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Authors: D. Damalas, K. Tsagarakis, V. Vassilopoulou, K.I. Stergiou (HCMR); A. Ligas, M. Sbrana (CIBM); A. Kallianiotis (NAGREF); F. Maynou (CSIC)

Contact person:
Dr. F. Maynou
maynouf@icm.csic.es

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Review of the study fisheries in terms of unwanted catches

1. Summary

The goal of deliverable D1.8 was **to characterize the unwanted catches** (undersized individuals of regulated species; non-commercial organisms) of case study fisheries **in quantitative terms**, exploiting the data bases created in WP1 and described in D1.1. The data collated in D1.1 regarded unwanted catches in South European fisheries case studies and were obtained from a variety of sources (European and national projects and, for recent years, the Data Collection Framework). Due to the quality of the available data, detailed quantitative analysis could be carried out for only 2 bottom trawl case studies: GSA09 (Ligurian and North Tyrrhenian Sea) and GSA22 (Aegean Sea).

The results for these case studies are revealing and can be extrapolated to the general situation regarding unwanted catches in Mediterranean European waters. The main results from this study are:

- Discarding of unwanted catches (both regulated fractions of commercial catches and non-regulated, non-commercial catches) varies greatly in time (seasons, years) and space (depth strata, geographical location).
- Some reasons behind discarding are predictable, in the sense that discarding can be expected when fishing on habitats rich in non-commercial invertebrates (e.g. habitat-forming echinoderms such as *Leptometra*; maërl) or locations regularly exhibiting "nursery" properties for recruits of highly prized species (e.g. hake; red mullets).
- However, significant amounts of discarding can also take place for socio-economic reasons, unrelated to ecological conditioning factors: individual vessels can have different marketing strategies for their product or sea conditions may limit the ability of crew of proper sorting, among other.
- From the management perspective, the study suggests that established Minimum Conservation Reference Size are (and have been historically) largely ignored. Also, the recent (2016-2017) Discard Management Plans designed by member states are likely to be ineffectual in tackling the discards problem because they are based on inconclusive scientific evidence and rely to a large extent on the mechanism of exemptions (permitted in Art. 15 of the CFP). In practice, the average Mediterranean bottom trawl will likely continue business as usual.

From a monitoring and control perspective, the analysis indicates that compliance will be very difficult to assess due to the complexity of the rules related to the Landing Obligation.

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2. Scientific manuscript

The discard problem in north Mediterranean fisheries, in the face of the EU landing obligation: the case of bottom trawling and implications for management

Damalas, D.[1,*], Ligas, A.[2], Tsagarakis, K.[1], Vassilopoulou, V.[1], Stergiou, K.I. [1,5], Kallianiotis, A.[4], Sbrana, M.[2], Maynou, F.[3]

[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

[3]Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia Applicata "G. Bacci" (CIBM), V.le N. Sauro 4, 57128 Livorno, Italy

[3]Institut de Ciencies del Mar (ICM-CSIC), Psg. Maritim de la Barceloneta 37-49, 08003 Barcelona, Spain

[4]Fisheries Research Institute, National Agricultural Research Foundation, Nea Peramos, Kavala, 64007, Greece

[5]Laboratory of Ichthyology, Department of Zoology, School of Biology, Aristotle University of Thessaloniki, PO Box 134, 541 24, Thessaloniki, Greece

***Corresponding author**: Dimitrios Damalas; e-mail: shark@hcmr.gr

ABSTRACT

Since the introduction of the landing obligation, the EU Mediterranean fisheries are facing some unforeseen challenges. The demersal bottom trawl fisheries, being the most significant contributors to the 'discard problem', are confronting the bigger challenges. Data from the Italian and the Greek fleet, over the past two decades, were analyzed with the intention to reveal the diversity and heterogeneity of the discard problem, especially for regulated species. Species composition of discards, as well as discarding rates, were proven to be irregular, fluctuating among areas, depth strata, seasons, and years. Although fish dominated the discarding volumes, benthic invertebrates (excluding cephalopods and crustaceans) were the ones discarded almost exclusively. Established minimum conservation reference size was largely ignored. From a management point of view, our investigation suggests that the recently established Discard Management Plans lack scientific evidence and provide such exemptions from the landing obligation that will practically allow the average Mediterranean bottom trawl vessel to continue business as usual. Moreover, detecting if these rules are actually respected is almost an impossible task for the Mediterranean control and enforcement authorities. It seems that EU fisheries management is largely ignoring scientific advice and is more an issue of political trade-offs. 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: discards; landing obligation; trawl; Mediterranean; management

INTRODUCTION

European Union (EU) fisheries are responsible for quite a high level of discarding (Feekings et al., 2012) attributed to unselective fishing techniques, excessive fishing effort, and patchy distribution of species (Johnsen and Eliasen, 2011). The European Commission (EC) has associated the 'discard problem' with poor economic performance and a significant component of marine ecosystem functioning (Commission's green paper on the reform of the CFP - COM 2009/163 final). Almost a hundred technical measures regulations (or amendments) have been introduced since the 1980s aiming to improve selectivity and 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 regulation 1380/2013) pursues the gradual elimination of unwanted catches and discarding practices, through the gradual introduction of a "landing obligation" (Art. 15). As a result, EU fisheries are currently transitioning to reducing discards and bringing all catches to land obligatorily. This represents a fundamental shift in the management approach to EU fisheries, switching from landings monitoring to catches monitoring. Furthermore, regionalised decision making becomes a management option.

The EU fisheries management scheme, that is to say the CFP, has always given a privileged treatment to the Mediterranean region and specific regulations (the so-called 'Mediterranean regulations'—COM 1626/1994 and COM 1967/2006) were explicitly introduced. In brief, instead of an output control system (e.g. landing quotas, TACs), input control through an effort-regulating regime has been considered as the most appropriate management strategy. Consequently, the landing obligation in the Mediterranean does not apply to the general rules of 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 COM 1976/2006). Implementation of the landing obligation to different types of fisheries is to be 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 most complex in the Mediterranean multi-specific demersal trawl fisheries, lacking clear target species, with the catch comprising 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).

Based on a series of data obtained on-board commercial bottom trawlers during the past two decades, this study aspires to reveal the complexity of the problem from a management point of view linking it to the recently introduced discard management plan (Commission Delegated Regulation EU 2017/86). Specific focus was given on more specific aspects of discarding fisheries, such as catch profiles, discarding trends of commercial and sensitive species (annual, seasonal, by depth), as well as fate of major species in relation to size (linked to MCRS-minimum conservation reference size limits compliance).

MATERIALS AND METHODS

Study area-Fisheries

The Mediterranean Sea constitutes less than 1% of the total water surface of 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. The Mediterranean Sea can be divided into two main basins: western and eastern separated by the Sicily–Tunisia ridge (Goffredo & Dubinsky, 2013). 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, in two selected Mediterranean geographical sub-regions (FAO GFCM GSA9: Ligurian and North Tyrrhenian Sea; GSA22: Aegean Sea), 35 vessels (16 Italian + 19 Greek) were monitored. A total of 1297 hauls (949 hauls in the Aegean Sea and 348 in the Ligurian and northern Tyrrhenian Seas) were conducted on board the aforementioned commercial otter bottom trawlers at depths between 15 and 580 m (Fig. 1). Typical otter bottom trawlers in this study were characterized by vessels usually more than 25 m of length and engine powers from 300 to 700 HP. Towing speed was approximately three nautical miles per hour (range 2.4 -3.6), and the average tow duration 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 weighing and counting for each species and fishing operational data recording (date, position, depth, and haul duration). The size of the specimens caught was recorded (total length (TL) for fish, mantle length (ML) for cephalopods, and carapace length (CL) 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 density, although the constant of proportionality (i.e., catchability) is unknown and may vary by species. However, catchability for each species was assumed invariant by haul, as all hauls were carried out by similar vessels and gear configuration.

Operational and economic characteristics of the fleets (vessel capacity, vessel energy consumption, 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[1] and the corresponding electronic annexes[2].

Statistical analyses - modeling

Catch profiles were analyzed as groups of major taxa (1. Fish; 2. Cephalopods; 3. Crustaceans and 4. other Invertebrates: other than cephalopods and crustaceans - Table S1) in relation to depth stratum, season, and year. Results were visualized as the contribution in total catch for the marketed and discarded fractions in polar coordinate plots.

[1] https://stecf.jrc.ec.europa.eu/reports/economic

[2] https://stecf.jrc.ec.europa.eu/data-reports

Discard trends were assessed through generalized additive models approaches, modelling the effects of various predictor variables (year, season, depth, longitude, latitude) on the relative abundance (expressed as CPUE) of total and sensitive taxa catch (invertebrates, elasmobranchs). The functional relationships between population density of marine species and environmental variables are neither linear nor monotonic. Assuming an inherent non-linearity, generalized additive models (GAMs; Hastie and 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.3.3.2 (R Core Team, 2016) using the package mgcv (Wood, 2006), according to the general formulation:

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

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 checking residual patterns. After selecting the appropriate error distribution family, an information theoretic approach was followed (Burnham and 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 one was selected on the basis of its AIC score.

For assessing the compliance to Minimum Conservation Reference Size (MCRS), the probability of discarding by size 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 is retained) and the selection range (L_{75} - L_{25}) was 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 (COM 1626/1994[3] and COM 1967/2006[4]).

The operational and economic characteristics of the fleets were linked to discards by regressing various factors (vessel capacity, vessel energy consumption, vessel annual landings value, fishing depth) against the percentage of discards 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, and in order to estimate what part of the fleet is eligible to an exemption from the landing obligation (discard plan - Commission Delegated Regulation EU 2017/86),

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1499606754867&uri=CELEX:31994R1626

[4] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1499606789913&uri=CELEX:32006R1967

species specific annual landings were expressed as percentage of total landings for all vessels under study.

RESULTS

Operational and economic characteristics of discarding bottom trawl fisheries

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. The reason was the clear difference in the sampling protocols among the two regions, with the Greek observers focusing mainly on target species related to the EU Fisheries Data Collection Framework (Tables S1 and S2). In view of the above fact, fishing depth was investigated only against the discarded fraction of the catch (in weight) and was found to be negatively related (r^2=0.54, p<0.05 - Fig. 2). Moreover, vessels being financially 'successful' and achieving higher revenues were also more likely to discard; landings value per vessel was positively associated to discarding rates (r^2=0.35, p<0.05 - Fig. 2).

Catch profiles

Aegean Sea

Fish comprised the majority of discards (in terms of weight), being more pronounced within the continental shelf (depths <200 m) and around autumn (Fig. 3 top). Out of a total of 139 fish species discarded (Table S2), just five of them accounted for more than a third of these discards (horse mackerel, hake, spotted catshark, bogue and pilchard). 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 S2), with the latter characterized by high market values and predominantly driven by deep water rose shrimp (Fig. 3 bottom). Furthermore, discarded fractions were considerably lower for crustaceans compared to fish. Invertebrates were largely discarded (Fig. 4).

Ligurian and northern Tyrrhenian Seas

Fish dominated both discards and landings, being more pronounced on the continental shelf (depths <200 m) and in the summer/autumn months (Fig. 5 top). 151 fish species were discarded (Table S2), with hake and pilchard accounting for more than 70% of them. In addition, 36 species of crustaceans and 26 species of cephalopods were discarded (Table S2). 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 S2), especially from deeper strata (>300 m) (Fig. 5 bottom). Invertebrates were mostly discarded in contrast to crustaceans and cephalopods (Fig. 6).

Discard trends

Modelling discard rates (Table S3) in relation to various driving factors, revealed interesting spatial-temporal differences and patterns.

Aegean Sea

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 depth. Discarding as a practice was less pronounced during winter and showed a diminishing trend through the years (Fig. 8). Absence of summer observations is attributed to the fact that the Greek bottom trawl fishery is regulated through a summer closure.

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

Ligurian and northern Tyrrhenian Seas

Discarding locations for the Italian bottom trawl fleet is shown in Figure 9. Higher discards occurred to the southern-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

Assessing 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 SR (selection 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 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

For European hake, although the overall investigation of pooled data indicated that most part of fish smaller than 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 <100 m (Fig. S3). No significant change in the retention size throughout the years was observed (Table 2 - Fig S3). For red mullet, fish between 9-11 cm of 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 MCRS

(Table 2). Horse mackerels were not discarded due to MCRS restrictions, but rather to market considerations. Almost all fish < 20 cm were discarded, this size being way above the MCRS threshold of 15 cm (Fig. 11). Deep-water rose shrimp 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, in the absence of any recent MCRS limitation, was 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 30cm MCRS the retention size was much higher, but still below the legal landing size (Table 2 and Fig. S3). Finally, all bogues discarded were above the national MCRS of 10 cm (Fig. 11 and 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 (Figs S3).

Ligurian and northern Tyrrhenian Seas

European 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 the period before 2006 (Fig. S4). The two discrete discard ogives evident on figure 12 denote two groups: the group before 2006, mostly ignoring the size limit and another group after 2006, partially respecting MCRS (Fig. S4b and Table 2). In both cases, the retention size was far from the legal size of 20cm. Although deep water rose shrimp MCRS was respected more than the hake one, still the retention size (15 mm) fell far from being ideal (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 actually most of them were above 20 cm TL (Fig. 12 - Table 2). Although global red mullets discard ogive gives the impression that very few specimens below MCRS were retained (Fig. 12), analysis by season, depth stratum and year revealed large quantities of undersized fish being marketed in the past and during spring (Fig. S4). Retention size increased significantly after 2006, but was still below MCRS (Table 2). Striped red mullet discards were irregular (Fig. 12), far from MCRS (Table 2) and with all specimens during spring and summer being retained for marketing (Fig. S4). As a rule, only large bogues were marketed (Fig. 12); however, back 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 the discard plan (25% of total landings during the reference period 2014-2015). No Italian vessel had annual hake landings exceeding 25% of 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 S4), 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.

DISCUSSION

Although discarding in the Mediterranean has been documented to vary highly along the basin, 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, years) and spatial locations exhibit quite diverse discarding patterns. This high heterogeneity and spatial-temporal 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 are accountable for a sizeable 230,000 t of discards annually or 18.6% of the average annual catches (Tsagarakis et al., 2014). Among them, the bottom trawl fisheries and especially the EU Mediterranean trawl fisheries, exhibit figures usually above 40%, being the most significant contributors to the 'discards problem'. The reasons for discarding are numerous and include legal [e.g. specimens smaller than the Minimum Conservation Reference Size (MCRS)], 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 and Trenkel, 2005; Tsagarakis et al., 2014, Uhlmann et al., 2014).

Discarding trends among the studied areas were contradictory; Aegean fisheries showed a diminishing trend through the years, while the Italian trawl fisheries in the Ligurian and Tyrrhenian Seas remained stable or at least showed an indication of an increasing annual trend, though not statistically significant. This, to some extent, confirms Uhlmann et al. (2014) findings, that discard rates are usually more homogeneous across fisheries than regions. Fish and invertebrates (other than cephalopods and crustaceans) comprised the major part of discards, however the latter were almost totally discarded. Apparently, the invertebrate species harvested by bottom trawlers are non-commercial or very low value species, and commercial invertebrates to be found in the Mediterranean markets are usually extracted in the wild by other means than bottom trawling or grown in farms. The full list of invertebrate species/taxa affected by bottom trawlers during 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' income (Sartor, 2011).

In the Aegean Sea, discard volumes almost exclusively originated 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 122 m (range 25-472 m), while the Italian ones spread out their activities further to the continental slope, at average depths of 235 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 (Greek fishery is regulated by a 4 month closure: 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 behavior 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 described also as "Heincke's Law" (Macpherson and Duarte, 1991) has been shown to be an important feature of 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 more or less ignored the established size limits of the specimens caught; Italian trawlers discards were only partly driven by 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 MCRS throughout the study period, confirming the strong local market demand for undersized fish and the notorious reputation of some Mediterranean fisheries, as having an inherent "culture for non-compliance" (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: in the case of a species whose capture is forbidden, when a species is exhibiting "high survivability", or situations that fall under *de minimis* exemptions. Under certain conditions, the *de minimis* exemption can be invoked, allowing fishers to discard species that would otherwise be subject to the landing obligation. To realize these beneficial exemptions, 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 (new CFP - Art. 10) has a key role for the stocks shared among different Members States (MSs). This implies to submit joint recommendations (e.g. multiannual plans) for achieving the objectives of the EU relevant conservation measures.

On 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 comments, more or less disqualifying the JRs, the European Commission adopted a discard plan (Commission Delegated Regulation EU 2017/86), pursuant to Article 15(4)(c) of Regulation (EU) No 1380/2013, 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****.*

Previously submitted JRs, concerning small pelagic fisheries in the Mediterranean, have also been considered as impossible to be assessed by the STECF, due to lack of information regarding the volumes of landings and discards (STECF, 2014). Once again, this did not discourage the European Commission from establishing a discard plan allowing for certain small pelagic species to be discarded (Commission Delegated Regulation EU 1392/2014). It seems that EU fisheries management is largely ignoring scientific advice and is more an issue of political trade-offs, or as the STECF so elegantly put it, a matter of "*relevant subjective criteria*".

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[5], erroneously refers to stripped red mullet and not red mullet. Apparently the regulation and the exemptions provided therein, once more serve the industry as an escape-way from the obligation to land all catches and continue business as usual (Damalas, 2015). Nevertheless, there is a more or less general consensus that in the absence of TACs, the Landing Obligation has little (or no) sense for 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).

To this end, it seems that scientists, managers and fishers will have to focus their attention into 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...*". 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. Currently we are dealing with the problem after it has occurred, by forcing fishers to bring dead animal 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 for cutting across science and society boundaries 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. Analytical techniques, observational technology and gear modifications are there to provide key information such as spatio-temporal delineation of sensitive habitats and real-time monitoring to support managers, policy makers and the industry (Catchpole et al., 2006; Rosen et al. 2013; Grazia Pennino et al., 2014; Colloca et al., 2015; Druon et al., 2015; Paradinas et

[5] http://eur-lex.europa.eu/legal-content/EL/TXT/?uri=CELEX:32017R0086&qid=1498726775467

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 (MSFD, Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008), is an important policy innovation, which could have important future effects for 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 at the same time 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.

ACKNOWLEDGEMENTS

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TABLE

Table 1. Summary description of some operational and economic characteristics of the discarding fisheries under study.

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	2004	281	122	26	395	369	166	33	324
GSA22	2005	284	124	22	373	351	165	30	1120
GSA22	2006	283	131	28	463	435	153	35	752
GSA22	2008	272	122	33	255	222	103	29	375
GSA22	2013	242	124	29	415	386	168	29	364
GSA22	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

Table 2. Retention size (L_{50}), selection range (SR) 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).

Area	Species	L_{50} (mm)		SR (mm)		MCRS (mm)	
		<=2006	>2006	<=2006	>2006	<=2006	>2006
Aegean Sea	*M. merluccius*	**139**	**141**	20	23	200	200
Aegean Sea	*M. barbatus*	**62**	**74**	28	18	110	110
Aegean Sea	*T. trachurus*	179	151	67	63	n.a.	150
Aegean Sea	*P. longirostris*	20	**18**	6	6	n.a.	20
Aegean Sea	*L. budegassa*	149	102	37	43	300	n.a
Aegean Sea	*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

Table 3. Species specific annual landings as percentage of total landings 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).

% of landings in total landings during 2014-2015	Vessel ID	Hake	Red mullet	Deep water rose shrimp
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%*	
Aegean Sea	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%***

FIGURES

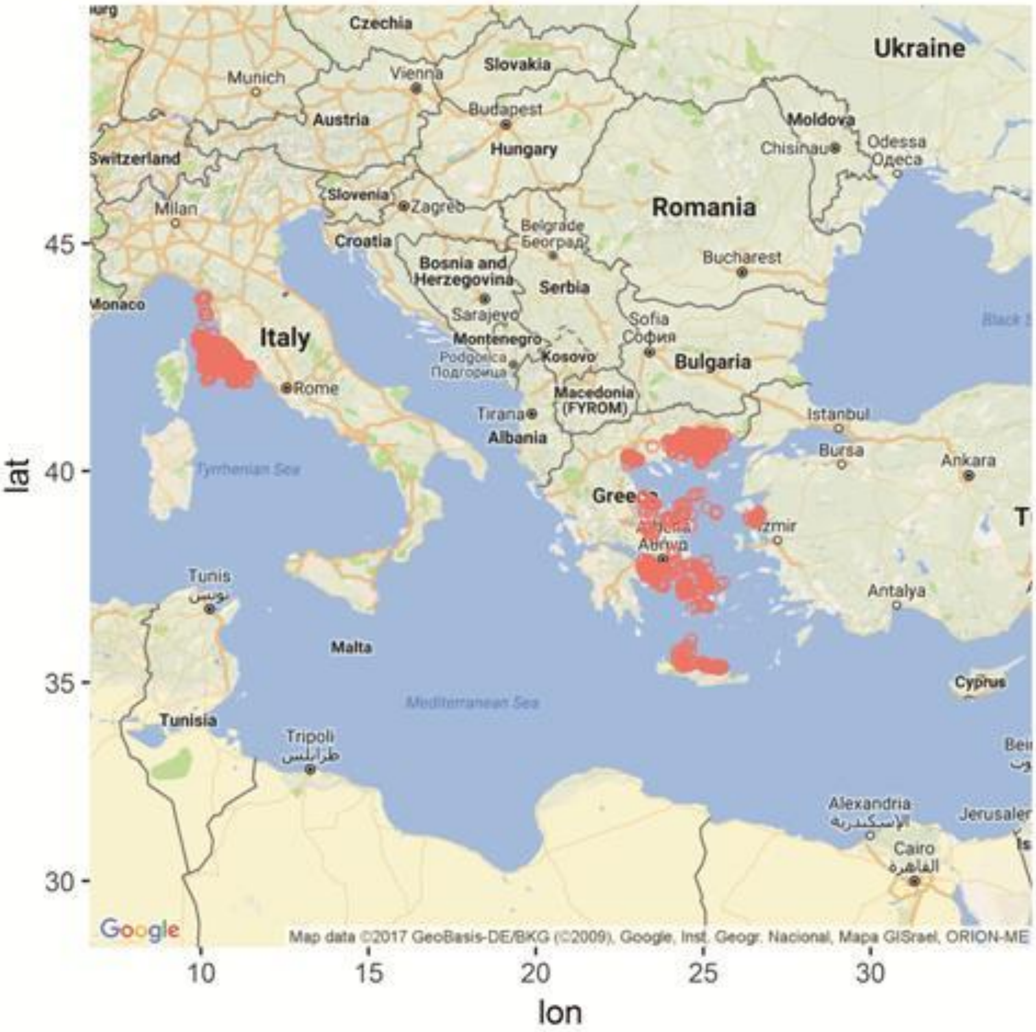


Figure 1. Map of the studied areas with the sampling locations indicated as red open circles.

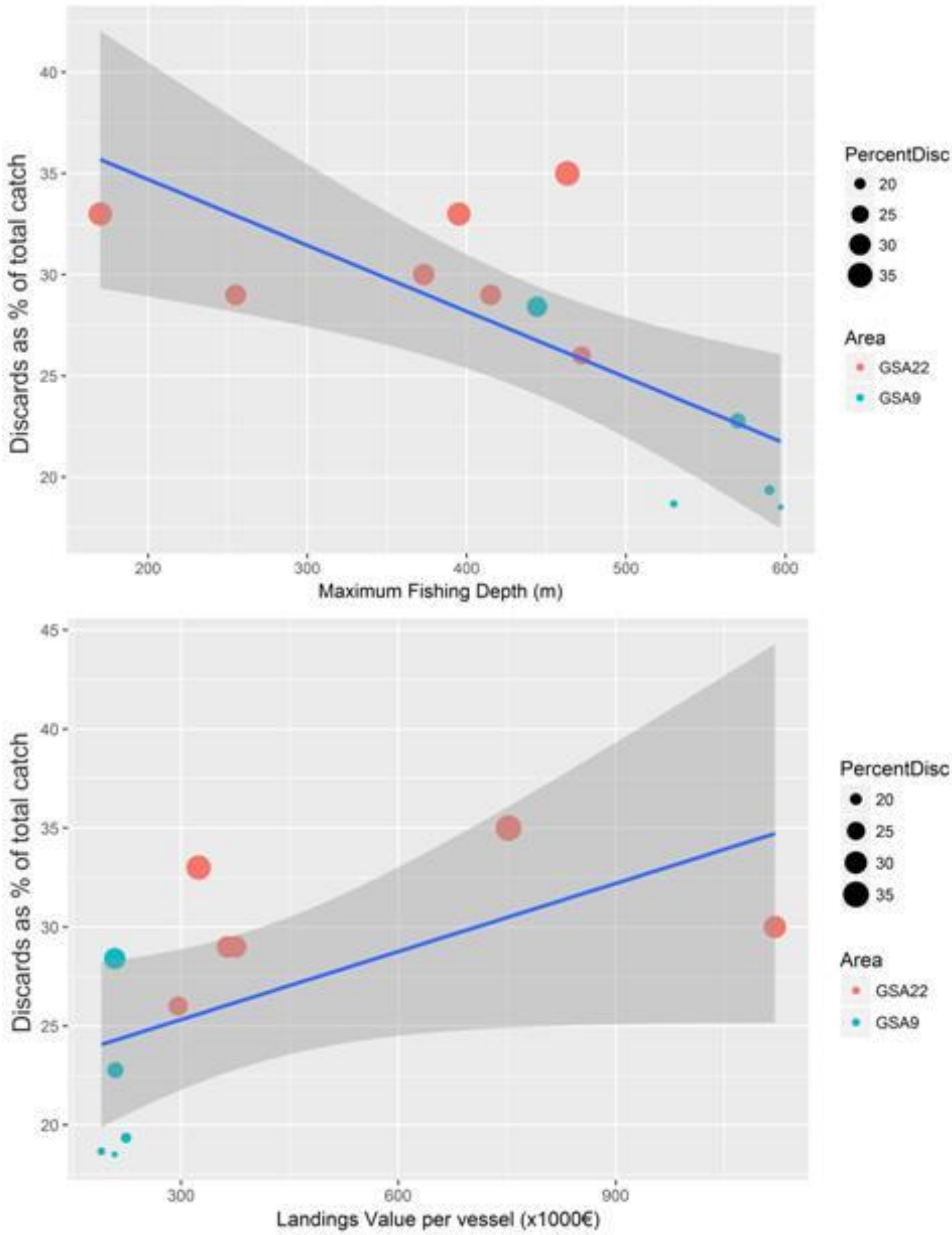


Figure 2. Maximum fishing depth (m) regressed upon percentage of total catch discarded (top) and Landings value per vessel (x1000 €) regressed upon percentage of total catch discarded (bottom). Results are depicted by geographical area studied.

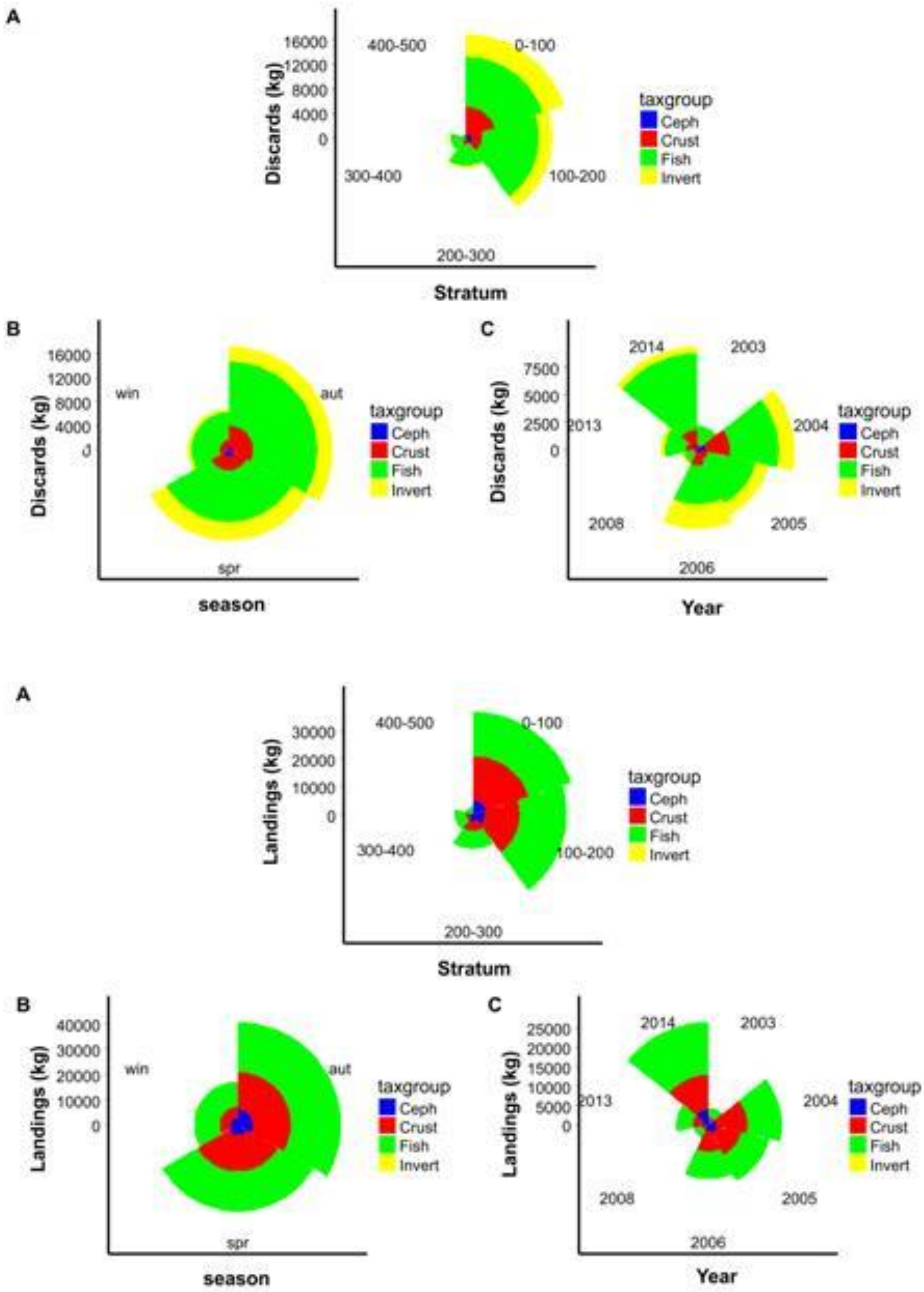


Figure 3. Discard (top) and Landings (Marketed; bottom) catch profiles of major taxonomic groups by depth stratum, season, and year in the Aegean Sea trawl fishery.

(Y-axis is expressing absolute values in kg)

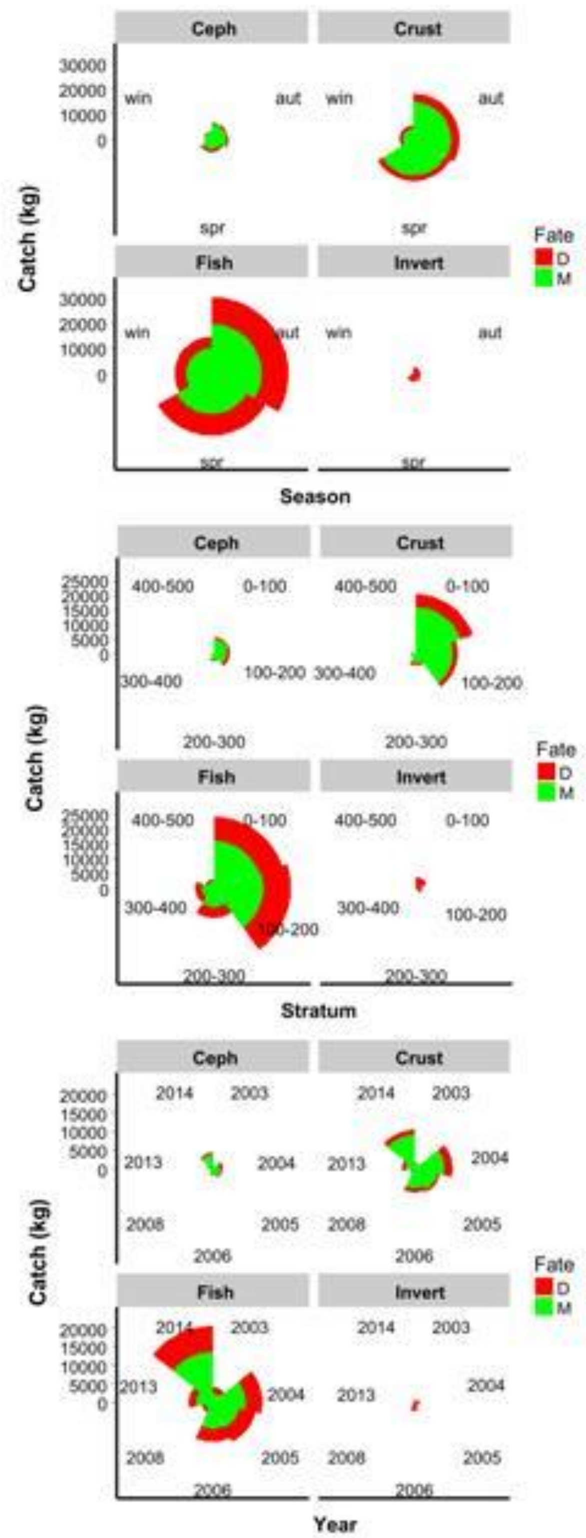


Figure 4. Fate (Discarded-Marketed) of major taxonomic groups by depth stratum, season, and year in the Aegean trawl fishery.

(Y-axis is expressing absolute values in kg)

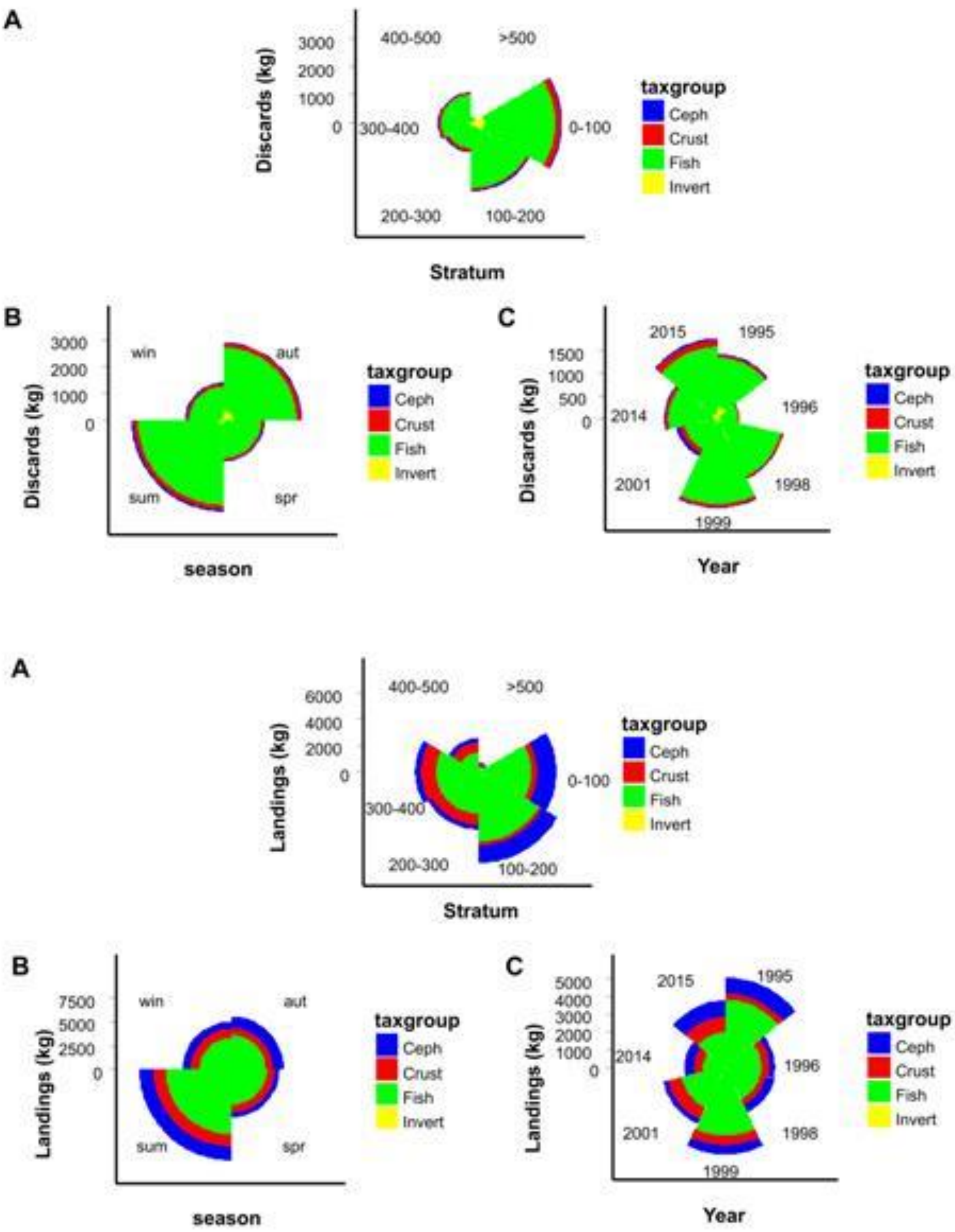


Figure 5. Discard (top) and Commercial (Marketed) catch profiles of major taxonomic groups by depth stratum, season, and year in the Ligurian and northern Tyrrhenian Seas trawl fisheries.

(Y-axis is expressing absolute values in kg)

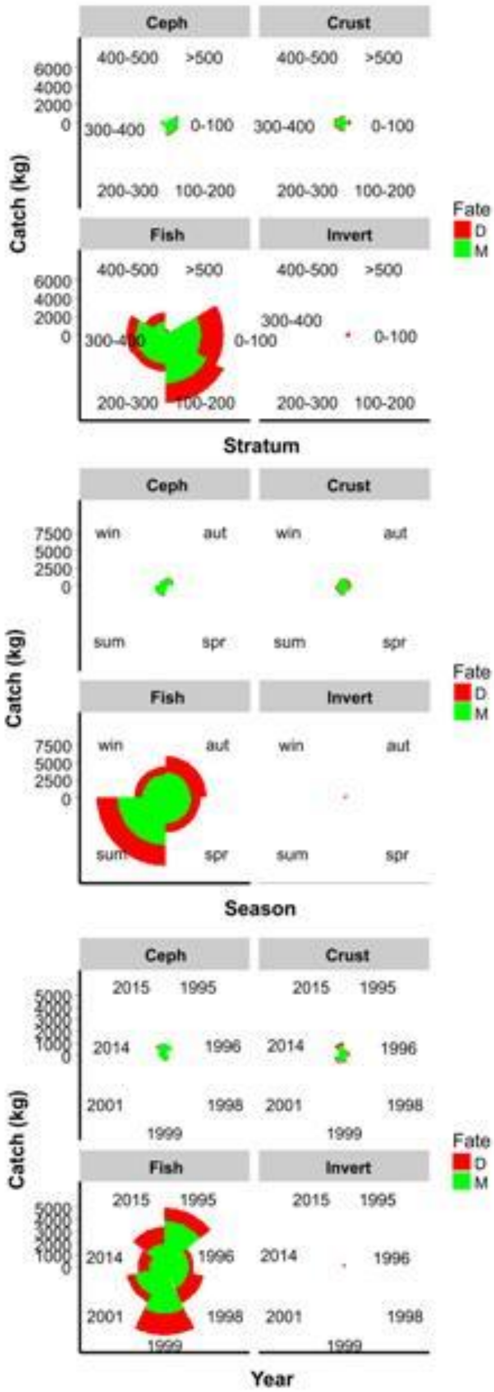


Figure 6. Fate (Discarded-Marketed) of major taxonomic groups by depth stratum, season, and year in the Ligurian and northern Tyrrhenian Seas trawl fisheries.

(Y-axis is expressing absolute values in kg)

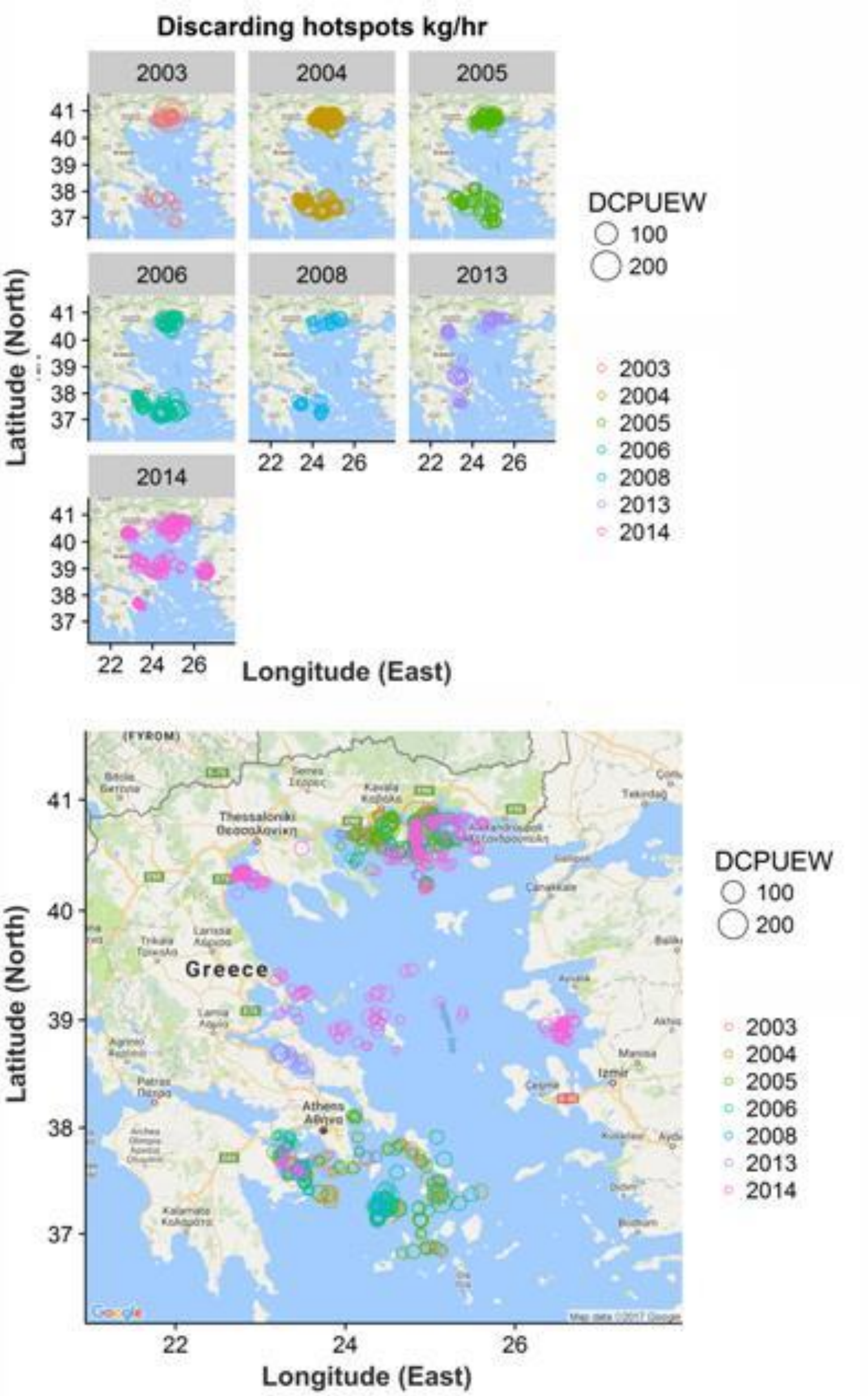


Figure 7. Map of discarding locations for the sampled Greek trawl fleet (by year and total) exploiting the Aegean Sea.

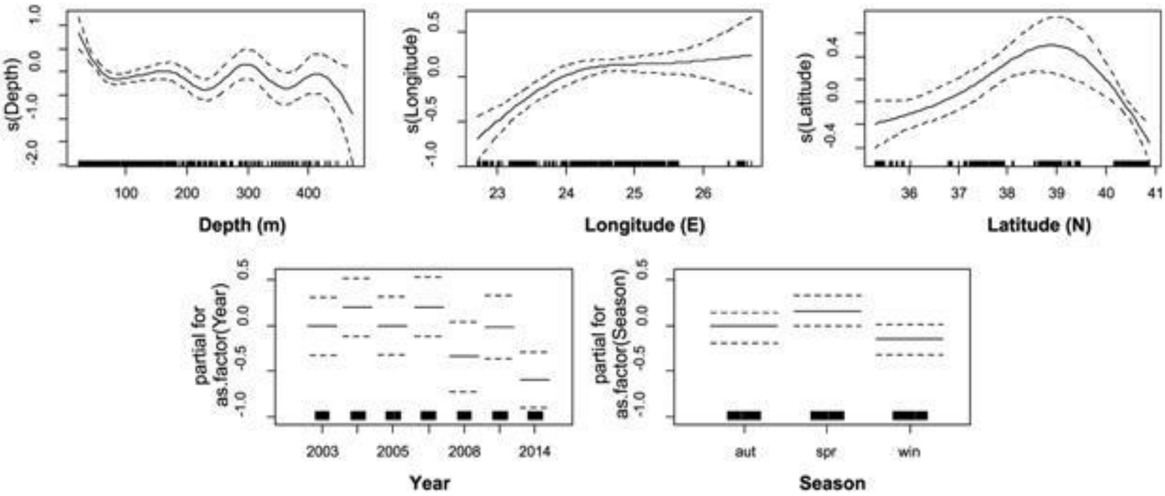


Figure 8. Generalized additive models (GAM) derived effects of various parameters on the discard probability of the catch in the Aegean trawl fishery. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

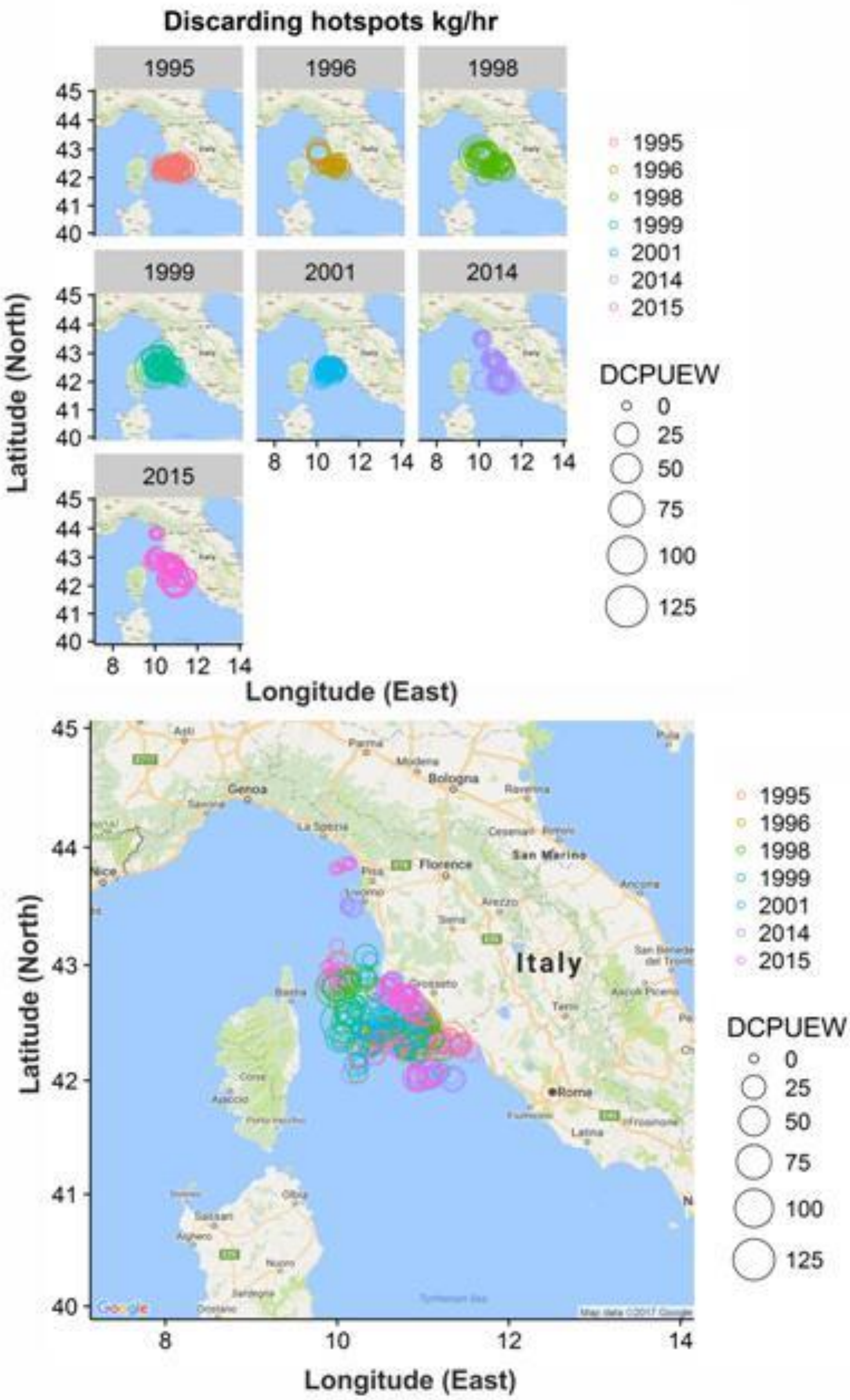


Figure 9. Map of discarding locations (annual and total) for the Italian trawl fleet exploiting the Ligurian and northern Tyrrhenian Seas.

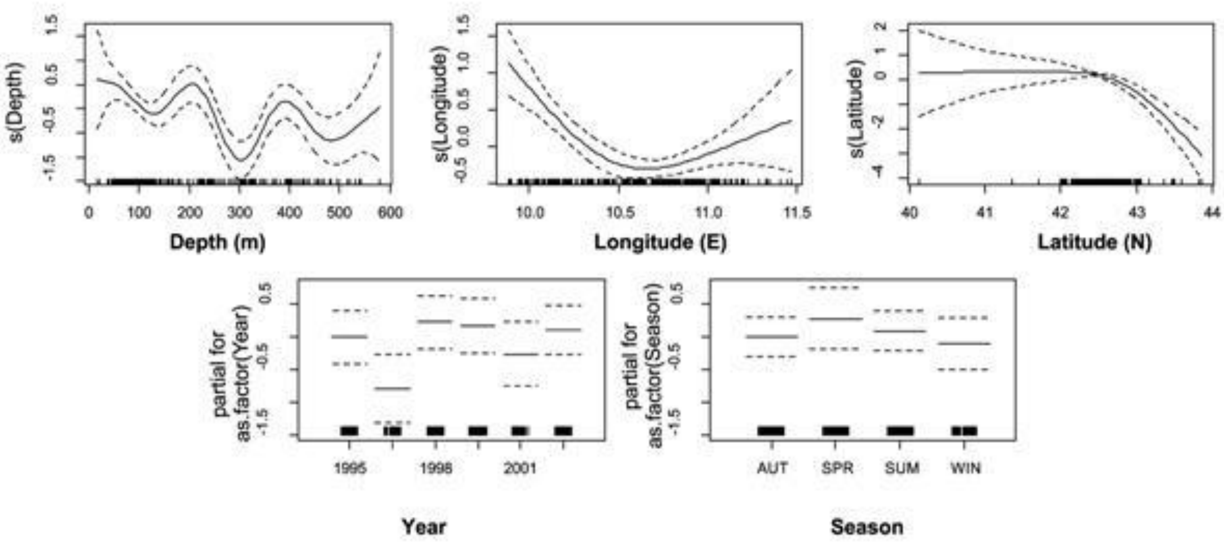


Figure 10. Generalized additive models (GAM) derived effects of various parameters on the discard probability of the catch in the Italian trawl fishery. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

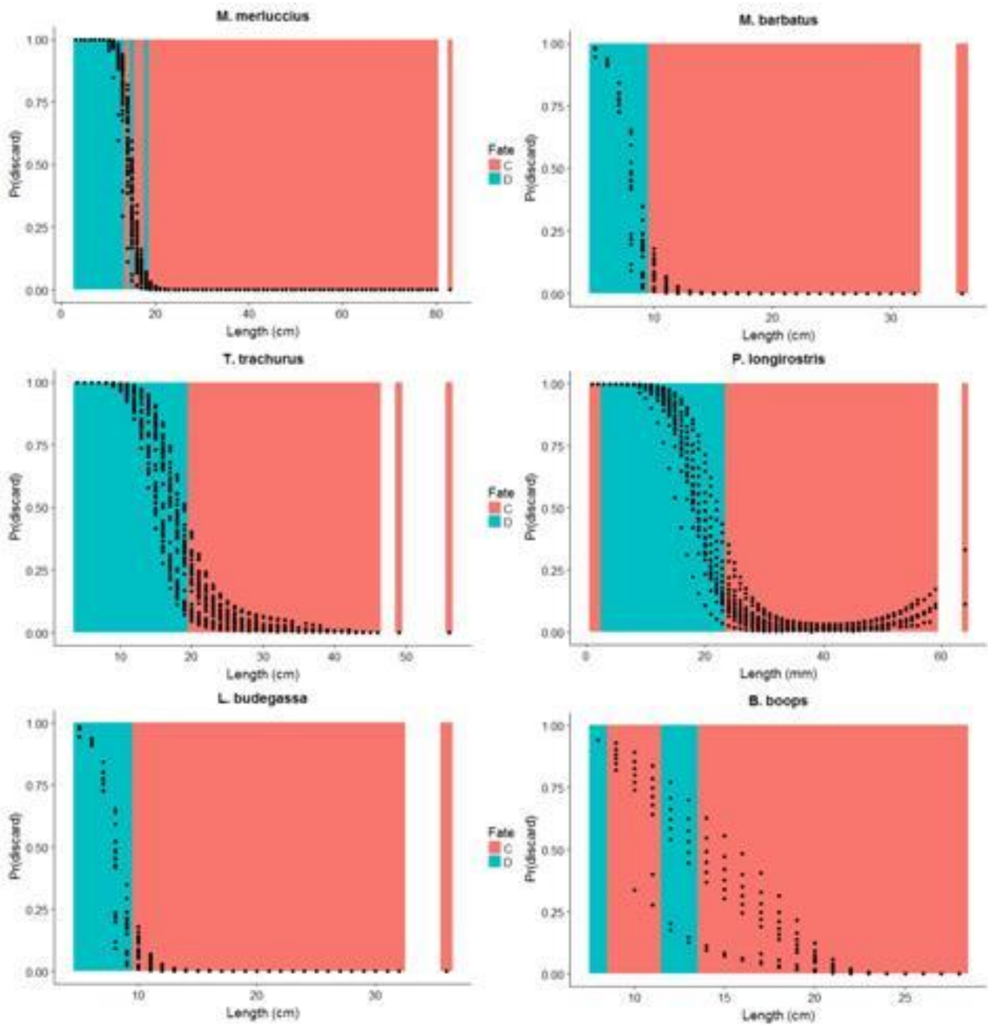


Figure 11. GAM derived discard probability by total length with super-imposed discard ogives for major commercial species discarded in the Greek trawl fisheries in the Aegean Sea.

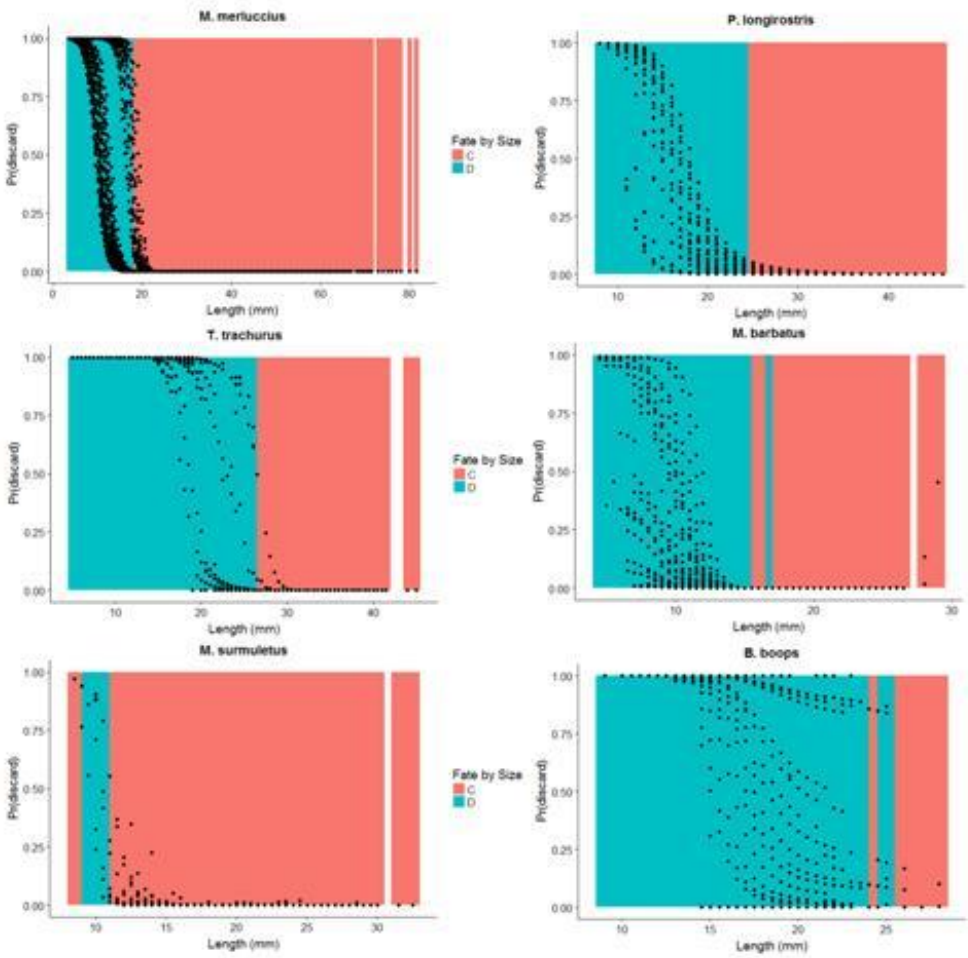


Figure 12. GAM derived discard probability by total length with super-imposed discard ogives for major commercial species discarded in the Italian trawl fisheries in the Ligurian and northern Tyrrhenian Seas .

ANNEX

Suplementary material

Table S1. List of non-commercial invertebrate species/taxa affected by the otter bottom trawlers of the Aegean, Ligurian and north Tyrrhenian Sea. (Listed as 'Other invertebrates' in the manuscript)

Aegean Sea	Ligurian and north Tyrrhenian Sea
Anomura	Acanthocardia aculeata (L.)
Aporrhais pespelecani	Acanthocardia echinata (L.)
Aporrhais spp	Acanthocardia paucicostata (G.B.Sowerby)
Ascidia	Acanthocardia spinosa (Solander)
Asteroidea	Aequipecten opercularis (Linneo.)
Aurelia aurita	Alcyonium palmatum
Brachyura	Anadara corbuloides (Monterosato)
Cidaris cidaris	Antedon mediterranea (Lam.)
Cnidaria	Anthozoa indet.
Corals	Aphrodita aculeata Linneo 1758
Echinaster sepositus	Aporrhais pespelecani (Linneo 1758)
Echinoidea	Aporrhais serresianus (Michaud 1828)
Echinus spp	Armina tigrina Rafinesque 1814
Goneplax rhomboides	Astropecten aranciacus (L.)
Holothuria forskali	Astropecten bispinosus (Otto)
Holothuroidea	Astropecten irregularis pentacanthus (D.Ch.)
Ophioderma spp	Bivalvi indet.
Ophiuridae	Bolinus brandaris (Linneo 1758)
Ostrea edulis	Buccinulum corneum (Linneo 1758)
Other unidentified invertebrates	Calliostoma granulatum (Born 1778)
Paracentrotus lividus	Cassidaria sp.
Parastichopus regalis	Cavolinia tridentata (Niebuhr 1775)
Porifera	Chlamys varia (L.)
Spongia officinalis	Cidaris cidaris (L.)
Spongia spp	Codium bursa (Linneo) Kutzing 1822
	Echinaster sepositus (Retz.)
	Echinocardium cordatum (Penn.)
	Echinoidea indet.
	Echinus acutus Lam.
	Echinus melo (Lamarck 1816)
	Fusinus rostratus (Olivi 1792)
	Galeodea (Cassidaria) echinofora (Linneo 1758)
	Galeodea (Cassidaria) rugosa (Linneo 1771)
	Glossus humanus (L.)
	Holothuria polii
	Holothuria tubulosa Gmelin 1788
	Hyalinoecia tubicola (O.F.Muller 1776)
	Isidella elongata

	Laetmonice hystrix (Savigny 1820)
	Leptometra phalangium (J.Mueller 1841)
	Marthasterias glacialis (L.)
	Microcosmus sabatieri Roule
	Microcosmus sp.
	Mytilus galloprovincialis Lamarck 1819
	Nassarius mutabilis (Linneo 1758)
	Naticarius hebrea (Martyn 1784)
	Naticarius sp.
	Naticarius stercusmuscarum (Gmelin 1791)
	Neopycnodonte coclear
	Nudibranchi indet.
	Ocnus planci (Brandt)
	Oloturie indet.
	Ophiothrix fragilis (Ab.)
	Ophiura texturata Lamark 1816
	Ophiuroidea indet.
	Opistobranchi sp.
	Ostrea edulis Linneo 1758
	Ostrea sp.
	Parastichopus regalis (Cuv.)
	Pecten jacobaeus (Linneo 1758)
	Pennatula phosphorea L.
	Pennatula rubra (Ell.)
	Pennatula sp.
	Porifera indet.
	Posidonia oceanica (Linneo) Delile 1813
	Psammechinus microtuberculatus (Bev.)
	Pteria hirundo (L.)
	Pteroides griseum Bohadsch
	Pyrosoma atlanticum
	Rhizostoma pulmo
	Scaphander lignarius (Linneo 1758)
	Schizaster canaliferus (Lam.)
	Spatangus purpureus Leske
	Sphaerechinus granularis (Lamarck)
	Sternaspis scutata (Renier 1807)
	Stylocidaris affinis (Phil.)
	Suberites domuncula (Olivi)
	Tethyaster subinermis (Phil.)
	Thenea muricata (Bowerb.)
	Trachythyone elongata (D.K.)
	Trachythyone tergestina (M.Sars)
	Turritella communis Risso 1826
	Gasteropod eggs

Table S2. Number of species/taxa discarded and marketed by major taxonomic group, by the otter bottom trawlers of the Aegean, Ligurian and north Tyrrhenian Sea during the study period 1995-2015.

	Taxonomic groups	Discarded	Marketed
Aegean Sea	Fish	139	123
	Crustaceans	13	20
	Cepaholopods	23	16
	Invertebrates (other than crustaceans & cephalopods)	15	1
N. Tyrrhenian & Ligurian Sea	Fish	151	136
	Crustaceans	36	45
	Cepaholopods	26	29
	Invertebrates (other than crustaceans & cephalopods)	69	19

Table S3a. Summarised results for the 'best' model selected for discarded CPUE of demersal species caught in the bottom trawl fishery of the Aegean Sea. *p*-values refer to the probabilities from an ANOVA F-ratio test. df are the estimated degrees of freedom.

GAM model

```
Family: Gamma
Link function: log
Formula:
DCPUEW + 0.1 ~ as.factor(year) + as.factor(season) + s(depth) +
s(Longitude, k = 4) + s(Latitude, k = 4)

Parametric Terms:
                  df      F  p-value
as.factor(year)    6 13.277 1.86e-14
as.factor(season)  2  5.665  0.00359

Approximate significance of smooth terms:
               edf Ref.df     F  p-value
s(depth)     8.553  8.941  4.61 6.12e-06
s(Longitude) 2.595  2.885 15.27 4.26-e-08
s(Latitude)  2.877  2.983  8.29 1.98e-05
```

Table S3b. Summarised results for the 'best' model selected for discarded CPUE of demersal species caught in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. *p*-values refer to the probabilities from an ANOVA F-ratio test. df are the estimated degrees of freedom

GAM model

```
Family: Gamma
Link function: log

Formula:
DCPUEW + 0.1 ~ as.factor(year) + as.factor(season) + s(depth) +
    s(Longitude, k = 4) + s(Latitude, k = 4)

Parametric Terms:
                  df     F  p-value
as.factor(year)    5 4.448 0.000642
as.factor(season)  3 1.298 0.275427

Approximate significance of smooth terms:
               edf Ref.df      F  p-value
s(depth)     7.969  8.722  4.767 5.81e-06
s(Longitude) 2.553  2.859 12.425 1.07e-06
s(Latitude)  2.815  2.969 14.581 7.35e-09
```

Table S4. Species specific annual landings as percentage of total landings during the whole study period (1995-2015), for the monitored commercial vessels of this study. (Vessel names are masked - values exceeding 25% are shown in bold).

% of landings in total landings during 1995-2015	Vessel ID	Hake	Red mullet	Deep water rose shrimp
Ligurian and north Tyrrhenian seas	Vessel ITA1	6.3%	0.5%	
	Vessel ITA2	2.7%	14.9%	
	Vessel ITA3	**37.7%**	11.7%	
	Vessel ITA4	**25.7%**	1.1%	
	Vessel ITA5	15.0%	0.1%	
	Vessel ITA6	12.6%	0.0%	
	Vessel ITA7	**36.0%**	10.5%	
	Vessel ITA8	**38.2%**	0.9%	
	Vessel ITA9	21.5%	**28.0%**	
	Vessel ITA10	4.7%	19.0%	
	Vessel ITA11	3.3%	0.0%	
	Vessel ITA12	2.0%	17.1%	
	Vessel ITA13	5.6%	4.5%	
	Vessel ITA14	8.5%	0.0%	
	Vessel ITA15	**29.8**%	0.4%	
	Vessel ITA16	12.6%	1.0%	
	Average	*21.1%*	*5.1%*	
Aegean Sea	Vessel GRC1	1.0%	5.4%	0.0%
	Vessel GRC2	**40.0%**	0.0%	**31.7%**
	Vessel GRC3	16.9%	2.2%	**37.6%**
	Vessel GRC4	1.4%	5.2%	0.0%
	Vessel GRC5	18.6%	4.6%	4.9%
	Vessel GRC6	14.4%	4.8%	**41.1%**
	Vessel GRC7	10.6%	2.2%	**63.2%**
	Vessel GRC8	8.8%	11.5%	10.0%
	Vessel GRC9	12.6%	8.3%	**25.7%**
	Vessel GRC10	16.3%	13.0%	4.3%

Vessel GRC11	18.7%	1.9%	**44.5%**
Vessel GRC12	**35.4%**	1.4%	**29.5%**
Vessel GRC13	14.7%	0.0%	13.7%
Vessel GRC14	**30.1%**	1.3%	**25.9%**
Vessel GRC15	11.3%	15.2%	21.0%
Vessel GRC16	**46.9%**	0.5%	**29.9%**
Vessel GRC17	16.5%	3.1%	**46.2%**
Vessel GRC18	11.6%	1.7%	**55.7%**
Vessel GRC19	13.0%	7.7%	22.0%
Average	*17.3%*	*4.6%*	***32.2%***

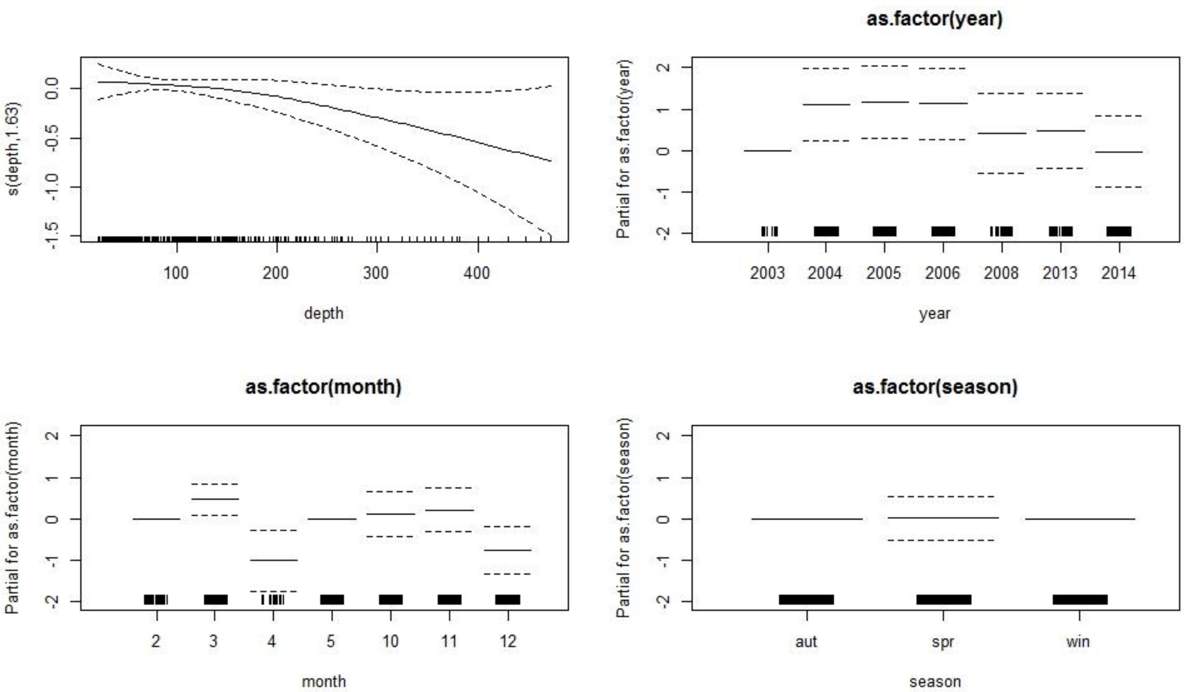


Figure S1a. Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **invertebrate** catch in the bottom trawl fishery of the Aegean Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

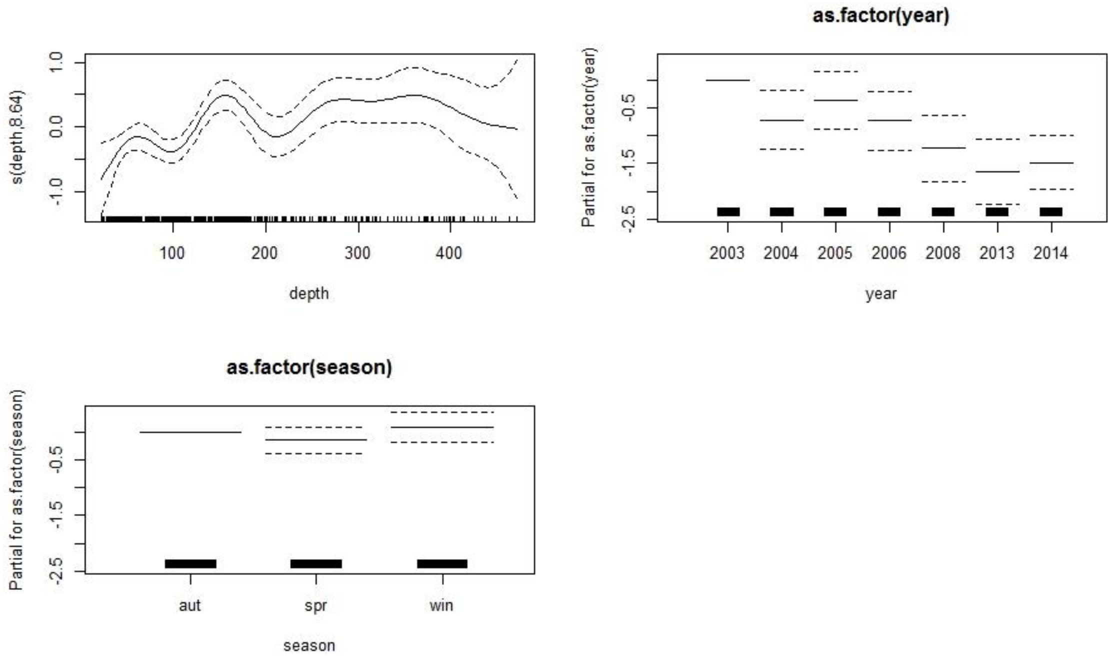


Figure S1b. Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **<u>elasmobranch</u>** catch in the bottom trawl fishery of the Aegean Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

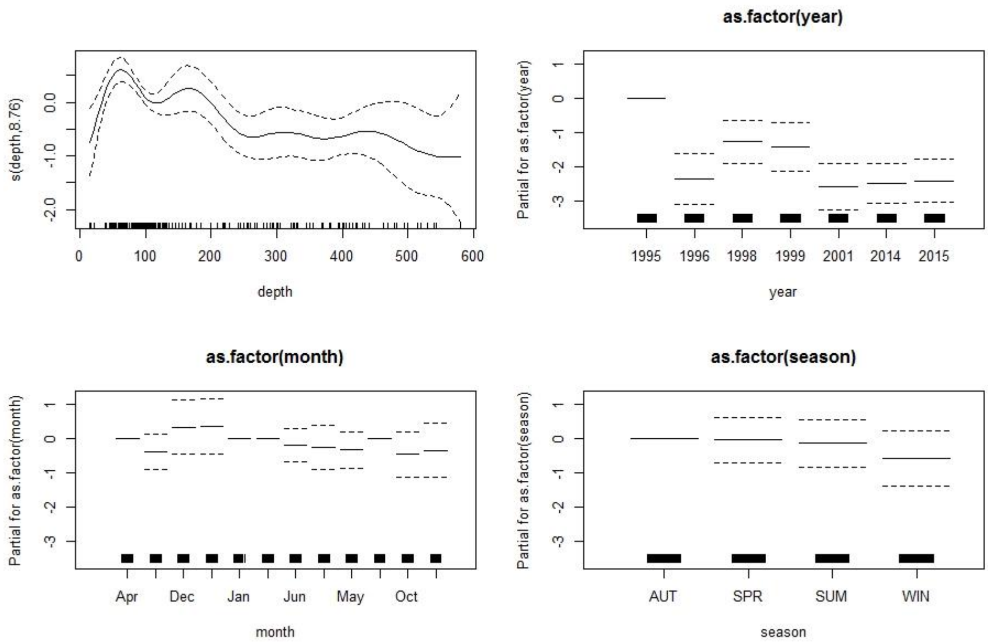


Figure S2a. Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **<u>invertebrate</u>** catch in the bottom trawl of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the 'rug' on the x-axis.

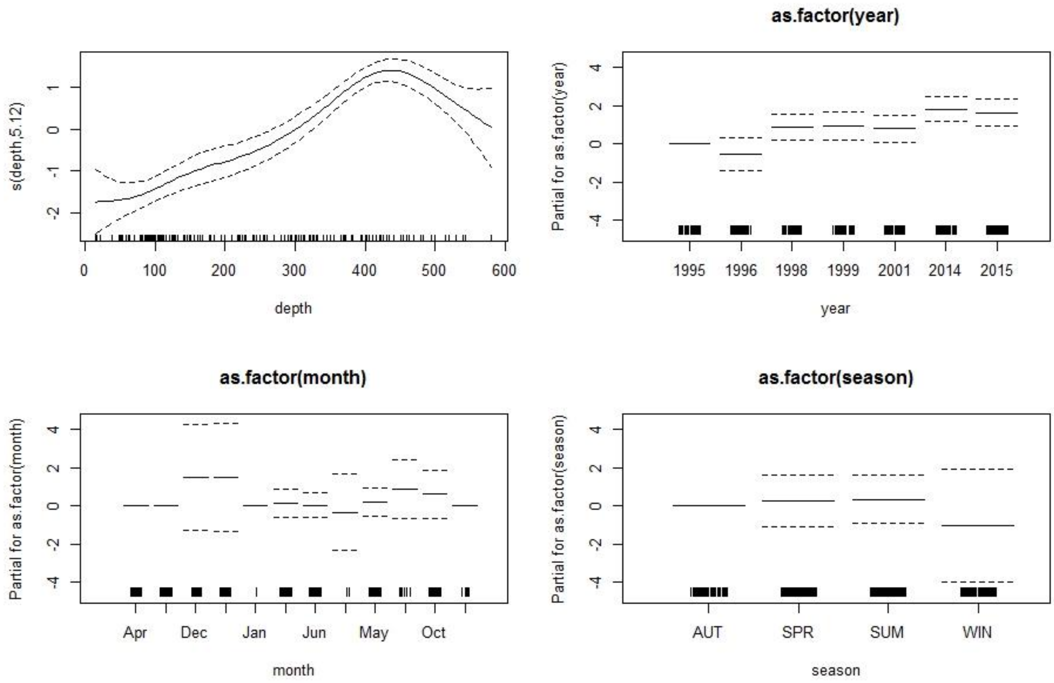


Figure S2b. Generalized additive models (GAM) derived effects of various parameters on the discarding probability of the **elasmobranch** catch in the bottom trawl fishery of the Ligurian and north Tyrrhenian Sea. Dashed lines indicate two standard errors above and below the estimates. Relative density of data points is shown by the ‘rug’ on the x-axis.

AEGEAN SEA

Merluccius merluccius (MCRS = 20cm)

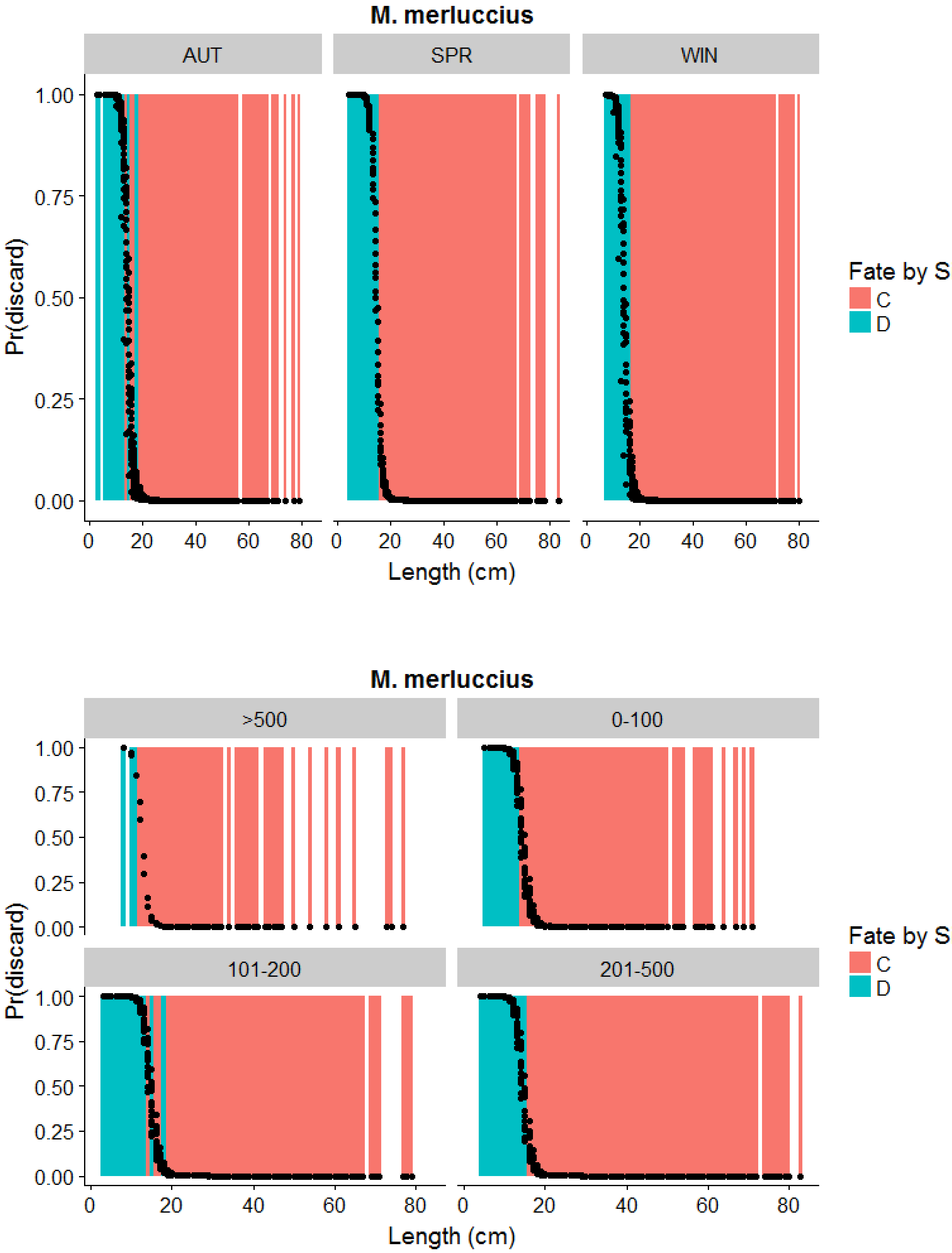


Figure S3a. GAM derived discard probability by total length with super-imposed discard ogive for hake (top-by season, bottom-by depth stratum).

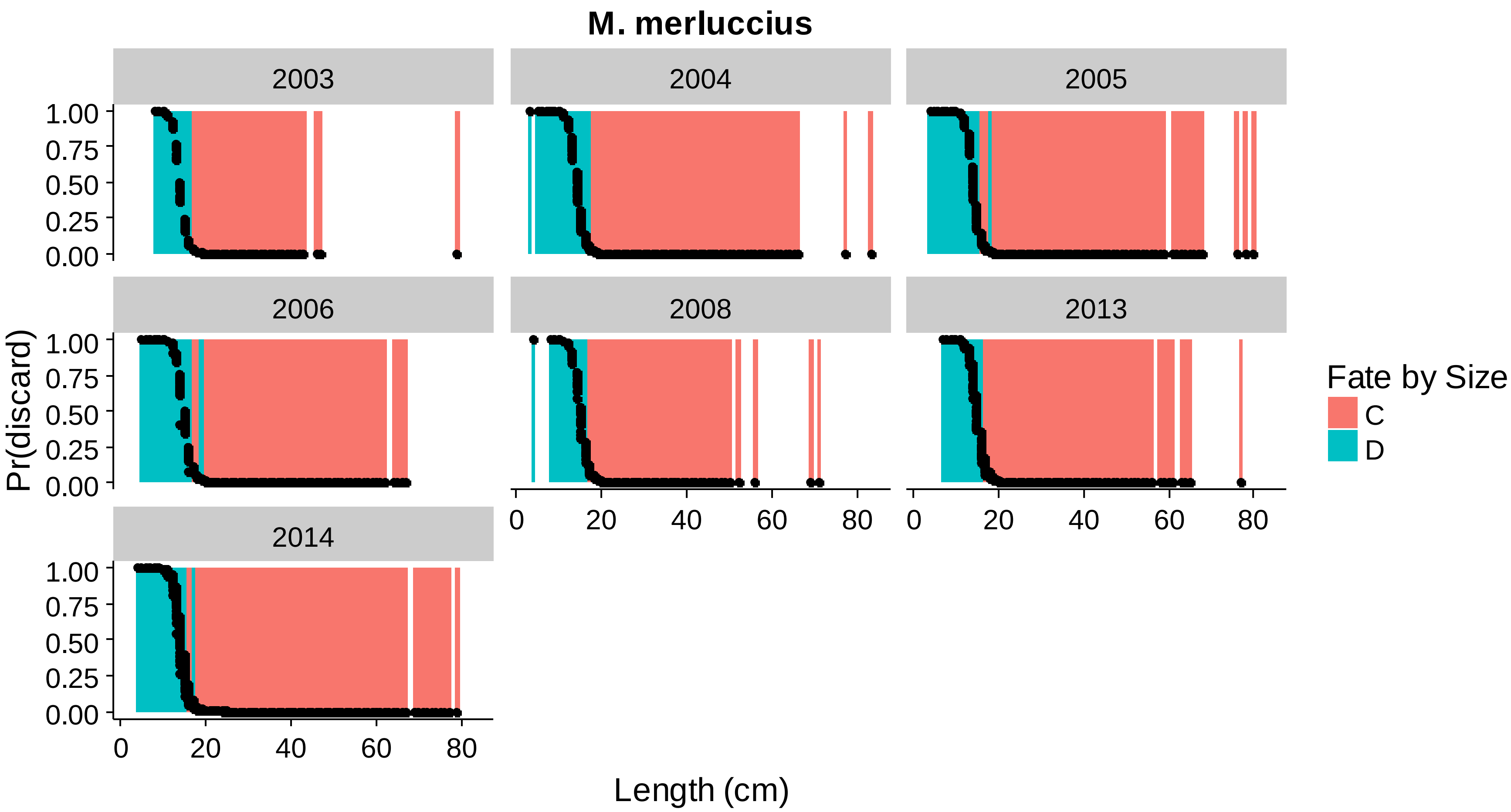


Figure S3b. GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

***Mullus barbatus* (MCRS= 11cm)**

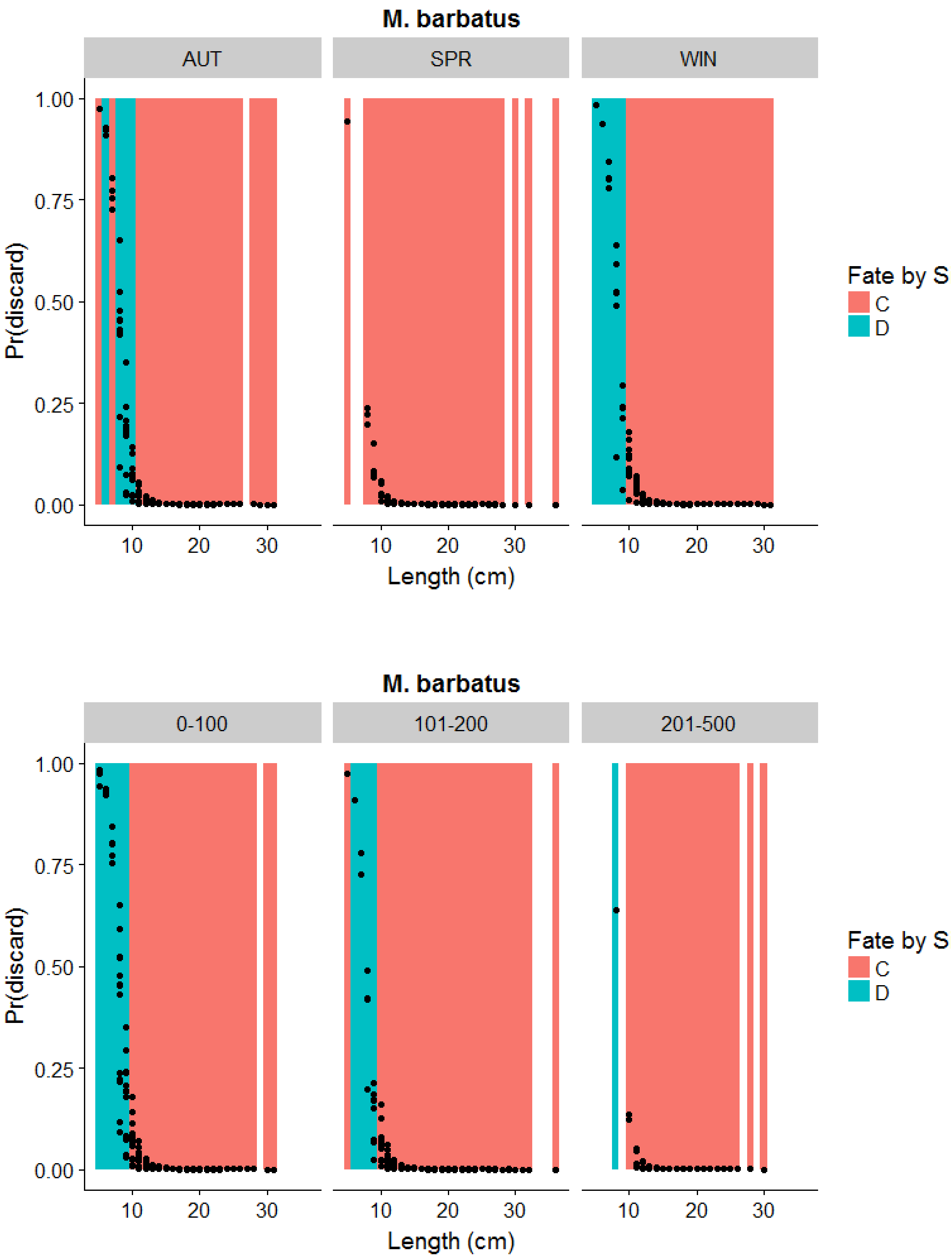


Figure S3c. GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top- by season, bottom-by depth stratum).

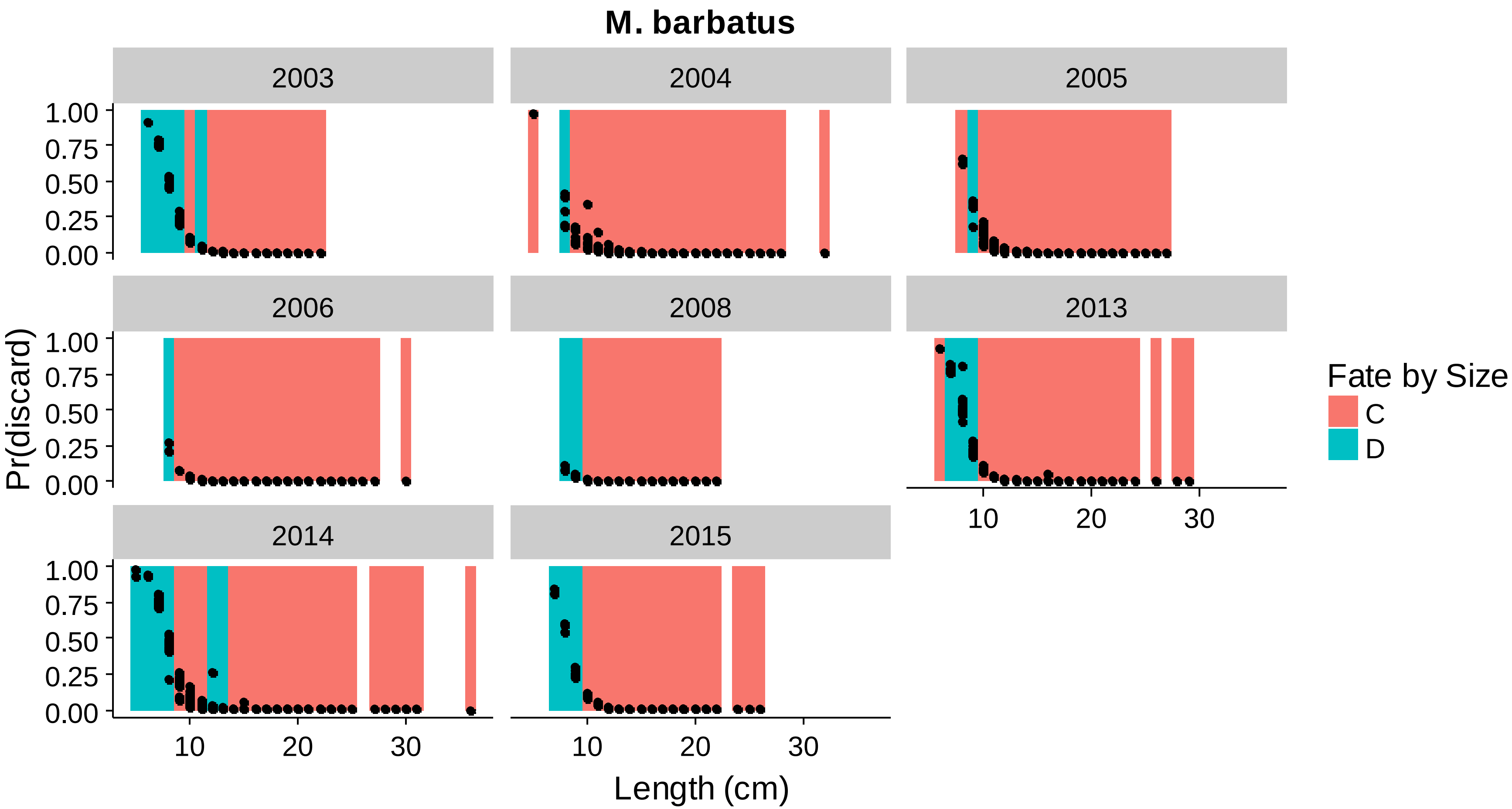
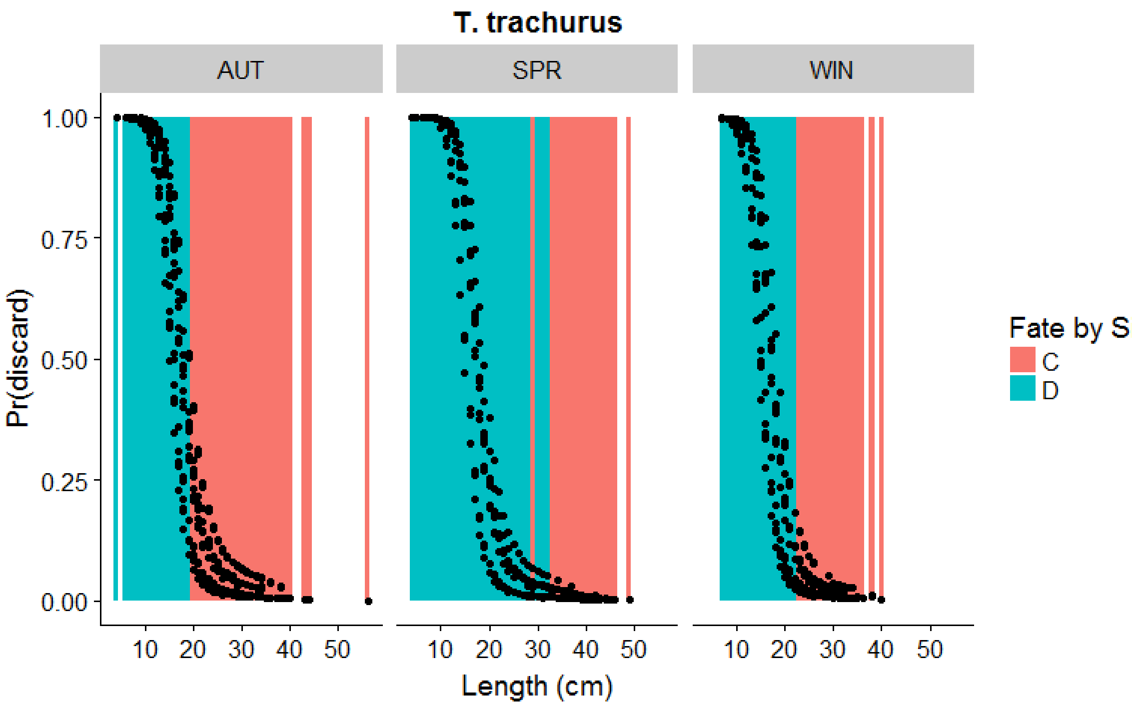


Figure S3d. GAM derived discard probability by total length with super-imposed discard ogive for red mulet (by year)

Trachurus trachurus (MCRS=15 cm)



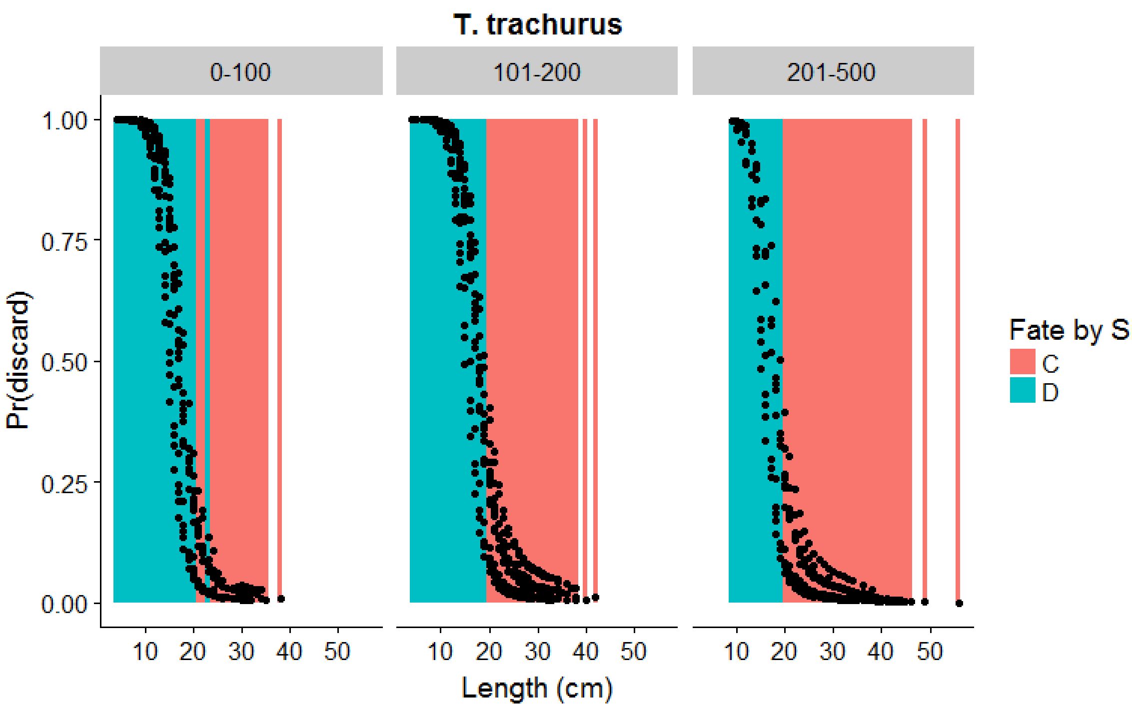


Figure S3e GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-global, mid-by season, bottom-by depth stratum).

Parapenaeus longirostris (MCRS = 20mm)

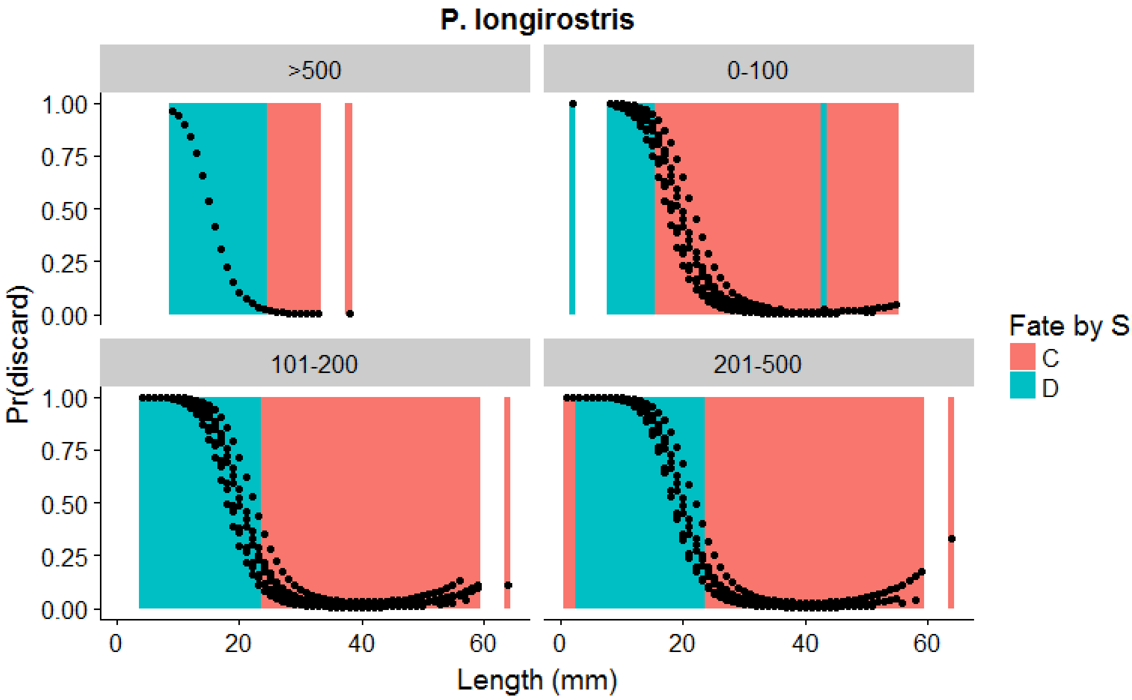


Figure S3f. GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (by depth stratum).

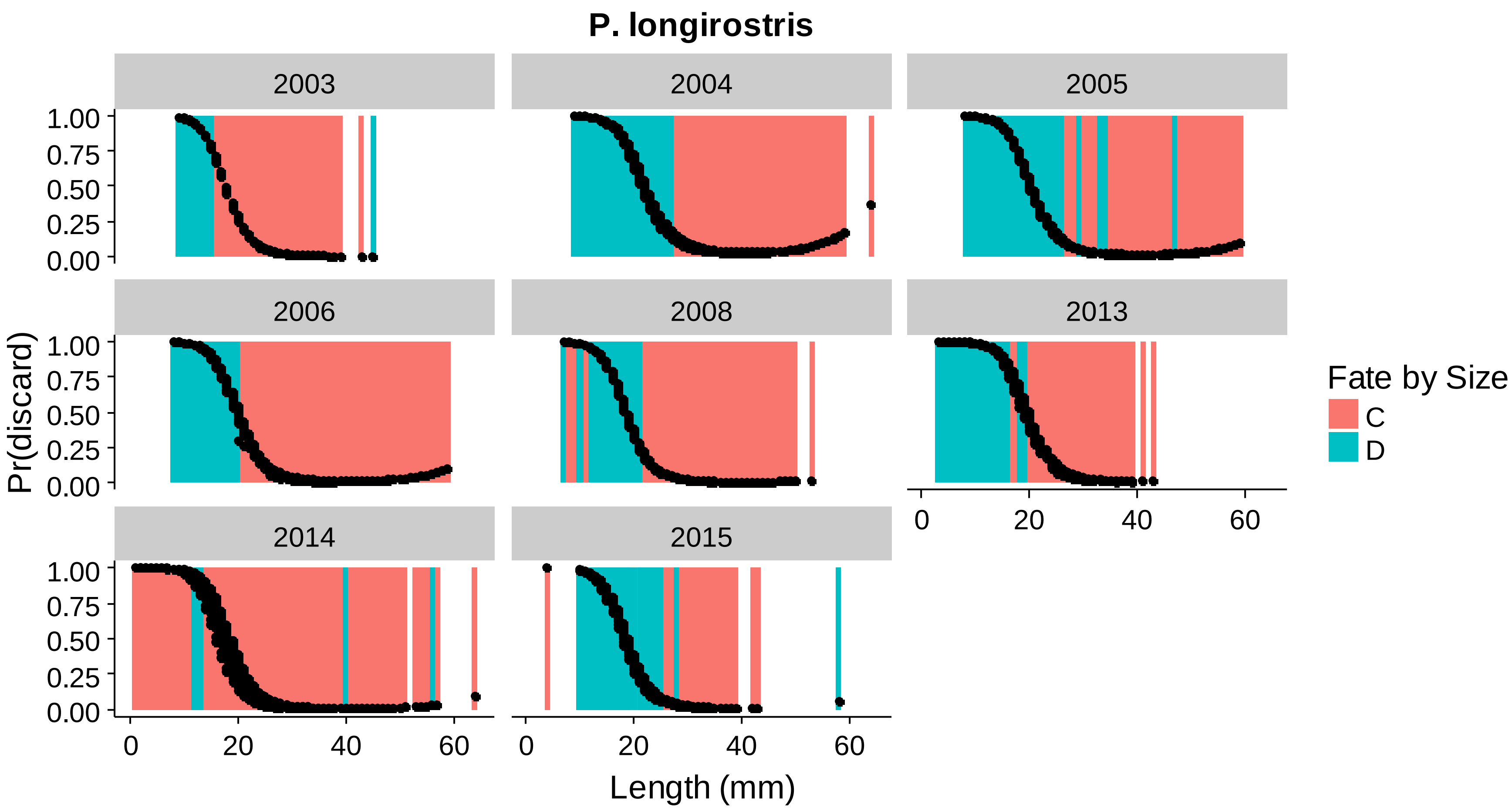


Figure S3g. GAM derived discard probability by total length with super-imposed discard ogive for deep water rose shrimp (by year).

Lophius budegassa (currently no MCRS - old MCRS =30 cm)

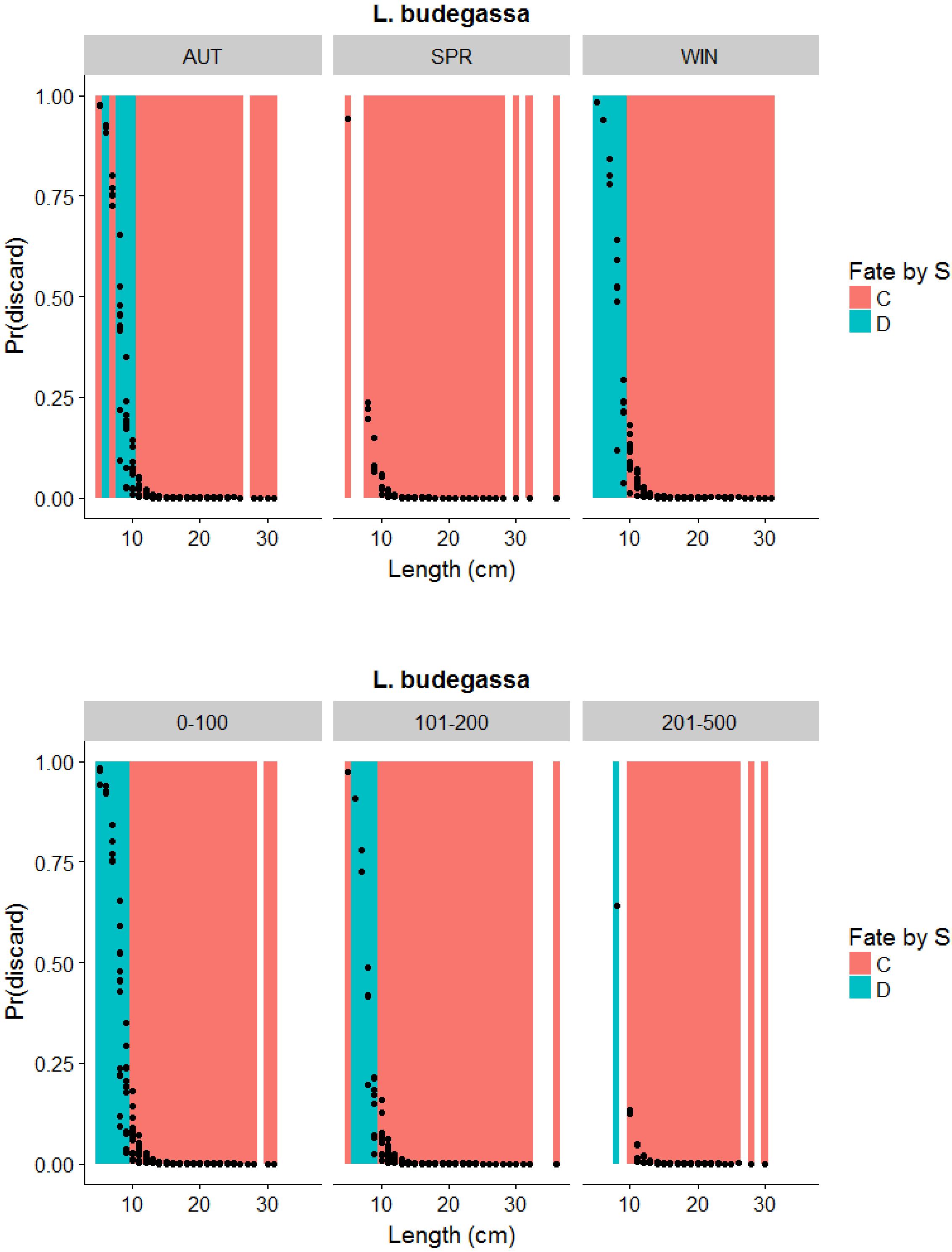


Figure S3h. GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (top- by season, bottom-by depth stratum).

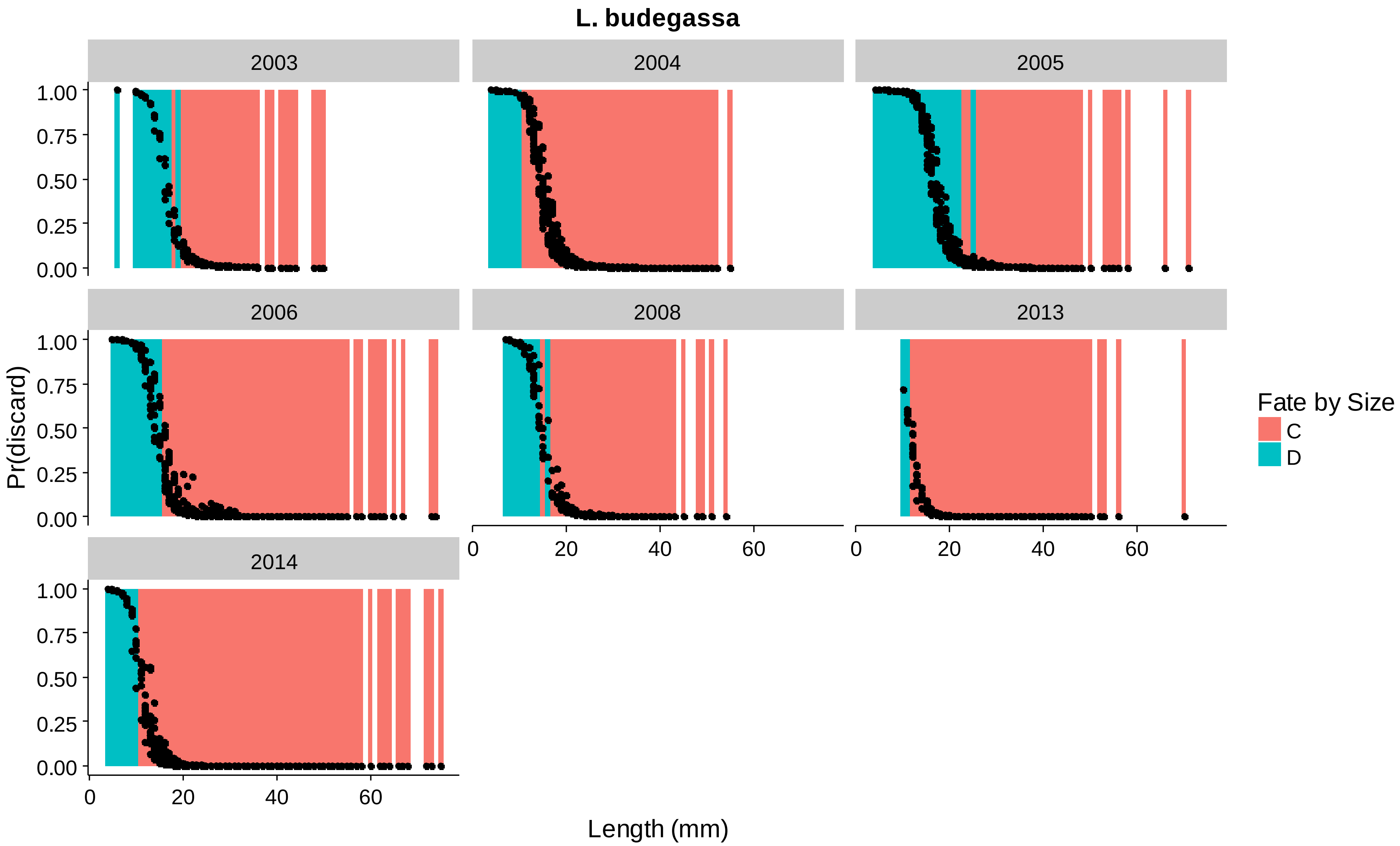
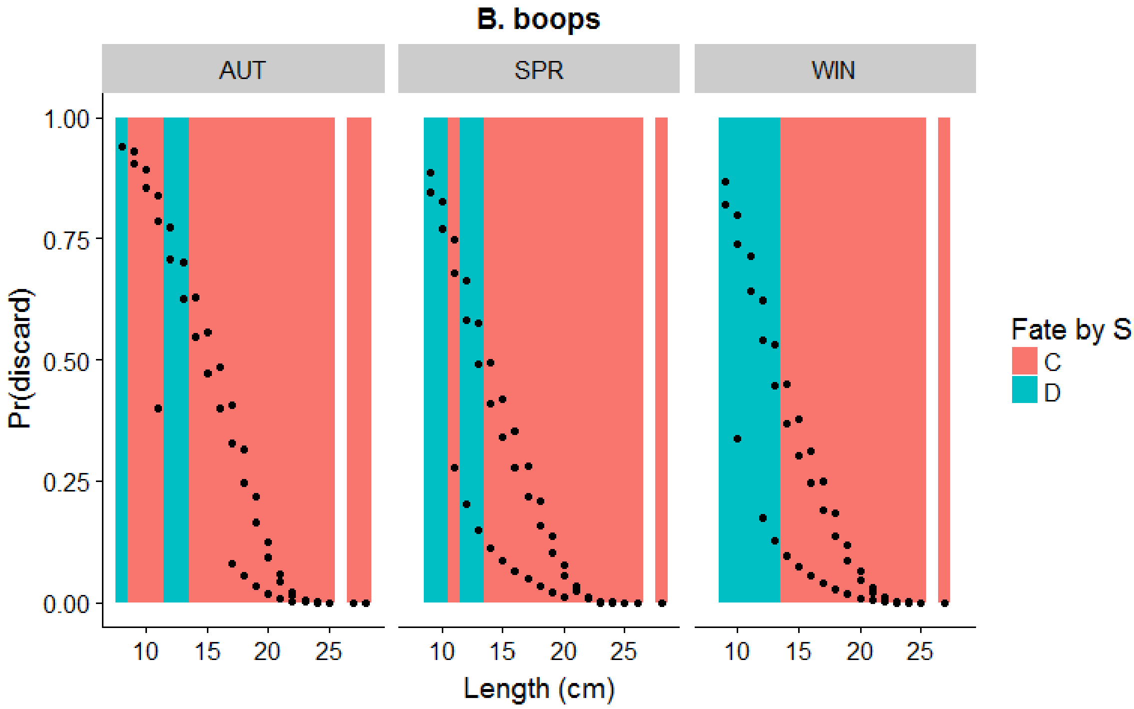


Figure S3i. GAM derived discard probability by total length with super-imposed discard ogive for anglerfish (by year).

***Boops boops* (MCRS= 10 cm)**



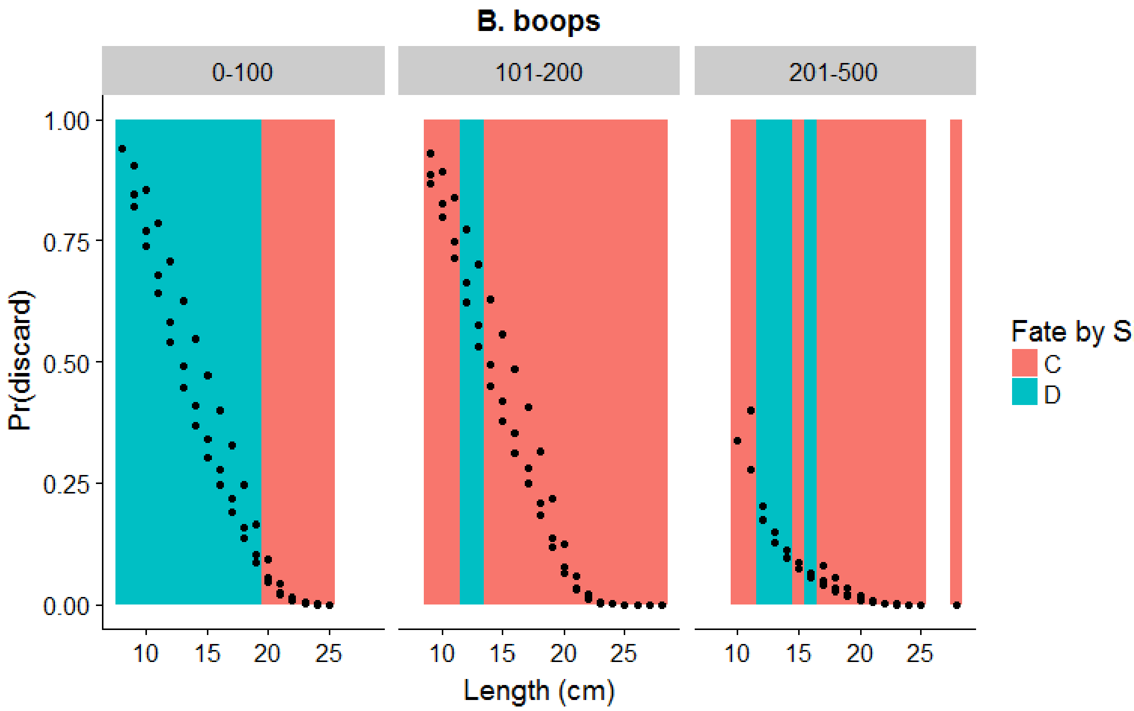
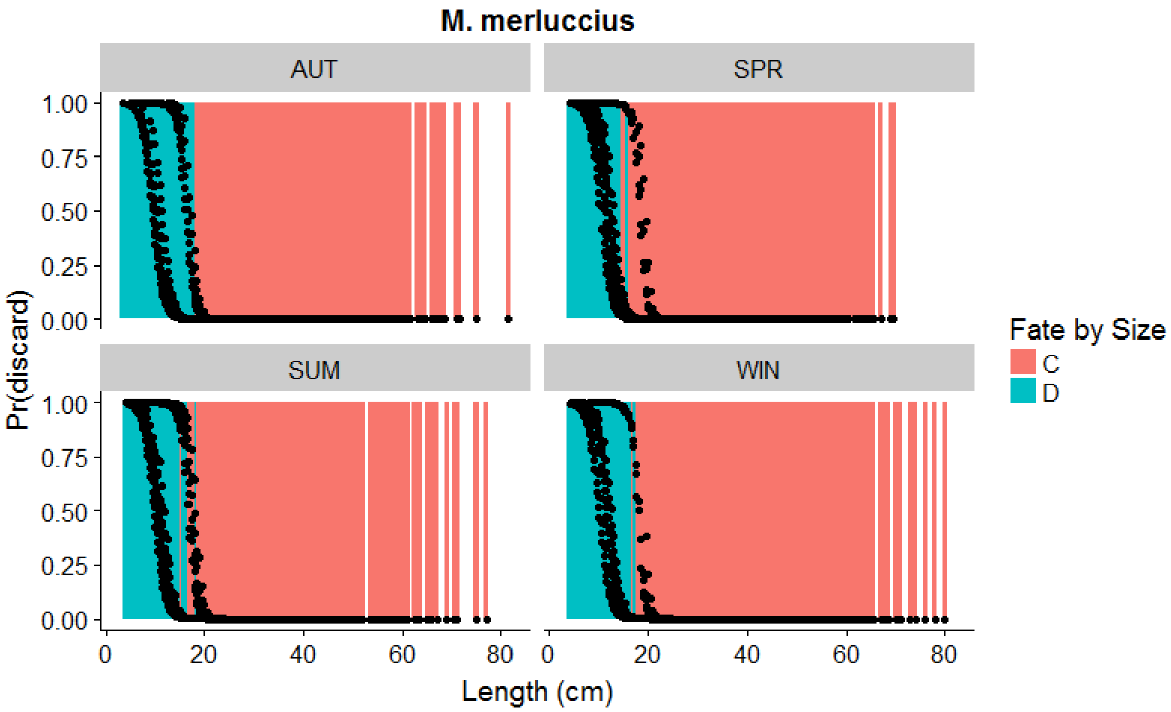


Figure S3j. GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-global, mid-by season, bottom-by depth stratum).

LIGURIAN & NORTH TYRRHENIAN SEA

Merluccius merluccius (MCRS=20cm)



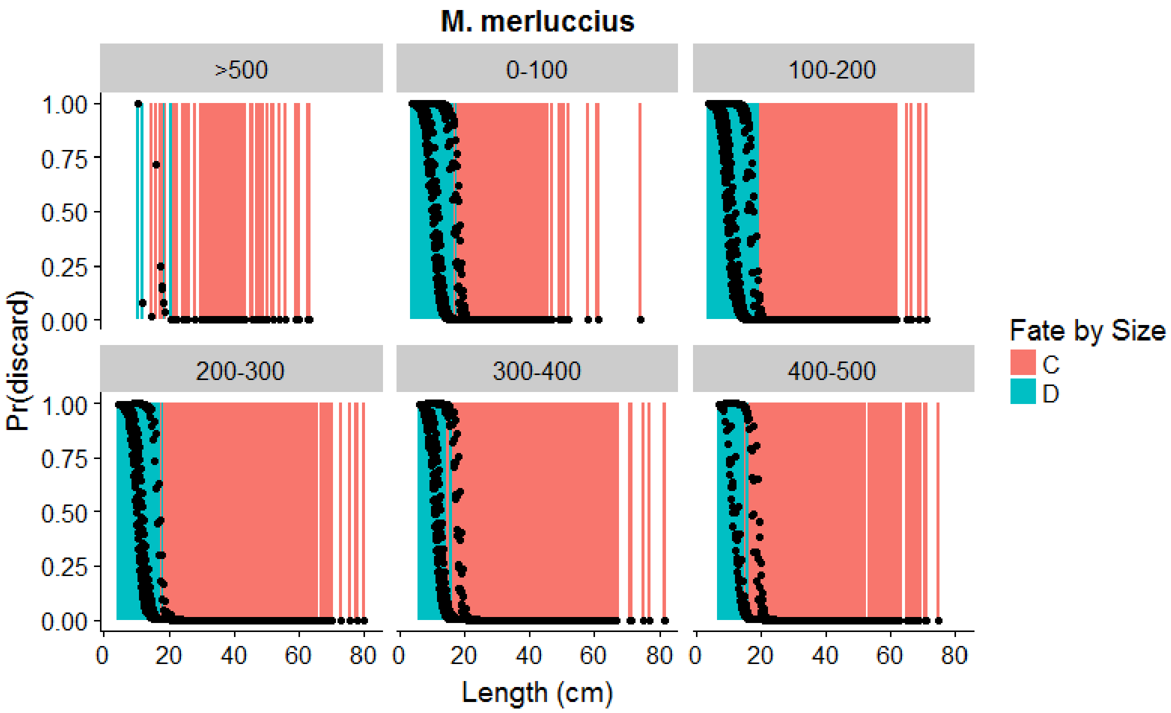


Figure S4a. GAM derived discard probability by total length with super-imposed discard ogive for hake (top - by season, bottom - by depth stratum)

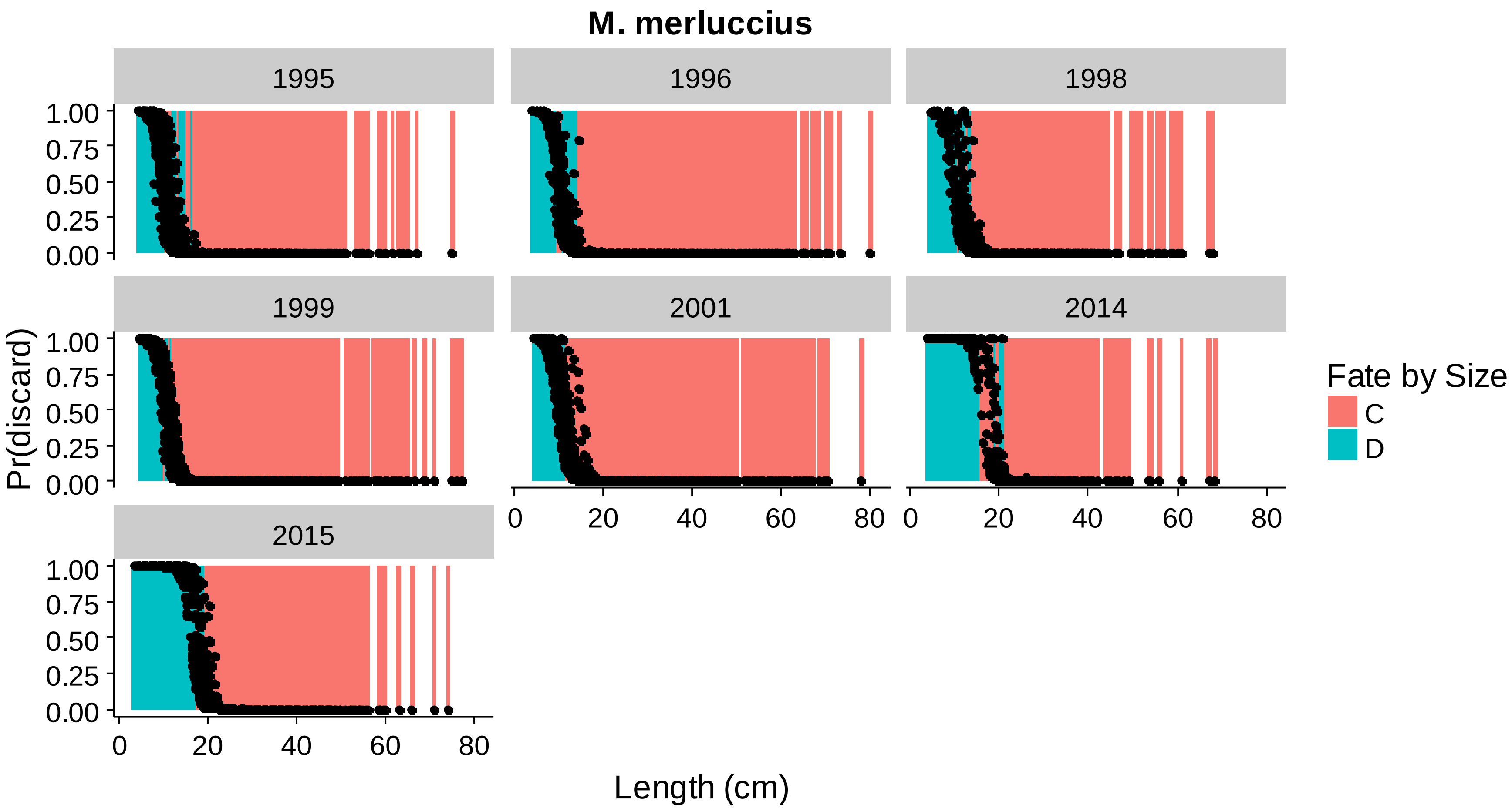


Figure S4b. GAM derived discard probability by total length with super-imposed discard ogive for hake (by year).

Parapenaeus longirostris (MCRS=20mm)

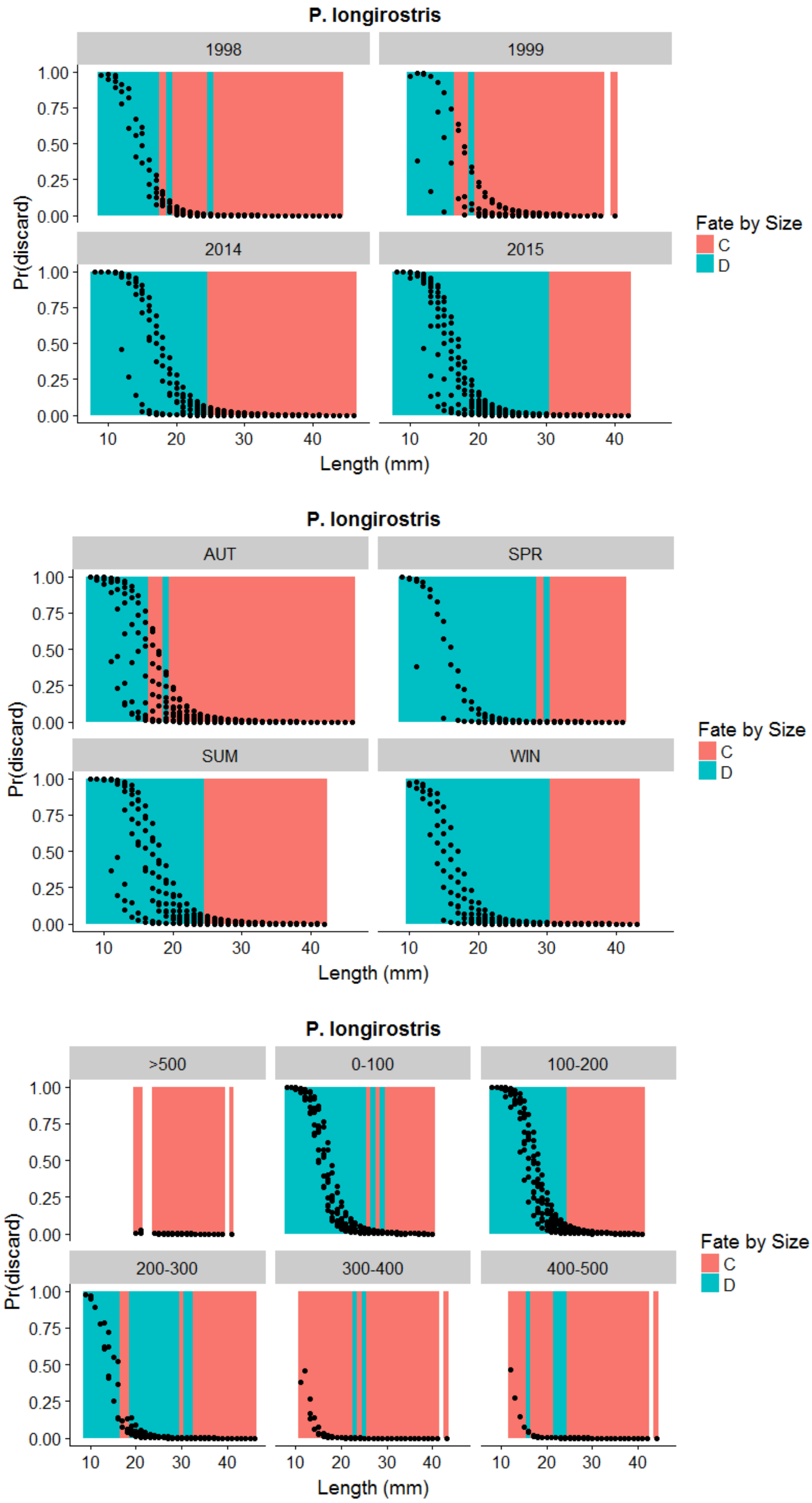


Figure S4c. GAM derived discard probability by total length with super-imposed discard ogive for deep-water rose shrimp (top-by year, mid-by season and bottom-by depth stratum).

Trachurus trachurus (MCRS=15cm)

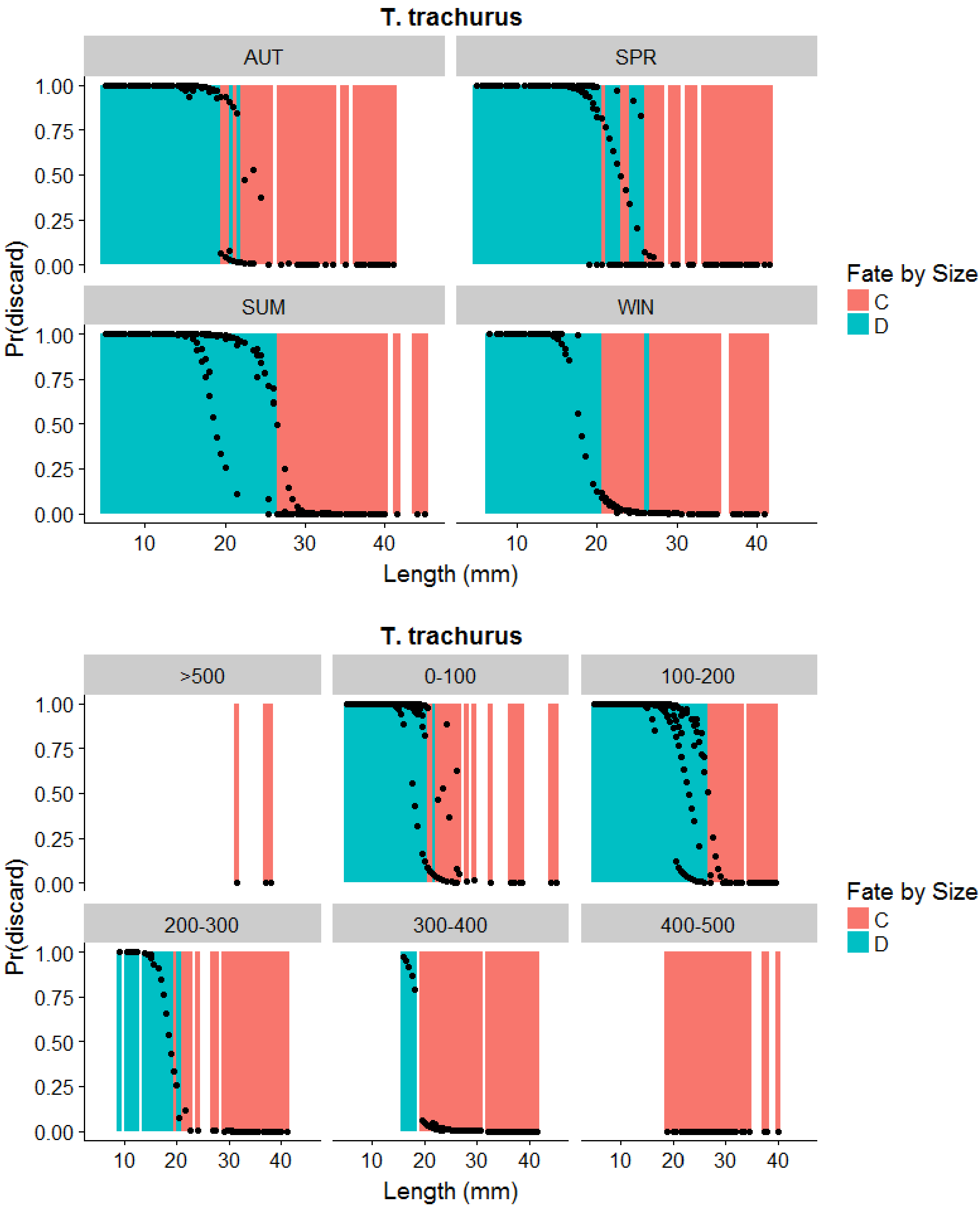
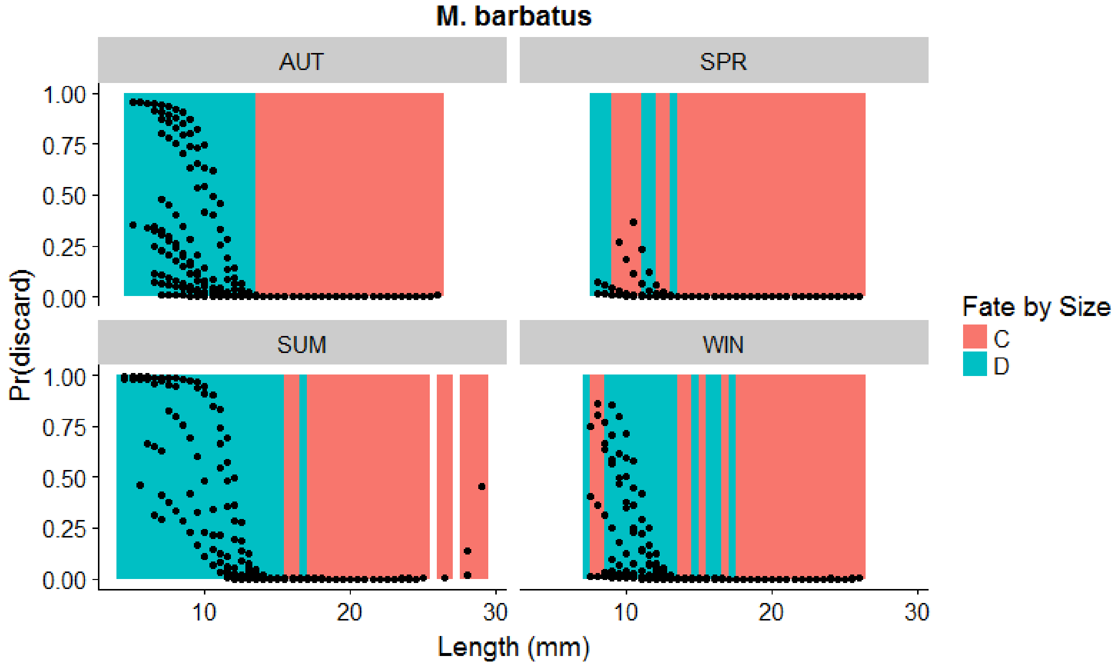


Figure S4d. GAM derived discard probability by total length with super-imposed discard ogive for horse mackerel (top-by season, bottom-by depth stratum).

Mullus barbatus (MCRS = 11cm)



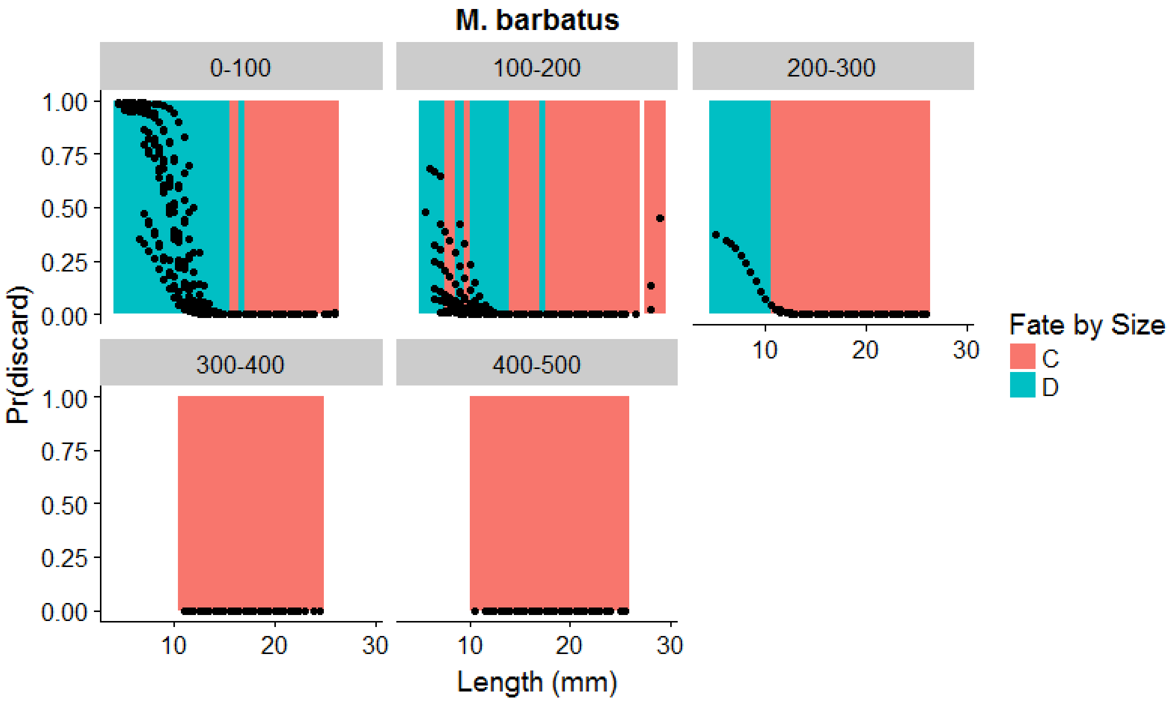


Figure S4e. GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

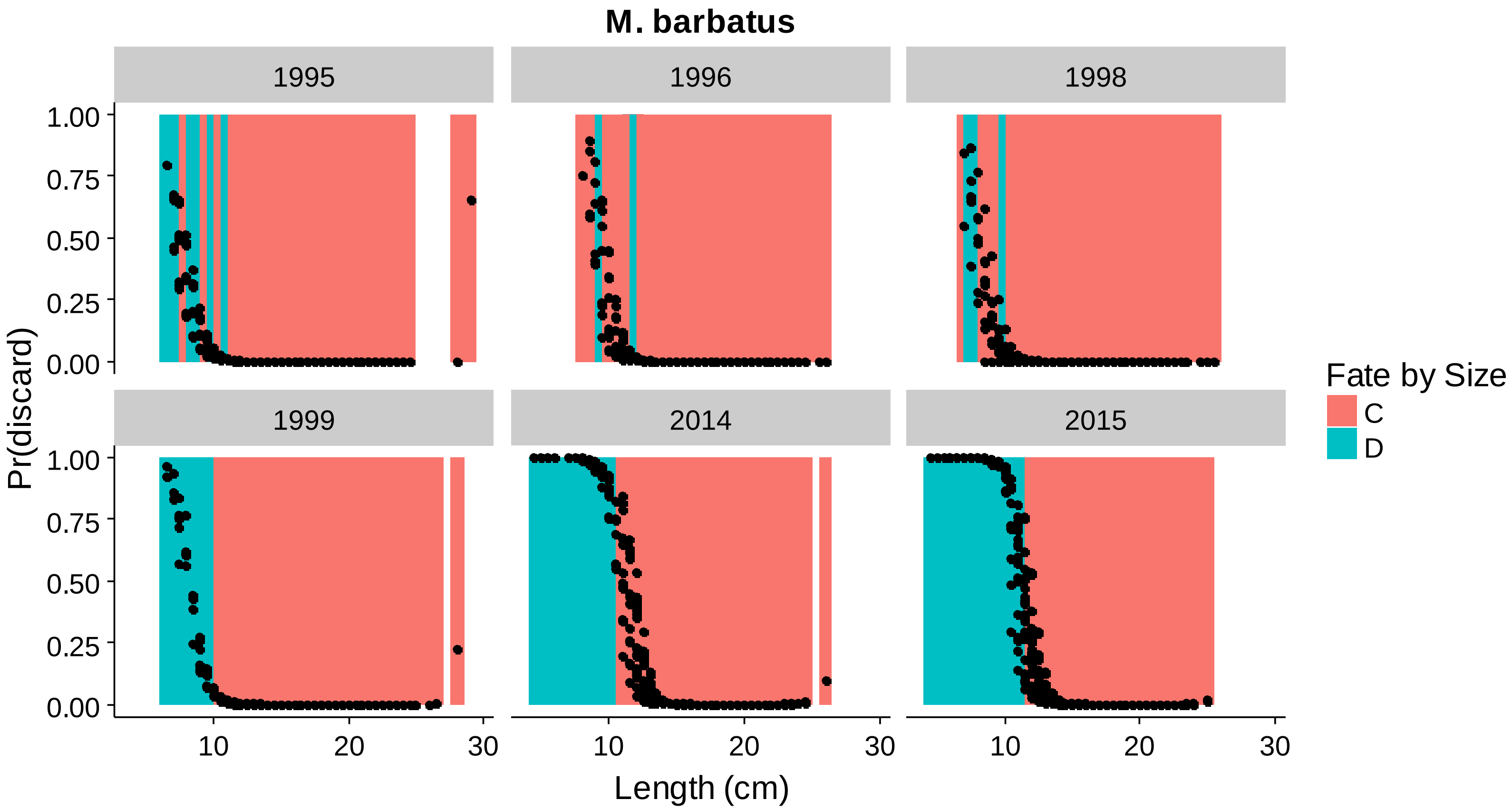
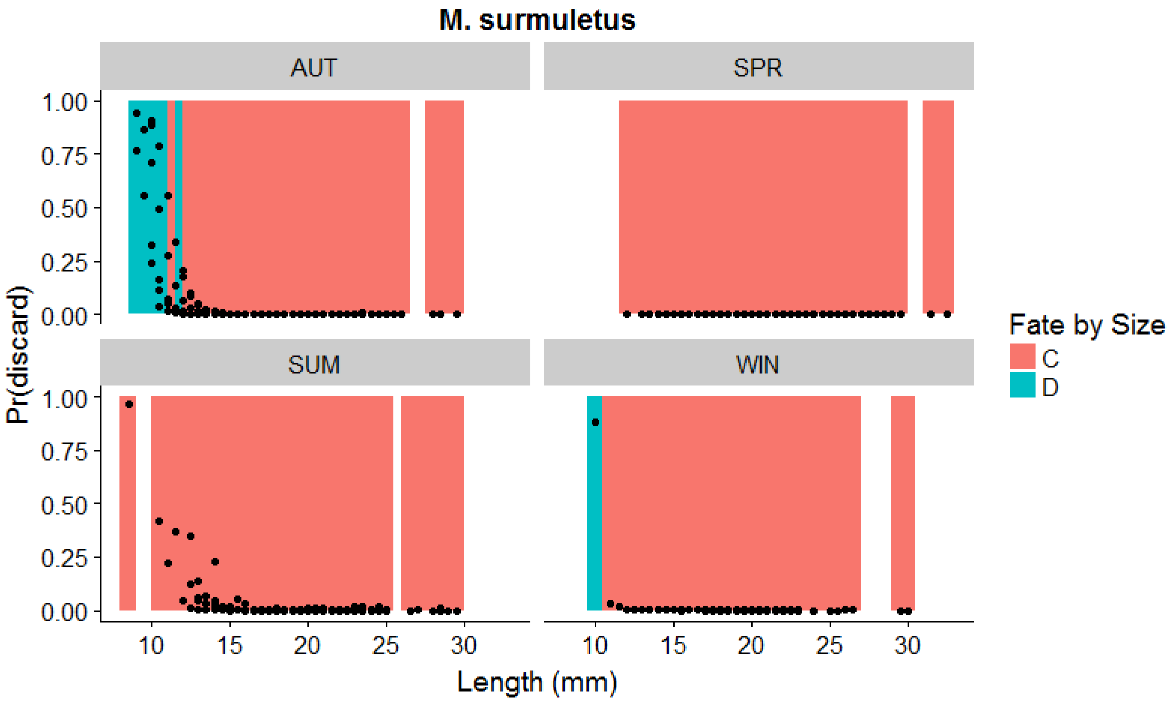


Figure S4f. GAM derived discard probability by total length with super-imposed discard ogive for red mullet (by year).

***Mullus surmuletus*(MCRS = 11cm)**



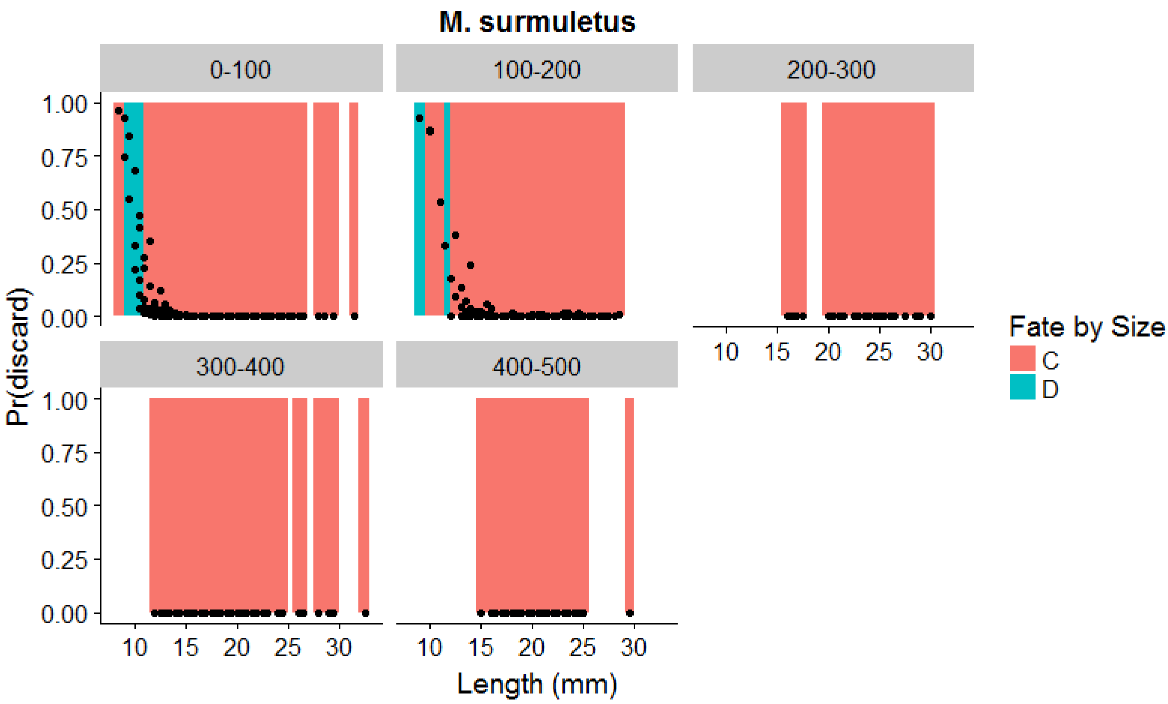


Figure S4g. GAM derived discard probability by total length with super-imposed discard ogive for red mullet (top-by season, bottom-by depth stratum).

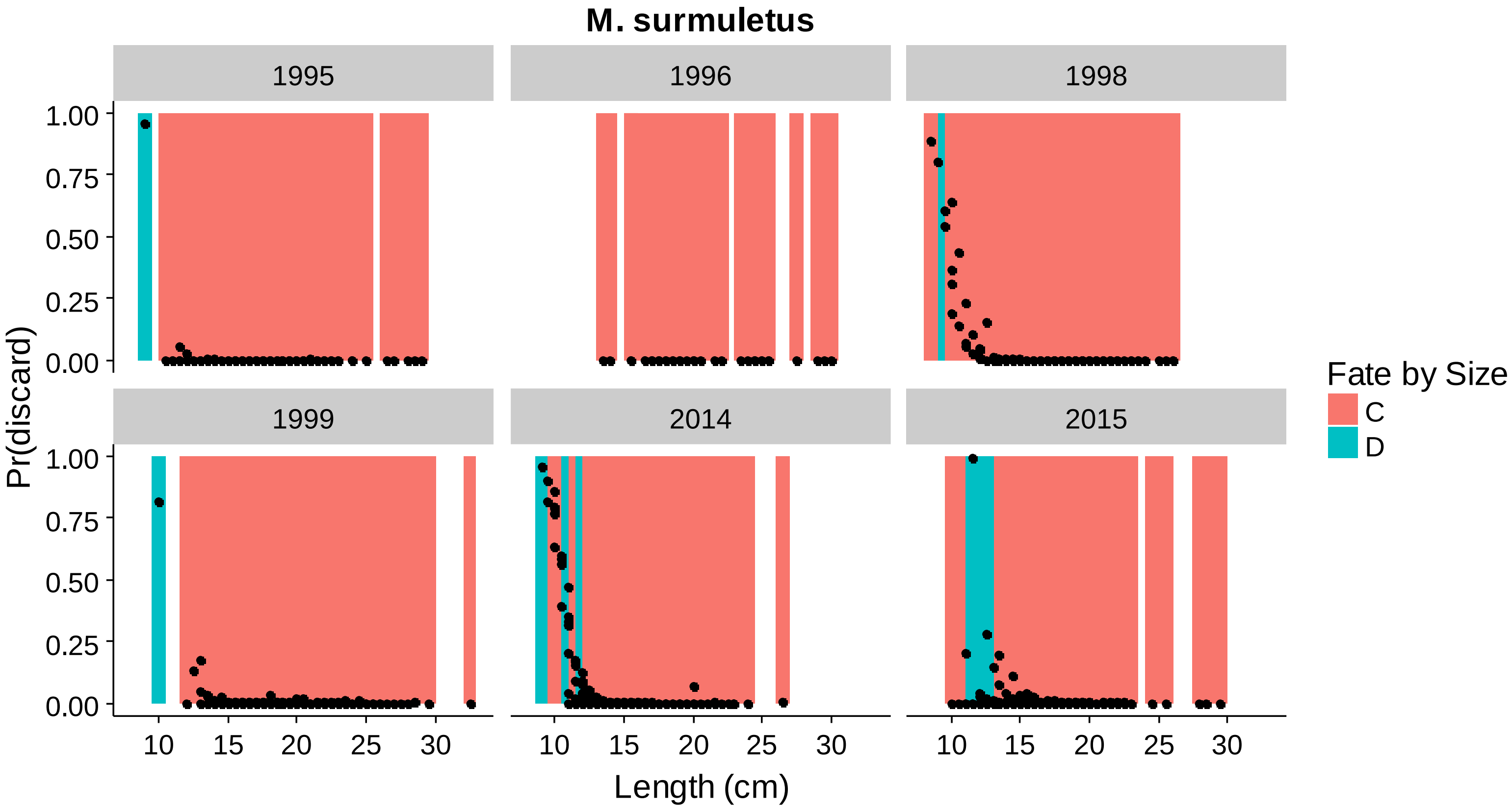
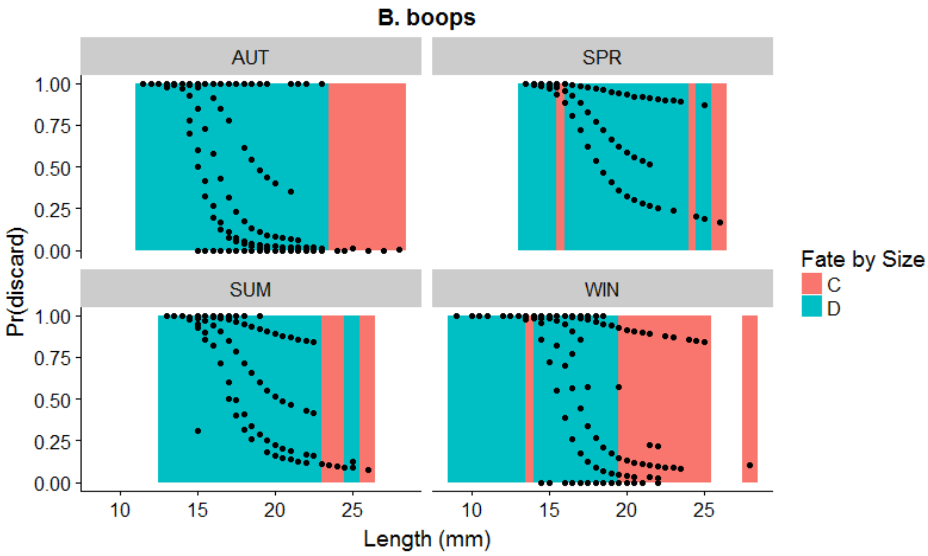
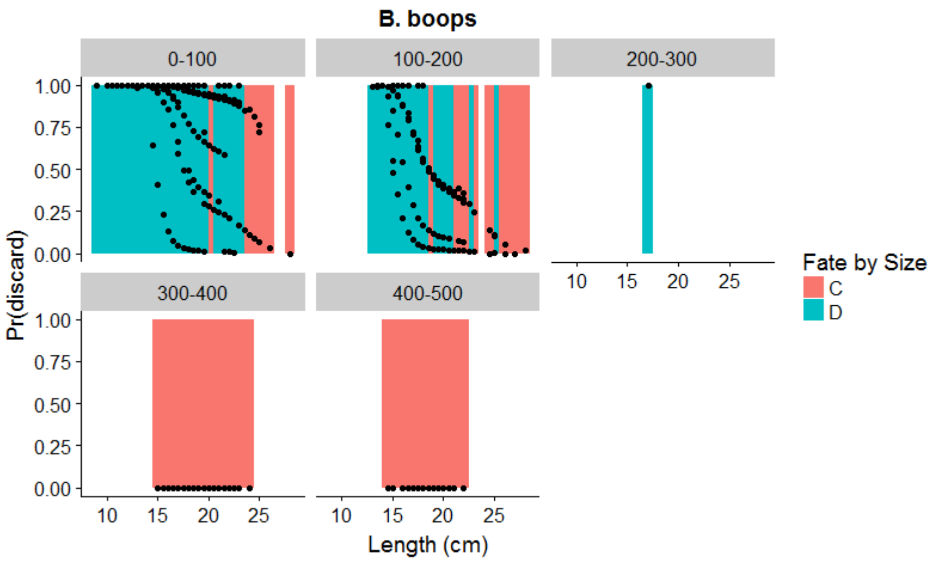


Figure S4h. GAM derived discard probability by total length with super-imposed discard ogive for striped red mullet (by year).

Boops boops


B. boops
AUT
SPR
SUM
WIN
Pr(discard)
1.00
0.75
0.50
0.25
0.00
10
15
20
25
Length (mm)
Fate by Size
C
D


B. boops
0-100
100-200
200-300
300-400
400-500
Pr(discard)
1.00
0.75
0.50
0.25
0.00
10
15
20
25
Length (cm)
Fate by Size
C
D

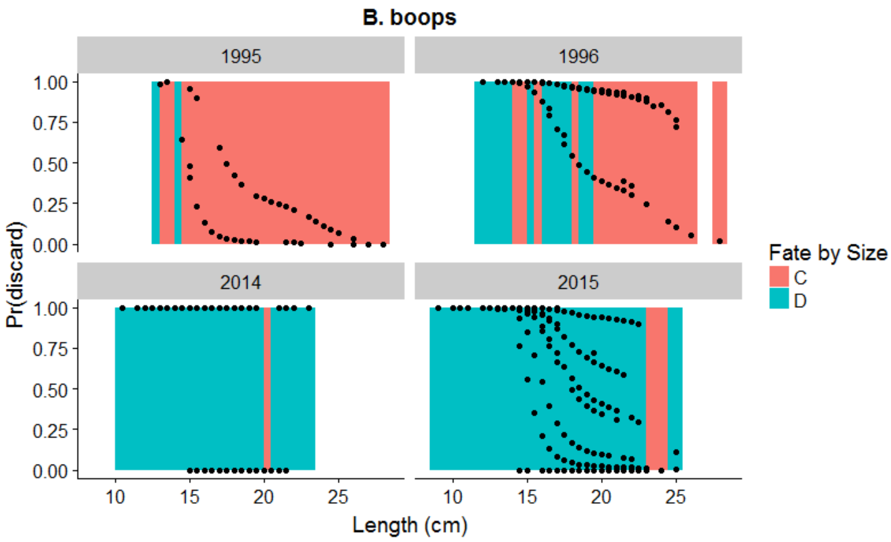


Figure S4i. GAM derived discard probability by total length with super-imposed discard ogive for bogue (top-by season, mid-by depth stratum, bottom-by Year)

The MINOUW Consortium

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