally discarded are still included in the catch (e.g. Edelist *et al.*, 2011: 62 species in the Israely coast; Machias *et al.*, 2001: 142 species in the Aegean and Ionian; Sánchez *et al.*, 2007: 49 species in the Adriatic and 35 species in the Catalan; Tsagarakis *et al.*, 2008: 47 fish species in the Ionian).

Purse-seines and midwater trawls for small pelagic fish

Purse-seines and midwater trawls are among the gears in the Mediterranean that have clear target species, i.e. small pelagic fish. These gears are responsible for the majority of landings in the whole basin (SAUP, 2012); midwater trawls mainly operate in Italy and France, whereas purse-seiners are distributed all along the Mediterranean with the majority of vessels registered in Algeria, Tunisia, and Egypt concerning the southern, and Croatia, Spain, Italy, and Greece concerning the northern basin (Sacchi, 2011). These gears have attracted little attention in examining discards, possibly because they produce low discards ratios. We were able to retrieve information for only few purse-seine fisheries and one midwater trawl fishery (based on three scientific papers); thus, these gears are presented together in Table 2.

Purse-seines are generally characterized by low bycatch and discards rates (Table 2). Target species in the Mediterranean purse-seine fisheries usually represent more than 90% of the catch (Tsagarakis *et al.*, 2012), and most of the bycatch largely consists of marketable species. Discards also mainly comprised marketable small pelagic species (e.g. anchovy *Engraulis encrasicolus*, sardine *Sardina pilchardus*, round sardinella *Sardinella aurita*) which were undersized or had low commercial value for some periods (Santojanni *et al.*, 2005; Tsagarakis *et al.*, 2012). Discards on the total catch ratio was negligible in the Lebanese purse-seine fishery (Bariche *et al.*, 2006), 2.2% in the eastern Ionian Sea, and slightly higher (4.6%) in the Greek Aegean Sea (Tsagarakis *et al.*, 2012; Table 2). Santojanni *et al.* (2005) estimated 2–15% mean annual discards rates for sardine (*S. pilchardus*) from purse-seine (lampara) and midwater trawl (volante) fisheries in the Adriatic. However, high temporal and spatial fluctuations were observed with the highest discards ratio for sardine caught with midwater trawls estimated at 53% in the Ancona fleet (ranging from 1 to 90% in a single year). Overall, these rates are comparable with the adjacent Turkish Black Sea where the discard rate for midwater trawls is estimated at 5.1% and the weighted global average discards ratio for purse-seines (1.6%; Kelleher, 2005).

Small-scale fishery and other fleets

Small-scale fisheries in the Mediterranean use a variety of fishing gears. Most of the existing discards studies analyse trammel-nets and gillnets but other gears (longlines, traps, boat seines, beach-seines, dredges) have also drawn some attention (Table 3). Several works report small-scale fishery discards as a whole, for all gears. However, discarding ratios and practices differ among different métiers, and for each species, different fishing operations may be responsible for the bulk of discards (Gonçalves *et al.*, 2007; Tzanatos *et al.*, 2007). Moreover, different hook and mesh sizes can produce lower discard rates (e.g. Sbrana *et al.*, 2007; Piovano *et al.*, 2010). These highlight the need to focus on analyses of different métiers, since the small-scale fishing fleet comprises many gears and exerts variable fishing practices in the Mediterranean.

Several studies report discards ratios lower than 15% for trammel-nets and gillnets (Table 3). However, certain net fisheries present higher discard rates. Examples are gillnets for hake in the Ionian Sea (29.5%; Tzanatos *et al.*, 2007) as well as trammel-nets for prawns in Izmir Bay (Gökçe and Metin, 2007) and common spiny lobster (*Palinurus elephas*) in Tunisia and Spain (Quetglas *et al.*, 2004) where discards may exceed 40% (Table 3).

Boat seines in Greece presented similar discards rates with static nets (Petrakis *et al.*, 2009) but a higher rate (28.5%) and substantial catches of juvenile fish were reported for the Croatian Adriatic ones operating over *Posidonia oceanica* meadows (Cetinić *et al.*, 2011). Currently, boat seining is banned in the EU countries and the same stands for every fishing activity using other towed nets, dredges, or purse-seines over seagrass beds (EC regulation no 1967/2006). Akyol (2003) analysed discards of beach seining in the Turkish Aegean Sea, and based on the relatively high discards ratio (21%) and juvenile catches that he found, he supported the prohibition of this fishery in most regions of Turkey, applied since 2001.

Traps and pots mainly targeting cephalopods and shrimps are among the most selective gears with little discards (Castriota *et al.*, 2004; Fabi and Grati, 2005), and the same stands for demersal longlines (Stergiou *et al.*, 2002) (0–9%; Table 3).

Concerning gears targeting large pelagic fish, tuna traps in the Mediterranean countries including Italy, Libya, and Tunisia are quite selective and have a low or negligible discard rate (Fromentin and Ravier, 2005; Kelleher, 2005), whereas longlines for tuna and swordfish have also low discards but they may present substantial catches of undersized individuals (Tudela, 2004). Catches of bluefin tuna, the target species in the Maltese tuna longline fishery, constituted 65.7%, whereas the rest of the catch was composed of commercial species (e.g. swordfish) and species of conservation concern (turtles and elasmobranchs; Burgess *et al.*, 2010). The latter is a common feature for this kind of fishery in the Mediterranean with the levels of bycatch of pelagic elasmobranchs and turtles varying in terms of quantities and species composition across the Mediterranean (Tudela, 2004; Marano *et al.*, 2005; Megalofonou *et al.*, 2005; Piovano *et al.*, 2009; Casale, 2011). Pelagic longlines were found to be responsible for the majority of sea turtles by caught in Mediterranean fisheries (57 000 captures per year) with almost one-third of them released dead (Casale, 2011). Furthermore, pelagic longlines present substantial, though lower than demersal longlines, bycatches of seabirds, especially Cory's shearwaters (*Calonectris diomedea*; Belda and Sánchez, 2001; Cooper *et al.*, 2003), and these two gear types together were estimated to kill 4–6% of its breeding population in the Columbretes Islands (Spain, western Mediterranean) each year (Belda and Sánchez, 2001).

Hydraulic dredge for clams is one of the highest discards generating practices in the Mediterranean. In the productive Adriatic Sea where this kind of fishery is a common practice, discards were estimated to be 50% of total catch, of which 30% were undersized target species and 20% were other benthic invertebrates (Morello *et al.*, 2005).

In general, artisanal fisheries are characterized by moderate to low discarding, with some exceptions mentioned above. In certain cases, discards are negligible, like in the Syrian, many of the north African (Kelleher, 2005) and Croatian artisanal fisheries

Table 4. Estimated discards ratios (discards/discards + landings) and discarded quantities per fishing gear in the Mediterranean Sea for year 2006 (SE, standard error).

Gear	Landings 2006 (t)	Discards ratio ± SE	Discards quantities (min – max) (t)
Bottom trawls	123 886	32.9 ± 2.8%	60 761 (53 349 – 68 821)
Shrimp trawl	35 867	43.2 ± 27.2%	27 224 (6 832 – 84 897)
Purse-seines and other seining nets	277 088	5.5 ± 3.3%	15 972 (6 033 – 26 633)
Midwater trawls	195 933	15.0[a]	34 576 (34 576 – 34 576)
Nets	158 508	17.8 ± 4.1%	34 240 (24 983 – 44 479)
Hooks	32 400	4.3 ± 2.1%	1 467 (745 – 2 222)
Traps	25 958	3.7 ± 2.0%	989 (449 – 1 552)
Dredges	30 467	55.7 ± 16.4%	38 314 (19 700 – 78 890)
Boat seines	29 138	19.3 ± 9.3%	6 946 (3 238 – 11 614)
Other gears	105 745	10.0 ± 5%[b]	11 749 (5 565 – 18 660)
Total (t)	1 014 990		232 239 (155 471 – 372 346)
Total (% of catch)			18.6% (13.3 – 26.8%)

[a]One study considered.
[b]Arbitrary values.

(Matić-Skoko *et al.*, 2011), since the bycatch of low commercial species is utilized by the fishers for personal consumption or bait (Kelleher, 2005; Matić-Skoko *et al.*, 2011).

Estimation of discarded quantities

Landings data (from SAUP, 2012) estimated discards ratios with their standard errors and estimated mean, and minimum and maximum discards per gear at the Mediterranean level are presented in Table 4. According to our calculations, an estimate of discards in the Mediterranean for year 2006 is 232 239 t or 18.6% of the total catch (Table 4). This estimation shows that the weighted discard rate for the Mediterranean (4.9% for all fleets) provided by Kelleher (2005) seems rather underestimated. Although not comparable, our estimate is closer to the one presented by Davies *et al.* (2009) who estimated bycatch at 21.1% of the total catch than the one reported by Kelleher (2005). However, the study by Davies *et al.* (2009) (i) includes also the Black Sea region, (ii) defines bycatch as "the catch that is either unused or unmanaged", thus it includes estimates of retained juvenile catches, and (iii) bycatch estimates are based only on trawling. Thus, we considered our estimate of discards a more complete one, despite that it relies on information with low spatial and gear resolution, highlighting, however, that it should be treated with caution because of the high spatio-temporal variability of landings and discards.

Our results confirm that trawls are responsible for the bulk of discards in the Mediterranean (Table 4, Figure 2) notwithstanding their relatively low contribution (15%) in total landings. Dredges produce substantial amounts of discards due to their high discards ratio. Midwater trawls, static nets, and to a lesser extent, purse-seiners, despite their lower discards rates, may still produce large amounts of discarded quantities, since they are responsible for the majority of landings.

Reasons for discarding and factors affecting discards

Discarding is a decision taken on board driven by economical and constrained by legal and technical reasons (Rochet and Trenkel, 2005). In addition, several factors have been shown to affect discarded quantities, such as species and size composition of the catch, fishing strategies, environmental conditions, and cultural characteristics. These factors often act in synergistic effect which may not be straightforward to disentangle, especially in multispecies fisheries like most of those exerted in the Mediterranean. As a result,

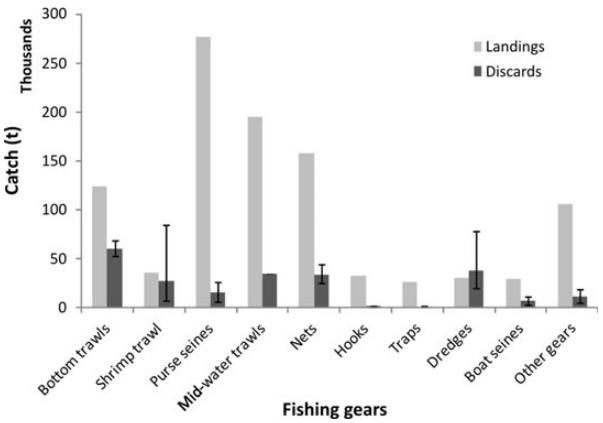

Figure 2. Graphical representation of landed and estimated discarded quantities with their standard errors in the Mediterranean Sea for year 2006.

high regional, seasonal, and interannual fluctuations are observed even within the same fishing gear. Eliasen and Christensen (2012) classified factors which may function as drivers for discarding, into four main categories: (i) natural conditions, (ii) community, (iii) state and regulations, and (iv) market. Associations of discarded quantities and/or discards ratios with some of these factors have been observed in several studies in the Mediterranean and are briefly described below and presented in Table 5, following the aforementioned classification.

Natural conditions influence

Species composition, abundance, and size structure of the catch affect fishers' behaviour and are, thus, an important driver for the decision on discarding. Landed quantities explained a considerable amount of the variability of discards in bottom-trawl fishery in the Aegean and Ionian Seas (Machias *et al.*, 2001). Specifically, both discarded quantities and the discards ratio increased with commercial yield (Machias *et al.*, 2001). Similarly, discarded quantities were positively correlated with hourly yields (Vassilopoulou and Haralabous, 2010) and discards rates increased with total catch (Stergiou *et al.*, 1998; D'Onghia *et al.*, 2003) in other Mediterranean trawl fisheries. These may be attributed to (i) decreased selectivity of the codend as it fills and meshes close

Table 5. Factors affecting discards in the Mediterranean, following the categorization by Eliasen and Christensen (2012).

Category	Factors
Natural conditions influence	Species composition, abundance, and size structure of the catch
	Availability of resources
	Life cycles of species
	Biological invasions
	Environmental factors (depth, seabed characteristics, productivity, etc.)
Community influence	Soak time, haul duration
	Sorting practices
State and regulation influence	Technical measures (gear selectivity)
	Spatio-temporal closures
	MLS
	Inspection by the authorities
Market influence	Low or no economic value of catches (damaged or undersized individuals, unwanted species)
	Resource use related to socio-economic factors
	Storage capacity of the vessel and sorting capacity of the crew

(Stergiou *et al.*, 1998), (ii) poor fish condition of the catch due to high packing in the codend when catches are high, and (iii) market influence, i.e. increased discarding when catches are high to avoid low prices. Landings also explained part of the discards variability in purse-seiners in the eastern Mediterranean but they were not proportional to landings with discards being low when the marketed catch was either low or high (Tsagarakis *et al.*, 2012).

The availability of resources, sometimes affected by the status of the stocks, has been shown to affect fluctuations of market demands and associate discarding practices in several cases in the Mediterranean Sea. Santojanni *et al.* (2005) report a change in discarding practices in the Adriatic small pelagics fisheries after 1987, when anchovy stock crashed. This crash was followed by an increase in anchovy's economic value. Since then a typical highgrading process is observed: discarding of small sardine increased and even cases of substantial discarding of larger sardines due to its low economic value in relation to anchovy have been recorded (Santojanni *et al.*, 2005). In both Adriatic and Catalan Seas, higher discards rates were found during the season of low fishing intensity (Sánchez *et al.*, 2007). Similarly, Tsagarakis *et al.* (2008) described a transfer of species from the "discards" to the "landings" fraction towards the end of the fishing season, when cumulative fishing pressure may have reduced resources. Moreover, total discarded catch in Greek trawl fishery is lower in winter because market prices increase due to the decrease in catches as a result of bad weather (Machias *et al.*, 2004b). These suggest that bycatch can be an important supplemental income for fishers and discarding practices are altered (discards are reduced) when the availability of fishery resources or access to them is limited.

In multispecies fisheries where a catch complex rather than a single species is targeted, it is a common feature for fishers to take into account the outcome of the catch in terms of species composition, sizes, and abundances to decide what will be discarded. Thus, when catches of the primary commercial species are not satisfactory, species and sizes of the lower commercial value are retained to a higher degree. This is the case for bogue *Boops boops*, picarel *Spicara smaris*, and round sardinella which constitute a supplementary source of income when catches of sardine and anchovy are low in Greek purse-seine fishery (Tsagarakis *et al.*, 2012). In the Adriatic small pelagics fisheries, discarding of sardine was greatly affected by the size composition and quantities of anchovy caught (Santojanni *et al.*, 2005). Interestingly, in contrast to what is expected, species of the high commercial value may be discarded if caught in quantities insufficient to guarantee sale (Gonçalves *et al.*, 2007).

Life cycles of species greatly affect the catch composition and accordingly the discarding process. Increased discarding of some species has been reported during their reproductive period when they migrate to shallow areas accessible to small-scale fisheries, thus larger quantities are caught and subsequently discarded (Tzanatos *et al.*, 2007). In addition, during the recruitment period of target species when large quantities of small individuals are caught, broad discarding may take place (Sánchez *et al.*, 2004; Tsagarakis *et al.*, 2012). Seasonal patterns in discarding have been observed in several fisheries (Moranta *et al.*, 2000; Castriota *et al.*, 2001; Quetglas *et al.*, 2004) and they are possibly related to species life cycles and/or changes in distribution grounds.

Biological invasions is an aspect barely examined in relation to fishery discards in the Mediterranean, although more than 150 alien fish species are now present in the basin (Zenetos *et al.*, 2012). Lessepsian migrants constituted 29.2% of the landed biomass in Israeli trawl fishery while 15 species (13 fish and 2 crustaceans) were always discarded (Edelist *et al.*, 2011). An increase in the abundance of lessepsian species substantially affected the species composition of discards in the late 2000s when compared with the 1980s in southeast Turkey (Gücü, 2012). However, commercial values of alien species and discarding practices vary substantially in different regions, possibly due to the slow familiarization of local markets and differences in at-sea abundance. Local population outbreaks and mass discarding of alien species have been also occasionally reported by fishers and their effect on fishing strategies remain to be examined.

Finally, environmental factors may substantially affect discarded quantities. Fishing depth has been greatly related to patterns in discarding, obviously due to varying catch composition and the relative biomass of target species in the different depth strata. Nevertheless, there does not seem to be a constant pattern related to the depth stratum. Although deep-sea trawl fishery for shrimps is often characterized by high discard rates (e.g. Castriota *et al.*, 2001) and several studies report a positive correlation of depth with the discard rate (e.g. Machias *et al.*, 2001; D'Onghia *et al.*, 2003), shallow operations may also produce high discard quantities (e.g. Moranta *et al.*, 2000; Sánchez *et al.*, 2004; Edelist *et al.*, 2011; Gücü, 2012). This is closely related to factors (e.g. substrate type, productivity, currents, etc.) affecting the species and length composition of the community as well as to the targets of the fishery, and although generalizations for the whole basin cannot be made, regional patterns are apparent.

Community influence

Fishers' attitude, approaches practiced, and experience have been also shown to affect discards. In general, discarding is not perceived as an important problem in Mediterranean waters, and in certain cases, fishers even consider it as a food source to certain organisms such as seabirds (Eliasen *et al.*, 2012).

Norms related to adopted fishing practices such as large soak time in trammel-nets (Gonçalves *et al.*, 2007) and haul duration in bottom trawls (Stergiou *et al.*, 1998) have been associated with increased discards rates in the Mediterranean. This seems to be related to the poor condition of the resulting catch, which has been reported to be one of the primary reasons for discarding commercially valuable species (Gonçalves *et al.*, 2007; Tzanatos *et al.*, 2007; Cetinić *et al.*, 2011). However, the opposite effect (negative

correlation of discards with tow duration) has been also reported, which was attributed to the proportionality of discards with total catch and to fishing strategies: in areas with high catches (and discards) tow duration was short, whereas in less productive areas, tow duration increased but hourly yields and discards decreased (Machias *et al.*, 2001). Obviously, this is also related to the ecosystem productivity in the sense that when catches are low, the retention increases due to fishers' seek for higher income.

State and regulation influence

Technical measures, and especially those referring to gear selectivity, affect the composition of the catch and subsequently discarding. In the EC Regulation 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean, Article 9 refers to minimum mesh sizes of gears. Specifically, codend mesh size for trawlers should be either 40 mm square or 50 mm diamond; the latter sizes, according to a number of studies (GFCM, 2010), appear to increase selectivity of the gear favouring reduction in the discards' fractions, although further studies are needed towards this direction (see also next section). Another point that should be underlined, however, is issues related to weak control and enforcement, resulting in low compliance for the adoption of the new gear (Papadopoulou *et al.*, 2012).

As for legal constraints concerning the minimum landing sizes (MLSs) of species, low compliance has been sometimes observed in various fisheries. A portion of undersized fish is landed, usually in low quantities, in bottom trawls (e.g. Machias *et al.*, 2004b; Edelist *et al.*, 2011; Damalas and Vassilopoulou, 2013), purse-seines (Tsagarakis *et al.*, 2012), swordfish longlines (Tudela, 2004), and small-scale fisheries (e.g. Tzanatos *et al.*, 2008; Cetinić *et al.*, 2011). TACs and quotas are not applied in the Mediterranean Sea except bluefin tuna; thus, no overquota discards are observed in contrast to the Atlantic (EC, 2011).

Finally, measures related to spatio-temporal closures affect discarding mainly in cases that they refer to nursery grounds of specific species, the reasoning being avoidance of juvenile specimens (see also next section). In Greek waters, according to the outcomes of interviews conducted to trawl fishers, they appeared to be in favour of such measures but they pointed out that most of those areas have been closed for decades without evaluation of the efficacy of the measure towards stock protection or discard reduction (Papadopoulou *et al.*, 2012).

Market influence

This category includes economic incentives (e.g. market prices) as well as investments in technology (fishing gear and vessel equipment). The latter is related, among others, to the storage capacity of the vessel and the sorting capacity of the crew which may sometimes affect discarding practices. In the Mediterranean fisheries, mass discarding may be observed in cases when catch is too high and exceeds these capacities, like in small pelagics fisheries (Anon., 2001; Santojanni *et al.*, 2005).

Most important driver is the low economic value since it has been proved to be the main reason for discarding. Discards of this category include the species of the low or no commercial value as well as damaged and/or smaller individuals of commercial species. Tzanatos *et al.* (2007) describe the low commercial value (78% of discards), damage at sea before retrieval of the gear (5%), and bad handling on-board (17%) as main reasons for discarding in small-scale fisheries in Greece, noting that market demands rather than fish size (legal reason) determines what is discarded. Similar reasons were identified in the Croatian boat seine fishery (Cetinić *et al.*, 2011). However, the economic value of the catch is not fixed and fluctuates according to market demands. For example, a limit in market demand for 1 d may exist driving fishers to discard the part of the catch exceeding this limit (Santojanni *et al.*, 2005).

Geographical patterns in discards ratios are apparent in the Mediterranean. As an example, discards ratios for trawls are generally lower in the eastern and southern basin (Table 1). As this is also probably related, among others, to communities' welfare, we examined the relation of per capita GDP and trawl fisheries discards ratios from Mediterranean countries that discards studies exist. Results revealed that there is a statistically significant ($p < 0.001$) effect of per capita GDP on the discards ratio (Figure 3), which explained 65.1% of the deviance. The graph clearly shows that increased per

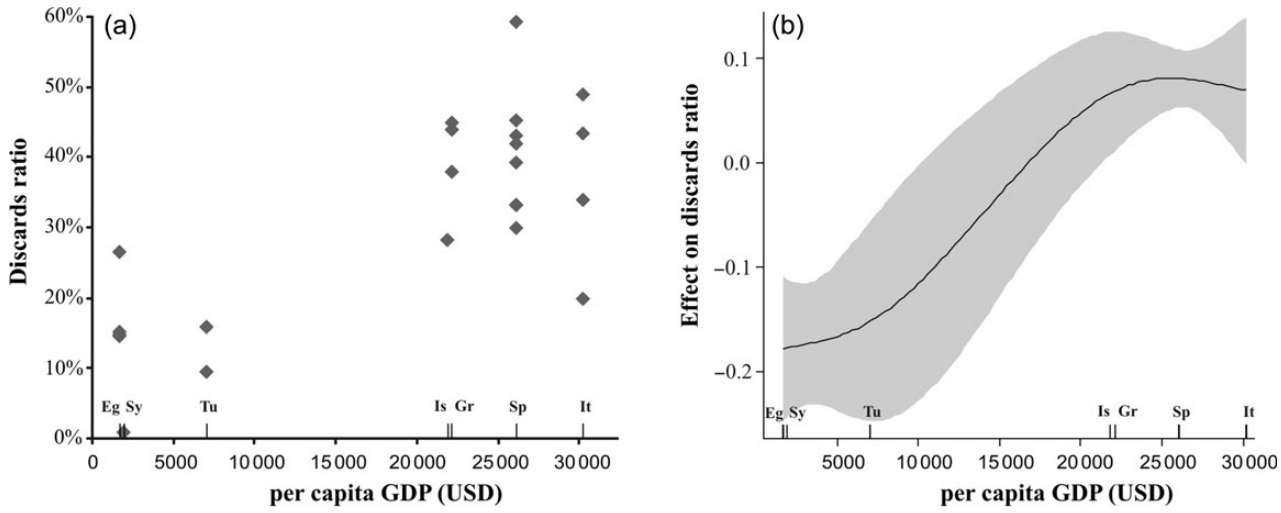

Figure 3. Discards ratios in the Mediterranean bottom-trawl fisheries in relation to countries' per capita GDP. (a) and GAM analysis of the effect of per capita GDP on discards ratio. (b) Rug plots show per capita GDP of the countries considered; Eg, Egypt; Sy, Syria; Tu, Turkey; Is, Israel; Gr, Greece; Sp, Spain; It, Italy.

capita GDP (wealthier communities) has a positive effect on discards (higher discard ratio). Obviously, this feature is regulated by regional market demands and nutritional habits. Wealthier societies seem more selective in resource use, whereas in poorer countries more species and possibly wider size ranges are marketed. For example, bogue is usually discarded in Spain (Sánchez *et al.*, 2004) in contrast to Greece that may constitute a substantial part of the landings (Tsagarakis *et al.*, 2012), whereas the alien (lessepsian migrant) rabbitfish (*Siganus rivulatus*) has no commercial value in most regions of Greece but is a highly commercial species in Egypt (Halim and Rizkalla, 2011). Information from additional countries might help further support or reject this hypothesis. However, we should also not exclude the possibility that stricter regulations and inspection by the authorities result in broader discarding of smaller individuals in some of the EU countries, in contrast to eastern and south Mediterranean ones.

Mitigation tools for bycatch and discards in the Mediterranean

Mitigation of bycatch and discards is a hot issue in modern fishery science, especially in the framework of the EAF. Hall *et al.* (2000) classified efforts to reduce bycatch in two categories: (i) reduce the fishing effort and (ii) reduce the average bycatch per fishing effort. Management policies such as ban of specific gears (e.g. drifnets), definition of marine protected areas (MPAs) and spatio-temporal closures of fishing fall under the first category, however in the latter case perhaps effort increases in other areas open to fishing (Hall *et al.*, 2000). The second category includes the technological progress of the fishing gears, alteration of fishing practices, training of fishers for bycatch reduction, as well as management actions such as setting of individual vessel bycatch limits, temporal and spatial switches of effort to avoid areas and seasons of high bycatches, ecolabelling, selective licensing, and economic advantages (e.g. licenses for the best areas, or for longer periods, or for preferred species) to those fishers that promote mitigation of bycatch (Hall *et al.*, 2000; Broadhurst *et al.*, 2007). Beyond such managerial measures, Hall and Mainprize (2005) suggest placing more effort in (i) dissemination and adoption of successful technologies, (ii) engaging the fishers in finding appropriate solutions, and (iii) clearly understanding the trade-offs between the benefits and costs of mitigation approaches.

As mentioned earlier, approaches contributing to discards mitigation in the Mediterranean mainly comprise technical measures, which are related to the improvement of selectivity and/or the avoidance of potential hot spots of discards. The latter mainly involves spatio-temporal closures for protecting species at certain stages of their life history (e.g. protection of juvenile nursery areas, or adult spawning grounds).

Selectivity improvement

Increasing size selectivity is a prerequisite not only for the mitigation of discards but also for rebuilding Mediterranean fisheries (Colloca *et al.*, 2013). Several studies in the Mediterranean explore fishing gear selectivity aiming to reduce the bycatch of undersized commercial and of non-commercial species. Some of these studies describe promising technical improvements that have already or should be taken into account in fisheries management in the basin. Still, effective technical measures may be gear- and fishery-specific (Broadhurst *et al.*, 2007) and their application should be tested in different areas. Moreover, short- and long-term economic losses and gains should be explored and counterbalanced before decision-making (Suuronen and Sarda, 2007), while possible measures needed for their application (e.g. inspection by authorities) should be taken into account.

Trawl selectivity

Several studies covering different subareas of the Mediterranean explore the effect of codend characteristics and the inclusion of bycatch reduction devices (BRDs) in bottom trawls. Many of them highlight the advantages of the use of a square mesh instead of a diamond shaped because square mesh tends to keep shape and stay open, better than diamond mesh. As a result, a 40-mm square mesh has been shown to reduce discards and improve size selectivity for several species without substantially affecting the catches of target species (e.g. Ordines *et al.*, 2006; Lucchetti, 2008; Sacchi, 2008 and references therein). A 40-mm codend square mesh (or a diamond mesh size of at least 50 mm after justified request) has been recently applied for the EU countries (EC No 1967/2006), while GFCM member countries should have also adopted and implemented these specifications by 2012 (REC.CM-GFCM/33/2009/2). Another important feature affecting trawl bycatch seems to be the codend circumference. Increasing codend circumferences undermines the positive effects on L_{50} for certain species derived by an increase in mesh size (Tokaç *et al.*, 2009; Sala and Lucchetti, 2011).

In addition, the inclusion of Turtle Excluder Devices (TEDs) seems to be an effective technology for the mitigation of bycatch, not only concerning turtles but fish species as well: total discards in the Adriatic Sea trawl fishery were reduced to around 20–60% but total commercial catches were not significantly affected by the use of TEDs (Sala *et al.*, 2011). The use of sorting grids can also provide beneficial results for bycatch reduction for certain species, like for juvenile hake (Sardà *et al.*, 2005). However, grids with narrow bar spacing (i.e. 15 mm) provide poor selectivity, and so instead the use of wider spacing and/or square mesh is recommended (Sardà *et al.*, 2006; Massutí *et al.*, 2009).

Selectivity of small-scale fisheries

Several gear specifications (hook and mesh size and shape) are applied in the Mediterranean small-scale fisheries depending on the target species; thus, selectivity experiments are meaningful only at the métiers level. In general, it seems that increasing hook or mesh size does not always result in a significant reduction in discards and, on the other hand, commercial catch may turn unfavourable. The commercial/total catch ratio did not differ either within or between gears in fishing experiments in the central Aegean Sea with different hook sizes for longlines and mesh sizes for gillnets and trammel-nets; however, the species composition of the catch and that of discards greatly differed (Stergiou *et al.*, 2002; Gonçalves *et al.*, 2007). Karakulak and Erk (2008) explored the catch of 16, 18, 20, and 22 mm bar length mesh for trammel-nets and gillnets in the north Aegean Sea and suggest that 18 mm mesh size is adequate since it considerably reduces the numbers of smaller individuals and discard species in the catch compared with 16-mm mesh size. Similarly, for the gillnet fishery in the northern Tyrrhenian Sea, although larger mesh sizes were also examined (53, 62.5, 70, and 82 mm), the 62.5 mm mesh size was proposed as the most adequate mesh for exploiting hake as it gives some protection to both immature specimens and large females (Sbrana *et al.*, 2007). Fabi *et al.* (2002) after examining three different mesh sizes (45, 70, and 90 mm) for traditional trammel-net, monofilament trammel-net,

and gillnet for the capture of striped sea bream (*Lithognathus mormyrus*), annular sea bream (*Diplodus annularis*), and red mullet in coastal areas of the Adriatic and Ligurian Seas reported that the selectivity of trammel-net was low and that the 45 mm size was the most appropriate for all gears, since it presented higher catch and largely spared the juveniles.

However, modifying gear specification may prove effective in the bycatch reduction in specific species. Piovano *et al.* (2010) tested several technical measures for the mitigation of the stingray (*Pteroplatytrygon violacea*) capture, a common bycatch species in the longline fishery at the Strait of Sicily. They concluded that (i) larger J hooks, resulted in decreased stingray captures, (ii) circle hooks were more effective than J hooks for the mitigation of stingray bycatch, and (iii) bait size, within the range of sizes explored, and the use of light attractors did not have significant effects on the stingray catch rate. Furthermore, circle hooks were shown to significantly reduce the bycatch of immature sea turtles *Caretta caretta* in the swordfish longline fishery without significantly affecting the catch of the target species (Piovano *et al.*, 2009). Modifications of the structure of the nets may also present a substantial reduction in bycatch quantities. Attaching guarding nets (net panels with very small mesh size) between the lead line and the trammel-net to rise the latter above the muddy ground was shown to reduce the discarding of demersal species in the Izmir Bay shrimp trammel-net fishery (Metin *et al.*, 2009). Aydin *et al.* (2008) conclude that it is not advisable to use monofilament gillnets near the shore, over *P. oceanica* beds, since multifilament gillnet catch rates for non-marketable species are significantly ($p < 0.05$) reduced to about one-third.

Spatio-temporal closures

More than 90 MPAs are established in the Mediterranean and the trend presents an increasing tendency in the last decades (Abdulla *et al.*, 2008). In certain of these MPAs, one of the scopes of their establishment has been the reduction in bycatches, mainly concerning vulnerable and charismatic species (Abdulla *et al.*, 2008), whereas the protection of nursery areas is also considered (García-Charton *et al.*, 2008). Size and age of marine reserves are important factors for the restoration of biodiversity and commercial species biomass (Claudet *et al.*, 2008) and should be taken into account for the evaluation of management measures. However, the biomass of non-commercial species may not be expected to increase since positive effects of reduced fishery may be counterbalanced by foodweb interactions caused by restored populations of commercial species (Claudet *et al.*, 2008).

In addition to MPA establishments, several spatial closures are imposed for one or more gears in Mediterranean regions. As examples, in EU countries, fishing is prohibited in sensitive habitats (e.g. coralligeanous, maërl beds) and over seagrass beds as well as trawling is prohibited in areas closer than 1.5 nm from the coast and shallower than 50-m depth (EC No 1967/2006). Also, several national regulations with regional applications fall under this category.

Temporal closures for specific fishing gears also exist and they usually aim to protect juvenile fish and their recruitment (UNEP, 2003). Examples include the ban of tuna purse-seine fishery from the first to 30 July for the whole Mediterranean, and at a local level, trawl fishery closures in the Spanish, Italian, Greek, and Turkish waters during summer (ban duration differs in each area). The designation of spatio-temporal closures in the GFCM area is not always based on scientific criteria and they often try to satisfy social demands. A more targeted designation, based on scientific results, may prove more effective in bycatch reduction and fisheries management in general (STECF, 2006).

However, although MPAs in bycatch hotspots and subsequent restrictions to fishing may reduce overall bycatch and discards quantities, their establishment does not necessarily mean management effectiveness (Abdulla *et al.*, 2008) and should be followed by strong surveillance (de Juan and Lleonart, 2010) and an analysis of the impacts of relocating the effort eliminated from the MPA to other areas.

Other mitigation tools

Most countries have enforced MLSs for several species in the Mediterranean mainly aiming to discourage fishing in areas with high portions of juvenile fish. However, the danger of increasing discarding through focusing heavily on regulating MLS is recognized (Caddy, 2009).

Local prohibitions of certain gears (e.g. boat seines) are mainly applied to protect juveniles of commercial species. In addition, the high bycatch of species of conservation concern has led to the banning of driftnets for the whole Mediterranean. Finally, awareness campaigns and recommendations by NGOs, governmental organizations, and GFCM aim to increase avoidance and/or reduce post-catch mortality of species of conservation concern by improving the handling of captured individuals (e.g. REC.CM-GFCM/35/2011/4, for turtles).

Discards-related trophic interactions in the Mediterranean

Discards are usually perceived as a waste of food having strong socio-economic impact and negative effects on the biological resources and ecosystem. The latter includes, among others, altering trophic interactions which may affect ecosystem structure and functioning. However, the positive role of discards as food source to species (i) of conservation concern and (ii) targeted by the fisheries, as well as their contribution to ecosystem productivity and even benthic-pelagic coupling (transfer of biomass from upper layers to benthos) have generally been overlooked. Discards create shortcuts in trophic interactions and enhance secondary productivity (Groenewold and Fonds, 2000). Especially in oligotrophic areas, like the Mediterranean, perhaps any waste input may produce positive effects in certain fish populations and fisheries, as it has been shown for nutrients deriving from aquaculture production (Machias *et al.*, 2004a; Machias *et al.*, 2006). The perception that, at least in some systems, we can define acceptable levels of discards that fulfil the objectives of the EAF has been expressed (Zhou, 2008) and applicability in the Mediterranean should be explored.

In the western Mediterranean, Bozzano and Sardà (2002) found that 48–64 and >90% of experimentally deployed baits at the seabed were consumed within 12 h over the shelf and at the slope, respectively. A great variety of species covering several taxonomic groups (e.g. isopods, amphipods, decapods, fish) were found scavenging on the baits, whereas time of attraction and densities differed for each scavenger. Non-scavenging or opportunistic scavenging commercial species (e.g. Norwegian lobster) were also attracted in some cases, which was mostly attributed to the presence of their prey. Therefore, it was concluded that continuous supply of discards can affect benthic community structure in favour of scavengers, especially under a regime of the removal of competitors and predators by fishing (Bozzano and Sardà, 2002).

A considerable number of studies have highlighted the significance of discards for seabird populations in the Mediterranean. Several seabird species have been reported to follow trawlers during the discarding process and to directly feed on discards (e.g. Oro and Ruiz, 1997; Martínez-Abraín *et al.*, 2002). Elimination of discards due to a trawling moratorium was found to significantly affect the breeding performance of the lesser black-backed (*Larus fuscus*) and Audouin's (*L. audouinii*) gulls colonies in the western Mediterranean (Oro, 1996; Oro *et al.*, 1996). Similar effects caused by the variability of discards were described for the Balearic shearwater (*Puffinus mauretanicus*; Louzao *et al.*, 2006), for which 40.8% of the energy obtained during the breeding season derived from trawl discards (Arcos and Oro, 2002). Shortage of food supply by fisheries has been shown to result in aggressive behaviours of the larger and more common yellow-legged gull (*L. cachinnans*) over the more vulnerable Audouin's gull, constituting a threat for the latter (González-Solís *et al.*, 1997). Therefore, management measures such as temporal closures should also take into account seabirds biology and ecology (e.g. reproductive period) to minimize effects on vulnerable species (Arcos *et al.*, 2007). Nevertheless, Furness *et al.* (2007) suggest that discards mitigation policies should not set back because of positive effects of discards on seabirds but other management measures aiming to reduce the interactions of seabirds with fisheries should be promoted instead. Concluding, since we do not know seabird population sizes before the initiation of fisheries to try to restore them, management objectives should aim not tilting the current ecological equilibrium in such a way that some seabird species is outcompeted by those using the fisheries discards.

Conclusions

Gaps of knowledge and further requirements

As revealed by the overview of collected information and as also noted by Kelleher (2005), there are several gaps of knowledge in the Mediterranean Sea. Bycatch studies are absent concerning certain fishing gears and subregions. The varying fishing and discarding practices among different gears, areas, seasons, fishing efforts, and availabilities of fisheries resources urge the need to expand relative studies to improve monitoring schemes, get fair estimations of discards quantities, and explore ways to reduce them. Towards this direction, analyses at the métiers level are of primary importance; however, as a first step, effort should be placed on the definition of métiers which is largely lacking in the basin, especially in small-scale fisheries (Tzanatos *et al.*, 2006).

Concerning the existing studies, many of them cover relatively short temporal and small spatial scales. Moreover, a considerable amount of the existing information is placed in grey literature, i.e. technical reports, publications of local interest, and possibly local databases. The spread of existing information, the standardization of approaches, the establishment or the expansion of well designed monitoring schemes, and the cooperation among partners and countries are essential steps for a holistic approach of the bycatch issue aiming to contribute to an upgrade of fisheries management in the Mediterranean.

Furthermore, we need to pass from descriptive to more analytic studies aiming to disentangle reasons for and factors affecting discarding as well as evaluate management measures and mitigation techniques. As part of the increasing interest towards this direction, there is an effort to develop, apply, and evaluate potential indices related to the discards issue. As an example, Catchpole *et al.* (2011) proposed a discard quantity index (annual estimated weight of discards), a discard rate index (adjusted for fishing days), and discard proportion indices (adjusted for the weight of total landings) as tools to reveal temporal changes in discard patterns. The use of such discards ratios can further disentangle the different ecological costs of production of different gears. Putting consumer and processing industry in the context, Hall *et al.* (2000) proposed "target utilization efficiency" and "biomass transfer efficiency" as indices to measure the part of the target catch and total catch, respectively, that reaches the consumer, highlighting the impact of discards plus other losses due to transportation, storage, and production loss. Additional discards-related metrics that may act as indicators to be applied at the total catch and/or the species level such as minimum, mean, and maximum size of catch and discards, selectivity-at-length curves, sorting size for species that are both retained and discarded, diversity indices, and trophic level have been proposed (Helmond and Uhlmann, 2011). Indicators should be easily interpretable by policy-makers and stakeholders to evaluate the performance of management measures or to validate the current status of ecosystem before the establishment of precautionary and mitigation actions. Towards this direction, a diagnostic framework based on unidirectional indicator trends such as the one developed by Rochet *et al.* (2012) may contribute to interpret changes in communities and discards practices. Recently established changes in fishing effort, fishing regulations, and fishing operations (e.g. banning of driftnets for the whole region, banning of boat seines, changes in mesh sizes, and changes in the regulation concerning the trawlable fishing grounds in EU countries), as well as changes in the Mediterranean ecosystem (climate change and resulting effects, alien species), urge the need to update studies and promote such tools to track resulting changes in discarding.

Management of discards

The issue of discards cannot be handled only with selective fishing, since this can affect foodweb structure and functioning. Simulations of improved trawl selectivity in the Catalan Sea resulted in an increase in the target species biomass with benefits for other fishing gears; however, invertebrates and smaller fish were expected to decrease due to trophic interactions (Coll *et al.*, 2008). Rochet *et al.* (2011) explored the theoretical impact of selective and non-selective fishing on community biodiversity and concluded that there is no "optimal" size selectivity to maintain biodiversity and that catching fewer species decreased community evenness and species richness. The selective removal of individuals may result in fisheries induced evolution towards smaller body sizes and earlier maturation (Law, 2000). The altered size composition of the stocks caused by selective fishing has been shown to lead to increased instability in population dynamics and highly varying fluctuations (Anderson *et al.*, 2008). In fact, balanced harvesting and utilization of a wider variety of products already comprised in the catch should be considered as an option of having a lower impact on the ecosystem, producing at the same time smaller amounts of discards (Garcia *et al.*, 2012). The exploration of such issues is essential for modern fisheries management, especially under the framework of ecosystem-based fisheries and clear management objectives should be set for decision-making on relevant issues.

Instead, the management of discards should be viewed as an inherent part of an ecosystem-based management rather than a segmental one. An effective management scheme should include different approaches aiming to address the mitigation of discards as well as the sustainability of resources, species of conservation

concern, and ecosystem structure. Such a scheme should not be restricted only to technical measures and gear modifications (BRDs, acoustic alarms, circle hooks, larger mesh sizes, etc.) which have proven effective in avoiding the bycatch of species of conservation concern and other unwanted species. Spatio-temporal restrictions could be an effective tool for the allocation of fishing effort in places with low abundance of juvenile fish (Feekings *et al.*, 2012) and/or species of conservation concern. Enforcement of regulations should be promoted by strict inspection as well as incentives to reduce discards such as selective licensing and eliminating subsidies for fisheries known to generate high discards quantities. Above all, controlling fishing pressure but maximizing the utilization of the catch should be the main management objective of a responsible fishery. For example, the obligation to land all catches, currently promoted under the forthcoming reform of the EU Common Fisheries Policy, although it will reduce or eliminate discards, it is likely to have little effect on the sustainability of resources by itself since overquota discarding is not an issue in the Mediterranean. However, it may act as an incentive to develop new markets for the catch, which together with a decrease in fishing effort may result in a more balanced harvesting, *sensu* Garcia *et al.* (2012), where both food supply and sustainability are ensured. Nevertheless, even this decision should be accompanied by a framework ensuring that catch of unwanted species/sizes is not increased.

Acknowledgements

We thank two anonymous reviewers for greatly helping improving the manuscript.

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Handling editor: Shijie Zhou