Mediterranean Marine Science

Vol 19, No 3 (2018)

The “discard problem” in Mediterranean fisheries, in the face of the European Union landing obligation: the case of bottom trawl fishery and implications for management

DIMITRIOS DAMALAS, ALESSANDRO LIGAS, KONSTANTINOS TSAGARAKIS, VASSILIKI VASSILOPOULOU, KONSTANTINOS I. STERGIOU, ARGYRIOS KALLIANIOTIS, MARIO SBRANA, FRANCESC MAYNOU

doi: [10.12681/mms.14195](https://doi.org/10.12681/mms.14195)

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available online at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.14195

The "discard problem" in Mediterranean fisheries, in the face of the European Union landing obligation: the case of bottom trawl fishery and implications for management

DIMITRIOS DAMALAS[1], ALESSANDRO LIGAS[2], KONSTANTINOS TSAGARAKIS[1], VASSILIKI VASSILOPOULOU[1], KONSTANTINOS I. STERGIOU[1], ARGYRIOS KALLIANIOTIS[3], MARIO SBRANA[2] and FRANCESC MAYNOU[4]

[1] Institute of Marine Biological Resources and Inland Waters, Hellenic Centre for Marine Research (HCMR), 46.7 Km Athens-Sounio, PO Box 712, 190 13, Anavissos, Attica, Greece
[2] Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia Applicata "G. Bacci" (CIBM), V.le N. Sauro 4, 57128 Livorno, Italy
[3] Fisheries Research Institute, National Agricultural Research Foundation, NeaPeramos, Kavala, 64007, Greece
[4] Institut de Ciencies del Mar (ICM-CSIC), Psg. Maritim de la Barceloneta 37-49, 08003 Barcelona, Spain

Corresponding author: shark@hcmr.gr
Handling Editor: Fabrizio Serena

Received: 13 July 2017; Accepted: 10 August 2018; Published on line: 19 September 2018

Abstract

Since the first introduction of the landing obligation (a.k.a. Discard ban) in 2015, the EU Mediterranean fisheries are facing some unforeseen challenges. The demersal bottom trawl fisheries, being the most significant contributors to the so-called 'discard problem', are confronted with the greatest challenges. Data from the Italian and the Greek fleet, spanning over two decades (1995–2015), were analysed with the intention of revealing the diversity and heterogeneity of the discard problem, especially for regulated species. Species composition of discards, as well as discarding rates, were shown to be irregular, fluctuating among areas, depth strata, seasons and years. Although fish dominated the discarded gross catch in weight, benthic invertebrates (other than commercial cephalopods and crustaceans) were the taxa discarded almost exclusively. The established minimum conservation reference size was largely ignored by fishers. From a management point of view, the present investigation suggests that the recently established Discard Management Plans lack scientific evidence (given the high intrinsic variability of the parameters and confusion regarding the rules) and provide exemptions from the landing obligation that will in practice allow the average Mediterranean bottom trawl vessel to continue business as usual. Moreover, detecting if these rules are actually respected is an almost impossible task for the Mediterranean control and enforcement authorities. Incentivizing the adoption of fishing technologies and practices that reduce pre-harvest mortality and post-harvest discards, while avoiding damage to sensitive marine species and habitats, seems the only way to move forward, rather than dealing with the problem after it has occurred.

Keywords: Discard ban; bottom trawl; North Tyrrhenian Sea; Aegean Sea; Mediterranean Sea.

Introduction

European Union (EU) fisheries are responsible for a high level of discarding (Kelleher, 2005; Feekings *et al*., 2012), which is attributed to low-selectivity fishing techniques, excessive fishing effort, low enforcement and a patchy species distribution (Johnsen & Eliasen, 2011). The European Commission (EC) has associated the 'discard problem' with poor economic performance and a significant component of marine ecosystem functioning (EU, 2009). Almost a hundred regulations and amendments (mainly technical measures) have been introduced since the 1980s that aim to reduce discards (Santurtun *et al*., 2014). In an attempt to solve the discard problem, the EU eventually decided to follow a more aggressive approach. The reformed Common Fisheries Policy (CFP-EU, 2013) pursues the gradual elimination of unwanted discarding practices at sea, through the gradual introduction of a "landing obligation" (Art. 15) for regulated species(originally scheduled to start from 2017 for demersal fisheries in the Mediterranean), which are subject to a Minimum Conservation Reference Size (MCRS) and/or Total Allowable Catch (TAC). As a result, EU fisheries are currently transitioning to reducing discards at sea and bringing all undersized catches of tabulated stocks to land obligatorily.This represents a fundamental shift in the management approach of EU fisheries, switching from landings monitoring to catch monitoring. Furthermore, regionalised decision making (e.g. at the Geographical Sub Area or GSA level) becomes a management option.

The EU fisheries management scheme, the CFP, has always given privileged treatment to the Mediterranean region and specific regulations were explicitly introduced to outline those regulations (the 'Mediterranean regulations', EU, 1994 and EU, 2006). In brief, instead of an output control system (e.g. landing quotas and TACs), input control through an effort-regulating regime has been considered the most appropriate management strategy, with few exceptions. Consequently, the landing obligation in the Mediterranean does not apply to the species subject to catch limits (i.e. TAC and quota species), but to those subject to minimum conservation reference size (currently 27 species/taxa in Annex III of EU, 2006).

Implementation of the landing obligation to different types of fisheries is being undertaken in stages according a timetable (2015-2019). In this context, the EU Mediterranean fisheries are facing some unforeseen challenges and are currently on the brink of a new era.

In general, reducing or eliminating discards is the most complex in the Mediterranean multi-specific demersal trawl fisheries, which lack clear target species and have catches comprised of numerous unwanted species of variable or zero value. In such fisheries, discard mitigation measures are difficult to develop and implement. On average, most of the discards in the Mediterranean Sea (>35% by weight of the total catch) are attributable to such fisheries (Tsagarakis *et al*., 2014).

This study is based on a series of data obtained onboard commercial bottom trawlers during the past two decades (1995-2015) and aspires to highlight the complexity of the problem from a management point of view, linking it to the recently introduced discard management plan (EU, 2017). Particular attention is paid to more specific aspects of discarding fisheries, such as catch profiles, discarding trends (annual, seasonal and by depth) of commercial and sensitive (e.g. long-lived, deep water and chondrichthyan) species, as well as the fate of major species in relation to length (linked to MCRS limits compliance).

Materials and Methods

Study area-Fisheries features

The Mediterranean Sea constitutes less than 1% of the total surface water on the planet, with 22 different countries bordering its coastline. It extends from the Straits of Gibraltar to the Near East for about 4000 km, reaching its maximum depth (5121 m) in the eastern Ionian Sea (Barale, 2008). The Mediterranean Sea can be divided into two main basins of almost equal size, the western basin and the eastern basin, connected by the Strait of Sicily. (Würtz, 2010). Despite its small size, the fish biodiversity and absolute number of species are relatively high: about 6% of the entire world's fish species occur in its waters (Fredj *et al*., 1992; Coll *et al*., 2010).

During the period 1995-2015, 35 vessels (16 Italian and 19 Greek) were monitored during years where onboard observations were available in three Mediterranean geographical sub-areas: FAO GFCM GSA 09: Ligurian and North Tyrrhenian Sea, GSA22: Aegean Sea and GSA23: Crete. The monitored vessels were chosen randomly and were representative of the ones operating in the study areas in terms of vessel size and fishing operations.

A total of 1297 hauls (949 hauls in the Aegean Sea/Crete and 348 in the Ligurian and northern Tyrrhenian Seas) were conducted on board the aforementioned commercial otter bottom trawlers at depths between 15 and 597 m (Fig. 1; Tables 1 and S1, S5). The vast majority of hauls in depths less than 50 m were conducted by the Greek fleet.

Table 1. Summary description of some operational and economic characteristics of the fisheries under study. GSA 22-23: Aegean Sea and Crete; GSA 09: Ligurian and North Tyrrhenian Sea. (Monitored vessels are shown in Table S4).

Area	Year	Nb Vessels	Fishing Depth (Avg)	Fishing Depth (Min)	Fishing Depth (Max)	Depth Range	Nb Species Discarded	% of catch Discarded	Landings Value per Vessel (x1000Euros)
GSA22-23	2004	281	122	26	395	369	166	33	324
GSA22-23	2005	284	124	22	373	351	165	30	1120
GSA22-23	2006	283	131	28	463	435	153	35	752
GSA22-23	2008	272	122	33	255	222	103	29	375
GSA22-23	2013	242	124	29	415	386	168	29	364
GSA22-23	2014	241	144	35	472	437	206	26	296
GSA9	2010	310	207	13	570	556	251	23	209
GSA9	2011	304	250	18	590	572	221	19	224
GSA9	2012	285	250	20	597	577	221	19	208
GSA9	2013	277	255	15	530	515	239	19	190
GSA9	2014	277	211	16	444	428	237	28	208

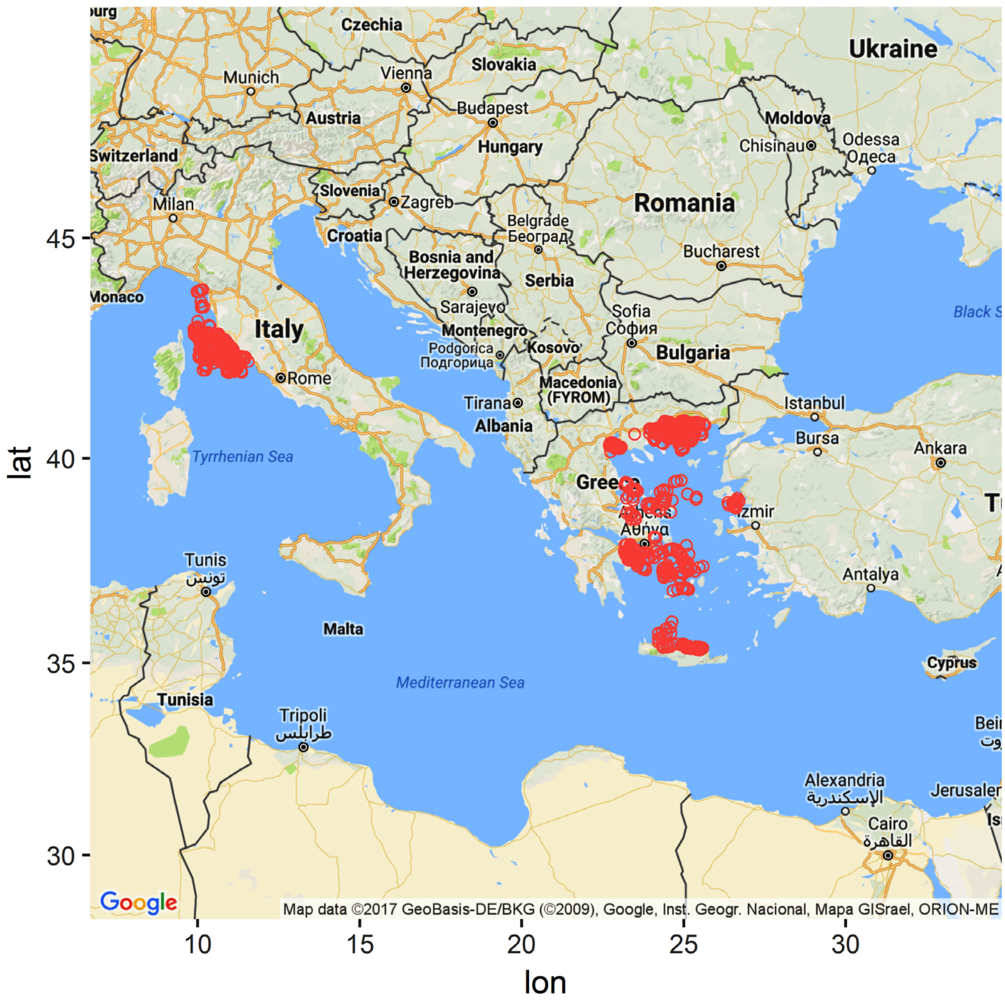

Fig. 1: Map of the studied areas with the sampling locations indicated as red open circles.

Typical otter bottom trawlers in this study were characterized by vessels usually longer than 25 m in length, with engine powers from 300 to 700 HP and mesh sizes of 40 mm squared/50 mm diamond. Towing speed was approximately three nautical miles per hour (range 2.4-3.6), and the average tow duration (with start considered right after the final stop of the winches) was 212 minutes (range 50-550 minutes).

Data were collected on board by scientific personnel, who did not interfere with the normal fishing practices of the crew. Observers performed species identification, discarded and marketed fraction weight and count for each species and recorded fishing operational data (date, position, depth and haul duration). The length of the specimens caught was recorded (total length or TL; 1 cm) for fish, mantle length (ML; 1 mm) for cephalopods, and carapace length (CL; 1 mm) for crustaceans. Catch per unit of effort (CPUE) was defined as the total weight of each species/taxon caught per hour of trawling, and it was considered a relative measure of population abundance in weight, although the proportionality constant (i.e. catchability, ranging from 0 to1 or more than 1 in the case of a herding effect) is unknown and may vary by species, season, daylight etc. However, catchability for each species was assumed invariant by haul, as all hauls were carried out by similar vessels and gear configuration in all GSAs.

Operational and economic characteristics of the fleets (vessel capacity, vessel energy consumption and vessel annual landings value) were available only for the most recent years and were derived from the Annual Economic Reports of the EU Fishing Fleet and the corresponding electronic annexes.

Statistical analyses-Modelling

Catch profiles of the monitored fishing operations were analysed as groups of major taxa: 1. Fish; 2. Cephalopods; 3. Crustaceans and 4. Other Invertebrates (Table S2), in relation to depth stratum (by 100 m), season and year. Results were visualized as the contribution in total catch for the marketed (retained) and discarded fractions in polar coordinate plots.

Discard trends were assessed through generalized additive model approaches, which modelled the effects of various predictor variables (year, season, depth, longitude and latitude) on the relative abundance (expressed as CPUE) of total and sensitive taxa catch (selected invertebrates and elasmobranchs). The functional relationships between population density of marine species and environmental variables are usually neither linear nor monotonic. Assuming an inherent non-linearity, generalized additive models (GAMs; Hastie & Tibshirani, 1990) were applied to identify influential variables, reveal the form of the relationships, and quantify their effect on the relative index of abundance (CPUE). Implementation was done in R v.3.5.0 (R Core Team, 2018) using the package mgcv (Wood, 2006), according to the general formulation:

$$f\left(E\left[CPUE_i\right]\right) = LP_i = c + \sum_m s_m\left(Z_{mi}\right)$$

where f is the link function, LP is the linear predictor, c is the intercept, $s_m()$ is the one-dimensional smooth function of covariate Z_m, and Z_{mi} is the value of covariate m for the i-th observation. The smooth function $s_m()$ was represented using penalized regression splines (cubic splines with basis dimension q=10), estimated by penalized iterative least squares. Identification of the underlying probability distribution for the errors in the dependent variable (CPUE) was performed using the Akaike information criterion (AIC; Akaike, 1973) and by checking residual patterns. After selecting the appropriate error distribution family, an information theoretic approach was followed (Burnham & Anderson, 2002) to discriminate among the best model including the most influential parameters affecting catches. A set of pre-defined candidate models were investigated, and the optimum model was selected based on the lowest AIC score.

To assess compliance with the MCRS, the probability of discarding by length was estimated for certain selected species driving the fisheries. The 'fate' of each individual fish (C=Commercial, D=Discarded) in relation to a series of predictor variables (size, year, season, depth) was modelled with GAMs. Discarding probabilities were visualized as a logistic curve (ogive) on a two-dimensional graph with distinctive two-level coloration. The 50% retention length (L_{50} - the size at which 50% of the specimens are retained) and the retention range (L_{75} - L_{25}) were also calculated for the aforementioned species. Analyses were partitioned in two periods (before and after 2006) related to the two EU regulations establishing size limits in the Mediterranean (EU, 1994 and EU, 2006).

The operational and economic characteristics of the fleets were linked to discards using a regression of various factors (vessel capacity, vessel energy consumption, vessel annual landings value and fishing depth) against the percentage of discards (Discards/Total Catch) or the total number of species/taxa discarded. The trends were evaluated by a simple linear regression, and significance was assessed by the super-imposed corresponding confidence intervals.

Finally, to estimate what percentage of the vessels (among the ones monitored) are eligible for an exemption from the landing obligation (discard plan-EU, 2017), species-specific annual landings were expressed as percentage of total landings for all vessels under study.

Results

Operational and economic characteristics of the bottom trawl fisheries under study

A brief summary description of the operational and economic characteristics of the discarding fisheries under study is given in Table 1. The number of species discarded was not regressed against fishing depth because there was a clear difference in the sampling protocols among the two GSAs, with the Greek observers focusing mainly on target species related to the EU Fisheries Data Collection Framework (Tables S2-S3). Due to this difference in sampling protocols, fishing depth was investigated only against the discard ratio (%) and was found to be significantly (although with a low r^2) negatively related (r^2=0.54, p<0.05; Fig. 2). Moreover, vessels that were financially 'successful' and achieved higher revenues were also more likely to discard. Landing value per vessel was positively and marginally significantly associated with discarding rates (r^2=0.35, p<0.05; Fig. 2).

Discarded and Marketed Catch profiles

Aegean Sea and Crete (GSA 22-23)

Fish comprised the majority of discards (in terms of weight) and were more prevalent within the continental shelf (<200m; first and second stratum and around autumn) (Fig. 3A). Out of a total of 139 fish species discarded (Table S3), just five of them accounted for more than a third of these discards (horse mackerel *Trachurus trachurus*, hake *Merluccius merluccius*, spotted catshark *Scyliorhinus canicula*, bogue *Boops boops* and pilchard *Sardina pilchardus*). The list of major taxa discarded included 13 species of crustaceans and 23 species of cephalopods. On the other hand, marketed species were mainly represented by fish (124 species) and crustaceans (20 species) (Table S3), with the latter characterized by high market values and predominantly driven by deep water rose shrimp (Fig. 3B). Furthermore, discarded fractions were considerably lower for crustaceans compared to fish. 'Other Invertebrates' were largely discarded (Fig. 4).

Ligurian and northern Tyrrhenian Seas (GSA 09)

Fish dominated both discards and landings and were more prevalent on the continental shelf (depths <200m) and in summer/autumn (Fig. 5A). One hundred fifty-one fish species were discarded (Table S3), with hake and pilchard accounting for more than 70% of discarded species. In addition, 36 species of crustaceans and 26 species

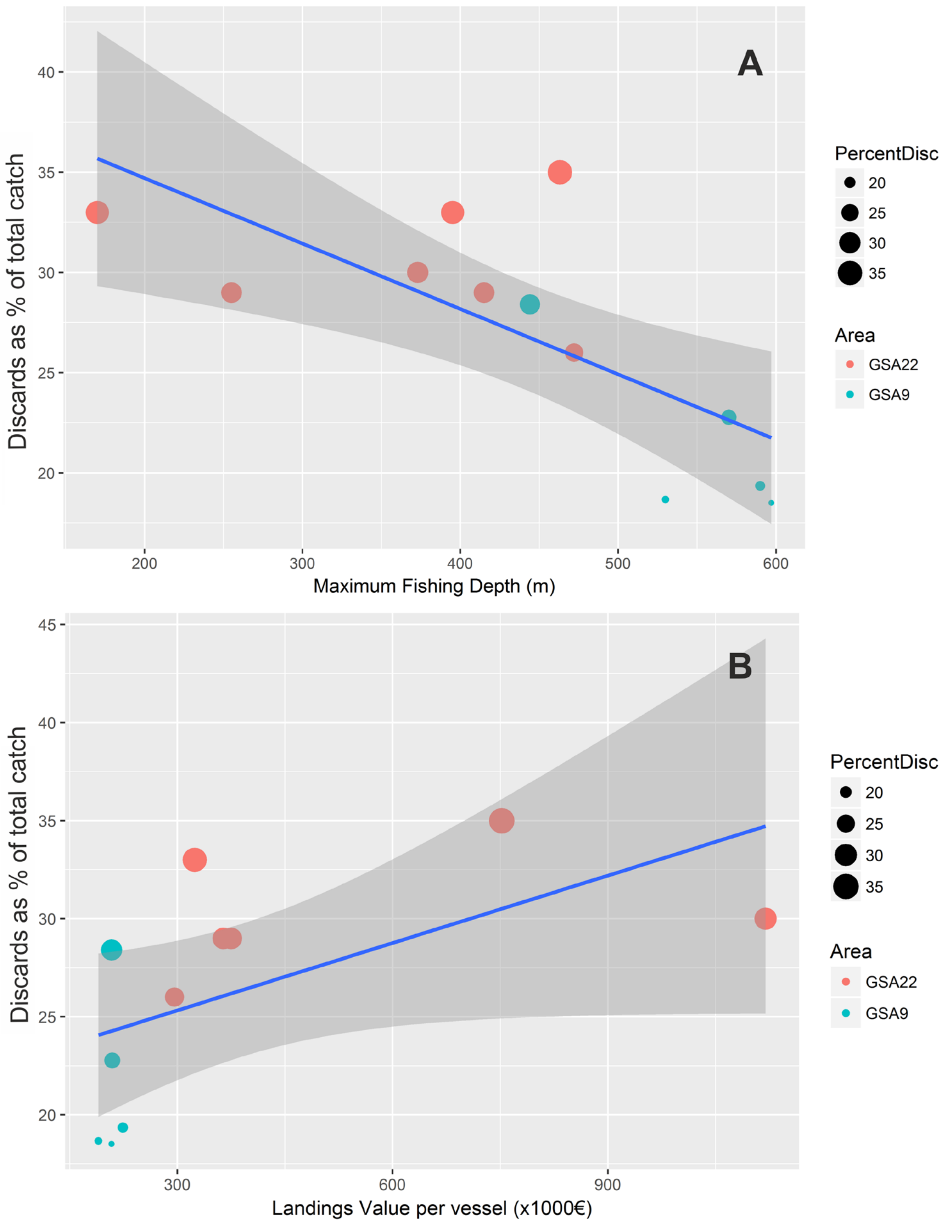

***Fig. 2**:* Maximum fishing depth (m) regressed upon percentage of total catch discarded (A) and Landings value per vessel (x1000 €) regressed upon percentage of total catch discarded (B). Results are depicted by geographical area studied.

of cephalopods were discarded (Table S3). In contrast, 136 fish species were landed, with horse mackerel comprising a quarter of these landings. Marketed species included significant quantities of crustaceans (45 species) and cephalopods (29 species) (Table S3), especially from deeper strata (>300m) (Fig. 5B). 'Other Invertebrates' were mostly discarded in contrast to crustaceans and cephalopods (Fig. 6).

Discard trends

Modelling discard rates (Table S4) in relation to various driving factors revealed interesting spatiotemporal differences and patterns.

Aegean Sea and Crete

Spatial depiction of discarding locations by year is shown in Figure 7. Higher discards occurred in the north-eastern part of the Aegean Sea, in waters less than 100 m deep. Discarding as a practice was less pronounced during winter and showed a diminishing trend through the years (Fig. 8). Summer observations are absent because the Greek bottom trawl fishery is regulated through a general summer closure.

Analysis of sensitive taxa (invertebrates other than crustaceans and cephalopods and elasmobranchs) did not indicate any dissimilar trends in comparison to all other taxa (Fig. S1).

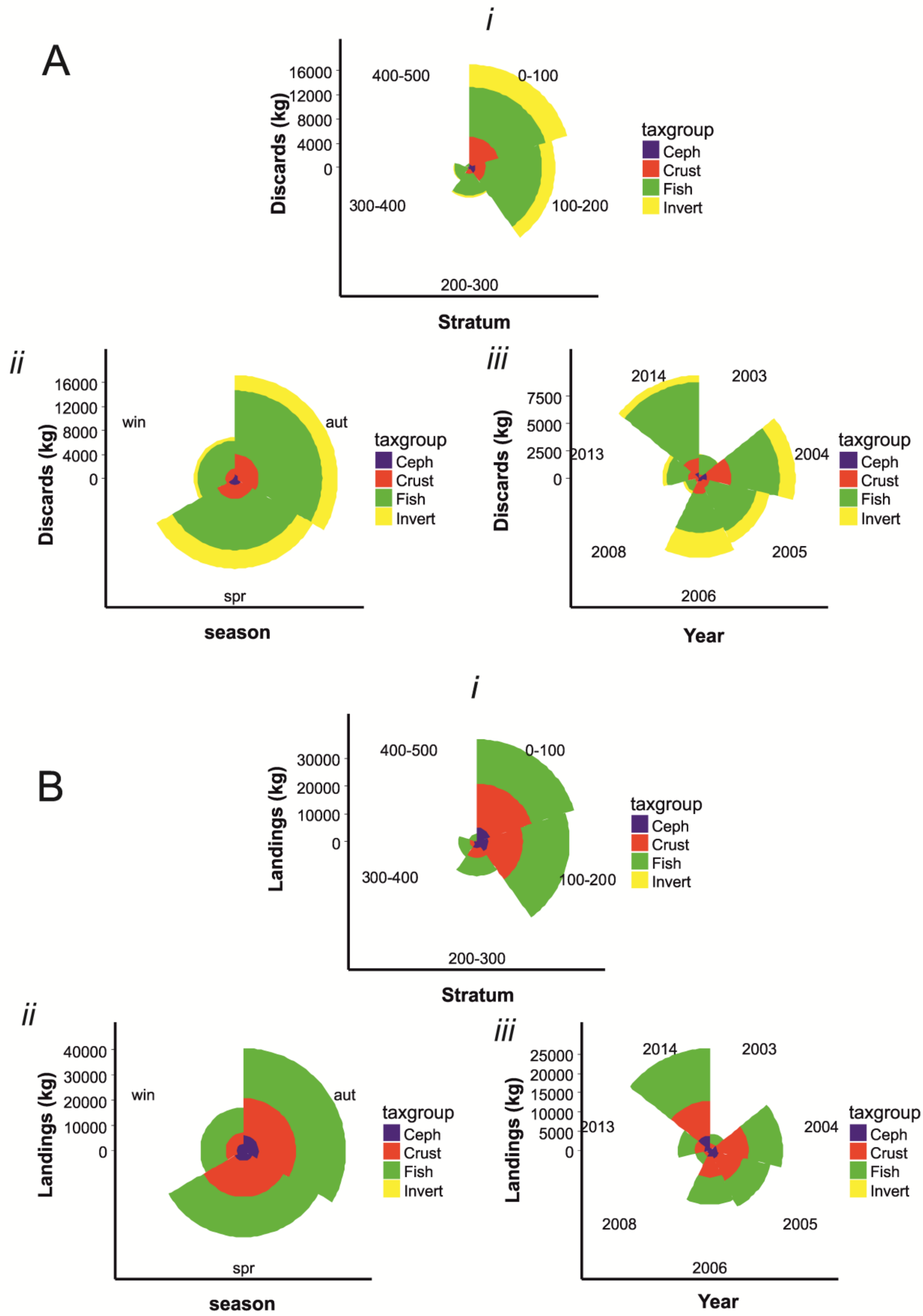

Fig. 3: Discard (A) and landings (marketed; B) catch profiles of major taxonomic groups by depth stratum, season and year in the Aegean Sea and Crete (GSA 22-23) trawl fishery. (Y-axis is expressing absolute values in kg). Invert denotes invertebrates other than cephalopods and crustaceans.

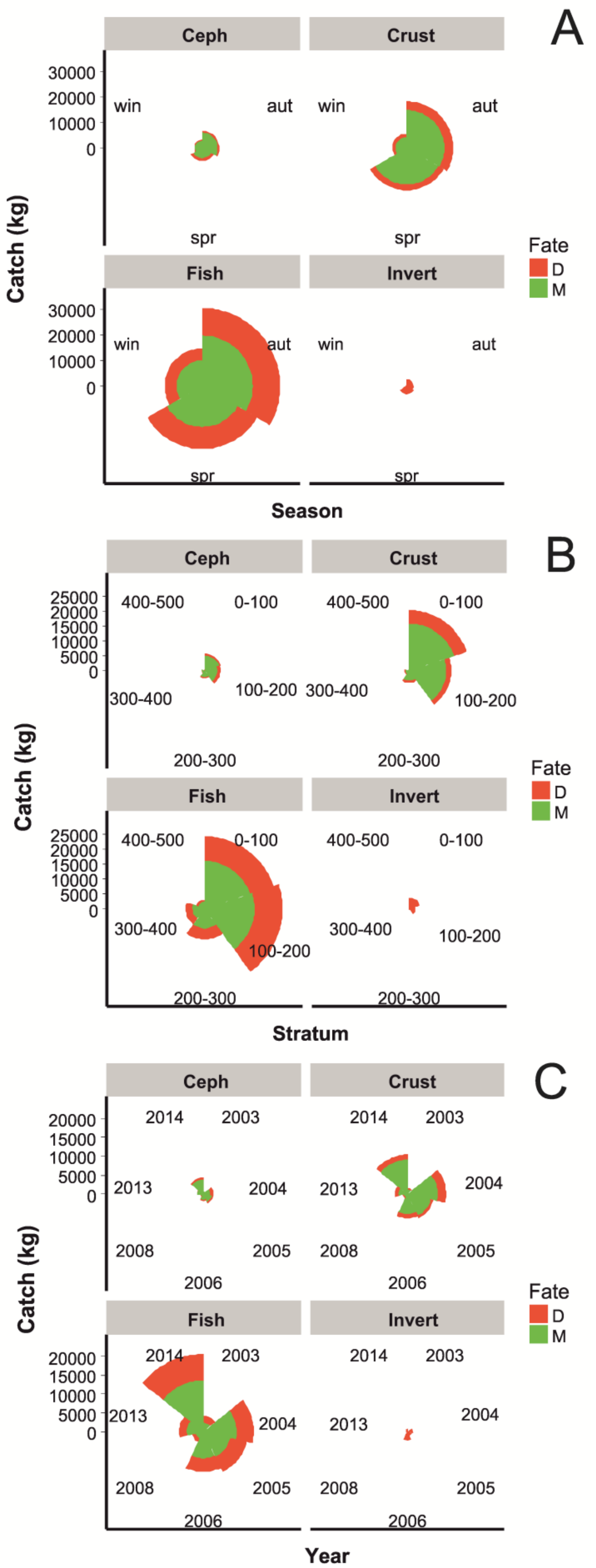

Fig. 4: Fate (discarded- or marketed) of major taxonomic groups by depth stratum, season and year in the Aegean Sea and Crete trawl fishery. (Y-axis is expressing absolute values in kg of the gross catch)

Ligurian and northern Tyrrhenian Seas

Discarding locations for the Italian bottom trawl fleet is shown in Figure 9. Higher discards occurred in the south-eastern sectors with a fluctuating pattern in relation to depth stratum (Fig. 10), indicating no extensive discarding within certain depth ranges. There was no apparent seasonal trend, with a non-significant increasing annual tendency.

Analysis of sensitive taxa showed that elasmobranchs residing in deeper waters were more prone to discarding (Fig. S2).

Discards of undersized regulated commercial species

Assessment of the probability of discarding by size, a feature linked to MCRS compliance, revealed that the prohibition of landing undersized individuals was not widely respected. Table 2 provides L_{50} retention size and ReR (Retention range) in comparison to established MCRS for the most common species. As a general rule, fishing in deeper strata resulted in catching larger individuals, and as a result, shallow coastal waters were more associated with specimens below the MCRS. To avoid any misinterpretations, it must be clarified here that the succeeding discard ogives (probabilities of a fish being discarded or not) depict the choice of fishers to retain the fish for marketing depending on its size. They do not reflect the actual selection curve of the catch, which is linked to operational features of the gears.

Aegean Sea and Crete

For hake, although the overall investigation of pooled data indicated that most fish smaller than the MCRS were discarded (Fig. 11), analyses by season and depth stratum revealed that numerous undersized specimens (between 17-19 cm TL) were landed in winter, mostly fished at depths <100m (Fig. S3). No significant change in the retention size throughout the years was observed (Table 2; Fig S3). For red mullet, *Mullus barbatus*, fish between 9-11 cm in total length were retained, largely ignoring the 11 cm MCRS (Fig. 11). Discarding occurred mostly for fish caught in waters less than 200 m of depth. Although retention size increased after 2006, it was still well below the MCRS (Table 2). Horse mackerels were not discarded due to MCRS restrictions, but rather because of market considerations. Almost all fish <20 cm were discarded, this size being far above the MCRS of 15 cm (Fig. 11). Deep-water rose shrimp (*Parapenaeus longirostris*) landings respected the established MCRS (20 mm CL) in general (Fig. 11; Table 2); however, this was largely ignored during winter (when all specimens above 17 mm were retained) and during 2014. Anglerfish (*Lophius budegassa*) in the absence of any recent MCRS limitation, were landed solely based on market demand. As a general rule, almost all fish <10 cm TL were discarded (Fig. 11). However, before 2006 when the species was regulated by a 30

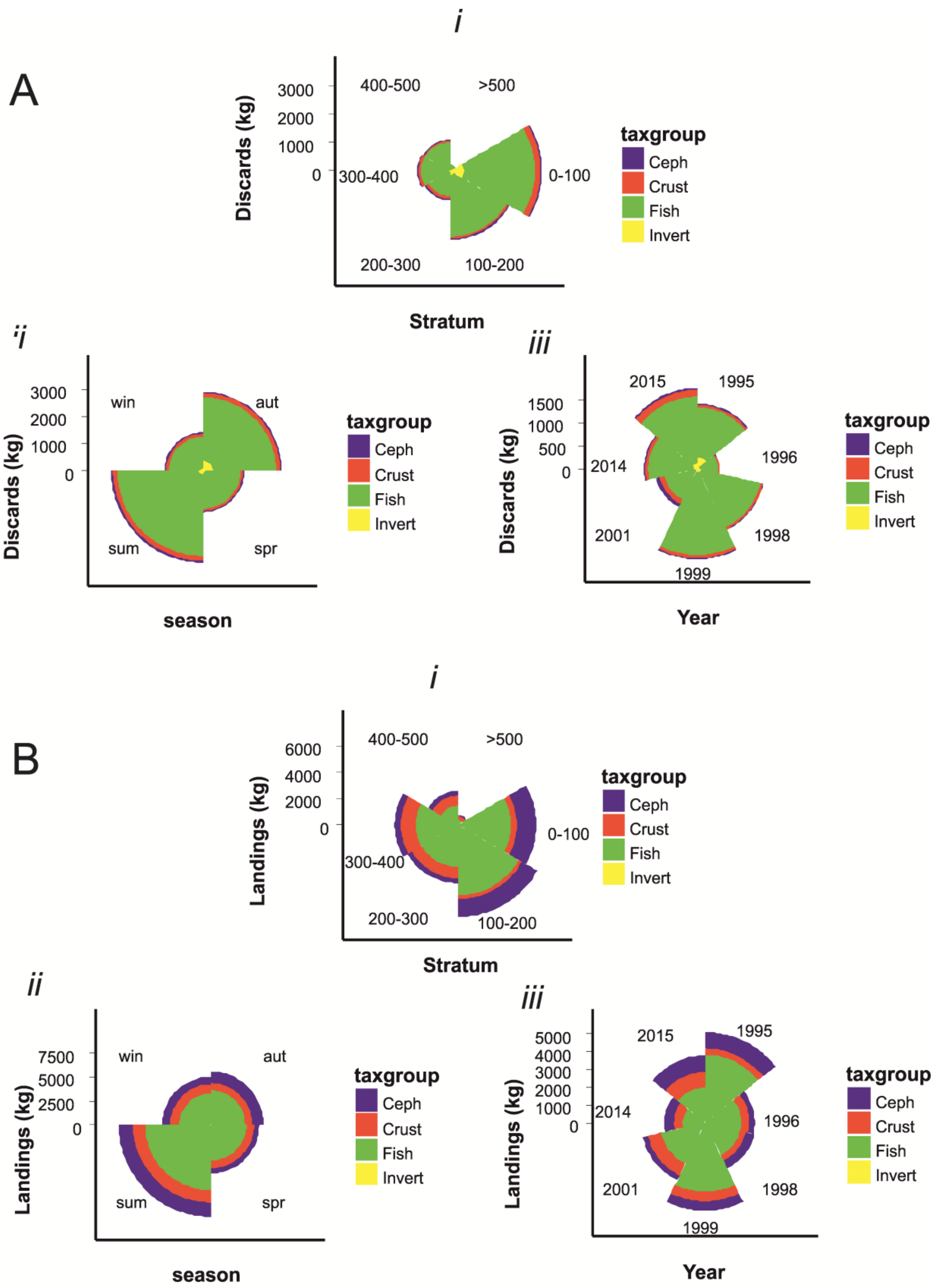

Fig. 5: Discard (A) and commercial (marketed - B) catch profiles of major taxonomic groups by depth stratum, season and year in the Ligurian and northern Tyrrhenian Seas trawl fisheries. (Y-axis is expressing absolute values in kg).

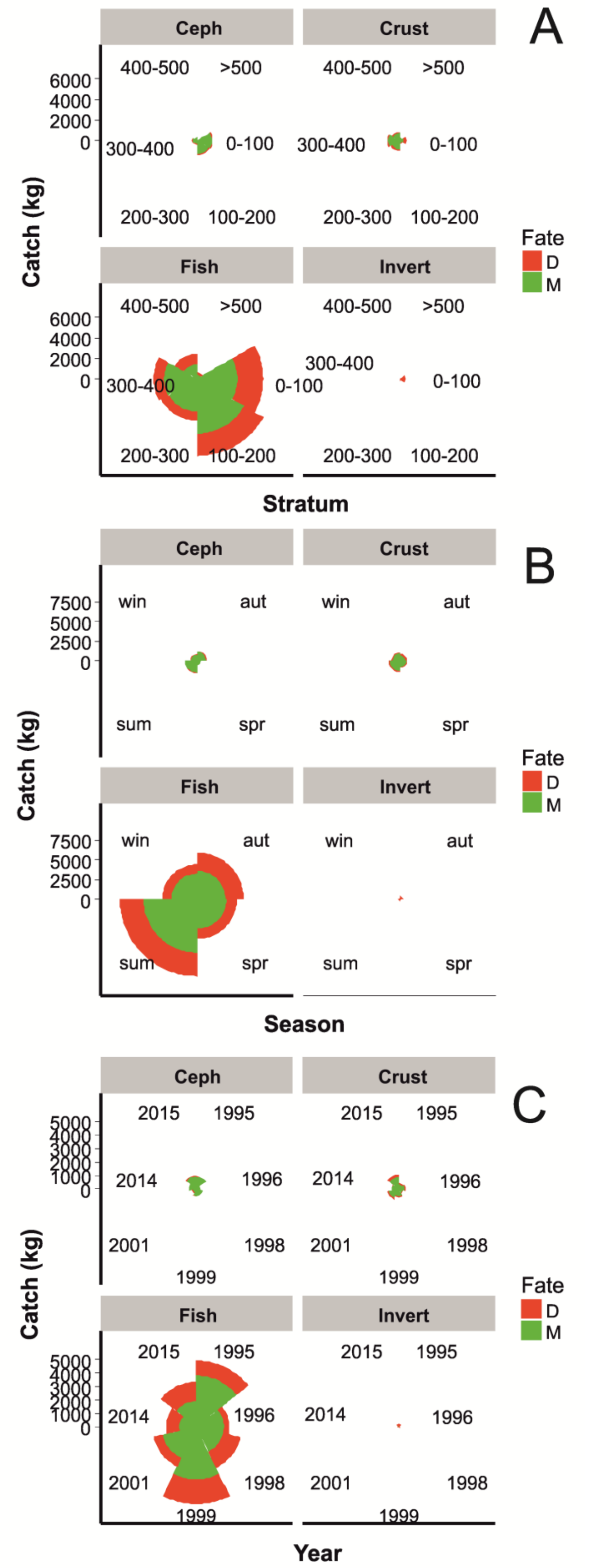

Fig. 6: Fate (discarded or marketed) of major taxonomic groups by depth stratum, season and year in the Ligurian and northern Tyrrhenian Seas trawl fisheries. (Y-axis is expressing absolute values in kg).

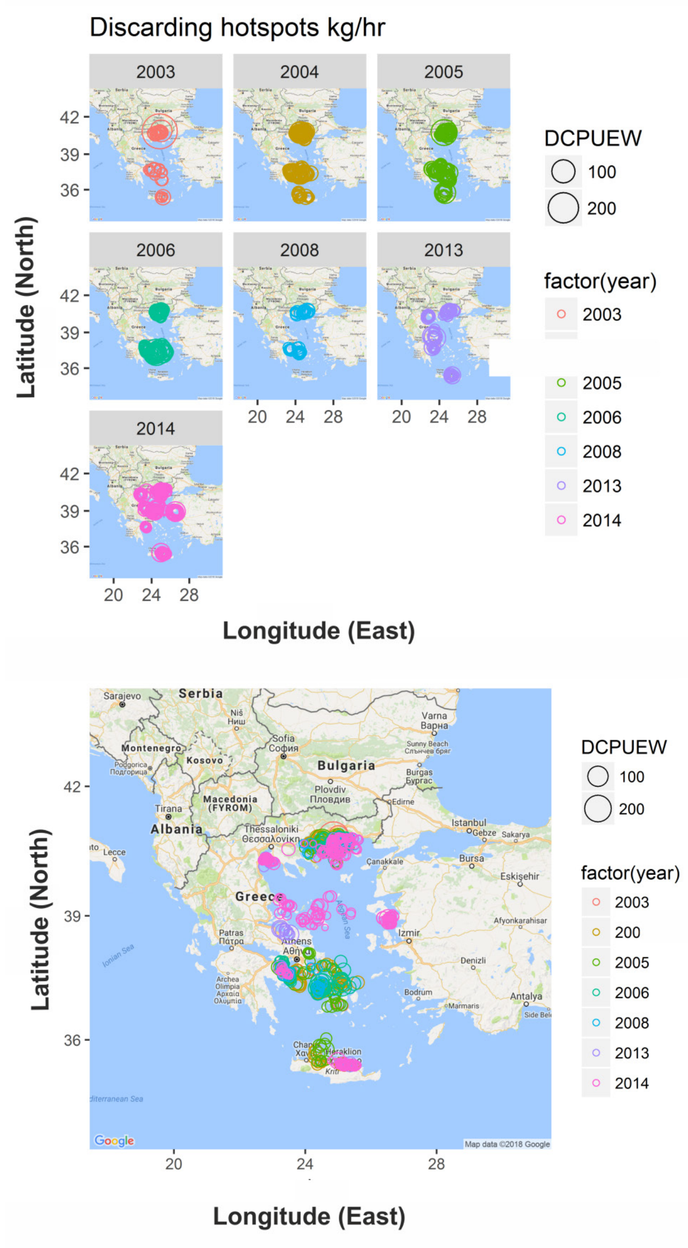

Fig. 7: Map of discarding locations for the sampled Greek trawl fleet (by year and total) exploiting the Aegean Sea and Crete area. (DCPUEW expresses discards in kg/hour).

cm MCRS, the retention size was much higher, but still below the MCRS (Table 2; Fig. S3). Finally, all bogues discarded were above the national MCRS of 10 cm (Fig. 11; Table 2). Detailed outputs of the GAM derived discard probabilities by size are given in the supplementary figures for various depth strata, years and seasons (Fig. S3).

Ligurian and northern Tyrrhenian Seas

Hake discarding was partly driven by MCRS compliance, (Fig. 12) with the exception of winter/spring (where numerous fish smaller than 20 cm TL were landed) and

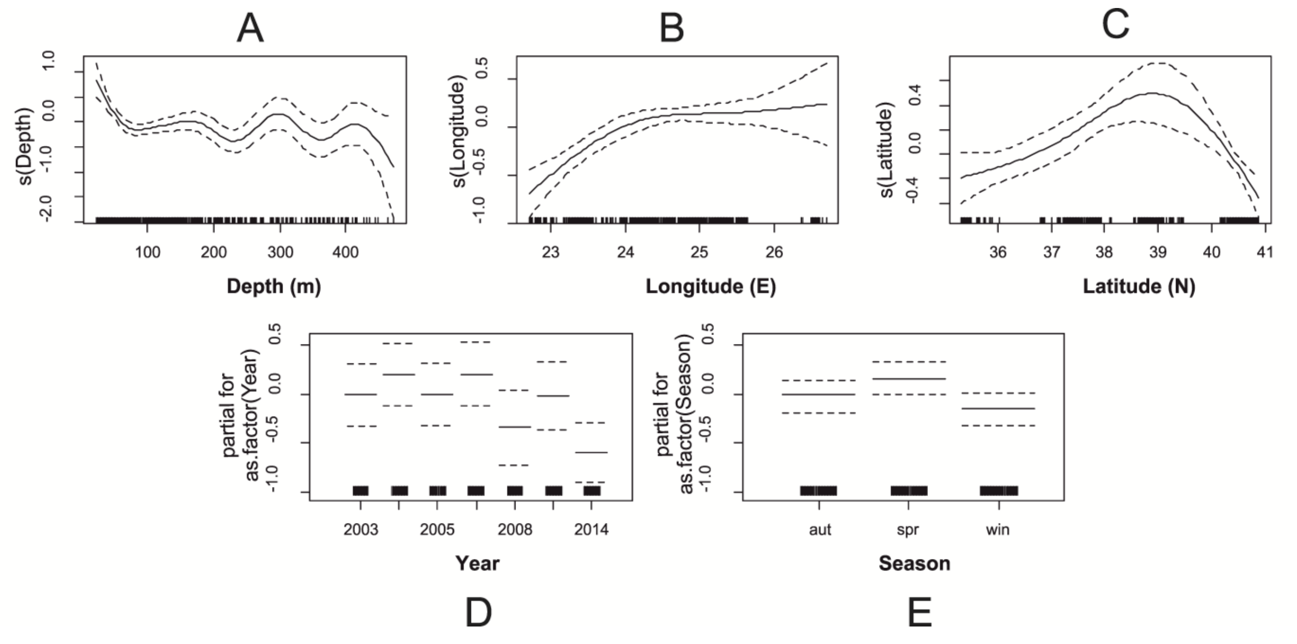

Fig. 8: Generalized additive models (GAM) derived effects of various parameters on the discard probability of the gross catch in the Greek trawl fishery. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

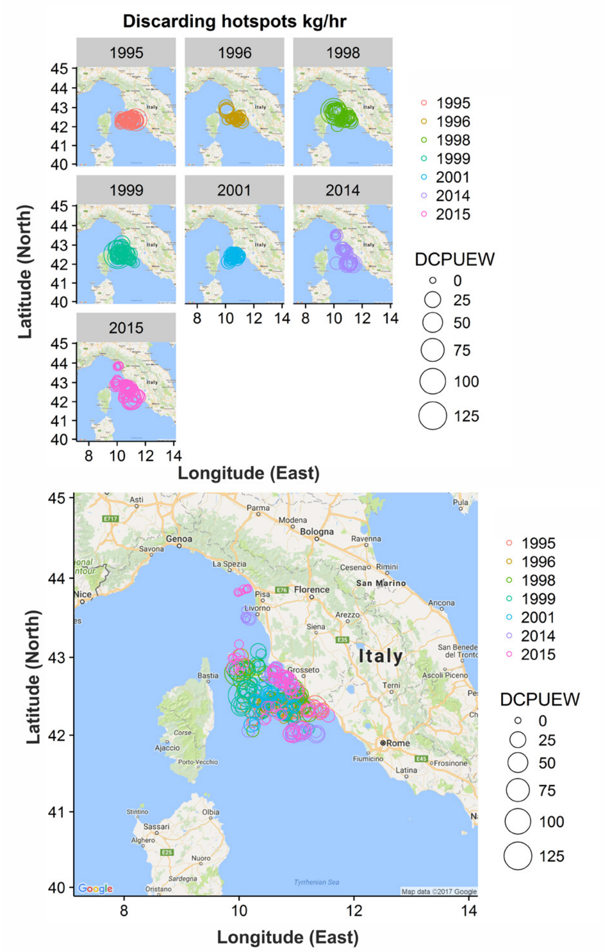

Fig. 9: Map of discarding locations (annual and total) for the Italian trawl fleet exploiting the Ligurian and northern Tyrrhenian Seas.

the period before 2006 (Fig. S4). The two discrete discard ogives evident in Figure 12 denote two groups: the group before 2006, which mostly ignored the size limit, and another group after 2006, which partially respected the MCRS (Fig. S4b; Table 2). In both cases, the retention size was far from the MCRS of 20 cm. Although the deep-water rose shrimp MCRS was respected more than the hake MCRS, the retention size (15 mm) fell far from being within legal limits (Fig. 12; Table 2). A conspicuous deviation was observed during autumn, when undersized specimens were landed. All horse mackerel marketed were above the MCRS of 15 cm TL, and most of them were actually above 20 cm TL (Fig. 12; Table 2). Although the global red mullets discard ogive gives the impression that very few specimens below the MCRS were retained (Fig. 12), analysis by season, depth stratum and year revealed large quantities of undersized fish being marketed in the distant past and during spring (Fig. S4). Retention size increased significantly after 2006 but was still below the MCRS (Table 2). Striped red mullet (*Mullus surmuletus*) discards were irregular (Fig. 12), far from the MCRS (Table 2), and all specimens during spring and summer were retained for marketing (Fig. S4). As a rule, only large bogues were marketed (Fig. 12); however, in 1995, even very small specimens were landed (Fig. S4). Detailed outputs of the GAM-derived discard probabilities by size are given in the supplementary figures for various depth strata, years and seasons (Fig. S4).

Species-specific annual landings linked to discard plan

Hake, red mullet and deep-water rose shrimp landings were checked to see if they exceed the threshold set in

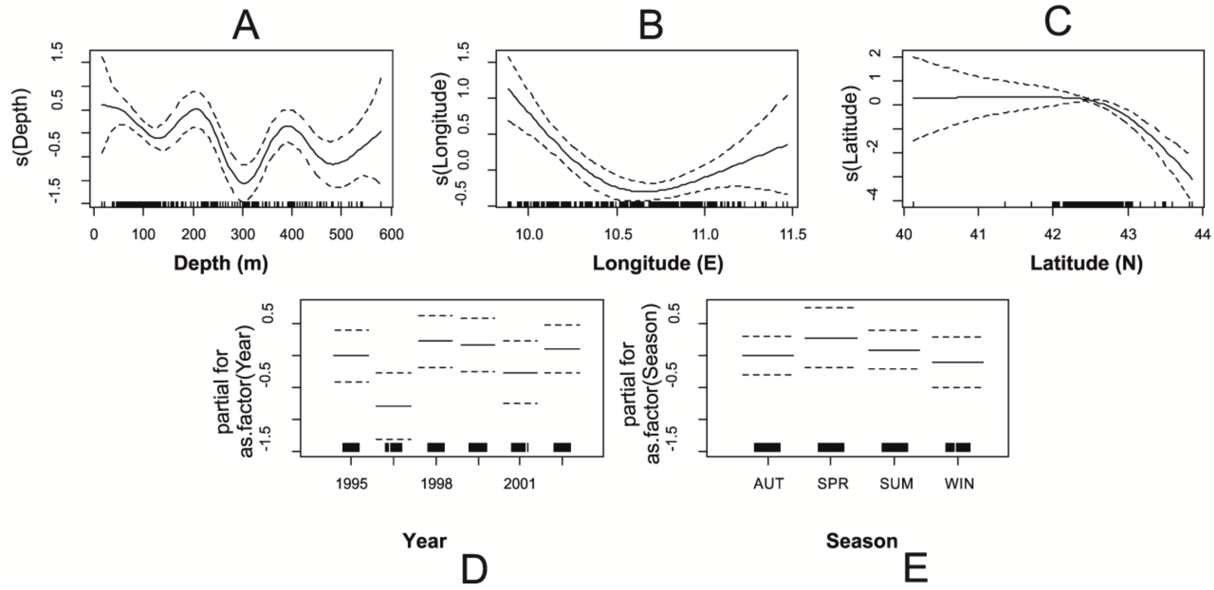

Fig. 10: Generalized additive models (GAM) derived effects of various parameters on the discard probability of the catch in the Italian trawl fishery. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

Table 2. Retention size (L_{50}), retention range (ReR) and Minimum Conservation Reference Size (MCRS) for most common species of the discarding fisheries under study. MCRSs refer to the size limits set in the relevant EU regulations: period before 2006 (COM 1626/94) and after 2006 (COM 1967/2006). (n.a. = not applicable).

Area	Species	L_{50} (mm)		ReR(mm)		MCRS (mm)	
		<=2006	>2006	<=2006	>2006	<=2006	>2006
Aegean Sea and Crete	*M. merluccius*	**139**	**141**	20	23	200	200
Aegean Sea and Crete	*M. barbatus*	**62**	**74**	28	18	110	110
Aegean Sea and Crete	*T. trachurus*	179	151	67	63	n.a.	150
Aegean Sea and Crete	*P. longirostris*	20	**18**	6	6	n.a.	20
Aegean Sea and Crete	*L. budegassa*	149	102	37	43	300	n.a
Aegean Sea and Crete	*B. boops*	136	129	58	69	n.a.	n.a
N. Tyrrhenian & Ligurian Sea	*M. merluccius*	**98**	**163**	26	22	200	200
N. Tyrrhenian & Ligurian Sea	*M. barbatus*	**62**	**71**	27	35	110	110
N. Tyrrhenian & Ligurian Sea	*M. surmuletus*	**85**	**57**	29	42	110	110
N. Tyrrhenian & Ligurian Sea	*P. longirostris*	**15**	**15**	4	4	n.a.	20
N. Tyrrhenian & Ligurian Sea	*T. trachurus*	260	190	90	30	n.a.	150
N. Tyrrhenian & Ligurian Sea	*B. boops*	210	160	40	30	n.a.	n.a

the discard plan (25% of total landings during the reference period 2014-2015). No Italian vessel had annual hake landings exceeding 25% of its total landings, and only one exceeded this threshold for red mullet and will have to comply with the landing obligation (Table 3). In the Greek fishery, no vessel exceeded the 25% threshold in hake or red mullet annual landings; however, 5 vessels were above this threshold for deep-water rose shrimp. Moreover, applying the previous calculations beyond the reference period of 2014-2015 and extending to the whole study period (1995-2015; Table S1) revealed that a third of the Italian vessels had hake landings above 25%, while the majority of Greek vessels exceeded this limit for deep water rose shrimp.

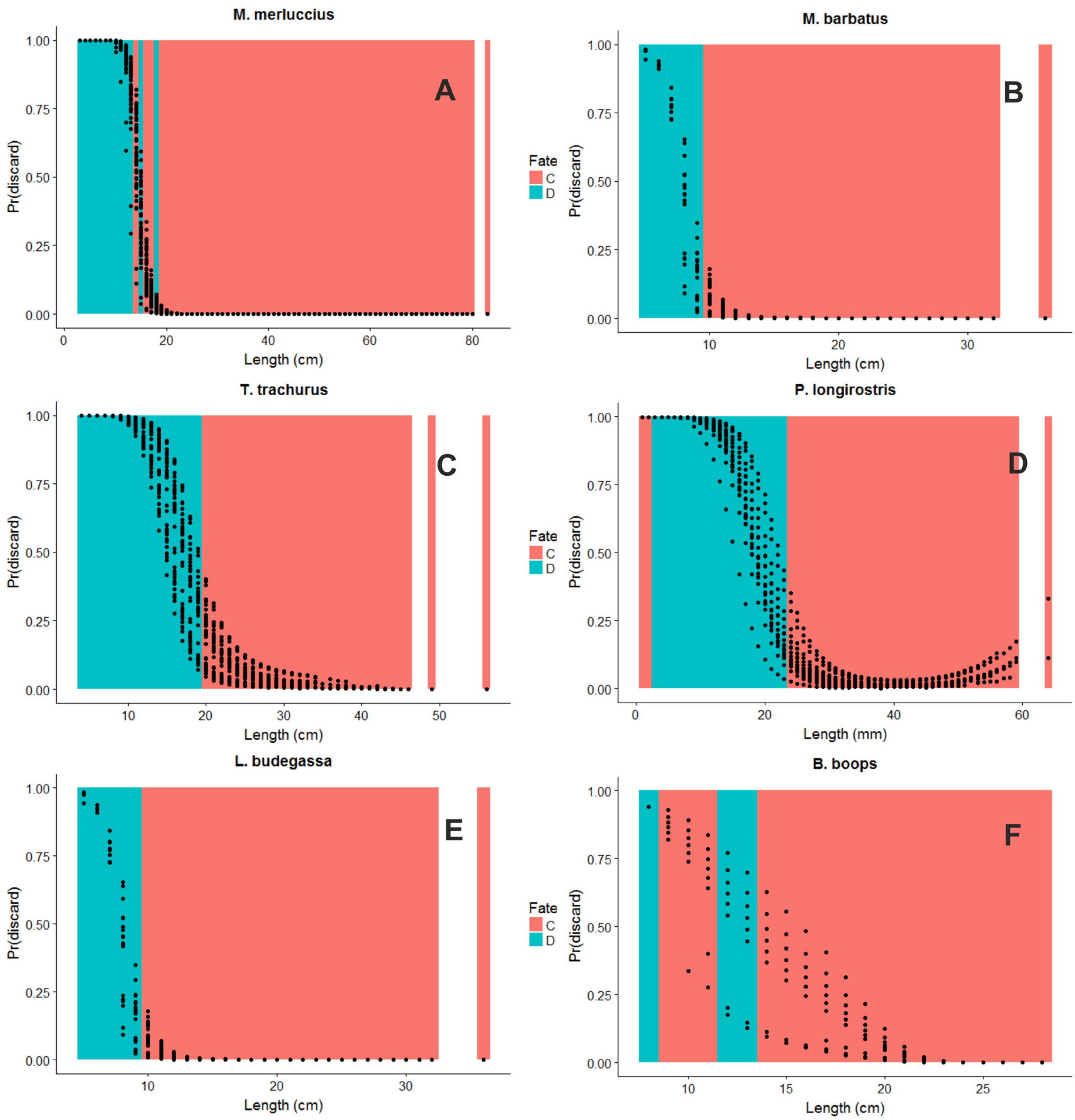

Fig. 11: GAM derived discard probability by total length with super-imposed discard ogives for major commercial species discarded in the Greek trawl fisheries in the Aegean Sea and Crete.

Discussion

Although discarding in the Mediterranean has been documented to vary highly across the different GSAs, both among species (Tsagarakis *et al*., 2017) and among the different fishing gears (Tsagarakis *et al*., 2014), this study provides evidence that even vessels operating the same gear during different time periods (seasons and years) and spatial locations exhibit quite diverse discarding patterns. This high heterogeneity and spatiotemporal variation in discarding practices make it even more challenging to apply the Landing Obligation because the quantities of catches affected by the regulation cannot be estimated with high accuracy.

The current status

The Mediterranean Sea fisheries account for a sizeable 230,000 t of discards annually or 18.6% of the average annual catches (Tsagarakis *et al*., 2014), although true values may be higher (Pauly & Zeller, 2016). Among them, the bottom trawl fisheries and especially the EU

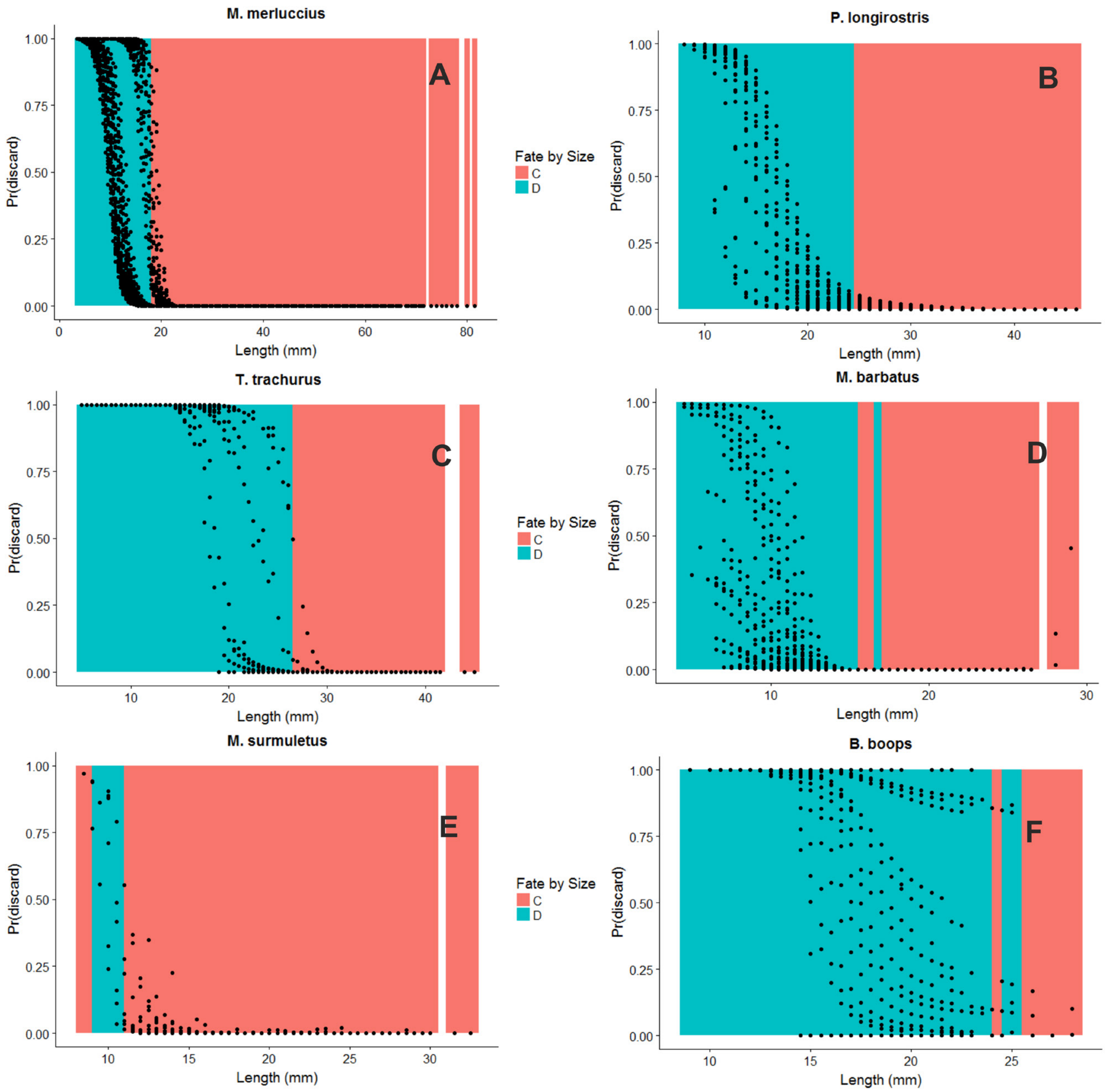

Fig. 12: GAM derived discard probability by total length with super-imposed discard ogives for major commercial species discarded in the Italian trawl fisheries in the Ligurian and northern Tyrrhenian Seas.

Mediterranean trawl fisheries, exhibit figures usually above 40%, being the most significant contributors to the ‘discard problem’. The reasons for discarding are numerous and include legal (e.g. specimens smaller than some prefixed minimum catchable/ retainable on board/landing size), economic (low market value and high-grading), technical (e.g. characteristics of fishing gears and vessel hold capacity), biological (e.g. species composition and recruitment period) and environmental aspects (e.g. weather conditions affecting sorting practices) (Stratoudakis *et al*., 1998; Rochet & Trenkel, 2005; Tsagarakis *et al*., 2014; Uhlmann *et al*., 2014).

Discarding trends among the studied areas were contradictory; Aegean Sea and Crete fisheries (GSA 22-23) showed a diminishing trend through the years, while the Italian trawl fisheries in the Ligurian and Tyrrhenian Seas (GSA 09) remained stable or at least showed an indication of an increasing annual trend, though not statistically significant. To some extent, this confirms the findings of Uhlmann *et al*. (2014) that discard rates are usually more homogeneous across fisheries than regions. Fish and invertebrates other than cephalopods and crustaceans comprised the largest proportion of discards; however, the latter were almost totally discarded. Apparently, the

Table 3. Species-specific annual landings as the percentage of total landings by vessel during the reference period 2014–2015 stated in the discard management plan (EU 2017/86), for the monitored commercial vessels of this study. (Vessel names are masked - values exceeding 25% are shown in bold).

GSA Geographical area	Vessel ID	Hake	Red mullet	Deep water rose shrimp
GSA 09 Ligurian and northern Tyrrhenian Seas	Vessel ITA 1	6.3%	0.5%	
	Vessel ITA 2	2.7%	14.9%	
	Vessel ITA 3	21.5%	28.0%	
	Vessel ITA 4	4.7%	19.0%	
	Vessel ITA 5	2.0%	17.1%	
	Average	5.6%	4.5%	
GSA 22-23 Aegean Sea and Crete	Vessel GRC 1	6.9%	11.5%	11.9%
	Vessel GRC 2	12.1%	9.7%	25.9%
	Vessel GRC 3	16.3%	13.0%	4.3%
	Vessel GRC 4	18.7%	1.9%	44.5%
	Vessel GRC 5	22.0%	2.6%	28.9%
	Vessel GRC 6	14.7%	0.0%	13.7%
	Vessel GRC 7	6.2%	19.9%	32.7%
	Vessel GRC 8	15.7%	3.0%	47.2%
	Vessel GRC 9	13.2%	2.6%	7.0%
	Average	14.4%	5.4%	27.4%

‘other invertebrate’ species harvested by bottom trawlers are currently non-commercial or very low-value species, and commercial invertebrates found in the Mediterranean markets are usually extracted in the wild by means other than bottom trawling or are grown in farms. The full list of other invertebrate species/taxa affected by bottom trawlers from this study is given in supplementary Table S1. On the other hand, most of the crustacean catch was directed to the market, indicating their high value in the local markets and their significant contribution to the fishers’ incomes (Sartor, 2011).

In the Aegean Sea and Crete, discard volumes originated almost exclusively from catches within the continental shelf (<200 m), while the Italian fisheries demonstrated significant discards even in the 200–400 m zone. This was obviously an effect of the distinct fishing activities; Greek trawlers operated at an average depth of 130 m (range of single values 25–472 m), while the Italian ones spread out their activities further to the continental slope, at average depths of 230 m (range 15-597 m). The extended depth ranges where trawlers operate force them to interact with a larger part of the marine biota and this is one of the main reasons why bottom trawlers demonstrate such high levels of unwanted catches (Machias *et al*., 2001; D’Onghia *et al*., 2003).

Seasonal variations observed in both areas can be attributed to: (i) the uneven fishing periods (the Greek fishery is regulated by a four-month closure from June to September), (ii) the biological traits of the harvested species affecting their seasonal abundance, usually by depth (Moranta *et al*., 2000; Castriota *et al*., 2001; Quetglas *et al*.,2004; Sanchez *et al*., 2004), (iii) the weather conditions dictating fishing behaviour and limiting access to distant waters during winter (Sanchez *et al*., 2007) and (iv) fluctuating market demand (Tsagarakis *et al*., 2014).

A tendency towards ‘‘larger-deeper’’ and ‘‘smaller-shallower’’ (indicating the relation between specimen size and depth strata) for most of the species has been confirmed. This phenomenon is described also as “Heincke’s Law” (Macpherson & Duarte, 1991) and has been shown to be an important feature for the majority of Mediterranean demersal species (Labropoulou *et al*., 2008). Some authors argue that this may have been an anthropogenic effect (Moranta *et al*., 2004), and significant changes may have occurred in exploited communities following increasing fishing pressures in the traditional shallow fishing grounds. Nevertheless, the two fleets generally ignored the established size limits of the specimens caught; Italian trawlers’ discards were only partly driven by the MCRS restrictions (mostly after 2006), indicating a recent moderate compliance to the established minimum sizes (Sartor, 2011). On the other hand, Greek trawlers largely ignored the MCRS throughout the study period, confirming the strong local market demand for undersized fish (Damalas & Vassilopoulou, 2013).

Management considerations

The official legal document establishing the Landings Obligation (EU Regulation 1380/2013) includes provisions so that in certain circumstances, the landings obligation may not apply. Exceptions might occur in the case of a protected species whose capture is forbidden, when a species is exhibiting “high survivability” or situations that fall under the *de minimis* exemptions.

Under certain conditions, the *de minimis* exemption can be invoked, allowing fishers to discard undersized specimens that would otherwise be subject to the landing obligation. To realize these exemptions that are beneficial for fishers a ‘discard management plan’ is required defining the survival rates, the percentage of discards and reasonable justification for doing so. Furthermore, the suggestion of a regionalization approach for management (EU, 2013, Art.10) has a key role for the stocks shared among different Members States (MSs). This implies submission of joint recommendations (e.g. multiannual plans) to achieve the objectives of the EU relevant conservation measures.

In July 2016, Mediterranean MSs submitted joint recommendations (JRs) to the European Commission concerning discard plans for demersal fisheries in the Adriatic Sea, the south/eastern Mediterranean Sea and the western Mediterranean Sea, respectively (background documents to STECF, 2016 - available at https:// stecf. jrc.ec.europa.eu/ plen1602). The competent authority for reviewing the Mediterranean JRs, the Scientific, Technical and Economic Committee for Fisheries (STECF), identified a number of general issues and limitations in the JRs, broadly related to inconsistencies in the definition of the fleets and gaps in the supporting documentation. It questioned whether the exemptions requested can be justified by robust scientific information and warned managers that such proposals can be considered only by using relevant subjective criteria (STECF, 2016). On the specific fisheries under study herein, STECF noted that "*Maximum discard rates for these three species (hake, red mullet, striped red mullet) are higher than the de minimis requested, and that even with a de minimis exemption there will still be a necessity to reduce discards further. STECF also notes that no justification was provided for de minimis on the grounds of: (i) selectivity difficult to achieve (although pilot projects on improving selectivity within 2 years are planned); (ii) insufficient justification was given on the grounds of disproportionate costs.*" Despite the aforementioned negative comments, the European Commission adopted a discard plan (EU, 2017, pursuant to Article 15(4)(c) of EU(2013), allowing for certain species to be discarded, as follows:

(a) in the western Mediterranean Sea (point 1 of the Annex):

(i) for hake (Merluccius merluccius) and red mullet (Mullus spp.*), up to a maximum of 7 % for 2017 and 2018 and up to a maximum of 6 % in 2019 of the total annual catches of these species by vessels using trawl nets; and...*

(c) in the south-eastern Mediterranean Sea (point 3 of the Annex):

(i) for hake (Merluccius merluccius) and red mullet (Mullus spp.*), up to 7 % for 2017 and 2018 and up to 6 % for 2019 of the total annual catches of these species by vessels using trawl nets; ... and*

(iii) for deep-water rose shrimp (*Parapenaeus longirostris*), up to 7 % for 2017 and 2018 and up to 6 % for 2019 of the total annual catches of this species by vessels using trawl nets.

*Annex-point 1: Where the total landings per vessel of all species in 2014 and 2015 consist of more than 25 % of hake, **the landing obligation shall apply to hake**. Where the total landings per vessel of all species in 2014 and 2015 consist of more than 25 % of red mullet, **the landing obligation shall apply to red mullet.***

*Annex-point 3: Where the total landings per vessel of all species in 2014 and 2015 consist of more than 25 % of either hake, or red mullet, or deep-water rose shrimp, **the landing obligation shall apply to hake, or red mullet, or deep-water rose shrimp, or all together**.*

Putting in practice the aforementioned regulation in the real world, and based on our data, we concluded that according to the discard plan criteria, the landing obligation could be frequently invoked only for deep-water rose shrimp in the Greek waters and occasionally for red mullet in the Italian fleet. It can be easily deduced that the average EU Mediterranean bottom trawl vessel is qualified to discard part of or the entire unwanted catch of hake and red mullets. Moreover, identifying if these rules are actually respected by the fishers is almost an impossible task. Documenting actual catches/discards in an effort-regulated regime lacking any output control (e.g. TACs or quotas), such as the one governing the Mediterranean fisheries, does not allow the control authorities to detect a violation against the unknown 'annual catches' of each vessel during the reference period of 2014–2015. Access to official reports of annual landings data, such as the ERS (Electronic Reporting System) may serve as a solution, if these data are actually available. In the Greek fisheries for example, ERS was introduced in 2015 and only on a few vessels as a pilot implementation. The system became fully operational after 2016. In addition, the Greek version of the discard plan, as published in the Official Journal of the European Union, erroneously refers to striped red mullet and not red mullet. Nevertheless, there is a more or less general consensus that in the absence of TACs, the Landing Obligation has little or no application to the Mediterranean fisheries (Tsagarakis *et al*., 2014; Damalas, 2015; Garcia-Rivera *et al*., 2015; Sardà *et al*., 2015; Veiga *et al*., 2016; Bellido *et al*., 2017). Furthermore, it seems that in the landing obligation legal document, economic considerations are not fully taken into account; the contribution of undersized catch to the Mediterranean fishers' income is far from negligible, as a recent study highlighted for the Italian fisheries (Mannini & Sabatella, 2015).

To this end, it seems that scientists, managers and fishers will have to focus their attention onto realizing another key aspiration of the landings obligation legal document: "*...it is necessary that Member States do their utmost to reduce unwanted catches. To this end, improvements of selective fishing techniques to avoid and reduce, as far as possible, unwanted catches must have high priority...*".

It seems that the only way to move forward is to incentivize the adoption of fishing technologies and practices that reduce pre-harvest mortality and post-harvest discards while avoiding damage to sensitive marine species and habitats. Currently we are dealing with the problem after it has occurred by forcing fishers to bring dead animals to land or allowing the wasteful practice of throwing them overboard. We need to change the mindset of fishers before they leave the harbor (Catchpole *et al*., 2017); they must be motivated to produce the right type of seafood without exposing themselves to bad practices and exposing the ecosystem to unsustainable exploitation. The complexity of the problem requires crossing the boundaries of science and society following a multi-actor approach, whereby scientists, fisheries technologists, fish producers and NGOs work collaboratively to provide the scientific and technical basis to achieve the gradual elimination of discards in European marine fisheries. Selectivity improvements, analytical techniques, observational technology and gear modifications are there to provide key information such as spatiotemporal delineation of sensitive habitats and real-time monitoring to support managers, policy makers and the industry (Catchpole *et al.*, 2006; Ragonese & Bianchini, 2006; Dimech *et al.*, 2012; Rosen *et al.*, 2013; Grazia Pennino *et al.*, 2014; Colloca *et al.*, 2015; Druon *et al.*, 2015; Paradinas *et al.*, 2016; Russo *et al.*, 2016a; Russo *et al.*, 2016b). The solutions for dealing with unwanted catches should be based on, in order of priority: avoidance, selection and utilization.

Finally, The EU Marine Strategy Framework Directive (EU, 2008), is an important policy innovation, which could have an important future impact on the sustainable exploitation of the fishery resources. MSFD requires that all EU Member States take measures to achieve a Good Environmental Status (GES) in their seas by 2020. Achieving GES involves protecting the marine environment, preventing its deterioration and restoring it where practical, whilst simultaneously providing for sustainable use of marine resources. Appropriate fisheries management measures will be critical to the achievement of the GES targets, and solving the discard problem seems to be a key priority of the MSFD agenda.

Ackowledgements

This research was funded by the European Commission's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 634495 for the project Science, Technology and Society Initiative to minimize Unwanted Catches in European Fisheries (MINOUW).

References

Akaike, H., 1973. Information theory and an extension of the maximum likelihood principle. p. 267-281. In: *Second International Symposium of Information Theory.* Petrov, B.N., Csaki, F. (Eds). Akademiai Kiado, Budapest.

Barale, V., 2008. The European marginal and enclosed seas: an overview. p. 3-22. In: *Remote sensing of the European seas*. Barale, V., Gade, M. (Eds). Springer, Dordrecht.

Bellido, J.M., García-Rodriguez, M., García-Jiménez, T., González-Aguilar, M., Carbonell-Quetglas, A., 2017. Could the obligation to land undersized individuals increase the black market for juveniles: evidence from the Mediterranean? *Fish and Fisheries*, 18 (1), 185-194.

Burnham, K.P., Anderson, D.R., 2002. *Model selection and multimodel inference: a practical information-theoretic approach*. Springer, New York, 488 pp.

Castriota, L., Campagnuolo, S., Andaloro, F., 2001. *Shrimp Trawl Fishery By-catch in the Straits of Sicily (Central Mediterranean Sea)*. Scientific Council Research Documents of the Northwest Atlantic Fisheries Organization, Serial No. N4501, No 01/113, 9pp.

Catchpole, T.L., Frid, C.L.J., Gray, T.S., 2006. Resolving the discard problem–A case study of the English Nephrops fishery. *Marine Policy*, 30 (6), 821-831.

Catchpole, T.L., Elliott, S., Peach, D., Mangi, S.C., Gray, T.S., 2017. How to deal with the EU landing obligation: lessons from an English discard ban sea trial. *ICES Journal of Marine Science*, 75 (1), 270-278.

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais-Lasram, F. *et al*., 2010. The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS ONE*, 5 (8), e11842.

Colloca, F., Garofalo, G., Bitetto, I., Facchini, M.T., Grati, F. *et al*., 2015. The seascape of demersal fish nursery areas in the North Mediterranean Sea, a first step towards the implementation of spatial planning for trawl fisheries. *PLoS ONE*, 10 (3), e0119590.

Damalas, D., Vassilopoulou, V., 2013. Slack regulation compliance in the Mediterranean fisheries: a paradigm from the Greek Aegean Sea demersal trawl fishery, modeling discard ogives. *Fisheries Management & Ecology*, 20 (1), 21-33.

Damalas, D., 2015. Mission impossible: Discard management plans for the EU Mediterranean fisheries under the reformed Common Fisheries Policy. *Fisheries Research*, 165, 96-99.

Dimech, M., Kaiser, M.J., Ragonese, S., Schembri, P.J., 2012. Ecosystem effects of fishing on the continental slope in the Central Mediterranean Sea. *Marine Ecology Progress Series*, 449, 41-54.

D'Onghia, G., Carlucci, R., Maiorano, P., Panza, M. 2003. Discards from deep-water bottom trawling in the eastern-central Mediterranean Sea and effects of mesh size changes. *Journal of Northwest Atlantic Fishery Science*, 31, 245-261.

Druon, J.N., Fiorentino, F., Murenu, M., Knittweis, L., Colloca, F. *et al*., 2015. Modelling of European hake nurseries in the Mediterranean Sea: an ecological niche approach. *Progress in Oceanography*, 130, 188-204.

EU, 1994. Council Regulation (EC) No 1626/94 of 27 June 1994 laying down certain technical measures for the conservation of fishery resources in the Mediterranean. OJ L 171, 6.7.1994, 1–6. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri =CELEX%3A31994R1626. (Accessed 31 July 2018).

EU, 2006. Council Regulation (EC) No 1967/2006 of 21 December 2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94. OJ L 409, 30.12.2006, 11-85. Available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32006R1967. (Accessed 31 July 2018).

EU, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance). OJ L 164, 25.6.2008, 19-40. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0056. (Accessed 31 July 2018).

EU, 2009. GREEN PAPER Reform of the Common Fisheries Policy. Brussels, 22.4.2009 COM(2009)163 final, 1-27. Available at: http:// eur-lex.europa.eu/LexUriServ/LexUriSer v.do?uri=COM:2009:0163:FIN:EN: PDF. (Accessed 31 July 2018).

EU, 2013. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC)

No 639/2004 and Council Decision 2004/585/EC. OJ L 354, 28.12.2013, 22-61. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/ ?uri=celex%3A32013R1380. (Accessed 31 July 2018).

EU, 2017. Commission Delegated Regulation (EU) 2017/86 of 20 October 2016 establishing a discard plan for certain demersal fisheries in the Mediterranean Sea. OJ L 14, 18.1.2017, 4-8. Available at: https: //eur-lex.europa.eu/legal-content/EN/TXT/?uri =CELEX:32017R0086. (Accessed 31 July 2018).

Feekings, J., Bartolino, V., Madsen, N., Catchpole, T., 2012. Fishery discards: factors affecting their variability within a demersal trawl fishery. *PLoS ONE*,7 (4), e36409.

Fredj, G., Bellan-Santin, D., Meinardi, M., 1992. État des connaissances sur la faune marine Méditerranéenne. *Bulletin de l'Institut Océanographique de Monaco*, 9, 133-145.

Garcia-Rivera, S., Lizaso, J.L.S., Millan, J.M.B., 2015. A quantitative and qualitative assessment of the discard ban in European Mediterranean waters. *Marine Policy*, 53, 149-158.

Grazia Pennino, M., Muñoz, F., Conesa, D., López-Quílez, A., Bellido, J.M., 2014. Bayesian spatio-temporal discard model in a demersal trawl fishery. *Journal of Sea Research*, 90, 44-53.

Hastie, T.J., Tibshirani, R.J. 1990. *Generalized Additive Models*. Chapman and Hall, London, 333 pp.

Johnsen, J.P., Eliasen, S., 2011. Solving complex fisheries management problems: what the EU can learn from the Nordic experiences of reduction of discards. *Marine Policy*, 35 (2), 130-139.

Kelleher, K., 2005. Discards in the world's marine fisheries. An update. Food and Agriculture Organization (FOA), FAO Fisheries Technical report, No 470. 131pp.

Labropoulou, M., Damalas, D., Papaconstantinou, C., 2008. Bathymetric trends in distribution and size of demersal fish species in the north Aegean Sea. *Journal of Natural History*, 42 (5), 673-686.

Machias, A., Vasilopoulou, V., Vatsos, D., Bekas, P., Kallianotis, A. *et al.*, 2001. Bottom trawl discards in the northeastern Mediterranean Sea. *Fisheries Research*, 53 (2), 181-195.

Macpherson, E., Duarte, C.M., 1991. Bathymetric trends in demersal fish size: is there a general relationship? *Marine Ecology Progress Series*, 71 (2), 103-112.

Mannini, A., Sabatella, R.F. (eds), 2015. *Annuario sullo stato delle risorse e sulle strutture produttive dei Mari Italiani*. Biologia Marina Mediterranea, 22 (Suppl. 1), 358pp. Available at: http://dcf-italia.cnr.it/assets/docs/doc11/Annuario%20SIBM%20 NISEA%202015.pdf.

Moranta, J., Massuti, E., Morales-Nin, B., 2000. Fish catch composition of the deep-sea decapod crustacean fisheries in the Balearic Islands (western Mediterranean). *Fisheries Research*, 45 (3), 253-264.

Moranta, J., Palmer, M., Massuti, E., Stefanescu, C., Morales-Nin, B., 2004. Body fish size tendencies within and among species in the deep-sea of the Western Mediterranean. *Scientia Marina*, 68 (Suppl. 3), 141-152.

Paradinas, I., Marín, M., Grazia Pennino, M., López-Quílez, A., Conesa, D. *et al.*, 2016. Identifying the best fishing-suitable areas under the new European discard ban. *ICES Journal of Marine Science,* 73 (10), 2479-2487.

Pauly, D., Zeller, D., 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, 7, 10244.

Quetglas, A., Gaamour, A., Renones, O., Missaoui, H., Zarrouk, T. *et al.*, 2004. Common spiny lobster (*Palinurus elephas* Fabricius 1787) fisheries in the western Mediterranean: A comparison of Spanish and Tunisian fisheries. *Bolleti de la Societat d'Historia Natural de les Balears*, 47, 63-80.

R Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Ragonese, S., Bianchini, M.L., 2006. Trawl selectivity trials on the deep-water rose shrimp (*Parapenaeus longirostris*) in Sicilian waters. *Hydrobiologia*, 557 (1), 113-119.

Rochet, M.J., Trenkel, V.M., 2005. Factors for the variability of discards: assumptions and field evidence. *Canadian Journal of Fisheries and Aquatic Sciences*, 62 (1), 224-235.

Rosen, S., Jörgensen, T., Hammersland-White, D., Holst, J.C., 2013. DeepVision: a stereo camera system provides highly accurate counts and lengths of fish passing inside a trawl. *Canadian Journal of Fisheries and Aquatic Science*, 70 (10), 1456-1467.

Russo, T., D'Andrea, L., Parisi., A., Martinelli, M., Belardinelli, A. *et al*., 2016a. Assessing the fishing footprint using data integrated from different tracking devices: Issues and opportunities. *Ecological Indicators*, 69, 818-827.

Russo, T., Carpentieri, P., Fiorentino, F., Arneri, E., Scardi, M. *et al*., 2016b. Modeling landings profiles of fishing vessels: An application of Self-Organizing Maps to VMS and logbook data. *Fisheries Research*, 181, 34-47.

Sanchez, P., Demestre, M., Martin, P., 2004. Characterisation of the discards generated by bottom trawling in the northwestern Mediterranean. *Fisheries Research*, 67 (1), 71-80.

Sanchez, P., Sartor, P., Recasens, L., Ligas, A., Martin, J. *et al*., 2007. Trawl catch composition during different fishing intensity periods in two Mediterranean demersal fishing grounds. *Scientia Marina*, 71, 765-773.

Santurtun, M., Prellezo, R., Arregi, L., Iriondo, A., Aranda, M. *et al*., 2014. *Characteristics of Multispecific Fisheries in the European Union*. IP/B/PECH/IC/2013-088. PE 529.053, 102pp. Available at: http://www.europarl.europa.eu/RegData/ etudes/etudes/join /2014/529053/IPOL-PECH_ET(2014)529053_EN.pdf (Accessed 12 July 2017).

Sardà, F., Coll, M., Heymans, J.J., Stergiou, K.I., 2015. Overlooked Impacts and Challenges of the New European Discard Ban. *Fish and Fisheries*, 16 (1), 175-180.

Sartor, P., 2011. *The 20th Century Evolution of Mediterranean Exploited Demersal Resources Under Increasing Fishing Disturbance and Environmental Change, EVOMED*. Final Report, 513pp. Available at: http://ec.europa.eu/fisheries / documentation/studies/ study_evolution_mediterranean/ index_en.htm. (Accessed 31 July 2018).

STECF, 2016. *Evaluation of the landing obligation joint recommendations.* Report of the Scientific, Technical and Economic Committee for Fisheries (STECF), No 16-10, 104 pp. doi: 10.2788/59074

Stratoudakis, Y., Fryer, R. J., Cook, R.M., 1998. Discarding practices for commercial gadoids in the North Sea. *Canadian Journal of Fisheries and Aquatic Sciences*, 55 (7), 1632-1644.

Tsagarakis, K., Palialexis, A., Vassilopoulou,V., 2014. Mediterranean fishery discards: Review of the existing knowledge. *ICES Journal of Marine Science*, 71 (5), 1219-1234.

Tsagarakis, K., Carbonell, A., Brčić, J., Bellido, J., Carbonara, P. *et al*., 2017. Old info for a new fisheries policy: Discard ratios and lengths at discarding in EU Mediterranean bottom trawl fisheries. *Frontiers in Marine Science*, 4, 99.

Uhlmann, S. S., van Helmond, A.T.M., Stefánsdóttir, E.K., Sigurðardóttir, S., Haralabous, J. *et al*., 2014. Discarded fish in European waters: general patterns and contrasts. *ICES Journal of Marine Science*, 71 (5), 1235-1245.

Veiga, P., Pita, C., Rangel, M., Gonçalves, J.M.S., Campos, A. *et al*., 2016. The EU landing obligation and European small-scale fisheries: What are the odds for success? *Marine Policy*, 64, 64-71.

Wood, S.N., 2006. *Generalized additive models: an introduction with R*. CRC/Chapman and Hall, Boca Raton, 391 pp.

Würtz, M., 2010. *Mediterranean pelagic habitat: oceanographic and biological processes, an overview*. IUCN, Malaga, 88pp.