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REVIEW OF EXISTING KNOWLEDGE ON FISHERIES BY-CATCHES AND DISCARDS IN THE GFCM AREA

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1. Introduction

By-catch has been acknowledged globally as an important issue for fisheries management (Hall *et al.* 2000). After the sustainability of the stocks themselves, the management and mitigation of by-catch is, perhaps, the most pressing issue facing the commercial fishing industry worldwide, and has also emerged as a major concern to conservation bodies (both governmental and nongovernmental) and the wider public (Hall & Mainprize, 2005). Several definitions of the term "by-catch" have been employed (Alverson *et al.* 1994, Hall *et al.* 2000), and it is usually considered as the incidental capture of non-target organisms. Thus, by-catch is defined in relation to target species, however, in multi-species, multi-gear fisheries, like most of the GFCM area fisheries (Papaconstantinou & Farrugio 2000), target species are not always clearly defined and the decision is based on the expected value of the catch complex (Alverson *et al.* 2004, Caddy 2009). By-catch consists of (i) undersized specimens of target species, (ii) non-target species and/or sizes with low commercial value, and (iii) non-marketed species. It may be sold, or it may also be unusable or unwanted and subsequently it is discarded.

Discards are defined as marine fauna brought onto the board and subsequently returned to the sea (Alverson *et al.* 1994) and may constitute a large amount of the total by-catch. Reasons for discarding include economical (e.g., low market prices), legal (e.g., Minimum Landing Sizes), environmental (e.g., weather conditions affecting sorting practices), technical (e.g., vessel capacity), biological (e.g., poisonous fish, jellyfish) issues, and personal decisions (Alverson *et al.* 1994, Hall *et al.* 2000, Machias *et al.* 2001, Rochet & Trenkel 2005). A number of countries have approached the problem of discarding by banning the practice through legislation, which is also currently considered under the reform of the European Union Common Fisheries Policy. It is widely accepted that solutions to by-catch/discards need to be tailored to specific fisheries and may differ between regions of the world (Alverson 1999; Bache 2002; Hall & Mainprize, 2005).

Kelleher (2005) noted that studies on by-catches/discards cover only a small portion of the total fishing activity in the Mediterranean and Black Seas. This gap of knowledge, along with the fact that several stocks are shared among countries, which is also the case in the GFCM area (Lleonart & Maynou 2003), highlight the need to expand by-catch/discard surveys and standardize practices in order to compare among fisheries, and test potential methods and tools aiming to their mitigation. In particular, the Mediterranean basin is considered a miniature ocean due to its hydrographic complexity (Lejeusne *et al.* 2010), and a crossroad of three continents, where different cultures co-exist. The use of marine resources highly depends on economic and cultural characteristics which regulate needs, demands and species prices (Rochet & Trenkel 2005). The multi-species/multi-gear nature of the Mediterranean fisheries result in highly varying fisheries geographically and among the different fishing gears (Lleonart & Maynou 2003) in terms of catches, target species, sorting practices and by-catch/discards composition. The numerous landing sites existing in the area create difficulties in recording the relevant information, which further intensifies the knowledge gap burdening sustainable management of the resources (Papaconstantinou & Farrugio 2000, Lleonart & Maynou 2003).

2. An overview of fisheries by-catch and discards per fleet in the GFCM area

2.1. Trawl fishery

In a multi-species fishery like demersal trawling in the Mediterranean and Black Sea, definition of target species is not a straightforward process. Stergiou *et al.* (2003) using landing quantities and market prices proposed a method to define target species in the Greek trawl fishery. This definition is crucial for the designation and estimation of by-catches. However, the general absence of clear identification of the target species has broadly led to the study of discards, the estimation of which is easier due to their more clear definition.

Most by-catch studies in the Mediterranean and Black Seas concern bottom trawls. Trawling is usually characterized by high discarding ratios (Hall *et al.* 2000) which seems also true for the GFCM area (15-65.5%; Table 1). Kelleher (2005) reports a mean of 45% - 50% for trawl fishery in the Mediterranean and Black Sea with some exceptions like the Syrian trawl fishery where discards are negligible. However, the range of discarding ratio fluctuates highly inter-annually, seasonally (e.g., Tsagarakis *et al.* 2008, Zengin & Akyol 2009) and locally (Table 1). Several studies from Egypt (Faltas *et al.* 1998, El-Mor *et al.* 2002), Turkey (Mersin bay: Atar & Malal 2010; Marmara Sea: Zengin & Akyol 2009) and from Italy (N. 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, 3) but are quite low compared to values from Greece (38-45%; Stergiou *et al.* 2008, Machias *et al.* 2001, Tsagarakis *et al.* 2008), Spain (26.7-64.5%; Moranta *et al.* 2000, Carbonell *et al.* 2003a, 2003b, Sánchez *et al.* 2004, 2007), the Adriatic (Sánchez *et al.* 2007) and the Straits of Sicily (49%; Castriota *et al.* 2001).

It is notable that in many cases when target species are clearly defined, by-catch and discards present even higher ratios. In the Balearic trawl fisheries for red mullets, hake and red shrimps, by-catch represents 96%, 95.9% and 74.9% respectively (Carbonell *et al.* 2003b), however a great amount of it is commercialized and discards are much lower. Similarly by-catch was >50% in Mersin Bay (e. Aegean Sea) but discards was much lower (10%; Atar & Malal 2010).Trawl gears targeting flatfish or scallops in the Adriatic, produce discards quantities higher by 2.27 and 9 times respectively than the landings quantities (Pranovi *et al.* 2001). Shrimp trawl fishery is considered a source of high generation of discards in the Gulf of Gabes (Kelleher 2005), Mersin Bay (Duruer *et al.* 2008), the Balearics (42%; Moranta *et al.* 2000), W. Ionian Sea (up to 50%; D'Onghia *et al.* 2003) and the straits of Sicily (49%; Castriota *et al.* 2001). In the latter, for 1 kg of shrimps 9.6 kg of by-catch were produced of which 5.2 kg were discarded (Castriota *et al.* 2001). A Mediterranean-wide estimate of discards of the deepwater trawl fishery for shrimps is 39.2% of total catch, while this ratio reaches 56.5% when targeting shrimps and Norvegian lobster (*Nephrops norvegicus*) (Kelleher 2005). Such fisheries also present substantial by-catches of sharks and rays (Tudela 2004, Kelleher 2005). However, some exceptions also exist, like in the case of coastal shrimp fishery in the Sea of Marmara, where by-catch represented 29% of which 45% was utilized (Zengin & Akyol 2009).

Table 1. Discards ratio (by weight) for Bottom trawls in the GFCM areas. Med: Mediterranean Sea

Country/ ecosystem	GFCM area	discards / catch (%)	discards / landings (%)	Reference	target species
Spain W. Med.	1,5,6	30%[1]		Carbonell *et al.* 2003a	
Spain Balearic islands	5	58.1%		Carbonell *et al.* 2003b	red mullets
Spain Balearic islands	5	42.7%		Carbonell *et al.* 2003b	hake
Spain Balearic islands	5	26.7%[1]		Carbonell *et al.* 2003b	red shrimp
Spain Balearic islands	5	42%[1]		Moranta *et al.* 2000	decapods
Spain Catalan	6	19.5% - 64.5% (1/3 on average)		Sánchez *et al.* 2004	
Spain Catalan	6	40.2-46.1%		Sánchez *et al.* 2007	
Spain Benidorm	6		23–175% median 64.8%	Martínez-Abraín *et al.* 2002	
Italy N. Tyrrhenian	9	20%[1]		Sartor *et al.* 2003	
Italy strait of Sicily	16	49%[1]		Castriota *et al.* 2001	shrimps
Italy Adriatic	17	39.1-47.8%		Sánchez *et al.* 2007	
Italy Adriatic	17		2.27:1 (227%)[2]	Pranovi *et al.* 2001	flatfish
Italy Adriatic	17		0.15:1 (15%)[2]	Pranovi *et al.* 2001	queen scallop
Italy Adriatic	17		9.37:1 (937%)[2]	Pranovi *et al.* 2001	scallop
Italy W. Ionian	19	20-50%[1]		D'Onghia *et al.* 2003	shrimps
Greece E. Ionian	20	38%	61%	Tsagarakis *et al.* 2008	
Greece E. Ionian & Aegean	20, 22	44% (39-49%)		Machias *et al.* 2001	
Greece E. Ionian & Aegean	20, 22	45%		Stergiou *et al.* 1998	
Turkey Mersin Bay	24		10.63%	Atar & Malal 2010	
Turkey Mersin Bay	24		2.37: 1 (237%)	Duruer *et al.* 2008	shrimps
Egupt S.E. Med.	26	15.3%	18%	Faltas *et al.* 1998	
Egupt S.E. Med.	26	26.6%		Rizkalla 1995	
Egupt Port Said	26	15-20%		El-Mor *et al.* 2002	
Israel E. Med.	27	28.3% (40.1%)[3]		Edelist *et al.* 2011	

Table 1. (continued)

Country/ ecosystem	GFCM area	discards / catch (%)	discards / landings (%)	Reference	target species
Turkey Marmara	28	35.6%[4]		Bayhan *et al.* 2006	rose shrimp
Turkey Marmara	28	16.2%[5]		Zengin & Akyol 2009	shrimps

[1]deep-sea trawl fishery; [2]rapido trawl fishery; [3]in shallow areas; [4]refers to by-catch; [5]Ratio estimated based on reported results

The aforementioned ratios concern the entire catch and can be very different for certain species. Most studies report a high number of species that are always totally discarded (e.g., Machias *et al.* 2001: 142 species; Tsagarakis *et al.* 2008: 47 fish species), and a high number of by-catch species which are occasionally landed the species-specific discard ratios of which vary a lot. For example, concerning elasmobranches, Carbonell *et al.* (2003b) and Damalas & Vassilopoulou (2011) report discard ratios of 65.5% and 63.8% respectively. Concerning the target species their discarded fractions may be negligible (e.g., D'Onghia *et al.* 2003, Carbonell *et al.* 2003b) and comprise of undersized or damaged specimens, but in certain cases undersized individuals are also landed (e.g., Machias *et al.* 2004).

Fishing depth seems to be an important factor affecting the by-catch/discarded quantities (e.g., Machias *et al.* 2001, D'Onghia *et al.* 2003, Sánchez *et al.* 2004). Nevertheless, there doesn't seem to be a constant pattern related to the depth stratum. Even though D'Onghia *et al.* (2003) report a positive correlation of depth with discard rate and deep-sea trawl fishery for shrimps is usually characterized by high discard rates, shallow operations may also produce high discard quantities (e.g., Sánchez *et al.* 2004, Edelist *et al.* 2011). Interestingly, in both Adriatic and Catalan Seas, higher discards rate were found during season of low fishing intensity (Sánchez *et al.* 2007). Tsagarakis *et al.* (2008) describe 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. These suggest that discarding practices are closely related to the availability of fishery resources and market demands and that by-catch can be an important supplemental income for fishers.

The estimation of Kelleher (2005) concerning the weighted discard rate for the Mediterranean (4.9% for all fleets) seems rather underestimated given that trawl landings correspond to approximately 15% of total Mediterranean and Black Sea catches (Sea Around Us project). Further investigation on by-catch across the GFCM area is needed, while geographical patterns of by-catch quantities, their composition and use of resource should be further explored and related to cultural habits.

2.2. Purse seines and midwater trawls

Purse seines targeting small pelagic fish are generally characterized by low by-catch and discarding rates (Table 2). According to Kelleher (2005) the weighted global average concerning the discards ratio for purse seines is 1.6%. Target species in Mediterranean and Black Sea purse seine fisheries usually represent more than 90% of the catch (Şahin *et al.* 2008, Tsagarakis *et al.* under revision), and most of the by-catch largely consists of commercialized species. As a result, discards on total catch ratio was negligible in the Lebanese purse seine fishery (Bariche *et al.* 2006), 2.2% in the Ionian Sea (Tsagarakis *et al.* under revision) and 1% in the Turkish Black Sea

(Şahin *et al.* 2007). Concerning the Black Sea, the low discarding ratio is also due to the fact, at least partly, that most by-catch is used for fishmeal (Kelleher 2005). Slightly higher rates (Table 2) are reported for the Greek Aegean Sea (Tsagarakis *et al.* under revision) and the Adriatic (Santojanni *et al.* 2005) purse seiners. Discard rates for midwater trawls were higher, 5.1% in the Turkish Black Sea (Kelleher 2005) and up to 15% in the Adriatic (Santojanni *et al.* 2005), but were generally lower compared to bottom trawls (Table 1). However, purse seine fishery is responsible for an important fraction of the total catch in the GFCM area (25% of landings; Sea Around Us project), meaning that these relatively low discard rates may still produce large amounts of discarded quantities.

Table 2. Discards ratio (by weight) for purse seines and midwater trawls in the GFCM areas. Med: Mediterranean Sea

Country/ ecosystem	GFCM area	Fishing gear	discards / catch (%)	Reference
weighted global average		purse seines	1.6%	Kelleher 2005
Italy Adriatic	17	purse seines & mid water trawl	2-15%	Santojanni *et al.* 2005
Greece Aegean	22	purse seines	4.6%	Tsagarakis *et al.* under revision
Greece E. Ionian	20	purse seines	2.2%	Tsagarakis *et al.* under revision
Lebanon E. Med.	27	purse seines	~0%	Bariche *et al.* 2006
Turkey Black Sea	29	purse seines	1%	Şahin *et al.* 2008
Turkey Black Sea	29	midwater trawlers	5.1%	Kelleher 2005

2.3. Small scale fishery and other fleets

Information on by-catch of the artisanal fishery in the GFCM area is relatively scarce. Most studies report a discards ratio of lower than 10% for longlines, trammel and gill nets (Table 3). In certain cases discards are negligible, like in the Syrian, many of the North African (Kelleher 2005) and Croatian artisanal fisheries (Matić-Skoko *et al.* 2011), since by-catch of low commercial species is utilized by the fishers for personal consumption. However, certain fisheries present higher discard rates. These include trammel nets for cuttlefish (25.5%; Kelleher 2005), shrimps (Gokce & Metin 2007) and common spiny lobster (*Palinurus elephas*) (Quetglas *et al.* 2004). For the latter, 53.6% and 44.3% of the by-catch in terms of numbers was discarded in Spain and Tunisia respectively (Quetglas *et al.* 2004). Tzanatos *et al.* (2007) describe 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. Different hook and mesh sizes can produce lower discard rates (e.g., Sbrana *et al.* 2007, Piovano *et al.* 2010). Tzanatos *et al.* (2007) found that discarding ratios and practices differ among different metiers and for each species different fishing operations were responsible for the bulk of discards. These highlight the need to focus on analyses of different metiers, since the small-scale fishing fleet comprises numerous gears and exerts variable fishing practices in the Mediterranean and Black Seas. Different metiers also target different species resulting in different by-catch composition and quantities.

Boat seines and coastal encircling nets also present similar discards ratios (Kelleher 2005, Petrakis *et al.* 2009) but a higher rate (28.5% by weight) was reported for the Croatian Adriatic boat seines operating over *Posidonia* meadows (Cetinić *et al.* 2011). This practice is now banned in the EU countries.

Table 3. Discards ratios (by weight) for small scale fishery and other fleets in the GFCM areas. Med: Mediterranean Sea

Country/ ecosystem	**GFCM area**	**Fishing gear/ metier**	**discards / catch (%)**	**Reference**
Spain Tabarca Marine Reserve	6	trammel nets, gillnets, trolling lines, handlines, traps, pots	4.13%	Forcada *et al.* 2010
Malta C. Med	15	tuna longlines	34.3%[1]	Burgess *et al.* 2010
Italy Adriatic	17	Hydraulic dredge for clam	~ 50%	Morello *et al.* 2005
Croatia E. Adriatic	17	boat seine	28.5%	Cetinić *et al.* 2011
Croatia C. Adriatic	17	trammel nets, gillnets, longlines, traps	~0%	Matić-Skoko et al 2011
Greece Ionian	20	trammel nets	12.9%	Vassilopoulou *et al.* 2007
Greece Aegean & Ionian	20, 22	boat seine	10%	Petrakis *et al.* 2009
Greece Patraikos gulf	20	trammel nets, gillnets, longlines	10%	Tzanatos *et al.* 2007
Greece C. Aegean	22	gill nets	2.9-7.3%	Stergiou *et al.* 2002
Greece C. Aegean	22	longlines	1.8-4.6%	Stergiou *et al.* 2002
Greece Aegean	22	trammel nets	10.6%	Vassilopoulou *et al.* 2007
Turkey Aegean	22	beach seine	21%	Akyol 2003
Turkey Aegean	22	trammel net	43.5%	Gokce & Metin 2007
E. Black Sea	29	coastal encircling gill net	7.4%	Kelleher 2005
Black Sea	29	sea snail dredge	11.5%	Kelleher 2005

[1]refers to by-catch

Tuna traps in the Mediterranean countries including Italy, Libya and Tunisia are quite selective and have a low, or negligible discard rate (Kelleher 2005), however longlines for tuna and swordfish may have substantial incidental catches of pelagic elasmobranches, which vary in terms of quantities and species composition across the Mediterranean (Tudela 2004, Megalofonou *et al.* 2005). Catches of bluefin tuna, the target species in the Maltese tuna longline fishery, constituted 65.7% while the rest of the catch was composed of commercial species (e.g. swordfish) and species of conservation concern (turtles and elasmobranches; Burgess et al. 2010).

Moreover, a large amount of the tuna and swordfish individuals caught in pelagic longlines are bellow their MLS (Tudela 2004 and references therein) and should be considered as by-catch.

Even though discards ratios are relatively low for the artisanal fishery, by-catch quantities are larger since smaller and unmarketable fish may be used either for auto consumption, or bait (Kelleher 2005). In addition, by-catch of charismatic and vulnerable species (e.g., seabirds, elasmobranches, sea turtles) can be quite high for certain artisanal fisheries, especially longlines (Tudela 2004, Casale 2011). Moreover, overall discarded quantities are quite high since artisanal fisheries are responsible for the bulk of GFCM area catches (>42%; Sea Around Us project) and methods or technologies aiming at the mitigation of discards should be further explored and relative managerial policies should be implemented.

2.4. Quality of the existing information

As revealed by the overview of collected information and as also noted by Kelleher (2005) there are several gaps of knowledge in the Mediterranean and Black Sea area. By-catch studies may be absent concerning certain fishing gears and sub-regions. 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 in order to get a fair estimation of by-catch quantities and explore ways to reduce them. Since the definition of by-catch is related to target species, definition of metier and their target species is needed to explore by-catch composition and quantities for specific operations.

Concerning the existing studies, many of them cover relatively small temporal and spatial scales. Moreover, large 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 cooperation among partners and countries are essential steps for an holistic approach of the by-catch issue in the GFCM area.

2.5. The BADMINTON project: an overview of existing discard data by metier and area, for the Mediterranean member states

The project (BADMINTON, 2011) analyzes the data derived from the national sampling programs of landings and discards under the EU Data Collection Framework (DCF) for the period 2003-2008. By-catch and discards are an integrated part of commercial fisheries and are of major concern between managers, stakeholders and scientists regarding the impact of fisheries to the ecosystem, populations and species. The available biological data were collected on a haul-by-haul basis and consisted of catch and discard observations of both non- and commercially-valuable species (including invertebrates such as crustaceans, mollusks and cephalopods). Information on the top landed and discarded species in the GSAs covered by the project is presented below.

GSA3701 Spanish Bottom Otter Trawls

The top landed species regarding their number of individuals as well as the weight per hour per trip of the Spanish Bottom Otter Trawler fleet in GSA3701 include *Trachurus*

trachurus, Micromesistius poutassou, Plesionika heterocarpus, Merluccius merluccius. The most discarded species include *Pagellus acarne , Boops boops and Helicolenus dactylopterus*. Other species that are discarded are *Aristeus antennatus, Galeus melastomus, Helicolenus dactylopterus, Pagellus bogaraveo, Phycis blennoides, Scyliorhinus canicula* and *Trachurus picturatus*.

Based on the IUCN Red List 2 vulnerable species (*Galeorhinus galeus* and *Mustelus mustelus*) and 2 endangered species (*Rhinobatos rhinobatos* and *Epinephelus marginatus*) are included in the catch of the Alboran Sea. *G. galeus* represents 0.117‰ of the total catch, from which nothing was discarded, *M. mustelus* represents 0.035‰ of the total catch, 40% from which was discarded, *R. Rhinobatos* represents 0.009‰ of the total catch, all of which discarded, and *E. marginatus* represents 0.019‰ of the total catch, 100% retained. All of them together represent 0.164‰ of the catch.

GSA3707 French Bottom Otter Trawls

The French Bottom Otter Trawl fisheries in GSA3707 landed mostly *Carcinus aestuarii, Trisopterus luscus, Aspitrigla cuculus, Lophius piscatorius* and *Merluccius merluccius*. The top discarded species were *Sardina pilchardus, Lophius piscatorius, Merluccius merluccius*.

GSA3707 French Midwater Otter Trawl

The French Midwater Otter Trawl fisheries in GSA3707 and particularly the small pelagic fish métier landed mainly the species: *Engraulis encrasicolus, Sardina pilchardus, Merluccius merluccius*. The fraction of the most discarded species included:: *Trachurus mediterraneus, Engraulis encrasicolus* and *Sardina pilchardus*.

GSA3720 Greek Bottom Otter trawl

The Greek Bottom Otter trawl fishery in GSA3720 landed mainly *Merluccius merluccius, Mullus barbatus* and *Parapenaeus longirostris*. The top discarded species consist of *Trachurus trachurus, Sardina pilchardus, Parapenaeus longirostris* and *Spicara smaris*.

GSA3722 Greek Bottom Otter trawl

The top landed species regarding their number of individuals as well as the weight per hour per trip of the Greek Bottom Otter Trawler fleet in GSA3722 include *Merluccius merluccius, Illex coindetii, Mullus barbatus, Parapenaeus longirostris* and *Mullus surmuletus*. On the other hand, the most discarded species include *Trachurus trachurus, Parapenaeus longirostris, Illex coindetii* and *Centracanthus cirrus*.

GSA3723 Greek Bottom Otter trawl

The top landed species regarding their weight per hour per trip of the Greek Bottom Otter Trawler fleet in GSA3723 include *Merluccius merluccius, Mullus barbatus* and *Parapenaeus longirostris*, while the most discarded species consisted of *Trachurus trachurus, Boops boops, Argentina sphyraena.*

GSA3720 Greek Set gillnets

According to the numbers per individuals and the weight per hour per trip of the Greek Set gillnets fleet in GSA3720 the most landed species are *Boops boops, Mullus surmuletus,* *Pagellus erythrinus* and *Sepia officinalis*. The most discarded species consisted of *Scorpaena porcus, Diplodus vulgaris* and *Scorpaena scrofa*.

GSA3722 Greek Set gillnets

The Greek Set gillnets fleet in GSA3722 mostly landed *Mullus surmuletus, Boops boops* and *Spicara smaris*, while the most discarded species based on the numbers per individuals and the weight per hour per trip were *Diplodus annularis, Sardinella aurita* and *Serranus cabrilla*.

GSA3720 Greek Trammel nets

The Greek Trammel nets fleet in GSA3720 mostly landed *Mullus surmuletus, Sepia officinalis, Sparisoma cretense* and *Boops boops*. Amongst the most discarded species were *Synodus saurus, Boops boops* and *Diplodus annularis*.

GSA3722 Greek Trammel nets

According to the numbers per individuals and the weight per hour per trip of the Greek trammel nets fleet in GSA3722 the most landed species were *Mullus surmuletus, Sardinella aurita, Solea spp*. and *Spicara flexuosa*. The most discarded species consist of *Sardinella aurita, Diplodus annularis, Pagellus acarne*.

Based on the IUCN Red List three vulnerable species (*Mustelus mustelus*, *Squalus acanthias, Oxynotus centrina*) and two endangered species (*Rhinobatos cemiculus, Rhinobatos rhinobatos*) were included in the catch of GSA3720 and GSA3722.

Restrictions such as minimum landing size and market opportunities mainly affect the discarding process. Specimens of a specific species, which are over the minimum landing size can be discarded for one or a combination of the following reasons: damaged/low quality of products, inconsistent markets, inconsistent sorting, catch composition regulations and quota restrictions (e.g., for blue fin tuna).

Some species present high discard rates, while they are also characterized by high landings rates (e.g., *Trachurus trachurus* and *Merluccius merluccius, Parapenaeus longirostris*). This fact could be attributed to the minimum landing sizes (obligation to discard undersized individuals) and the unselective gear (capturing a large quantity of undersized individuals).

Several species that are included in the IUCN red list were registered amongst the species that were landed or discarded (e.g., *Raja clavata, Mustelus mustelus*). Although one would expect that naturally some of these species are being caught on rare occasions, their listing among frequently discarded organisms illustrates that fishing may have a disproportionate impact on these long-lived and late-maturing species such as sharks and rays (Hoffmann *et al.* 2010).

3. Mitigation tools for by-catch in the GFCM area

Mitigation of by-catch is a hot issue in modern fishery science, especially in the framework of ecosystem approach to fisheries management. Hall *et al.* (2000) classified efforts to reduce by-catch in two categories: (i) reduce the fishing effort and (ii) reduce the average by-catch per fishing effort. Management policies such as ban of specific gears (e.g., drifnets), definition of Marine Protected Areas (MPAs) and spatiotemporal closures of fishing (Soykan *et al.* 2008) fall under the first category, however in the latter case it is possible that effort increases in other areas open to fishing (Hall *et al.* 2000). The second category includes technological progress of the fishing gears, alteration of fishing practices, training of fishers for by-catch reduction and management actions such as setting of individual vessel by-catch limits, temporal and spatial switches of effort to avoid areas and seasons of high by-catches, eco-labelling, 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 by-catch (Hall *et al.* 2000, Broadhurst *et al.* 2007).

In the GFCM area by-catch mitigation tools mainly comprise technical approaches, which are related to improvement of selectivity through modifications to fishing gears, and/or avoidance, the latter involving spatio-temporal closures for protecting species at certain stages of their life history (eg., protection of juvenile nursery areas, or adult spawning grounds). An overview of these approaches is presented below. However, it should be pointed out that, as Hall & Mainprize (2005) argue, there are three broad approaches applying to the by-catch/discards issue that, if adopted, will help improve the environmental sustainability of the world's fisheries. First, disseminate successful technologies more widely and encourage their adoption. Second, comprehensively engage fishers themselves in finding appropriate solutions. And lastly, make greater efforts to understand the trade-offs that obtain when a particular approach is chosen and develop the institutional and legislative frameworks that recognize and account for these trade-offs.

3.1. Selectivity improvement

Several studies in the GFCM area explore fishing gear selectivity aiming to reduce by-catch of undersized commercial and of non commercial species. Some of these studies describe promising technical improvements that should be taken into account in fisheries management in the GFCM area. 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 & Sarda 2007), while possible measures needed for their application (e.g., inspection by authorities) should be taken into account.

However, the issue of selective fishing is not that simple since it can affect food-web structure and functioning. Simulations of improved trawl selectivity in the Catalan Sea resulted in an increase of the target species biomass with benefits for other fishing gears, however invertebrates and small-sized fish were expected to decrease due to trophic interactions (Coll *et al.* 2008). Rochet *et al.* (2011) explored 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.

In fact, diversification of harvest, seen as learning to utilize 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. 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.

3.1.1. Trawl selectivity

Most of the relative studies concern the effect of codend characteristics and inclusion of By-catch Reduction Devices (BRD) in bottom trawls (see also Sacchi 2008 and references therein). The effect of mesh size and shape has been explored by several scientists in several sub-areas of the Mediterranean. Several studies highlight the advantages of the use of a square mesh instead of a diamond shaped. The use of square mesh escape window in the forward part of the top panel increased the escape of juvenile red mullet, annular sea bream and common Pandora in the E. Aegean Sea (Metin *et al.* 2005). Lucchetti (2008) found that a 40 mm square-mesh codend allowed a substantial reduction of the fraction discarded at sea in comparison to the traditional diamond-mesh used in Adriatic. Even though the mean catch with the experimental codend was lower the short-term economic losses were low and length selectivity of the juveniles of European hake was much better. Square mesh (40 mm) also led to an increase in the mean selection length for several species and to a significant reduction of discarded fish off the Balearic Islands without reducing the catches of target species, except for *Spicara smaris* (Massutí *et al.* 2005, Ordines *et al.* 2006). Similar results were obtained for the upper slope off the Balearic Islands (Guijarro & Massutí 2006) and the Gulf of Alicante (García-Rodríguez & Fernández 2005), suggesting that the use of the 40 mm square-shaped cod-end mesh could be beneficial to the fishery due to the increase of the size at first capture and to the ecosystem because of the reduction of by-catch (García-Rodríguez & Fernández 2005). Concerning the increase in mesh size, positive results have been reported by Stergiou *et al.* (1997) and Ragonese *et al.* (2002), however the currently used mesh sizes are now larger than the ones tested (14 and 20 mm). On the other hand, similar results were observed for 36 and 40 mm diamond shaped meshes in the Sea of Marmara (Bök *et al.* 2011). Another important feature affecting trawl by-catch seems to be the codend circumference. Sala and Lucchetti (2011) tested two codend mesh sizes, 48 and 56 mm, and two different nominal circumferences for each mesh size in two fishing grounds in the Central Adriatic Sea. They found a positive effect on L_{50} of certain species when increasing mesh size, which could be meaningless if followed by an increase in codend circumference. Decreased circumference resulted in higher L_{50} for rose shrimp (*Parapenaeus longirostris*) in the Aegean Sea (Tokaç *et al.* 2009) and similar results were obtained with the traditional codend equipped with a square mesh panel, however these codend modifications were not sufficient to release immature specimens for most species considered (Tokaç *et al.* 2009, 2010).

In addition, the inclusion of Turtle Excluder Devices (TEDs) seems to be an effective technology for the mitigation of by-catch, not only for turtles but for 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 reduced by the use of TEDs (Sala *et al.* 2011). The use of sorting grids can also provide beneficial results for by-catch reduction for certain species, like in the case of juvenile hake and horse mackerel (Sardà *et al.* 2004, 2005). However, grids with narrow bar spacing (i.e., 15mm) provide poor selectivity, so instead the use of wider spacing and/or square mesh is recommended (Sardà *et al.* 2006, Massuti *et al.* 2009). Finally, short haul duration is known to reduce discards rate (Stergiou *et al.* 1998, Moranta *et al.* 2000).

3.1.2. Selectivity of small-scale fisheries

Several experimental surveys have explored the effect of mesh and hook size and shape on small scale fisheries along the Mediterranean and Black Seas. Piovano *et al.* (2010) tested several technical measures for the mitigation of the stingray (*Pteroplatytrygon violace*a) capture, a common by-catch 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 by-catch, while (iii) bait size, within the range of sizes assessed, and use of light attractors did not have significant effects on stingray catch rate. Stergiou *et al.* (2002) explored the effect of longlines with different hook sizes (11, 12, 13 and 15) and gill nets of different mesh sizes (22, 24, 26 and 28 mm, nominal bar length) on the catch composition in the C. Aegean Sea and concluded that the commercial/total catch ratio was very high (more than 90%) and did not differ either within and between gears but catch species composition differed greatly with mesh and hook size. Karakulak & Erk (2008) explored the catch of 16, 18, 20 and 22 mm mesh size for trammel and gillnets in the N. Aegean Sea and suggest that 18 mm mesh size is adequate since it considerably reduces the numbers of small sized individuals and discard species in the catch compared to 16 mm mesh size. Similarly, for the gillnet fishery in the northern Tyrrhenian Sea, despite the fact that 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 (*Mullus barbatus*) in coastal areas of the Adriatic an Lingurian 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.

Modifications of the structure of the nets may also present substantial reduction in by-catch quantities. Rising of the net above the lead line from muddy ground using guarding nets showed that it can lead to reduced 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 *Posidonia oceanica* beds, since multifilament gillnet rates for non-marketable species are significantly reduced (from 77.8% to 22.8%).

3.2. Spatio-temporal closures

In the GFCM area, spatiotemporal closures have been applied for the protection of juvenile fish and charismatic species. According to Abdulla *et al.* (2008) more than 90 MPAs are established in the Mediterranean and their number presents an increasing tendency, while several MPAs also exist in the Black Sea (Todorova *et al.* 2007). One of the scopes of their establishment has been the reduction of by-catches, mainly concerning vulnerable and charismatic species (Abdulla *et al.* 2008). Protection of nursery areas is also a goal for several MPAs in the Mediterranean (Garcia-Charton *et al.* 2008). Thus, establishment of MPAs in by-catch hotspots and subsequent restrictions to fishing may overall reduce by-catch quantities. However legal establishment of a MPA does not necessarily mean management effectiveness (Abdulla *et al.* 2008) and should be followed by strong surveillance (de Juan & Lleonart 2010). 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 1st to the 30th of July for the whole Mediterranean, while at a local level, trawl fishery closes in the Catalan, Adriatic and Greek Seas 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 often try to satisfy social demands. A more targeted designation, based on scientific results may prove more effective in by-catch reduction and fisheries management in general (STECF 2006).

4. Indicators as tools for describing by-catch and discards of different fleets and fisheries

The use of indicators as tools to identify changes, quantify problems and monitor the implementation of policies and regulations is developed rapidly in fisheries and ecosystem fields. The selection of a robust set of informative and easily interpretable indicators is required by the policymakers, managers and stakeholders, in order to evaluate the performance of management measures or to validate the current status of ecosystem before the establishment of precautionary and mitigation actions. Fisheries are highly related to impacts on aquatic environment not only through the reduction of targeted species, but also through the reduction of non-targeted species that are recorded as discards and by-catch. Several vulnerable and endangered species were included in the aforementioned categories. It should be also highlighted that developing indicators relevant to by-catch/discarding issues, can be also used to provide further insight into the perspective of determining appropriate Good Environmental Status (GES) targets under the Marine Strategy Framework Directive (MSFD) (ICES CM 2011/ACOM:58). The MSFD (Annex I) proposes 11 descriptors of the GES (Biological diversity, Alien species, Commercial Fish, Food webs, Eutrophication, Sea floor integrity, Hydrography, Contaminants, Contaminants in food, Marine litter, Energy including noise) that cover the most common components relevant for likely operational objectives. Several task groups developed a suit of 83 indicators for those descriptors (2010/477/EU).

Rice & Rochet (2005) proposed a framework for the objective selection of a suite of indicators to be used in fisheries management. The eight steps that compile the indicator selection framework are: (1) identification of user groups and their needs, featuring the setting of operational objectives, (2) identification of a corresponding list of candidate indicators, (3) assigning weights to nine screening criteria for the candidate indicators: *concreteness, theoretical basis, public awareness, cost, measurement, historic data, sensitivity, responsiveness, and specificity*, (4) scoring indicators against the criteria, (5) summarizing the results, (6) deciding how many indicators are needed, (7) making the final selection of complementary suites of indicators and (8) presenting to all users of the information contained in the final selected indicators.

In the EU there is intensive data collection of by-catch and discard onboard commercial vessels, but there have been few attempts to describe the general patterns in these data, and still less to understand the factors that determine what and how much is discarded. The latter step is crucial for developing operational indicators and proposing mitigation tools for fisheries management. In the framework of the Marifish Badminton Project, a provisional list of pressure, state and response indicators was drawn to tackle specific issues related to catch and discarding practices in European fisheries and fleets. Candidate state indicators describing the ecosystem or fish community, that can be quantified using data derived through fishery independent surveys, pressure indicators describing the intensity and selectivity of fishing (input to the fishing activity) as well as the catch & discards (output of the fishing activity), depending on records made by observers on board commercial vessels, and response indicators reflecting management efficiency for limiting by-catch and discards appear in Table 4.

Table 4. List of candidate indicators for describing by-catch and discards of different fleets and fisheries (source BADMINTON mid-term report).

Type of indicator	Proposed indicators
Pressure indicators describing the intensity and selectivity of fishing (input to the fishing activity)	- selectivity-at-length curves by gear / fleet / fishery - number of vessels, fishing time, fishing time × power by gear / fleet / fishery
Pressure indicators describing catch & discards (output of the fishing activity)	- catch and discards amount: whole catch / per species - minimum, mean and maximum size of catch & discards (whole catch / per species) - sorting size for species that are both retained and discarded - diversity indices (richness, evenness) of total catch - trophic level of total catch
State indicators describing the ecosystem or fish community	Stock level: - total biomass or SSB - descriptors of age or length structure (e.g., 25%, the 75% percentile of the length distribution) Community / ecosystem level: - total biomass - diversity indices (richness, evenness) of the community - mean trophic level of the community - descriptors of size structure (e.g., proportion of large fish) - proportion of non-commercial species
Response indicators describing the regulations intended to improve selectivity / limit discarding	- stock-specific Minimum Landing Size - mesh size regulation - selective devices regulations - discarding regulations

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