DISCATCH Final Project Report

Deliverable D0.6

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General information on the DISCATCH project

Starting date: 29/12/2013; End date: 29/09/2015; Duration: 21 months
Total project costs: 624,843 Euro; Requested Union funding: 499,875 Euro

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General description of the project components

Conservation standards for sustainable exploitation, within an ecosystem approach to fisheries management, increasingly urge the elimination of the wasteful practice of biomass discarding at sea. Understanding the reasons for discarding and identification of solutions to tackle the bycatches of unwanted species and specimens is essential if discards are to be eliminated without affecting the minimum requirements of conservation standards. To strengthen the scientific basis for the ecosystem approach to fisheries management the EU requires knowledge on the impact of fishing on the structure, functioning and services of the ecosystem as well as on the socio-economic aspect of innovations in fisheries technology and management. The current project will provide this basis. The success of this multi-disciplinary project, however, will critically depend on a clear a priori understanding of how these different topics are inter-linked and fit into the overall framework of the project.

The aim of DISCATCH will be to support the identification of viable solutions to address factors determining the catches of unwanted species and specimens in trawl fisheries with a view to reducing unwanted catches and eliminating discards. The main objectives of DISCATCH are:

- to provide an overall assessment of the fishing fleet discarding behaviour and to identify the main reasons for discarding in Mediterranean continental shelf demersal and small pelagic trawl fisheries.
- to identify measures, including technical ones related to fishing gear characteristics, to mitigate or eliminate bycatches of unwanted species and measures to eliminate discarding based on existing or new measures.

DISCATCH will cover seven non-adjacent Mediterranean sub-regions, as identified by the FAO Statistical Divisions, within the Western, Central and Eastern Mediterranean Basin, where relevant demersal and small pelagic trawl fisheries occur. For every Mediterranean sub region covered by this proposal, project will provide:

- a comprehensive review and analysis of scientific papers and technical reports covering fisheries for demersal and small pelagic fisheries in the selected area;
- a description of commercial yields, discard rates, selectivity parameters in relation to different mesh sizes/shapes and/or net structures through existing simulation models;
- a comprehensive analysis of the relevant data collected through the Commission Decision No 2010/93/EU adopting a multiannual Community programme for the collection, management and use of data in the fisheries sector. Where applicable, data shortcomings will be described in detail, and if needed, scientific surveys on board of commercial vessels to address such shortcomings will be performed;
- statistically significant sea trials, both for demersal and small pelagic trawls, supplemented by predictive simulation models to test the use of different mesh sizes, shapes and net structure.

To ensure that DISCATCH will provide a long term basis for partnership, all simulation models will be duly documented and will include clear visual outputs.

Executive summary

Review and analysis of scientific papers and technical reports on discards quantities, composition, practices and mitigation tools in the Mediterranean

Information concerning trawl fisheries discards in the Mediterranean Sea from scientific papers and grey literature, including technical reports has been collected. The review aimed to present an overview of the evolution of research projects on discards in the Mediterranean and to summarize available information in relation to discard ratios at the fishery and the species level, as well as on sizes of discards. Moreover, we identified reasons and factors for discarding and characterised mitigation tools and management measures for the avoidance of unwanted catches.

- the first projects started in the mid '90s involving partners from several EU countries. This increased standardization of methodologies. An important step was the integration of onboard sampling in the EU Data Collection Regulation. However, further standardization should take place, especially on raising methodologies;
- discards ratios in the EU Mediterranean bottom trawl fisheries are usually in the range 26-50% but there are cases with much lower (<20%) or higher (90%) ratios;
- discards ratios can highly fluctuate seasonally and/or annually as well as between fisheries and areas at local or basin scale;
- they also differ according to target species/group and gear used;
- discarded fractions of the so-called target species (e.g., hake, red mullets, red shrimps, rose shrimp, Norway lobster) are usually very low or even negligible (usually between zero and 10%) and comprise damaged or undersized specimens;
- nevertheless, most studies report relatively low proportion of key commercial (i.e. target) species in the catch. Thus commercial by-catch has usually higher discards ratios than the most valuable species; as an example, discarding for bogue and horse mackerels usually exceed 70% and 40% respectively;
- species-specific discards ratios also exhibit large scale geographical variations;
- despite the commercialization of several non-target species, a large number of species that are always totally discarded are included in the catch;
- discards L50s, the length at which 50% of the individuals are discarded, are small in the Mediterranean as they are based on massive catches of juveniles of certain species that can be sustained throughout the years; however there are important market demands for small individuals as well, often resulting in retaining individuals even smaller than the Minimum Landing Size;
- factors which may function as drivers for discarding were classified into four main categories, following previous suggestions in the literature: (i) natural and structural conditions, (ii) community, (iii) state (and regulations) and (iv) market, which they name "the institutional basis of discarding";
- these factors often act in synergistic effect which may not be straightforward to disentangle, especially in multi-species fisheries like most of those exerted in the Mediterranean;
- natural conditions (e.g., depth, productivity, substrate type), affect species composition, abundance and size structure of the catch, which in turn influence fishers' behaviour;
- fishing strategies and legal constrains substantially affect composition and quantities of discards;

- still, discarding in the Mediterranean is mainly regulated by market demands;
- geographical differences, apart from the effect of natural conditions, seem to be related to socio-cultural characteristics such as community welfare, nutritional habits and familiarization with some species, which affect market demands;
- mitigation tools mainly comprise selectivity improvement and spatio-temporal closures;
- several gear modifications (mesh size and shape, sorting grids, codend circumference) have been tested leading in an increase in mesh size during the last years, while trials are still ongoing since it is a dynamic field;
- spatio-temporal closures mainly aim the avoidance of charismatic species and/or undersized fish and invertebrates and can provide effective solutions;
- among the remaining mitigation tools the MLS mainly aims to discourage fishing juvenile fish, however it is possible that discards quantities increase in some cases due to discarding of unavoidable undersized catch;
- however, a whole set of tools, mainly awareness campaigns and economic incentives for more selective fishing (e.g., selective licensing, eco-labelling) are totally absent or have had very limited application in the Mediterranean Sea.

Data Collection Framework analysis

The main subject was represented by the particularities of inherent Mediterranean onboard sampling data, the exploration of data collection framework sampling strategies, precision and accuracy and different methodological approaches related to the analysis of discard data. Indeed, the use of modelling approaches to analyse the discard process might help to disentangle the effects of different drivers, allowing insights into the potential effectiveness of technological and area/time management measures for reducing fishery discards.

The purposes were:

1) to explore the possibilities of the use of a common format for Atlantic and Mediterranean EU seas, such as Fishframe format. Moreover, a review of Mediterranean fishery monitoring programmes under DCR and DCF EU regulations, allowed an exploration of their bias, weakness and gaps.
2) The use of Generalised Additive Models (GAMs) allowed to explore the main drivers of discard process through exploratory variables linked to spatial (for example linked to the position of nursery areas), temporal, technical (for example influenced by the selectivity process) and economic (for example linked to the economic values of the catches).

Using Hierarchical Bayesian models describe discarding behaviours and factors influencing discard rates on their spatio-temporal pattern. This study was focused in modelling total discards and discard ratio , in order to characterize the factors that influence discards. Although the Mediterranean fishery research group in the Regional Coordination Meeting for Data Collection Framework (*Report of the 10th Regional Coordination Meeting for the Mediterranean and Black Sea 2013, point 4.1: Regional database: update/actual status since 2012, and Annex III*) as a responsible working group implementing the EU Commission questions and reweaving the data collection framework (DCR/DCF) and development in the different countries at generic terms, was expressed their intention to maintain a separated database at different aggregation levels and with different accessibility from countries to EU level, it could be interesting to create a working group to bring postures closer in order to establish common and comparable data framework to catch and discard data over different aggregation figures for the Atlantic and Mediterranean countries.

Quality data, spatial and temporal coverture, sampling intensity, and fishery data availability analysis indicates a common basic information from on-board sampling programmes for the Mediterranean countries. Notwithstanding it will be improved throughout establishing different basic step by step procedures to gathering data. Based on models information it will be improved discards rates estimation and spatial and temporal discards estimation by species distributions particularities for the trawl Mediterranean fishery. On the basis of analysis carried out, a more in deep exploration of the selectivity parameters of the fishing gears, of the consequences of different mesh sizes on the amount of discard and on the population at sea would be needed.

Predicting commercial yields, discards rates and selectivity by towed gears from fishing gear characteristics

The most advanced simulations models in FISHSELECT (Herrmann et al., 2009), which can simulate the basic size selective properties for nettings with arbitrary mesh shape and size for different fish species, have been used. For trawls these methods are developed so as to provide reliable predictions (Herrmann, 2005; O'Neill and Herrmann, 2007). The specific objectives are: i) to predict the expected size selectivity of a range of species for many different codend constructions (e.g. mesh sizes, mesh type, twine thickness); ii) to validate the model results using selectivity data from both the pelagic and demersal fisheries. We analysed currently legislated codends and different designs not tested at sea. We estimated the selectivity propriety for three different mesh geometries: diamond-, square- and hexagonal-mesh. A total of 11 species were investigated: 2 pelagic (anchovy and sardine), 5 demersal fish species (hake, Mediterranean horse mackerel, European horse mackerel, red mullet, striped red mullet and 4 crustaceans species (giant red shrimp, red shrimp, deep-water rose shrimp, Nephrops). Simulation results allowed us also to conclude that in most Mediterranean bottom trawls, opening angle of diamond mesh codends usually spans from 25° to 60°, with majority being between 30° and 40°. Finally, the basic selective propriety of each mesh, were collected in a design guide, which are plots showing simulated L50 as isocurves for a range of mesh size versus mesh openings for each mesh type. The design guide can be used to identify the conditions required to obtain a specific and constant selection during a fishing process and therefore they are critical for management purposes, because they allow setting the desired selection parameter ranges based on the two key technical parameters.

Quantifying, modelling catch and discard composition in trawl net fisheries

BEMTOOL simulation approach

BEMTOOL simulation approach has been used in the DISCATCH project with the aim to forecast the effect of different mesh sizes/shapes scenario on spawning stock biomass of target species, commercial yields and discards rates, as well as to assess the different performances of selected technical measures on population, production and economic indicators. Three case studies have been implemented: on the demersal fishery of GSA 18 (south Adriatic), in GSA22 (Aegean Sea) and on GSA16 (Strait of Sicily). As reported in the EU-LANDMED project (2015), the results of the selectivity study confirmed the lack of size selectivity for the mid-water trawling and purse seiners; for these two gears the increases in selectivity is very difficult to achieve. The use of large meshes in the codend has been tested in the Chioggia harbor with results not satisfactory. In fact, if large meshes are used in the codend of pelagic trawl, there could be the possibility that the anchovies entering the codend can be gilled or enmeshed. For this reason, simulations have been carried out only for demersal fisheries case studies of Table 1 in WP 3, as for demersal species gear selectivity can be considered a technical measure able to contribute at improving the exploitation pattern of the affected stocks.

In GSA 18 (target species European hake, deep water pink shrimp, Norway lobster, red mullet) and GSA16 (target species European hake, deep water pink shrimp, and giant red shrimp), for status quo scenario a diamond mesh of size 50 mm have been assumed and then compared to:

- a square mesh of size 50 mm;
- hexagonal mesh of size 50 mm.

The selectivity of the other gears remained unchanged in the projections. In GSA 22, for status quo scenario a diamond mesh of size 40 mm has been assumed and then compared to:

- a diamond mesh of size 50 mm;
- a square mesh of size 50 mm;
- hexagonal mesh of size 50 mm.

The selectivity of the other gears remained unchanged in the projections. The scenarios of improved selectivity were designed for four species (Hake, Deep-water pink shrimp, Red mullet and Horse mackerels). The BEMTOOL simulations allowed exploring the effects of different selectivity scenarios on the relevant indicators. In particular, the focus was on SSB, overall catch, landing, discard, discard ratio, mean length in catches, revenues and average wage indicators. The main findings of BEMTOOL can be summarized as follows.

- The 40D mesh represents the configuration producing the smaller level in SSB respect to the other configurations, while the 50S mesh size corresponds to the highest improvement in SSB;
- In the medium term the 50S mesh allows to obtain the highest catches, while the 40D the lowest;
- In the short and medium term the 50S mesh allows to obtain the lowest discard amount and discard ratio, while the 40D mesh the highest;
- The increase in mesh size of trawlers determines an improvement of the catches also of the other gears, because the smaller individuals left by the trawlers are left to growth and are then available to them, thus can be caught at higher sizes by all the gears (trawlers and not);
- The 40D mesh represents the configuration producing the smaller mean length in catches respect to the other configurations, while the 50S mesh size corresponds to the highest mean length, that in turns could implies more valuable products ;
- The 40D mesh represents the scenario producing the lowest revenues and average wage, while the square scenario corresponds to the highest ones;
- For all the points the hexagonal mesh gives intermediate results.

For the case study in GSA 22 the two approaches BEMTOOL and EwE have been applied in a complementary way, i.e. the outputs of the bioeconomic population model in terms of fishing mortality by fleet and species for the different harvesting scenarios are used in the ecosystem model to design the scenarios in respect to the reference scenario (gear mesh size 40D). The specific objective of Task 4.2 of DISCATCH was to investigate ecosystem effects of improved trawl selectivity in the NAS.

Ecosystem modelling integrates available information to study direct and indirect trophic interactions among ecosystem compartments, including fishing activities and the environment. We used as basis a previously developed Ecopath model representing the North Aegean Sea ecosystem in the mid-2000s in order to construct a model for the early 1990s and to further develop its time dynamic module (Ecosim) calibrated with time series. This calibrated model aims to constitute a tool to investigate policy options towards an ecosystem-based management of fisheries in the North Aegean Sea.

- The 1990s model has 40 Functional Groups (FGs) (38 living FGs, and two detritus FGs) and considers five fishing fleets: (1) bottom trawls, (2) purse seines, (3) static nets, (4) longlines and troll baits and (5) pots.
- Input data included bottom trawl and other surveys, landings and discards information, as well as information on biological parameters and feeding habits from the literature.
- Time series of biomasses for the period 1993-2008 were used to calibrate the model in the sense of optimization of the trophic interactions among the FGs. Fishing effort data (1993-2010) and an environmental anomaly variable were used to drive the model.
- Increasing trends under the improved selectivity scenarios were observed for Total Catch, Catch/Biomass and Fisheries in Balance index, while the mean Trophic Level of the Catch was almost constant. According to these, the ecosystem wide exploitation status showed improvement under increased selectivity.
- The biomass of shrimps decreased in the short term but increased in the long term, red mullets were relatively constant while small and large improvements were simulated for hake and horse mackerels respectively. These responses were the result not only of modified F but also of changes in predation, prey availability and competition.
- Yield decreased for these four species except horse mackerel whose population increase was large enough to overcome the decrease in F.
- Spill-over effects concerning biomass and yield were observed for several FGs. Total biomass increased -depending on the scenario- by 0.5-2% and by 0.9-3.9% after five and ten years of simulations respectively. The increase in total yield was higher and reached 2-7.8% in the long term.
- Improved selectivity seemed to affect the whole spectrum of the food web, including mid and high trophic level functional groups (FGs) but also pelagic and demersal/benthic ones. This is because of the complexity of the food web and the benthic-pelagic coupling. The FGs that seemed to benefit more were top predators while the biomass of prey FGs decreased in most cases.
- Among the scenarios the 50S had the best response on the food web and the ecosystem components, while 50S and 50H showed similar results, slightly improved compared to the reference one (40D). These improvements were more obvious in the long term (decade). It seems that the ecosystem as a whole and its components could benefit from improvements in selectivity but benefits may not be evidenced immediately.

Ecopath with Ecosim approach

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- Time series of biomasses for the period 1993-2008 were used to calibrate the model in the sense of optimization of the trophic interactions among the FGs. Fishing effort data (1993-2010) and an environmental anomaly variable were used to drive the model.
- The scenarios of improved selectivity for four species (Hake, Deep-water pink shrimp, Red mullet and Horse mackerels) were set based on the BEMTOOL outcomes from DISCATCH Task 4.1. These included (i) a reference scenario with 40mm Diamond (40D) mesh which was applied in the area at least until 2010, (ii) a 50mm Diamond mesh (50D) which is stated in the the EC Reg. 1967/2006 and two more selective mesh configurations (iii) 50mm Square (50S) and (iv) 50mm Hexagonal (50H). Relative (compared to the reference scenario) fishing mortalities from BEMTOOL outputs were used as inputs for the EwE scenarios.
- Increasing trends under the improved selectivity scenarios were observed for Total Catch, Catch/Biomass and Fisheries in Balance index, while the mean Trophic Level of the Catch was almost constant. According to these, the ecosystem wide exploitation status showed improvement under increased selectivity.
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Framework and synthesis

An evaluation of national discards programs has been done by identifying all potential loopholes in methodology. Different technical and environmental factors that influence discard rates have been identified and summarized. Furthermore, selective properties of demersal and pelagic trawls have been summarized in relation with the MLS and landing obligation Regulation, in order to assess the efficacy of these technical measures. Finally, the stakeholder's perceptions on the discard issue and their opinions and options have been integrated. The main results achieved have been:

- Discard amount fluctuates among fisheries and areas, usually from < 20 % to 70 %, due to a biological, technical, environmental, legal and socio-economic factors.
- The complexity of the fishing activity in the Mediterranean basin is influenced by many factors: multi-target species, the geographical peculiarities, the multi-gear use, the seasonality etc.
- The Mediterranean onboard national discard programmes seem to have low levels of bias in the sampling protocols, with the higher level of risk of bias linked to low sampling coverage and landings and effort statistics.
- Discarding in the Mediterranean is affected by numerous reasons and several factors which is difficult to disentangle (commercially unimportant invertebrate and fish species, commercially important but undersized species (under MLS), commercially important species which fishermen could not sell on the market or have very low market price).
- High regional, seasonal and interannual fluctuations are observed even within the same fishing gear.
- Increased discarding of some species has been reported during the recruitment period when they migrate from shallow waters to off-shore areas accessible to bottom trawling.
- Fishing depth has been greatly related to patterns in discarding, obviously due to varying catch composition and the relative biomass of target species in the different depth strata even if there doesn't seem to be a constant pattern related to the depth stratum for the whole basin.
- The availability of resources, sometimes affected by the status of the stocks, has been shown to affect fluctuations of market demands and associate discarding practices.
- Fishers' attitude, approaches practiced and experience, both the captain's and the crews have been also shown to affect discards.
- Nutritional habits of the community affect fishing and discarding practices. At small scale, some species may be marketable only in some areas.
- At larger scale, discards ratios for trawls are generally lower in the easternmost and southern basin.
- The low level of discarding of MLS-regulated species in certain Mediterranean trawl fisheries may be a consequence of a quota-independent management system of demersal trawl fisheries and, even more importantly, a consequence of low compliance by fishermen and weak control and enforcement in certain areas.
- Market demands rather than fish size (legal reason) determines what is discarded in Mediterranean fisheries.
- The existing MLSs are ecologically inefficient for sustainable management and MCRS should be redefined for several species.
- Mediterranean trawling produces the bulk of discards and this is the reason why most studies focus on trawling activities. In general, fisheries targeting fish or mixed categories presented higher discard ratios compared to the ones targeting shrimps. Several shrimp fisheries operate throughout the Mediterranean with varying generation of discards according to the species targeted and the depth stratum that they operate
- The majority of selectivity studies were focused on the species that have highest commercial values; some studies show that a simple change from a 40 mm diamond to a 40 mm square mesh improves the selectivity for some target species, it also results in economic losses due to escapement of some accompanying species;

- The MLS of species commonly caught in Mediterranean trawl fisheries are not harmonised with the species length at first maturity, indicating that most of the species that are caught are not allowed to spawn at least once in their life time.
- All these suggest that current codends used in Mediterranean trawl fisheries are not adequate and that some additional improvements in selectivity are needed.

The deliverable *D 0.2. A working document on factors affecting the selective behaviour related to discarding* offered the opportunity to contribute further to our understanding of factors that drives fishers' behaviours to a higher or lower discard level and also towards exploring effective discard mitigation measures. The main results achieved have been:

- At the level of the fisher, the act of discarding involves a short term economic decision
- Economic, regulatory and environmental/natural factors, as well as individual characteristics related to the fisher, fishing operations and vessel seem to have a synergistic effect in the decision-making process of discarding, which is sometimes difficult to disentangle.
- The efficacy of technical measures (eg. Minimum Mesh Sizes (MMSs), Minimum Conservation reference Sizes (MCRSs), closed areas and seasons) mainly depend on the level of rule compliance and enforcement effort, on the collaboration between fishermen and the willingness of fleets to share information.
- Stakeholder engagement showed that cost compensation, commercialising species caught in a sustainable manner and overall economic incentives have been seen positively as potential interventions.
- Concerns have been expressed about providing discards to the fishmeal industry and aquaculture, needed facilities and infrastructure and control/fines, which are already strict. The main concern was that if the landed discards can be re-used for other purposes, (fishmeal for instance), fishermen will be stimulated to catch more fish.
- Reducing discarding is a complex issue which involves combinations of management measures (e.g., use of avoidance and gear selective strategies along with campaigns to increase awareness) or a single method/tool.
- Reducing discards should be designed for specific fisheries and fleet characteristics and may differ between regions.
- Reducing discards should incorporate stakeholders' knowledge and in particular fishers since they have unique knowledge concerning local features, needs and better understanding of impacts of measures.
- Reducing discards should take human behaviour into account as an important source of variability.

In the deliverable *D 0.3. Report on the management options for the discard reduction* different combinations of scenarios developed in each study area/fleet that will advise on the effects of selectivity-related management measures have been reviewed together with the results obtained from the two stakeholders meetings.

- Approaches contributing to discards mitigation in the Mediterranean mainly comprise technical measures, which are related to improvement of selectivity and/or avoidance of potential hot spots of discards.
- Technical measures may be gear- and fishery-specific and their application should be tested in different areas

- Trawl selectivity indicator graphs provide a good opportunity to compare MLS and lengths at first maturity. The results show that the Lengths at first maturity for the investigated DISCATCH species for the majority of species show that MLSs are well below the size at first maturity.
- This goal can be achieved by promoting bottom trawl replacement with more selective fishing gears or promoting changes to the selective performance of bottom trawling through technical changes (square mesh codend, sorting grids etc.).
- Many studies highlight the advantages of the use of a square mesh instead of a diamond shaped due to the fact that square mesh tends to keep shape and stay open, better than diamond mesh.
- The existing MLSs are ecologically inefficient for sustainable management; thus, the selective performance of bottom trawls in the Mediterranean Sea should be improved in order to fulfil ecological and biological targets.
- Spatio-temporal closures for specific fishing gears exist and they usually aim to protect juvenile fish
- The designation of spatio-temporal closures in the GFCM area is not always based on scientific criteria and they often try to satisfy social demands. A more targeted designation, based on scientific results may prove more effective in by-catch reduction and fisheries management in general
- The results of stakeholders meeting show that there is not a clear trend of the topics that stakeholders consider as having a paramount importance.
- The costs to shift from the traditional to more selective gears is the most important topic for stakeholders, who consider any modification of the gear needed to reduce discarding should be funded by the national authorities or by the EU.
- Stakeholders seem to be not available to pay for more selective gears; on the other hand they also consider that retaining and selling undersize fish shall not increase their income, mainly because the undersized fish products are not effectively utilized.
- Stakeholders consider the current design of bottom trawl gears as highly unselective and they seem to be well aware of the potential positive effects of improving selective form an ecological (discards reduction, positive effects on the biodiversity) as well as technological (better catch quality and marketing opportunities, reduction of time devoted to sorting the catch ecc.) point of view.
- The stakeholders consider the maintaining of a safe level of reproductive potential as one of the main management objectives while the discards reduction is perceived as a minor issue.
- As regards the ecological indicators the most important issue seems to be the “mean size of the spawners”.
- Considering the economic indicators, the stakeholders gave their preference to “revenue” in comparison to “production” and to “fuel costs” in comparison to “crew costs”.
- Stakeholders consider the “fleet withdrawal” (scraping) as the worst option for the management strategies to achieve a sustainable fishery management in the long term
- The combination of three measures is considered as the best option: Spatial fishing ban (Protection of nursery and spawning areas), seasonal fishing ban, improved gear selectivity.
- Overall, the stakeholders do not consider the discards ban implemented in the framework of EU Reg. No 1380/2013 as a proper management measure to improve the status of the commercial stocks since: 1) there is uncertainty on the long term gains; 2) the retaining and selling of undersized fish will not increase their income; 3) the compliance with the EU provision will not easily be achieved.

Establishment of stakeholders' platform and project information management

The consortium partners, who represent considerable expertise in the fishery science and a range of key stakeholders, organized in a multi-stakeholder platform (MEDAC, Mediterranean Advisory Council) have interacted in this project to make sure scientific findings were grounded with real and up-to-date knowledge of what happens at sea, such as the one fishermen have. The multi-stakeholder platform to ensure interaction with all relevant stakeholders in the fishery sector has been established through the organization of a more interactive website used to inform and get feedback from stakeholders. In addition, the organization of two large multi-stakeholder events ensured the interaction between stakeholders and scientists at the beginning using a survey with a questionnaire and at the end of the project using Multi-Criteria Decision Analysis (MCDA) techniques to address and finally consent on complex issues among many participants, with different background, knowledge and, sometimes, conflicting objectives or preferences. Bottlenecks, challenges, and solutions or mitigation strategies were presented at the stakeholder events based upon state-of-the-art of knowledge for the sector.

Review and analysis of scientific papers and technical reports on discards quantities, composition, practices and mitigation tools in the Mediterranean (WP1)

Review of existing information on discards from demersal and small pelagic trawl fisheries, with reference to data sources, monitoring processes and methodological analysis (Task 1.1)

In the framework of this task we collected information concerning trawl fisheries discards in the Mediterranean Sea from scientific papers and grey literature, including technical reports. All partners were in close collaboration and the allocation of work was based on geographic criteria. The information concerned three aspects.

First we summarized information on monitoring and research projects which were either partly or exclusively related to fisheries discards. The collected information included the scope, the time period, the season(s), the technical characteristics of the gears examined, the number of hauls or trips as well as the raising methodology (if any) of each project. This information was the basis for a discussion on the evolution and comparison of the different methodologies applied in the Mediterranean Sea.

The first projects started in the mid '90s and were EU funded, while several of them concerned cooperation of more than one EU countries, such as Spain, Italy and Greece. Soon after, few national projects took place (especially in Spain) aiming at the study of discards and/or gear selectivity. Even though studies on discards were scarce before the 2000s, much progress has been made in recent years after (i) the establishment of the Ecosystem Approach to Fisheries (EAF) as an integrated management approach that considers the entire ecosystem as well as (ii) the implementation of the EU Data Collection Regulation (Commission Regulation (EC) No 1639/2001; currently, Data Collection Framework, Council Regulation (EC) No 199/2008).

Despite the majority of the projects covering only a narrow time period, a regular succession after their initiation ensured the existence of important time series in most EU areas. Furthermore, monitoring programs gradually switched their focus from fleet-based to métier-based level (STECF, 2008), the importance of the latter being obvious considering the high variability of discards across gears, seasons, and targeted assemblages. As a result of the almost simultaneous implementation of discards projects in several countries, along with the international cooperation of scientists, efforts of standardization of sampling methodologies and analyses took place. Despite some common methodologies differences are still obvious. These include, among others (a) the sampling intensity, (b) the target categories, (c) the time periods examined, (d) the sampling design (stratified, random or a combination of both) (STECF, 2008) and (e) the raising methodologies.

Raising of discards to the whole fishery level is important particularly for stock assessments and management measures, however, only few studies have tackled this issue. Raising can be estimated based on landings or effort, using simple or advanced statistical techniques. Lately, the applications of advanced statistical techniques, such as Bayesian models, are becoming more popular since they offer a better quantification of the uncertainty and more accurate predictions (Pennino et al., 2014). Therefore, the standardization of such methods is an important field for future works in the Mediterranean. Moreover, additional parameters such as weather conditions and state of the discarded individuals, which affect discarding and are currently not regularly collected, should be included in the relevant protocols.

Discards at the fishery level

The second step concerned information on discards at the fishery level. We focused on studies that examined discards ratios (discards/total catch; total catch includes retained plus discarded catch) for the whole community, not accounting for species specific information. As most of the trawl fisheries (especially bottom trawl) are multi-species in nature, the definition of target-species is usually not a straightforward approach, thus we followed an expert-based knowledge approach when we refer to target species/category.

Information on discards ratios (discards on total catch) from several Mediterranean bottom trawl fisheries was collected and presented by Country and Geographical Sub-Areas (GSA according to GFCM division; see Figure 1). Additional information on the fishery under study (operating depth, target category, cod-end characteristics) as well as on the sampling (period, seasons) was compiled when possible. Most of this information comes from EU Mediterranean countries, especially Spain, Italy, Croatia and Greece while four non EU countries (Turkey, Egypt, Israel, Syria) are also represented. Based on this information we tried to identify some similarities and differences in discarding, and infer conclusions, where possible.

Regarding otter trawls, several studies from the Eastern and Southern Mediterranean but also from the EU Mediterranean report discards on total catch ratios no more than 20%. These values are in general lower compared to the majority of trawl fisheries from the EU Mediterranean where discards are usually in the range 26-50% and may even reach 90% in exceptional cases. Obviously, there is a high range of discards ratios and even within the same fishery or area the discards ratio can highly fluctuate seasonally and/or annually as evidenced by results in e.g., the exhaustively monitored Spanish Mediterranean.

Geographic and temporal differences are due to environmental characteristics such as substrate type, depth and productivity, which affect the species composition of the communities, as well as due to fishing practices (gear type and target species), commercial preferences and socioeconomic factors (Tsagarakis et al., 2014). Overall, discards ratios in the Mediterranean are similar to values from European Atlantic trawl fisheries (Uhlman et al., 2014). In D1.1 we also categorized fisheries based on the target species/group.

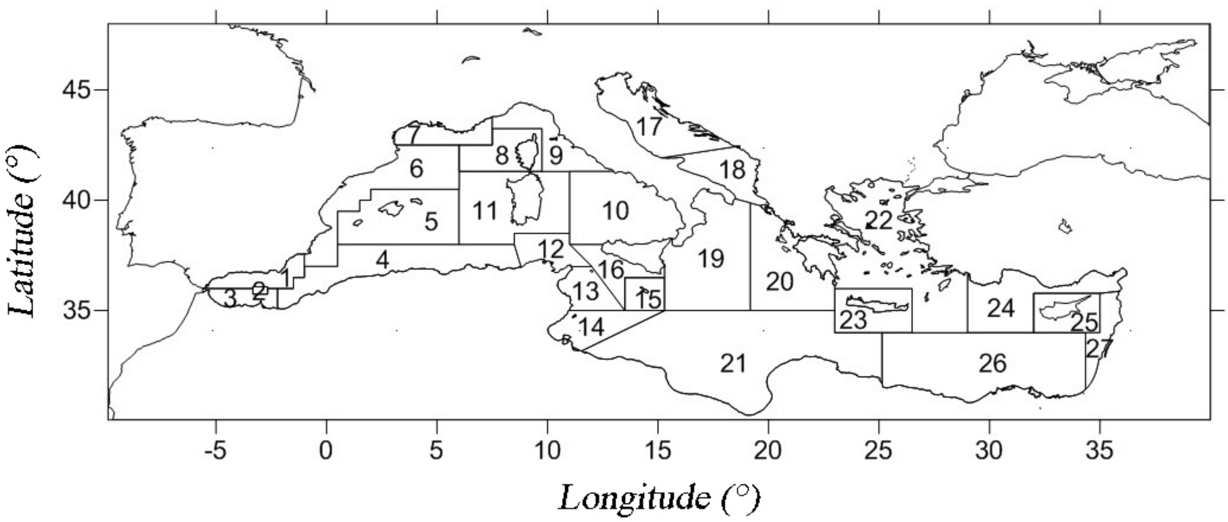


Figure 1. Geographical Sub-Areas (GSA) according to GFCM division.

The discards ratio for bottom trawl fisheries targeting i) fish, ii) fish and invertebrates, iii) fish and decapods, iv) fish and cephalopods, v) decapods or vi) NA - when the target category was unknown - is presented in Figure 2. In general fisheries targeting fish or mixed categories presented higher discards ratios compared to the ones targeting shrimps (Figure 2). However, it must be noted that i) there is high variability in the discards ratios in all categories, as evidenced by the high standard deviation (Figure 2) and ii) there is high heterogeneity in the species composition in the categories we have used, which limits the importance of these findings.

Furthermore, different gears, may present quite different discard rates. Even if the majority of bottom trawl fisheries use otter trawls, some beam trawls, rapido trawls and other modified trawling gears operate regionally exhibiting varying discards ratios. As concerns midwater trawls, discards studies are extremely scarce. Santojanni et al. (2005) estimated 2-15% mean annual discards ratio for sardine (*Sardina pilchardus*) from purse seine (*lampara*) and mid-water trawl (volante) fisheries in the Adriatic. On the other hand, high temporal and spatial fluctuations were observed with the highest discards ratio for sardine caught with mid-water trawls estimated at 53% in the Ancona fleet (ranging from 1% to 90% in a single year).

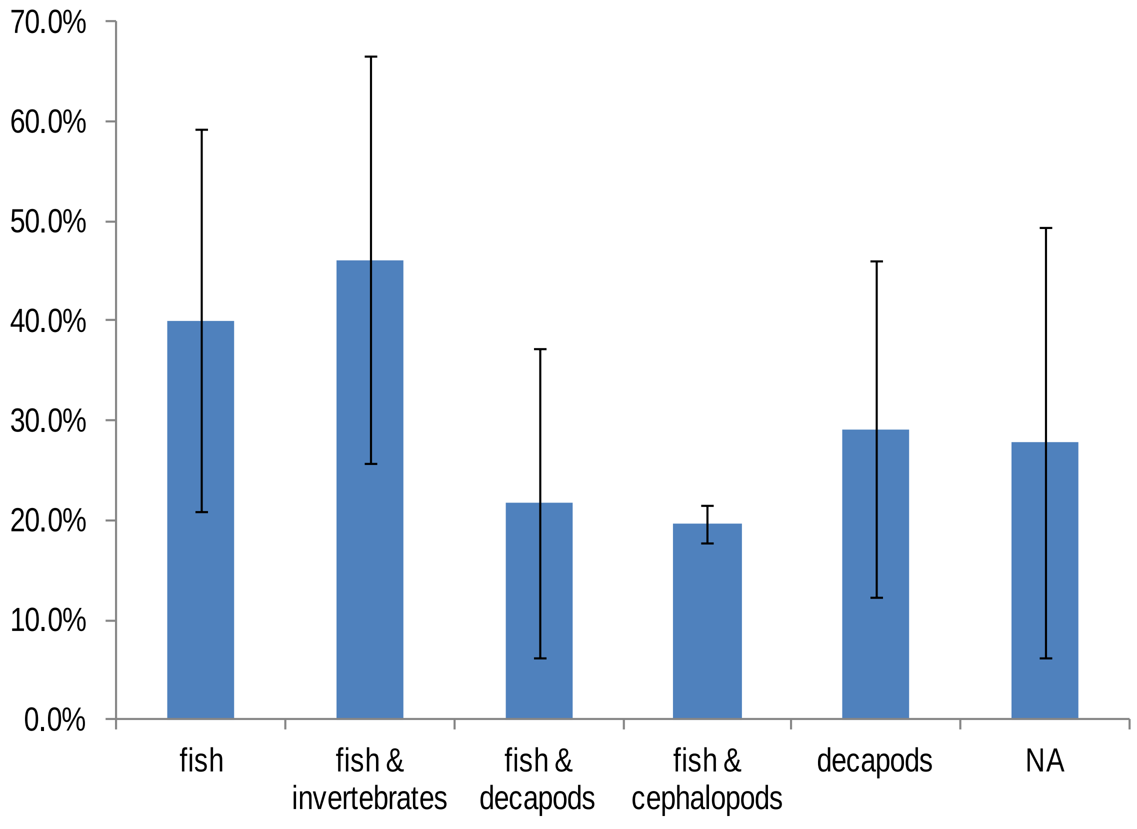


Figure 2. Discards ratios (% Discards/Total catch) for bottom trawl fisheries by main target category. "NA" category includes all fisheries where information on the target category was not available. Error bars are standard deviation.

Discards at the species level

Finally, we collected information from several studies that have reported species specific discards ratios. This information is important because species specific discards may vary greatly, from zero (for some highly commercial species in some fisheries) to total discarding (for non-commercial species). In addition, commercial by-catch is important in most fisheries and constitutes a substantial source of income for the fishers, thus such ratios, which are mainly regulated by market demands and catch composition, may greatly vary seasonally or geographically.

In our review we tried to focus on a) the species with the highest commercial importance, b) charismatic fish species (elasmobranches) and c) some abundant by-catch species with commercial fraction. Where possible, we also reported information on lengths of discards, i.e. length range or L50 (the length at which 50% of the individuals are discarded). Figure 3 summarizes Mediterranean-wide discards ratios for some decapods, bonyfish and elasmobranchs based on the information that was collected; both target species, such as hake, red mullet and red shrimps, and some abundant commercial by-catch species (bogue, horse mackerels) were selected for this analysis. Great differences are observed among species. In general, discarded fractions of the so considered target species (e.g., hake, red mullet, red shrimps) are usually very low or even negligible and comprise damaged or undersized specimens.

Discards ratios for red shrimp, hake, red mullet Norway lobster and rose shrimp are very low (usually <10%). Nevertheless, most studies report relatively low proportion of key commercial (i.e. target) species in the catch, even in cases that target species are clearly defined, while a large fraction of commercial by-catch is usually included. This commercial by-catch has usually higher discards ratios than the most valuable species; as an example, discarding for bogue and horse mackerels usually exceeded 70% and 40% respectively (Figure 3).

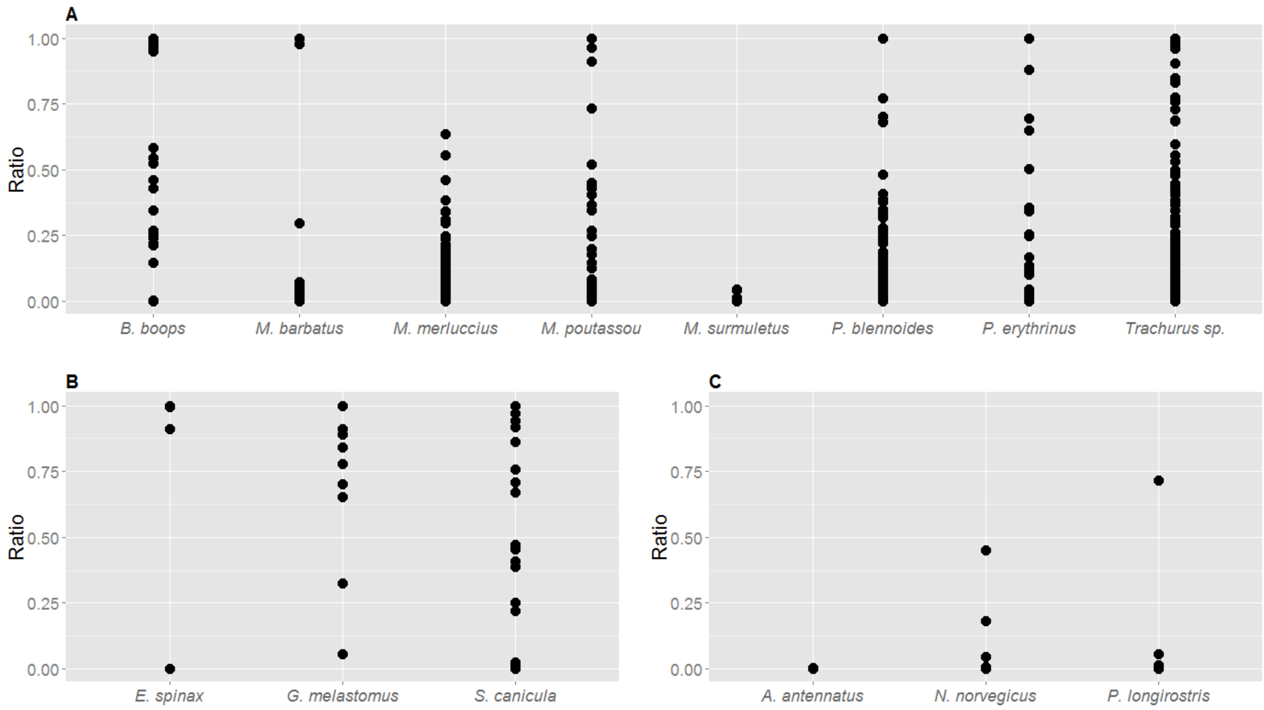


Figure 3. Discards ratios (discards/total species catch) in Mediterranean bottom trawl fisheries for some bonyfish (A), elasmobranch (B) and decapod (C) species.

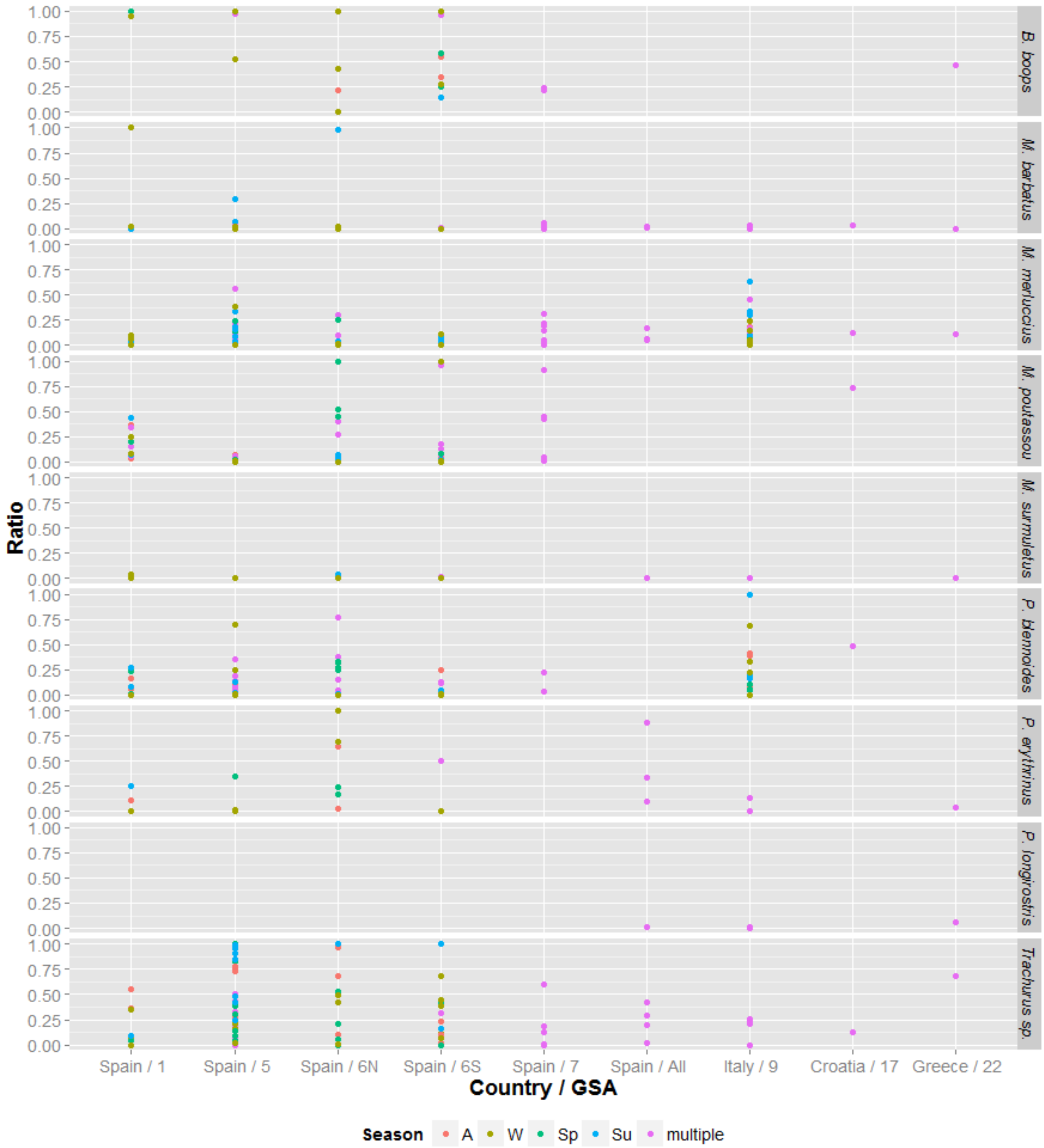


Figure 4. Discards ratio for the main target species and bycatch species with commercial importance, per GSA. The season of sampling is indicated with different colours

Species-specific discards ratios also exhibit geographical variations, as seen in the analysis of discards ratios per GSAs (Figure 4). These fluctuations are influenced by ecological and biological factors (catch composition, length frequencies of the populations) as well as by economic and socio-cultural traits which eventually affect market demands. Despite the commercialization of several non-target species, a large number of species that are always totally discarded are included in the catch. Information on lengths at discarding was also collected in Task 1.1 and L50s, the length at which 50 % of the individuals are discarded, were presented for some of the target and most important commercial bycatch species (Figure 5). In general, L50s are small in the Mediterranean due to the low sizes in the basin; however there are important market demands for small individuals as well, often resulting in retaining individuals even smaller than the Minimum Landing Size (MLS). Species specific lengths at discarding are linked to the market value of the species. For example, even though the body size (e.g. in terms of maximum length) of hake is larger than the one of horse mackerel, small individuals of hake are retained in contrast to horse mackerel (Figure 5).

Similarly, *A. antennatus* presents similar (even smaller in several cases) retention sizes than *P. longirostris* (Figure 5), despite the fact that the latter is a species with generally smaller body size. The level of discarding of MLS-regulated species, such as hake, among Mediterranean otter-trawl fisheries is lower in relation to other EU regions (Uhlmann et al., 2014) which may be a consequence of smaller MLS applied in the Mediterranean, a lack of MLS-compliance, and the absence of over-quota discards in a quota-independent management system of Mediterranean demersal trawl fisheries. Finally, species specific lengths at discarding also differ among areas; for example L50 of hake is higher in Greece compared to Spain and Italy (Figure 6) suggesting differences in discarding practices.

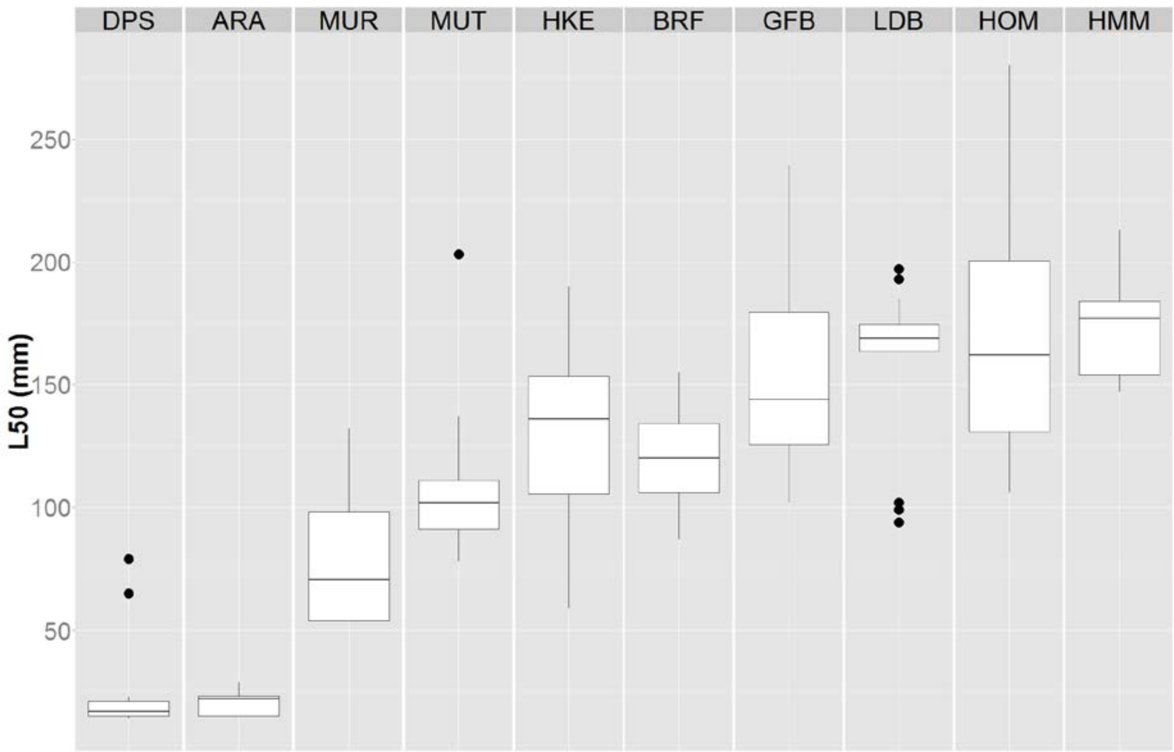


Figure 5. Box-plots of L50s (lengths at which 50% of individuals are discarded) records for some main decapod and fish species, overall for the whole Mediterranean. See. L50s for crustaceans (DPS, ARA) refer to carapace length while for fish to total length.

All this information was presented in the deliverable *D 0.1. Review on fishery discards from Mediterranean demersal and pelagic trawl fisheries with particular reference on processes adopted for sampling and analysis*, which was submitted in early July 2014. In this deliverable, apart from the description of the methodology, the presentation of the results and a discussion, several tables were included in the appendix. These presented:

- an inventory of discards projects per country and GSA (50 records);
- discards ratios at the fishery level (194 records), with additional information for each fishery considered, if available;
- species specific discards ratios for bottom trawl fisheries in the Mediterranean (920 records);
- lengths of discards per species (262 records).

The task is completed with the submission of the deliverable *D 0.3. Draft paper for a peer-reviewed journal on the existing knowledge of fishery discards, the associated factors and reasons, and the implemented management tools*, a draft paper for a peer-reviewed journal on the existing knowledge of fishery discards, the associated factors and reasons, and the implemented management tools. D1.3 aims to present the findings of (mainly) D1.1 and *D 0.2. Review on factors, reasons and mitigation measures associated with fishery discards from Mediterranean trawl fisheries* and has to be in form of a scientific paper suitable for publication in peer-reviewed journal.

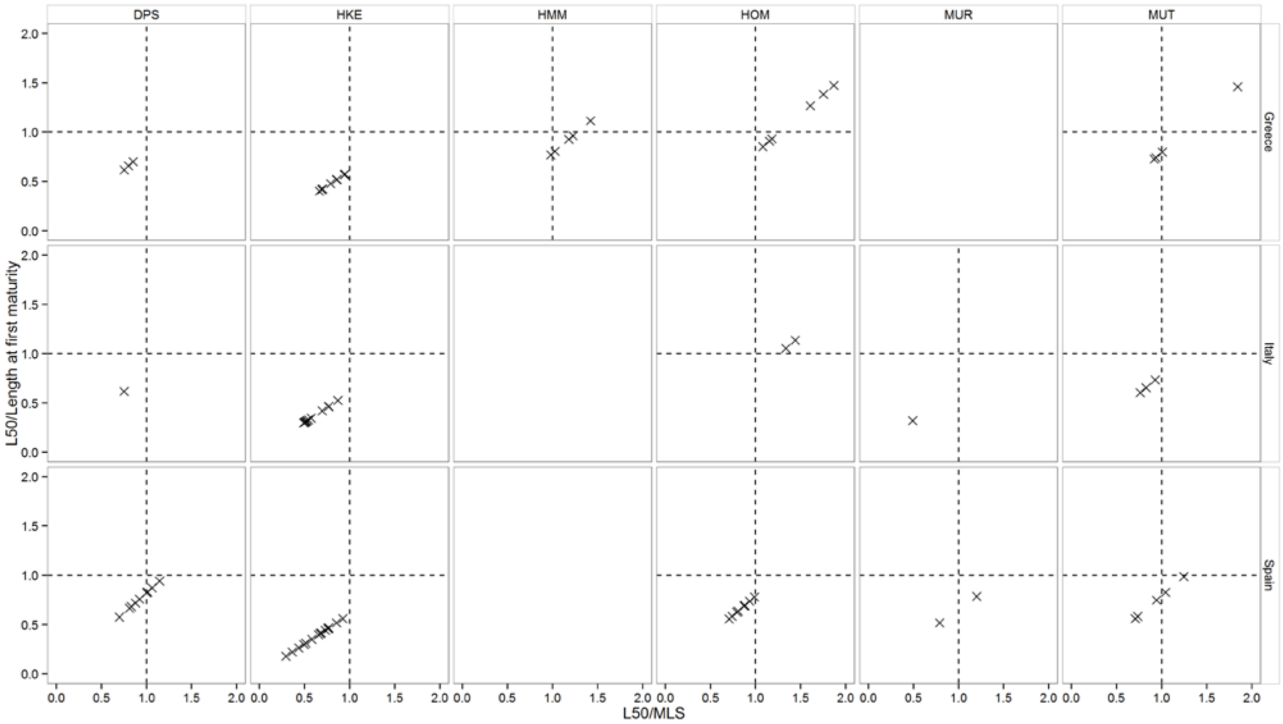


Figure 6. Graphical presentation of the ratios L50/Length at first maturity against L50/MLS at the Country level for the most frequent species with defined MLS.

This means that it should be concise and should be a novel contribution to the scientific literature. In order to cope with this framework and to have higher chances for final publication in the journal that it will be submitted, we reduced the subject(s) and findings of D1.1 and D1.2.

The limitations that we had to tackle were:

- other review and/or synthesis papers on fisheries discards at the fishery level in EU and Mediterranean countries have recently been published (e.g., Tsagarakis et al., 2014, Uhlmann et al., 2014), and therefore, there is no meaning to provide similar information with other papers;
- the amount of information that we managed to obtain from the whole Mediterranean is highly variable for different countries/geographic locations and is quite low (with some exceptions) for non-EU Mediterranean countries. It is also very possible that national reports written in native languages exist but we were not able to access them. Therefore we chose to exclude non-EU Mediterranean countries from this presentation;
- finally, in order to increase cohesion of the manuscript we focus on bottom trawl discards since discards information coming from pelagic trawling is much more limited.

As a result of the above, in this draft paper we focused on discards at the species level for bottom trawl fisheries only from EU countries. The presented information is a review of discards ratios as well as lengths at discarding for different species with emphasis on target species, commercial bycatch species and species of conservation concern. The understanding of factors affecting and reasons for discarding that emerge from our findings were also discussed. This information is quite novel and will be an addition to the scientific literature as well as to the effort of estimating amounts of discards and identifying species with high discards rates.

Review of the factors affecting discard patterns, the reasons linked with fishers' incentives and the policy framework in different management systems (Task 1.2)

The work done under Task 1.2 is included in D1.2, while in addition it constituted a basis for the deliverable *D 0.2. A working document on factors affecting the selective behaviour related to discarding*. Collaborative efforts among partners were held to collect information concerning trawl fisheries discards in the Mediterranean Sea from scientific papers, including reports and other grey literature with the aim to identify reasons for discarding and factors affecting discards. To this end the previously collected information in task 1.1 and presented in the D1.1 has also proved helpful. For the purpose of this work we used the categorization by Eliasen and Christensen (2012) who classified factors which may function as drivers for discarding, into four main categories: (i) natural and structural conditions, (ii) community, (iii) state (and regulations) and (iv) market, which they name "the institutional basis of discarding" (Figure 7). They consider the natural conditions very dynamic, but external to the individual fisher as well as the institutional orders (State, Capital and Market), even though in the medium and long term can influence the natural conditions. Associations of discarded quantities and/or discards ratios with some of these factors have been observed in several studies in the Mediterranean. Factors discussed are thus the ones identified in the Mediterranean Sea but placed in a broader context.

These factors often act in synergistic effect which may not be straightforward to disentangle, especially in multi-species fisheries like most of those exerted in the Mediterranean. Natural conditions (e.g., depth, productivity, and substrate type), affect species composition, abundance and size structure of the catch, which in turn influence fishers' behaviour. Fishing strategies and legal constrains substantially affect composition and quantities of discards, however discarding in the Mediterranean is mainly regulated by market demands; Geographical differences, apart from the effect of natural conditions, seem to be related to socio-cultural characteristics such as community welfare, nutritional habits and familiarization with some species, which affect market demands.

In the multi-species Mediterranean trawl fishery marketable by-catch may constitute an important supplemental source of income, especially when abundance of target species is low. In addition, a market for specimens below Minimum Landing Size (MLS) is apparent in several cases.

Our review of the discards issue further summarized mitigation tools and management measures aiming at the avoidance of unwanted catches, which are applied in the Mediterranean Sea. Mitigation tools mainly comprise selectivity improvement and spatio-temporal closures. Increasing size selectivity is a prerequisite not only for the mitigation of discards but for the rebuilding of the stocks (Colloca et al., 2013). Several gear modifications (mesh size and shape, sorting grids, codend circumference) have been tested leading in an increase in mesh size during the last years, while trials are still ongoing since it is a dynamic field.

Spatio-temporal closures mainly aim the avoidance of charismatic species and/or undersized fish and invertebrates and can provide effective solutions. Among the remaining mitigation tools the MLS mainly aims to discourage fishing juvenile fish, however it is possible that discards quantities increase in some cases due to discarding of unavoidable undersized catch. However, a whole set of tools, mainly awareness campaigns and economic incentives for more selective fishing (e.g., selective licensing, eco-labelling) are totally absent or have very limited application in the Mediterranean Sea.

Currently the reform of the common fisheries policy includes the banning of discards for certain species. However, the enforcement and application of management measures has to take into account fishers perception and the discards issue must be seen under the framework of Ecosystem Approach to Fisheries in order to be effective and viable.

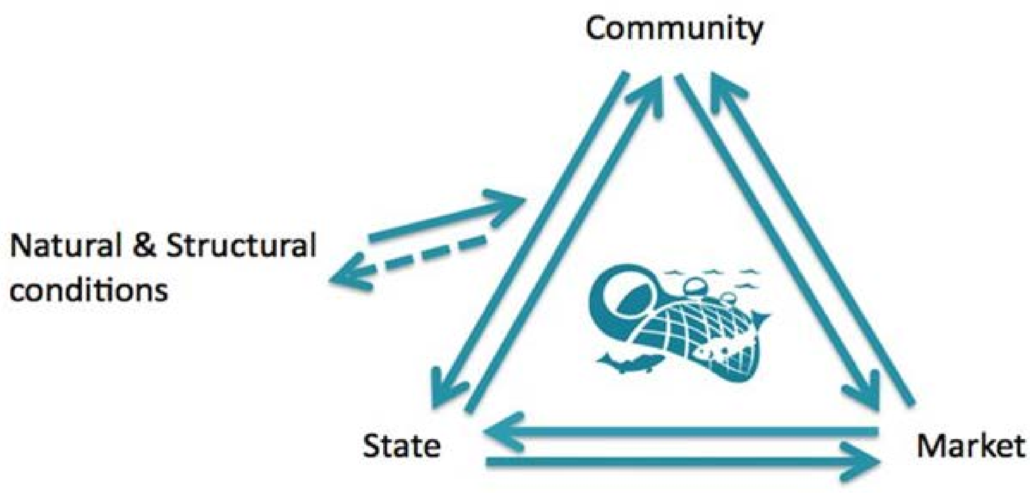


Figure 7. The model of the institutional embedded fishing practice. Fishing practice embedded in the Community, State, Market interrelation and the natural conditions (from: Eliasen and Christensen, 2012).

Data Collection Framework analysis (WP2)

The main subject of this work package was represented by the particularities of inherent Mediterranean onboard sampling data, the exploration of data collection framework sampling strategies, precision and accuracy and different methodological approaches related to the analysis of discard data. Indeed, the use of modelling approaches to analyse the discard process might help to disentangle the effects of different drivers, allowing insights into the potential effectiveness of technological and area/time management measures for reducing fishery discards.

The purposes were:

3) to explore the possibilities of the use of a common format for Atlantic and Mediterranean EU seas, such as Fishframe format. Moreover, a review of Mediterranean fishery monitoring programmes under DCR and DCF EU regulations, allowed an exploration of their bias, weakness and gaps.
4) The use of Generalised Additive Models (GAMs) allowed to explore the main drivers of discard process through exploratory variables linked to spatial (for example linked to the position of nursery areas), temporal, technical (for example influenced by the selectivity process) and economic (for example linked to the economic values of the catches).
5) Using Hierarchical Bayesian models describe discarding behaviours and factors influencing discard rates on their spatio-temporal pattern. This study was focused in modelling total discards and discard ratio, in order to characterize the factors that influence discards.

Findings

The number of countries with current onboard sampling programmes is still low in comparisons of Atlantic Seas. It can be seen that about 70% of the Mediterranean GSA have been established a current sampling programme, although the number of countries that have current onboard sampling programmes is around 30%. In terms of the quantity of data collected under the last Data Collection framework (DCF) from 2008 has increased. In particular, the establishment to record data at métier level with the aim of increasing the precision of estimations.

A comparison with variables used in “Fishframe” COST format for the North Atlantic and North Sea EU regions have been done checking the availability of the similar Mediterranean variables on the GSAs case studies. COST Fishframe format consists in 7 matrices. Shared variables, the same for Atlantic and Mediterranean Sea fishery data in the COST matrices ranges between 0 (Sex-Maturity-Age-Weight-Length matrix) and 80% (others) depending on the matrix. The main inconsistencies with the COST format were in relationship of: 1) spatial aggregation level, 2) non homogeneous commercial categories, and non-established standardized commercial categories at Mediterranean Sea level and 3) the lack of homogeneous information to raise discards from sampling to fleets, métiers, or harbours depending on the Mediterranean country. It makes that COST script format cannot be used without modification. Notwithstanding the data available make advisable to build similar formats for the Mediterranean data exchange to of the Atlantic and Northern Sea.

Sampling conducting on onboard trawlers presented a well-established monitoring with low bias for onboard sampling protocol. Sampling protocols in general are well established and presented high-quality both in sampling designs and sampling accuracy. However almost in all GSAs are based on vessels opportunistic selection., Considering the fleets are small in number of vessels and power fishing in more limited areas the possible bias related to the vessels selection (spatial, vessels power, etc.) may be lower than in the Atlantic Sea, although it will have tested, since most models applied showed significance for the vessel by itself when it was introduced as a variable.

GAMs models applied seemed to explain a satisfactory level of deviance, ranging between 50 and 85% in GSA 18 and 63 and 89% in GSA 22. In both areas a decrease in discards volumes and discard ratios resulted strictly related to an increasing of mean length in the catch for all analyzed species.

In both case studies a significant positive relationship was detected between discards and total catch; apart from the obvious proportionality of discards and landings, this could be partially explained by the loss of catch quality. In GSA 18 discard process was closely related to the recruitment, both from seasonal and spatial view as the qualitative comparison with MEDISEH project (on the identification of nursery areas) revealed. In GSA 22 no seasonal effect for *M. merluccius* and Trachurus spp was showed by the result of models fitting, instead it was for *P. longirostris*, although no direct association with periods of high discarding was possible, because recruitment for this species is distributed throughout the year. Although limited information on nursery areas was available for GSA 22 higher discarding seems coincide, at least partially, with the presence of nursery zones.

Depth was significant for *M. merluccius* in agreement with the tendency of larger individuals to inhabit deeper grounds in the GSA 18, as well as in GSA 22 for *P. longirostris*, for which juveniles are associated with shallower waters. There was also found time series variability due to decreasing trend of discards in GSA 18, and interannual variability in GSA 22 for all species with a general pattern of increasing discards for *M. merluccius* and *P. longirostris* in this GSA.Total catch of species in GSA 18 as explanatory variable included in the discard of *Trachurus trachurus* modelling was significant; increasing absolute discards values have been found when *Trachurus* catch increases, but discard ratio decreases with increasing mean length of *Trachurus trachurus* in the catches. This suggested a different behaviour of fishermen that prefer to sell bigger individuals, discarding the smaller ones. For *P. longirostris* discard ratio decreases with the increasing number of hauls during a trip, this seems to link discard ratio with the duration of the haul.

In GSA 22 increasing marketable catch seems to have a negative effect on discards, notwithstanding increasing discards per unit effort for *M. merluccius* have the opposite trend. Thus landing on species of low marketable values were more likely when they are present in large quantities. In this GSA the haul duration seems to have also an important role in the discards process, producing more discards for *M. merluccius* but less for *T. trachurus*.

The main for Bayesian model applied in the OTB_DES (Otter Trawl Bottom Demersal Species) and OTB_DWS (Otter Trawl Bottom Depth Water Species) in the GSA 6 implemented plotted maps to illustrate the predicted DPUE in this area. In addition, the posterior mean and standard deviation of the spatial component were displayed to detect hidden spatial patterns.

For OTB_DES factors influencing discards were bathymetry with a negative DPUE relationship, indicating an increase in depth of 100 m implied expect value of discards reduced in approximatively 9 Kg per hour. Inversely Catch per Unit Effort (CPUE) showed a positive relationship with the amount of DPUE. Environmental variables such as moon phase showed a lower negative relationship with DPUE, with respect to the reference level (new moon), with the crescent moon phase as the lunar category with the highest DPUE abundance for OTB _DES métier. Quarter (season) of the year showed significant influence on DPUE, in particular the second quarter shows the higher estimated DPUE.

For OTB_DWS factors influencing discards was smoothly for moon phase, although declining effect from the full moon through to waning phase with respect to the reference level was found. Rocky seabed substratum showed the lowest estimated DPUE, with respect to the sand substratum and muddy substratum. Depth was not relevant and neither the slope orientation.

The second quarter of the year showed the highest estimated DPUE with respect to the first quarter (reference level), while the fourth quarter showed the lowest estimated coefficient. The vessel random effect and the vessel length were significant for all fitted models, in particular longer vessels showed higher DPUE values.

Conclusions

Mediterranean and Black Sea Regional Database (RDB) Steering Committee have developed management rules for common data exchange. A common format matrices with similar variables stocked in the different countries will be also host in the General Fishery Commission Mediterranean ((GFCM)-FAO) platform. A good quality of the sampling protocols was found for on board sampling, with the main bias linked to the vessel selection, which is based on opportunistic selection. For the other hand, the main sources of bias are linked to the sampling coverage by metier or fishery statistics. Mediterranean trawl fishery can be considered integrated in the EU Fishery Data Collection Framework for Spain, Italy and Greece, and recently was implemented for Bulgaria, Rumania, and Croatia for different métiers. Whereas countries as Turkey or Maghreb countries have also onboard sampling discards studies, but not regular onboard programmes.

A variety of factors and patterns are identified to affect discards of the different examined species, with some factors explaining the majority of the variability of the dependent variables. In GSA 22 these were the marketable catch of the species concerned, the total haul catch, year and geographical location, while in GSA 18 the main drivers were the total catch of the species, the mean length in the catch, the month, the year and geographical location of the fishing trip. Increased discarding was highly associated with high catches, fishing zone and small mean lengths in the catch.

Our findings are in agreement with other works that showed spatial and temporal variability in discards. These could support fisheries managers in the implementation of mitigation measures aiming the protection of juveniles in a general strategy to reduce discards. In particular, according to the results of the present work, it could important to implement modifications to technical characteristics to the fishing gears (e.g. mesh size) as well as the use of adaptive spatial closures, in order to avoid the fishing in nursery areas during recruitment periods.

The knowledge on the spatio-temporal pattern of discards, which tend to be highly variable in space and time provide a better understanding of the discarding problem, there is a need of more quantitative studies regarding discarding behaviours. This study focus in modeling discards at different levels such as total discards, discard ratios and species specific discarding patterns, in order to characterize the factors that influence discards at the different levels using Bayesian kriging approach was adopted to calculate posterior predictive distributions of the Discards per unit of effort (DPUE).

Bayesian kriging incorporated uncertainty into the prediction process by treating the parameters as random variables. Results for Bayesian model showed, moon phase as relevant factor on discard variability, this could be related with the distribution and movement of some species highly discarded, such as elasmobranches, with the lunar phases. The type of sea-bed was also relevant indicating a sensitive habitat coincides for some species with the most discarded ones. Depth for OTB_DES and seasonality for OTB_DES and OTB_DWS were the other factors influencing discards and may be linked to the variations of species composition and length distributions.

Recommendations

Although the Mediterranean fishery research group in the Regional Coordination Meeting for Data Collection Framework (Report of the 10th Regional Coordination Meeting for the Mediterranean and Black Sea 2013, point 4.1: Regional database: update/actual status since 2012, and Annex III) as a responsible working group implementing the EU Commission questions and reweaving the data collection framework (DCR/DCF) and development in the different countries at generic terms, was expressed their intention to maintain a separated database at different aggregation levels and with different accessibility from countries to EU level, it could be interesting to create a working group to bring postures closer in order to establish common and comparable data framework to catch and discard data over different aggregation figures for the Atlantic and Mediterranean countries.

Quality data, spatial and temporal coverture, sampling intensity, and fishery data availability analysis indicates a common basic information from on-board sampling programmes for the Mediterranean countries. Notwithstanding it will be improved throughout establishing different basic step by step procedures to gathering data. Based on models information it will be improved discards rates estimation and spatial and temporal discards estimation by species distributions particularities for the trawl Mediterranean fishery.

On the basis of analysis carried out, a more in deep exploration of the selectivity parameters of the fishing gears, of the consequences of different mesh sizes on the amount of discard and on the population at sea would be needed.

Limitations of the work package

Although it was an extended and available literature of the subject of Mediterranean fishery data collection and available literature in agreements and recommendations at the Regional Coordination Meeting for Mediterranean & Black Sea for fishery data, it still being disperse or no-available for all Mediterranean countries, with lacks of information even on fishery sampling for EU countries under DCR or DCF framework, that makes the synthesis carried no exhaustive, and therefore potentially improved. To do this improvement, it is necessary to establish a detailed and systematic system to provide the same information for the different Mediterranean countries with the purpose of assess and verify if the set of Mediterranean onboard sampling programme protocols are consistent with the objectives set.

DCF programmes still present low level of ranking métiers, merging data and biological and economic records of different métiers, the small size of the Mediterranean fleets and the diversity of métiers that can be different at regional scale may make too costly disentangle data from different métiers, this has e.g. the Otter trawl Mixed Demersal and Deep Water Species (OTB_MDD), which is a rag bag with low precision for their estimations, and difficulties to establish fishing effort or economy data.

There are no studies or exploration on the spatial and temporal representativeness of the sampling on board for the trawl fisheries in the Mediterranean Sea (VMS comparisons). Attempts to know representativeness of sampling and accuracy of estimations selecting different sampling models following the ontogenic distribution and phenology of species and fishery distribution require more time and research investment to be well established.

The use of modeling approaches to discards data provides the possibility to reduce uncertainty in estimations, understanding the reasons for discarding and the identification of solutions to tackle the catches of unwanted species. The present work package applied two methods to different cases studies, but more investigation is needed to develop robust and accurate methods to distinguish stable to spurious models results.

Predicting commercial yields, discards rates and selectivity by towed gears from fishing gear characteristics (WP3)

Objectives

The most advanced simulations models in FISHSELECT (Herrmann et al., 2009), which can simulate the basic size selective properties for nettings with arbitrary mesh shape and size for different fish species, have been used. For trawls these methods are developed so as to provide reliable predictions (Herrmann, 2005; O'Neill and Herrmann, 2007). These tools have also been used to provide international advice to the EU and ICES.

The specific objectives of WP3 are: *i)* to predict the expected size selectivity of a range of species for many different codend constructions (e.g. mesh sizes, mesh type, twine thickness); *ii)* to validate the model results using selectivity data from both the pelagic and demersal fisheries. In this workpackage, we present the prediction of codend size-selectivity relative to species being investigated in the DISCATCH project (Table 1 and Table 2). We analyse currently legislated codends and different designs not tested at sea. We estimated the selectivity propriety for three different mesh geometries: diamond-, square- and hexagonal-mesh. The simulated size selectivity of the different codends presented in this deliverable has been carried out by the FISHSELECT software (Hermann et al., 2009).

Table 1: List of species investigate in the DISCATCH project

Investigated species
Pelagic
ANE: European anchovy (*Engraulis encrasicolus*)
PIL: European pilchard (*Sardina pilchardus*)
Demersal
HKE: Hake (*Merluccius merluccius*)
HMM: Mediterranean horse mackerel (*Trachurus mediterraneus*)
HOM: Atlantic horse mackerel (*Trachurus trachurus*)
MUT: Red mullet (*Mullus barbatus*)
MUR: Striped red mullet (*Mullus surmuletus*)
ARA: Giant red shrimp (*Aristaeomorpha foliacea*)
ARS: Red shrimp (*Aristeus antennatus*)
DPS: Deep-water rose shrimp (*Parapenaeus longirostris*)
NEP: Norway lobster (*Nephrops norvegicus*)

Table 2. Relevant trawl fisheries covered by the DISCATCH project.

Demersal trawl fisheries		
Country	Sub-region / fisheries	Species examined
Italy	Continental shelf and the upper slope in the Strait of Sicily (GSA16)	ARS, DPS, HKE
Italy	South Adriatic (GSA18)	DPS, HKE, HOM, MUT, NEP
Spain	Continental shelf and the upper slope off Iberian Peninsula (GSA1, GSA6)	ARA, HKE, MUT
Spain	Balearic Islands (GSA5)	ARA, HKE, MUR
Greece	Aegean Sea (GSA22)	DPS, HKE, HOM, MUT
Pelagic trawl fisheries		
Italy	North-Central Adriatic (GSA17)	ANE, PIL
Italy	Central-Southern Tyrrhenian Sea (GSA10)	ANE

Provide data on the cross sectional morphology of the species being investigated (Task 3.1)

Data on the cross sectional size and shape for different length of the species being investigated can be obtained by using the FISHSELECT tools and software (Herrmann et al., 2009) if such data is not already available for the species of interest. Thus, the FISHSELECT morphometer (Figure 8) and software was applied to collect cross-sectional data for the species of interest. Besides providing morphology data to run FISHSELECT this information can be used to produce so called design guides (Figure 8) which quantify the basic size selective properties of meshes of different shape and size for the species being investigated. Such design guides can be produced for any kind of mesh type and is a valuable tool for fisheries managers and gear designer. In addition it can be used to judge the risk for stickers (fish which, due to the impossibility of going completely through, become enmeshed while trying to pass through the netting) in different parts of a trawl when we have knowledge on the size structure entering the gear. Thus this can be applied to try to mitigate sticking problems by aiding gear design.

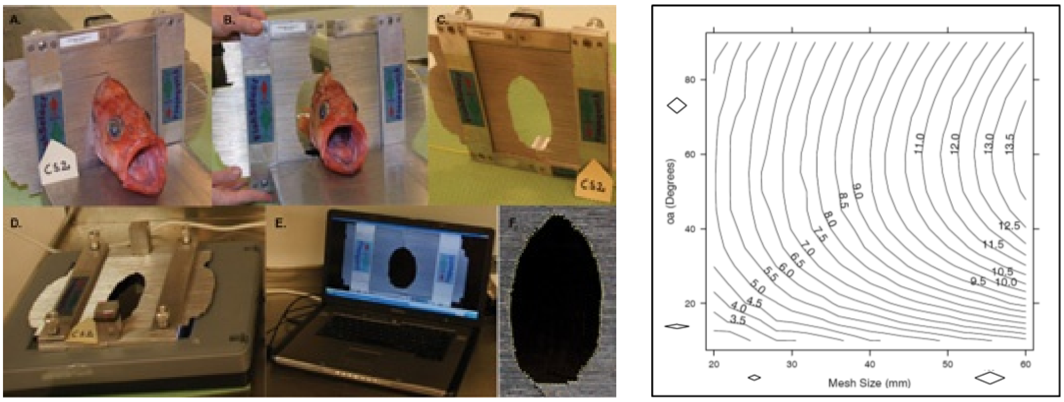


Figure 8. Fish being measured using FISHSELECT morphometer *(left)*; example on Design Guide for diamond meshes for a specific species *(right)*. It shows ISO curves for the size of fish that based on morphology would be able to escape through diamond meshes of different mesh size (*X*-axis) and different opening angle (*Y*-axis).

Initial experiments: pilot study

In general, fish targeted by trawls have good swimming ability relative to the towing speed used in these fisheries. Several species of fish also have been observed to orientate themselves in relation to the trawl netting during the capturing process e.g. Wardle (1993). In contrast to fish, smaller invertebrates such as shrimps and prawns tend to display a more limited response to stimuli from the trawl (Lochhead, 1961; Newland and Chapman, 1989). Therefore, the selectivity process for these species in trawls is expected to resemble a sieving process in which the individuals may meet the trawl netting with a more random orientation (in contrast to what has been observed for fish).

The FISHSELECT methodology was used in a pilot study to identify potential contact modes and evaluate their relative importance in the selection process. The aim of the pilot study was to identify a limited number of contact modes, which, in combination, could be deemed capable of reproducing size selection of shrimps and/or Nephrops in a trawl codend.

The shrimp species tested were: red shrimp (*Aristeus antennatus*, ARA); giant red shrimp (*Aristaeomorpha foliacea*, ARS); deep-water rose shrimp (*Parapenaeus longirostris*, DPS). While for Norway lobster (*Nephrops norvegicus*, NEP) the results from Frandsen et al. (2010) have been used. For each species, around 35-40 specimens were tested for their ability to penetrate meshes in a standard FISHSELECT fall-through setup (Herrmann et al., 2009). A 56.9 mm square-mesh netting template was chosen for the experiment. Use of approximately the same mesh size as those used in the field experiments (Sala et al., 2015) allowed us to evaluate the test results against the experimental data.

Eight contact modes representing different angles of contact between the individual and the netting were identified and investigated including the contact mode with the smallest cross-section which was optimal for mesh penetration. An example for ARS is reported in the Deliverable *D 0.3. Morphology data for species being investigated* (Figure 6), which is valid for ARA, DPS and NEP as well. The same fresh specimens were subsequently used for both morphological and shape measurement. The outcome of this comparison allowed us to evaluate which of the eight investigated contact modes could be potential candidates to simulate size selection for both the shrimp species and Nephrops. Contact modes that resulted in simulated retention data that obviously conflicted with the experimentally determined selective range were eliminated from further fish-shape analyses (see *§Measurement and estimation of cross-section shapes*). Based on the procedures described above, three contact modes (see *a, d*, and *e,* in the Deliverable D3.3) were found which, in combination, could be used to simulate size selection for the three shrimps and Nephrops in trawl codends, these three modes were selected also for the final fall-through experiment. The benefit of applying the more simple procedure for the pilot study is that it eliminated the need to measure and model a large number of different and complicated cross-sections, some of which were bound to be eliminated later in the process.

Measurement and estimation of cross-section shapes

We used the FISHSELECT methodology (Herrmann et al., 2009) to investigate and predict the selectivity properties of multiple codend types for the Mediterranean. FISHSELECT is a framework of methods, tools, and software developed to determine whether or not a fish is able to penetrate a certain mesh. The method includes collecting morphometric measurements for the species being investigated and estimating selectivity parameters by comparing the cross-sectional geometry of individual and the geometry of the mesh. Because the final aim is to be able to predict the selective properties for a diversity of codends, the method requires that the morphometric characteristics of the largest possible size range be measured for each of the species being investigated. Therefore, apart from the condition of the fish, shrimps or Nephrops, the only other selection criterion was the need to cover the widest possible size range for each species.

In FISHSELECT, the morphological characteristics of each individual are defined by the shape of the cross-section (CS) of its body at different points. To determine the shape of the different CSs measured for each fish/shrimp, we used a mechanical sensing tool called the Morphometer (see Herrmann et al., 2009).

The shapes registered on the Morphometer were converted to a digital image by a flatbed scanner and were further analysed using an image analysis function in the FISHSELECT software. The result of the image analysis function is a contour for each CS (Figure 9). To model these contour obtained for each CS, a variety of different geometrical shapes were tried. Figure 10 shows the position of these CSs for each species. The CSs were chosen so that the points that could be critical for the fish to pass through the different selection devices were covered. The maximum girth for the head and the maximum girth for the fish were included for all species as CS1 and CS2, respectively.

For crustaceans (ARA, ARS, DPS and NEP) a further cross-sectional area (CS3) corresponding at the folded body as showed in Figure 10a was investigated. For each individual, the total length (in mm), the weight (in g), the width and height (in mm) at each CS level were also measured (Figure 11). Comparisons of length vs. CS size allowed us to investigate the between-individual variability of each CS. Furthermore, modelling the relationship between length, width and height, vs. the parameters defining the shape for each CS allowed us to simulate virtual populations of all species with defined CSs as detailed in the *§Run FISHSELECT simulations to predict size selectivity in different codends not tested at sea (Task 3.5).*

Fish Shape and cross-section results

The measured cross sections, CS1 and CS2 for fishes with the addition of CS3 for crustaceans, had different cross section shapes. For a given cross section, a unique best model describing all species doesn't exist. We therefore present for each species the fit statistics and the best model with the lowest AIC value, which is the most preferable accordingly to Akaike (1973). For each species, the best models were chosen for use in the subsequent simulation of mesh selectivity (Table 3 and Table 4).

The morphology of several fish and crustacean species related to the two (fish) or three (crustaceans) contact modes could be well described by parametric shapes and all cross-section parameters could be estimated from total body length (TL, for fish) or carapace length (CL, for crustaceans) with high precision. This fact justifies implementation of the structurally based FISHSELECT methodology, as it uses nothing but morphology and mesh configuration to predict selectivity of nettings. The creation of virtual populations with TLs or CLs were based on extrapolations for both the small and the large individuals.

Fish morphology affects the size selectivity of towed fishing gears. In the present study we applied the FISHSELECT methodology and tools (Herrmann et al., 2009) to assess the morphological component of the size selection process of eleven species (7 fish and 4 crustaceans) related to diamond-, square-, and hexagonal-mesh codends. Fish behaviour can be important in the capture process of some fish, especially in the trawl mouth (Engås et al., 1998), but our method does not explicitly account for behavioural aspects.

Cross-sections were fitted to seven different geometric shapes. The simplest shape tested was an ellipse, but for all cross-sections more complex shapes, requiring more parameters, were needed to describe the contours satisfactorily. Based on the AIC-values obtained, the Flex-Ellipse1 was the best shape for describing both CS1 and CS2, and the Bottle was the best shape for describing CS3 (for crustaceans). The parameters (*c1, c2, c3*) of the geometric shapes are related to total body length (TL) and carapace length (CL), respectively for fish and crustaceans. The R^2 value (percentage of variance explained) for the regressions ranged from 0.62 to 0.99 for parameters *c1* and *c2*. These parameters define height and width of the geometric shape and were expected to be strongly correlated with length (either TL or CL). The lowest R^2 values were attributed to the *c3* parameter, which defines deviation from an ellipse.

R^2 values for the regressions of *c3* versus CL were particularly low (-0.032 and 0.585). However, as its effect on the length-based regressions of virtual populations is expected to be small, we considered the length relationships of the cross-section shapes to be well defined anyway. Using the combination of this morphological description, realistic mesh shape (i.e. mesh size, mesh opening angle, mesh configuration), and experimental selectivity data, we will be able to predict the selectivity for all the investigated species for different mesh sizes.

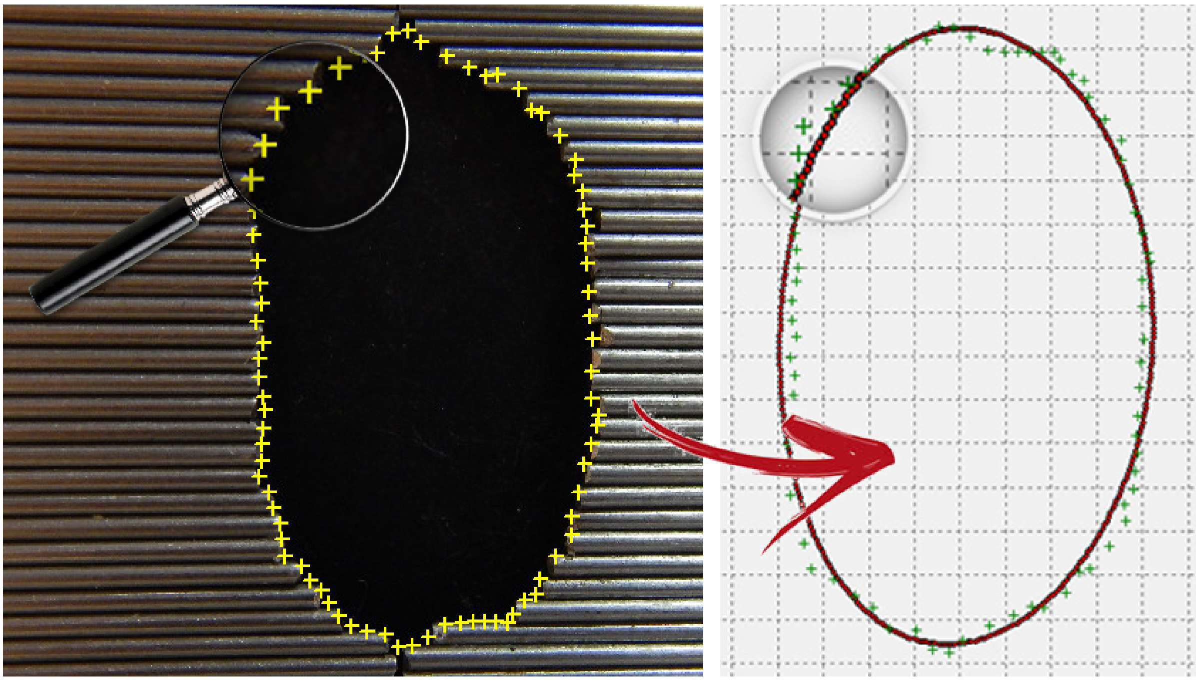


Figure 9. Example of a scanned Morphometer image with a mechanical replica of the outer cross-section contour of a red mullet (left picture). The crosses are digitized points along the contour detected by contour acquisition routines implemented in the FISHSELECT software. The magnified blow-up small picture shows part of the digitized contour and the individual Morphometer sticks in greater detail. The right picture shows the fit of an ellipse to the digitized contour with the top blow-up picture showing details.

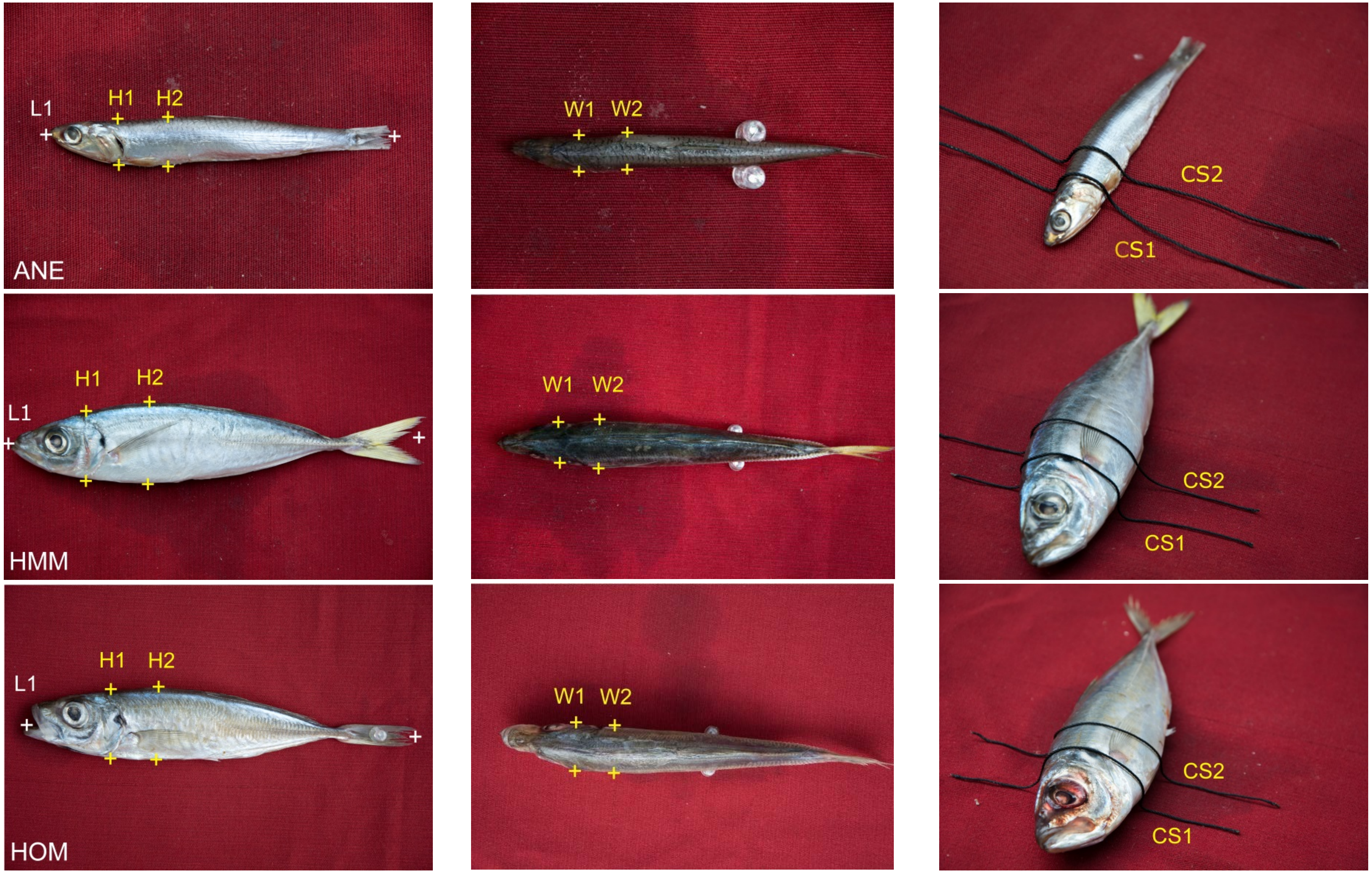

L1
H1
H2
ANE
W1
W2
CS2
CS1
L1
H1
H2
HMM
W1
W2
CS2
CS1
L1
H1
H2
HOM
W1
W2
CS2
CS1

Figure 10. Measured length (L1), heights (H1, H2), widths (W1, W2) and cross-sectional areas CSs (CS1, CS2) for the fish species.

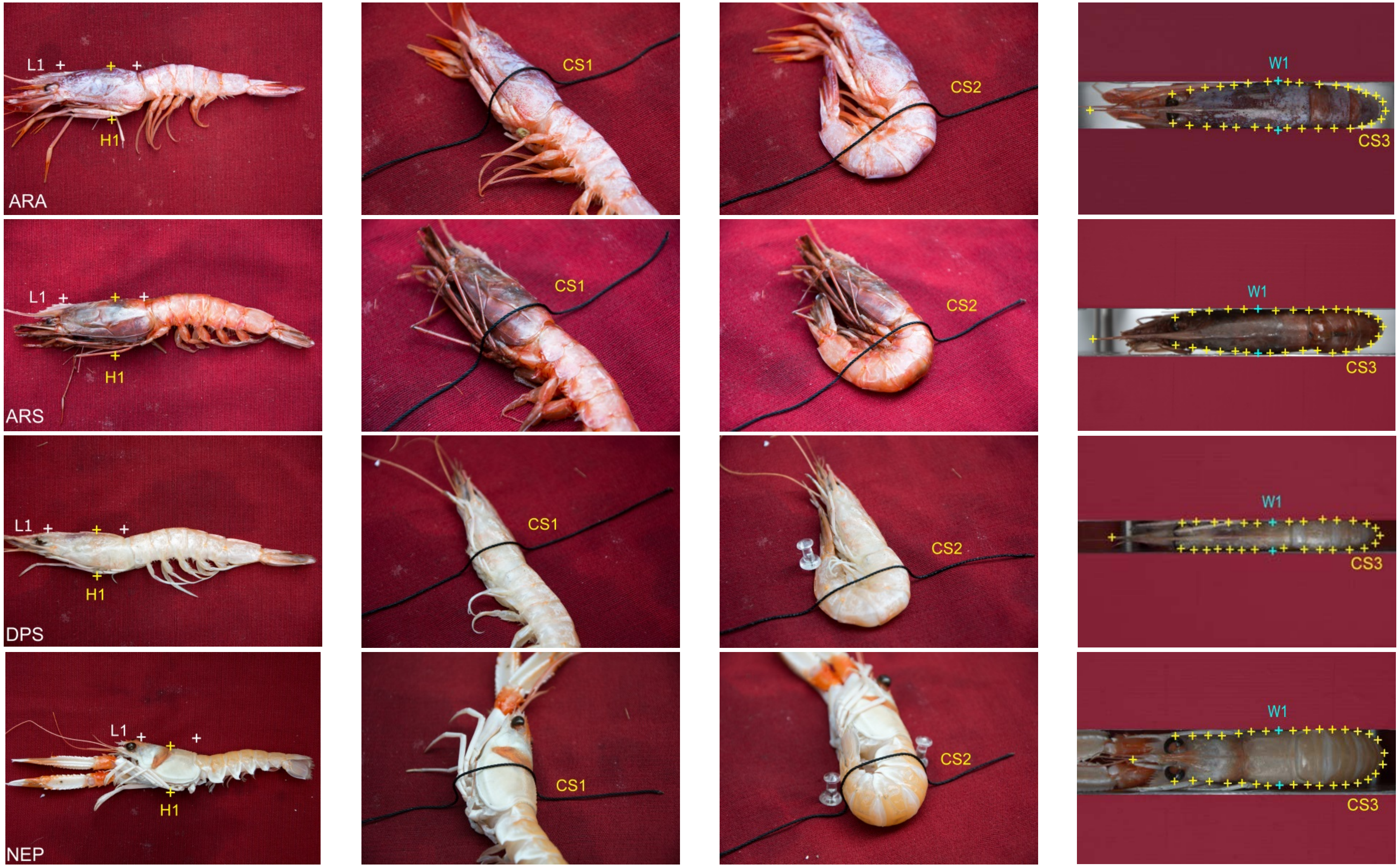


Figure 11. Measured total length, height, width (L1, H1, W1, respectively) and cross-sections (CS1, CS2, CS3) for each crustacean species.

Table 3. Model parameters and fit statistics for **fishes** given as mean, standard deviation (*SD*) and R-squared (*Rsq*) of the merit value of the geometric shapes fitted to the measured cross-sections (CS1 and CS2). Type of shape (*Type*) to represent the cross sections of the fish and crustaceans and meaning of the parameters c_1, c_2 and c_3 are reported in the deliverable *D 0.3. Morphology data for species being investigated*. Formulas are based on trigonometric functions in the FISHSELECT software tool.

Species	Par. vs length	*Type*	CS1			*Type*	CS2			*Type*	CS3		
			Mean	SD	*Rsq*		Mean	SD	*Rsq*		Mean	SD	*Rsq*
ANE	*Girth*	FLEX_ELLIPSE1	0.565	0.025	*0.973*	FLEX_DROPE2	0.283	0.017	*0.971*		-	-	-
	Area		0.020	0.002	*0.959*		0.006	0.001	*0.960*		-	-	-
	c1		0.025	0.002	*0.949*		0.015	0.002	*0.946*	'	-	-	-
	c2		0.174	0.008	*0.960*		0.083	0.006	*0.955*		-	-	-
	c3		-0.246	0.198	*-0.003*		-0.054	0.039	*-0.035*		-	-	-
HKE	*Girth*	FLEX_ELLIPSE1	0.305	0.025	*0.987*	FLEX_ELLIPSE1	0.247	0.018	*0.985*		-	-	-
	Area		0.014	0.003	*0.987*		0.008	0.001	*0.977*		-	-	-
	c1		0.050	0.005	*0.981*		0.038	0.003	*0.985*	'	-	-	-
	c2		0.053	0.004	*0.983*		0.041	0.003	*0.982*		-	-	-
	c3		0.000	0.000	*0.410*		0.000	0.000	*0.291*		-	-	-
HMM	*Girth*	FLEX_DROPE2	0.490	0.015	*0.993*	FLEX_DROPE2	0.428	0.018	*0.990*		-	-	-
	Area		0.014	0.001	*0.989*		0.017	0.002	*0.981*		-	-	-
	c1		0.041	0.002	*0.991*		0.037	0.002	*0.980*	'	-	-	-
	c2		0.108	0.004	*0.991*		0.094	0.004	*0.988*		-	-	-
	c3		-0.041	0.020	*-0.023*		-0.034	0.026	*-0.013*		-	-	-
HOM	*Girth*	FLEX_DROPE2	0.418	0.030	*0.992*	FLEX_DROPE	0.421	0.032	*0.990*		-	-	-
	Area		0.009	0.001	*0.993*		0.010	0.001	*0.991*		-	-	-
	c1		0.026	0.002	*0.989*		0.028	0.002	*0.987*	'	-	-	-
	c2		0.102	0.007	*0.990*		0.104	0.008	*0.988*		-	-	-
	c3		-0.045	0.022	*-0.032*		-0.001	0.001	*0.464*		-	-	-
MUR	*Girth*	BOTTLE	0.850	0.051	*0.776*	BOTTLE	0.919	0.056	*0.787*		-	-	-
	Area		0.017	0.002	*0.836*		0.032	0.004	*0.842*		-	-	-
	c1		0.067	0.004	*0.830*		0.115	0.009	*0.710*	'	-	-	-
	c2		0.203	0.014	*0.712*		0.169	0.010	*0.776*		-	-	-
	c3		0.014	0.010	*-0.003*		0.016	0.012	*-0.006*		-	-	-
MUT	*Girth*	SHIP	0.278	0.007	*0.986*	SHIP	0.224	0.005	*0.991*		-	-	-
	Area		0.005	0.000	*0.980*		0.003	0.000	*0.988*		-	-	-
	c1		0.020	0.001	*0.967*		0.016	0.001	*0.981*	'	-	-	-
	c2		0.069	0.002	*0.987*		0.055	0.002	*0.984*		-	-	-
	c3		0.000	0.000	*0.425*		0.001	0.001	*0.168*		-	-	-
PIL	*Girth*	FLEX_DROPE	0.128	0.005	*0.966*	FLEX_DROPE	0.123	0.006	*0.946*		-	-	-
	Area		0.001	0.000	*0.956*		0.001	0.000	*0.922*		-	-	-
	c1		0.007	0.000	*0.948*		0.007	0.000	*0.909*	'	-	-	-
	c2		0.036	0.001	*0.954*		0.034	0.002	*0.934*		-	-	-
	c3		0.000	0.000	*0.585*		0.000	0.000	*0.556*		-	-	-

Table 4. Model parameters and fit statistics for **crustaceans** given as mean, standard deviation (*SD*) and R-squared (*Rsq*) of the merit value of the geometric shapes fitted to the measured cross-sections (CS1 and CS2). Type of shape (*Type*) to represent the cross sections of the fish and crustaceans and meaning of the parameters c_1, c_2 and c_3 are reported in the deliverable *D 0.3. Morphology data for species being investigated*. Formulas are based on trigonometric functions in the FISHSELECT software tool.

Species	Par. vs length	*Type*	CS1			*Type*	CS2			*Type*	CS3		
			Mean	SD	*Rsq*		Mean	SD	*Rsq*		Mean	SD	*Rsq*
ARA	*Girth*	FLEX_DROPE	2.074	0.184	*0.742*	FLEX_ELLIPSE1	4.562	0.139	*0.940*	BOTTLE	11.460	0.749	*0.762*
	Area		0.513	0.096	*0.732*		2.444	0.178	*0.889*		5.706	0.561	*0.821*
	c1		0.559	0.044	*0.684*		0.610	0.045	*0.623*		0.588	0.026	*0.840*
	c2		0.241	0.025	*0.726*		1.099	0.044	*0.886*		2.652	0.186	*0.739*
	c3		-0.021	0.015	*0.041*		-	-	-		0.084	0.021	*0.018*
ARS	*Girth*	FLEX_ELLIPSE1	1.371	0.060	*0.981*	FLEX_ELLIPSE1	3.166	0.189	*0.951*	BOTTLE	9.073	1.044	*0.818*
	Area		0.140	0.012	*0.980*		0.518	0.070	*0.941*		1.356	0.129	*0.970*
	c1		0.175	0.010	*0.966*		0.194	0.017	*0.921*		0.177	0.018	*0.889*
	c2		0.255	0.014	*0.969*		0.755	0.048	*0.941*		2.272	0.279	*0.792*
	c3		-0.113	0.282	*-0.003*		-	-	-		0.119	0.067	*-0.010*
DPS	*Girth*	SHIP	1.916	0.134	*0.959*	FLEX_ELLIPSE1	5.149	0.200	*0.979*	BOTTLE	27.753	3.387	*0.703*
	Area		0.288	0.040	*0.964*		0.806	0.059	*0.988*		2.563	0.266	*0.971*
	c1		0.210	0.015	*0.949*		0.259	0.017	*0.945*		0.114	0.011	*0.924*
	c2		0.395	0.035	*0.922*		1.094	0.051	*0.966*		7.216	0.930	*0.666*
	c3		0.000	0.000	*0.390*		-	-	-		0.278	0.057	*-0.112*
NEP	*Girth*	FLEX_ELLIPSE1	2.063	0.083	*0.953*	FLEX_ELLIPSE1	2.379	0.131	*0.902*	FLEX_ELLIPSE1	5.429	0.246	*0.933*
	Area		0.320	0.026	*0.966*		0.370	0.036	*0.935*		0.740	0.059	*0.959*
	c1		0.304	0.013	*0.944*		0.254	0.009	*0.964*		0.158	0.008	*0.947*
	c2		0.360	0.017	*0.934*		0.496	0.035	*0.838*		1.339	0.067	*0.914*
	c3		0.059	0.029	*0.060*		0.000	0.000	*0.358*		0.264	0.055	*0.364*

Provide experimental size selectivity data for some codends (Task 3.2)

In Mediterranean bottom trawl fishery, most restrictions are universally focused on the mesh geometry and mesh size. Because of its multi-species character, output control is less commonly used in Mediterranean fisheries and is not considered a viable solution in most cases (Spagnolo, 2010). The definition of minimum size of the fish that can legally be landed (MLS) can be considered as the only output control in bottom trawl fishery. This is strongly dependent on the definition of minimum mesh size (MMS) and should always be addressed simultaneously (Suuronen et al., 2007). In the Mediterranean countries undersized fish have high market value and changes in MMS can seriously affect the overall profitability of the fishery (Kelleher, 2005).

According to that, minimum mesh size needs to be chosen to minimize retention of undersize fish while keeping fishing profitable. Some studies showed that minimum landing sizes in Mediterranean fisheries are inadequate from ecological point of view and are not harmonised with the life history of species (Stergiou et al., 2009), while some authors suggested that MLS should be abolished from the legislation (Sala and Lucchetti, 2011). As of the 11th of December 2013, new EC Reg. 1380/2013 states that in the Mediterranean, catches of species which are subjected to minimum sizes defined in Annex III of EC Reg. 1967/2006, caught during fishing activities in Union waters or by Union fishing vessels outside Union waters shall be brought and retained on board the fishing vessels, recorded and landed. In order to ensure conservation and sustainable exploitation of marine biological resources new CFP promotes measures that contribute to more selective fishing and the avoidance and reduction of unwanted catches. The purpose of this deliverable is to collect all available literature sources that can help us assess the current selective properties of Mediterranean bottom trawls.

For the purpose of this deliverable we have collected all available references ranging from grey literature (national reports, conference proceedings etc.) to papers published in different peer reviewed scientific journals. Only references that reported the length of fish that has a 50% probability of being retained after entering the codend (L50%) and selection range (SR - difference in length between the fish that has a 75% probability of retention and that with a 25% probability of retention), have been considered in this report. Papers dealing with the Black Sea, the Sea of Marmara and the Atlantic were not considered. When dating the studies, we used the year when the selectivity experiment was conducted, and if this information was not available we used the year of the publication. This was done because some papers were published many years after the experiment was finished. If the experiment was conducted during the period of two or more years we used the year when experiment was finished.

We provided general relationships between selectivity parameters (L50%, SR and SF) and different codend technical parameters known to affect selectivity. The technical parameters considered are mesh size, mesh configuration and codend circumference because these parameters are frequently reported in the literature. We mostly focused on the diamond-mesh (DM) codends because for majority of DISCATCH species data on square-mesh (SM) codend selectivity are scarce. For each DISCATCH species we are going to graphically represent ratio of selection parameter L50% and minimum landing size (MLS) versus ratio of L50% and length at first maturity (Figure 12). If species MLS is not defined in the EU Regulation 1967/2006 only length at first maturity was used. Further in text we are going to refer to those graphs as *trawl selectivity indicator graphs*.

These graphs enable us to instantaneously evaluate if a certain codend is catching mature or immature individuals, below or above MLS. From strictly technological point of view we want to catch mature individuals bigger than the MLS (see the upper right corner of Figure 12). If we are catching mature individuals below MLS (upper left corner of Figure 12) then MLS for that species is not appropriate and should be redefined in order to prevent discarding.

If the gear is catching immature individuals below MLS, then selectivity of the analysed codend needs to be improved (see the bottom left part of Figure 12). Finally, if we are catching immature individuals above MLS (bottom right of Figure 12), MLS for that species has to be rapidly redefined.

In order to define the length at first maturity (LFM) for each species, we collected data from the literature (Table 5). When more than one literature source was found for a species, the average LFM was calculated. If LFM was available for both genders the more conservative average value was used.

For the purpose of this deliverable we have analysed 74 references on trawl selectivty in the Mediterranean Sea. We focused mainly on the species covered by the DISCATCH proposal: *Engraulis encrasicolus* (ANE), *Aristeus antennatus* (ARA), *Aristaeomorpha foliacea* (ARS), *Parapenaeus longirostris* (DPS), *Merluccius merluccius* (HKE), *Trachurus spp.* (HOM), *Mullus barbatus* (MUT), *Mullus surmuletus* (MUR), *Nephrops norvegicus* (NEP) and *Sardina pilchardus* (PIL). To deal with the multi-species character of the Mediterranean bottom trawl fishery we also considered “non DISCATCH” species. In total we have collected 567 records, on 56 different species (Table 6.). Most of the DISCATCH species are relatively well covered in the literature, with the exception of *Mullus surmuletus* (MUR) and *Sardina pilchardus* (PIL).

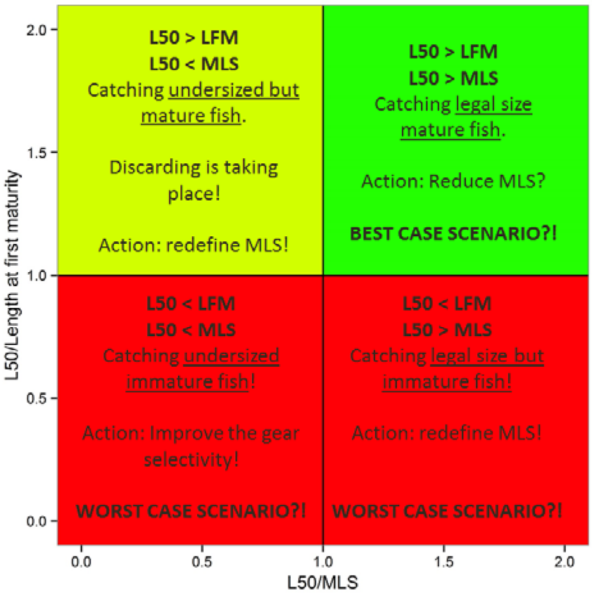


Figure 12. Trawl selectivity indicator graph.

Table 5. Average length at first maturity (LFM in cm) for DISCATCH species. For crustaceans LFM refers to the carapace length.

Species	Avg LFM	
	F	M
Aristaeomorpha foliacea	4.12	NA
Aristeus antennatus	2.73	NA
Merluccius merluccius	33.70	26.92
Mullus barbatus	12.50	13.19
Mullus surmuletus	16.70	14.53
Nephrops norvegicus	2.77	NA
Parapenaeus longirostris	1.82	NA
Trachurus spp	18.85	18.75

In this selectivity review we covered papers published in the last 48 years (1966-2014). The majority of studies have been performed during the 2002-2005 period, exactly before the EC Regulation 1967/2006 came into force. Older selectivity studies focused exclusively on DM mesh codends probably because square-mesh was first legally defined in the EC Regulation 1967/2006. DISCATCH project is mainly focused on the GSAs 1, 5, 6, 10, 16, 17, 18, 22 (as defined by the proposal) but data were also collected for other GSAs in order to have better overall picture of bottom trawl selectivity experiments in the Mediterranean Sea. The majority of studies analysed the influence of mesh size and mesh geometry on the selectivity of Mediterranean bottom trawls (Stewart, 2002).

According to data from the literature, experiments were more often performed on diamond-mesh (DM) than on square-mesh (SM), while only a few studies focused on the hexagon and T90 codends. On the species level, only for *M. merluccius* (HKE) and *M. barbatus* (MUT) there is sufficient number of data records both for DM and SM codends, while for other DISCATCH species only a few experiments with the SM codends have been reported. Majority of the studies have been performed on the 40 mm diamond and 40 mm square-mesh. The way mesh size was reported in literature differs between the studies. Older studies reported only mesh size without specifying is it nominal (NMS) or measured value (MMS - refers to the inside mesh size or more correctly the mesh opening). Recent papers often included both values, and in some cases difference between NMS and MMS was as high as 6.38 mm.

Reporting only NMS or not specifying whether the reported mesh size is NMS or MMS can be misleading, especially if we want to calculate relationship between mesh size and selectivity parameters L50% and/or SR. Prior to 1995, selectivity studies in the Mediterranean Sea used exclusively polyamide (PA) codends. In time, polyethylene (PE) codends became more common, but they never completely replaced PA codends. Tokaç et al. (2004) showed how codend made of PA netting generally provides better selectivity than codend made of PE netting. The majority of papers collected in this study (53) reported the codend material, but twine thickness, which is also known to affect species selectivity in the Mediterranean bottom trawl fisheries (Sala et al., 2007a; 2007b), was only reported in 13 different references. Another controllable technical parameter that is known to affect the selectivity of bottom trawls is the number of meshes around the codend circumference (Reeves et al., 1992; Wienbeck et al., 2011). In the Mediterranean bottom trawl fisheries it has been shown that the increase in the number of meshes around the circumference both in diamond (Ozbilgin et al., 2005a; Tokaç et al., 2009; Sala and Lucchetti, 2010; 2011) and square-mesh codends (Sala et al., 2008) negatively influences selectivity for certain commercially important species.

The majority of revised papers reported the number of meshes around the circumference, both for DM and SM codends. Instead of codend circumference some authors prefer to report codend rigging ratio (Sala and Lucchetti, 2011) because it is a technical parameter enforced in the EC Regulation 1967/2006.

When exploring general relationship between the codend circumference and different selectivity parameters, information on rigging ratio between codend and extension can be more valuable than just reported number of meshes around the codend circumference. This is because two identical codends rigged to extensions that have different number of meshes around their circumferences can have completely different selective properties.

Codend catch weight is considered as an important uncontrollable parameter that influences selectivity of bottom trawls (O'Neill and Kynoch, 1996; Dahm et al., 2002; Herrmann, 2005). Few studies tested this effect in Mediterranean, where it was shown how large codend catches have negative effect on selectivity parameter L50% for *M. barbatus*, *N. norvegicus*, *P. longirostris* and *M. merluccius,* and small positive effect on SR in case of *N. norvegicus* (Sala et al., 2008; Sala and Lucchetti, 2010a).

Table 6. List of species covered by the literature review.

Code	Scientific name	English name	Code	Scientific name	English name
MTS	*Squilla mantis*	Spottail mantis squillid	SHO	*Galeus melastomus*	Blackmouth catshark
ITW	*Sepietta oweniana*	Common bobtail squid	LKT	*Plesionika martia*	Golden shrimp
OQT	*Octopus salutii*	Spider octopus	SRJ	*Serranus hepatus*	Brown comber
EOI	*Eledone cirrosa*	Horned octopus	BOG	*Boops boops*	Bogue
LDV	*Lepidotrigla cavillone*	Large-scaled gurnard	SBA	*Pagellus acarne*	Axillary seabream
CIL	*Citharus linguatula*	Spotted flounder	DEL	*Dentex macrophthalmus*	Large-eye dentex
SYC	*Scyliorhinus canicula*	Small-spotted catshark	ANN	*Diplodus annularis*	Annular seabream
PAC	*Pagellus erythrinus*	Common pandora	SPC	*Spicara smaris*	Picarel
BPI	*Spicara maena*	Blotched picarel	WHG	*Merlangius merlangus*	Whiting
POD	*Trisopterus minutus*	Poor cod	RPG	*Pagrus pagrus*	Red porgy
CQL	*Caelorinchus caelorhincus*	Hollowsnout grenadier	SPCF	*Spicara flexuosa*	Picarel
EJE	*Sepia elegans*	Elegant cuttlefish	SQR	*Loligo vulgaris*	European squid
OCC	*Octopus vulgaris*	Common octopus	SQM	*Illex coindetii*	Broadtail shortfin squid
OUM	*Alloteuthis media*	Midsize squid	IAR	*Sepia orbignyana*	Pink cuttlefish
ANE	*Engraulis encrasicolus*	European anchovy	ARY	*Argentina sphyraena*	Argentine
ARA	*Aristeus antennatus*	red shrimp	MSF	*Arnoglossus laterna*	Mediterranean scaldfish
ARS	*Aristaeomorpha foliacea*	Giant red shrimp	MAC	*Scomber scombrus*	Atlantic mackerel
DPS	*Parapenaeus longirostris*	Deep-water rose shrimp	GUX	Triglidae	Gurnards, searobins nei
HKE	*Merluccius merluccius*	European hake	GSM	*Buglossidium luteum*	Solenette
HOM	*Trachurus spp.*	Horse mackerels	GRQ	*Geryon longipes*	Mediterranean geryon
MUT	*Mullus barbatus*	Red mullet	CTZ	*Chelidonichthys lastoviza*	Streaked gurnard
MUR	*Mullus surmuletus*	Striped red mullet	SNQ	*Scorpaena notata*	Small red scorpionfish
NEP	*Nephrops norvegicus*	Norway lobster	RSE	*Scorpaena scrofa*	Red scorpionfish
PIL	*Sardina pilchardus*	European pilchard	CBR	*Serranus cabrilla*	Comber
GFB	*Phycis blennoides*	Greater forkbeard	GUR	*Aspitrigla cuculus*	Red gurnard
WHB	*Micromesistius poutassou*	Blue whiting	WEG	*Trachinus draco*	Greater weever
BRF	*Helicolenus dactylopterus*	Blackbelly rosefish	CASG	*Chlorophthalmus agassizi*	Shortnose greeneye
LDB	*Lepidorhombus boscii*	Four-spot megrim	UPM	*Upeneus moluccensis*	Goldband goatfish

Selectivity of Mediterranean bottom trawls at the species level

Merluccius merluccius (Linnaeus, 1758)

Merluccius merluccius is an important commercial species in the Mediterranean and it is most represented species in the selectivity literature. Data were collected for seven different GFCM GSAs, with majority of the references originating from GSA 17 and GSA 22. For diamond-mesh codends, L50% and SR values increase with mesh size while SF remains constant (Figure 13, Table 7). For square-mesh codend data were insufficient to explore the trends. However, the mean value was plotted and we can see that L50% values were always higher than for the DM mesh of comparable size. Furthermore, for DM codends, L50% correlates negatively with number of meshes in codend circumference, while for SR no significant relationship was found (Figure 14,Table 8). Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for *M. merluccius* are shown on Figure 15. From the graph we can see that all points on all three graphs are aggregated in the lower left corner (<MLS & <LFM) suggesting that for this species all three mesh sizes and shapes are inadequate.

Table 7. Models describing the linear correlations between the L50 (cm), SR (cm), SF and mesh size (mm) for DM codends for *M. merluccius*.

		Estimate	SE	p	R2
L50	intercept	-1.28	1.56	ns	0.51
	slope	0.30	0.04	< 0.01	
SR	intercept	-1.08	1.71	ns	0.20
	slope	0.12	0.04	< 0.01	
SF	intercept	2.79	0.60	< 0.01	0.00003
	slope	0.001	0.01	ns	

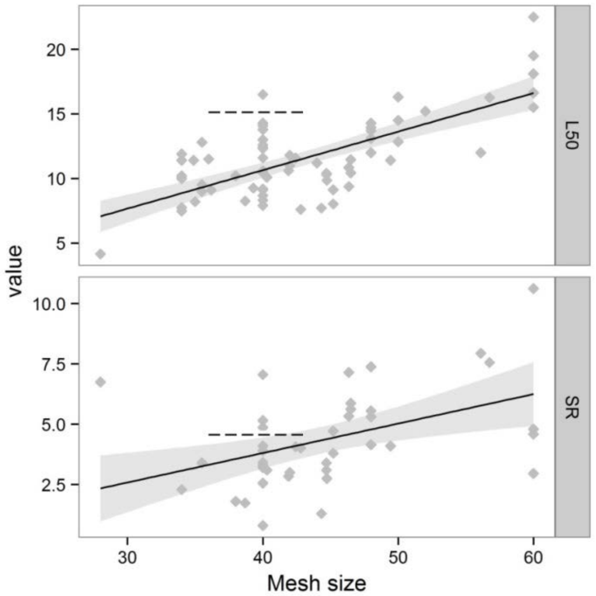


Figure 13. Relationship between selectivity parameters (L50% and SR) and mesh size for *M. merluccius*. Solid line represents DM codends, dashed line represents average value for SM codends.

Table 8. Models describing the linear correlations between the L50(cm), SR(cm) and the number of meshes around the codend circumference for DM codends for *M. merluccius*.

		Estimate	SE	p	R2
L50	intercept	15.35	1.09	< 0.01	0.37
	slope	-0.02	0.004	< 0.01	
SR	intercept	4.81	0.85	< 0.01	0.01
	slope	-0.002	0.003	ns	

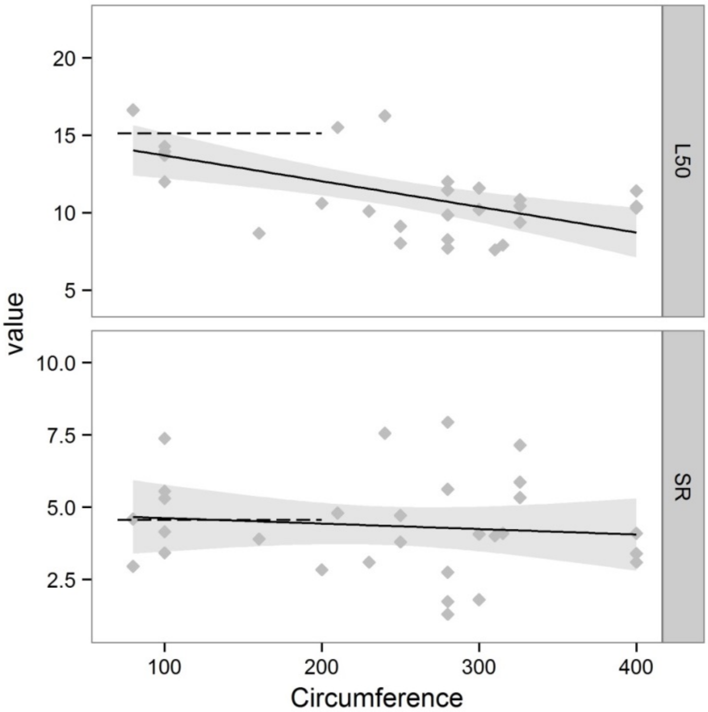


Figure 14. Relationship between selectivity parameters (L50% and SR) and codend circumference for DM codends for *M. merluccius*. Solid line represents DM codends, dashed line represents average value for SM codends.

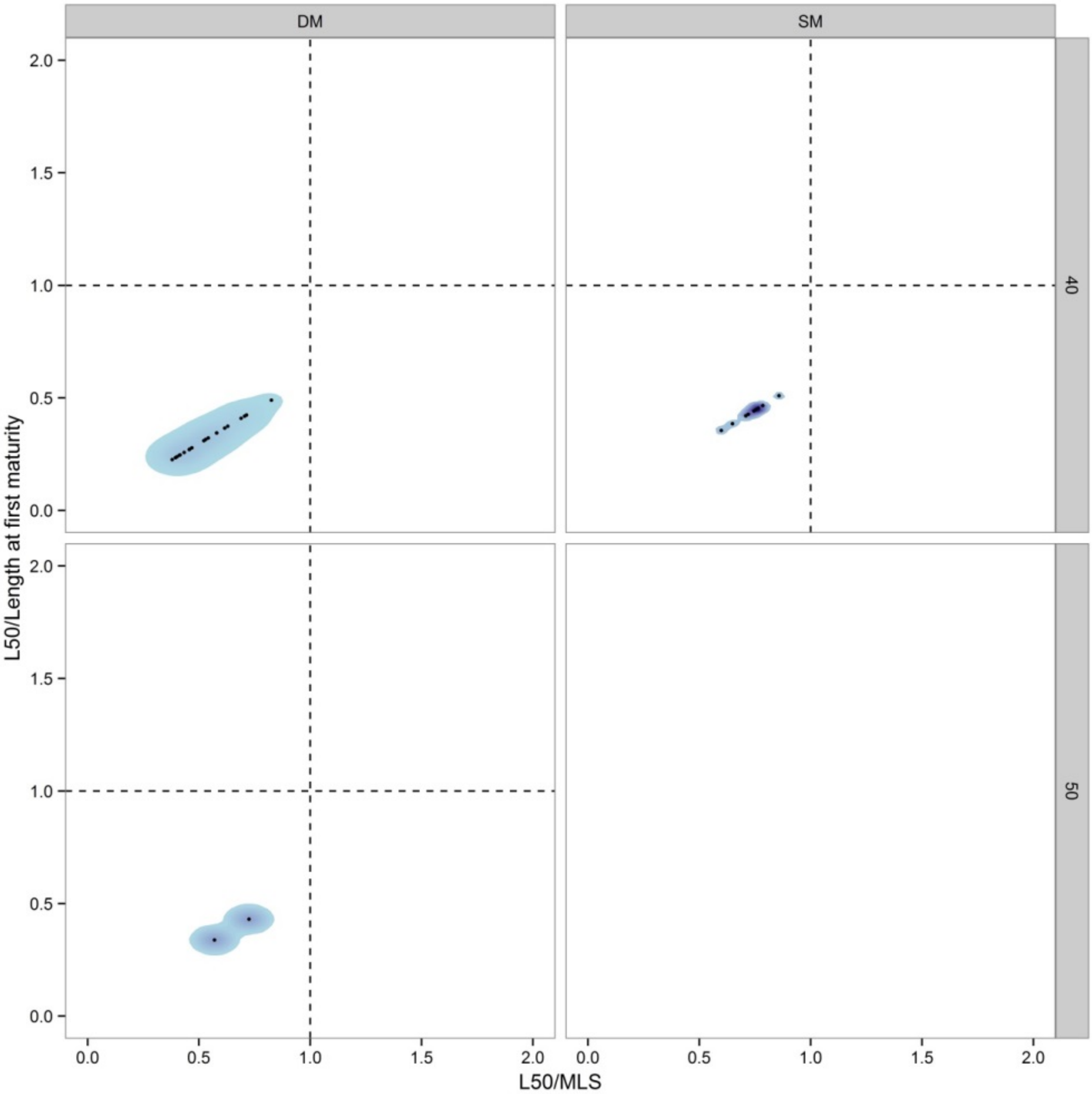


Figure 15. Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for *M. merluccius*.

Mullus barbatus (Linnaeus, 1758)

Data were collected for eight different GFCM GSAs. For diamond-mesh codends, L50% and SR values increase with mesh size while SF remains constant (Figure 16). For square-mesh codend data were insufficient to explore the trends so the mean value was plotted as in previous case. Furthermore, for DM codends, L50% correlates negatively with number of meshes in codend circumference, while for SR no significant relationship was found (Figure 17). Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for this species are shown on Figure 18. From the above mentioned graphs we can see that the points for both DM40 and SM40 are aggregated around the middle of the graph with slight tendency toward the upper right corner (>MLS & >LFM) in case of SM40. This is even more pronounced for DM50, suggesting that for this species, DM50 codends perform better than DM40 and SM40 codends.

Table 9. Models describing the linear correlations between the L50(cm), SR(cm) and mesh size (mm) for DM codends for *M. barbatus*.

		Estimate	SE	p	R2
L50	intercept	2.85	2.34	ns	0.18
	slope	0.19	0.05	< 0.01	
SR	intercept	-4.67	1.05	< 0.01	0.50
	slope	0.17	0.02	< 0.01	

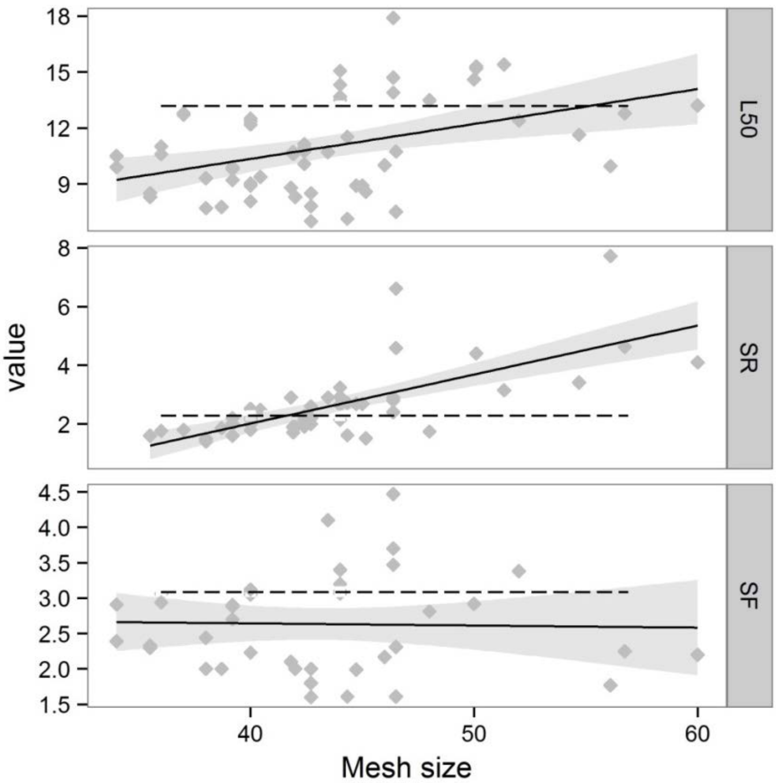


Figure 16. Relationship between selectivity parameters (L50% and SR) and mesh size for *M. barbatus*. Solid line represents DM codends, dashed line represents average value for SM codends.

Table 10. Model describing the linear correlations between the L50(cm) and the number of meshes around the codend circumference for DM codends for *M. barbatus*.

		Estimate	SE	p	R2
L50	intercept	17.56	1.30	< 0.01	0.46
	slope	-0.03	0.006	< 0.01	

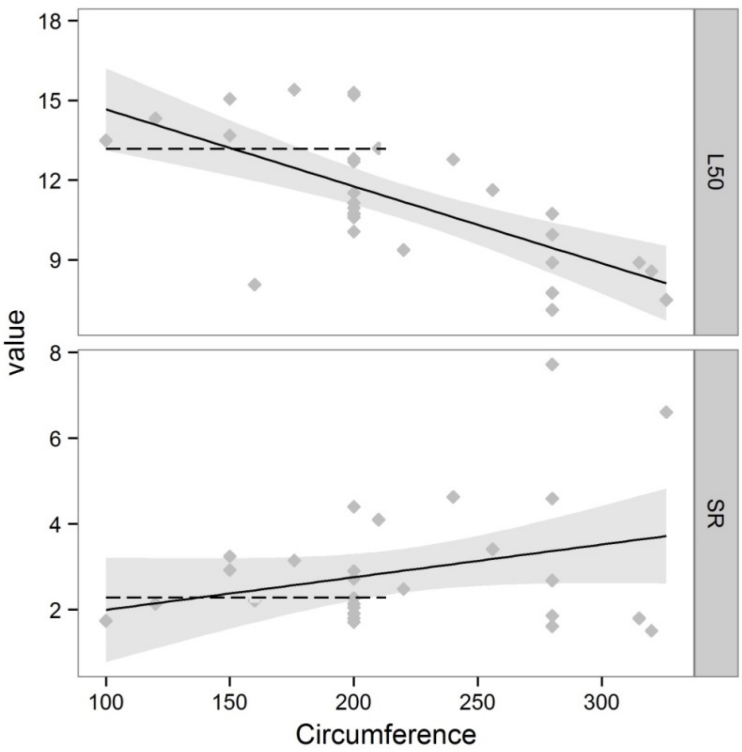


Figure 17. Relationship between selectivity parameters (L50% and SR) and codend circumference for *M. barbatus*. Solid line represents DM codends, dashed line represents average value for SM codends.

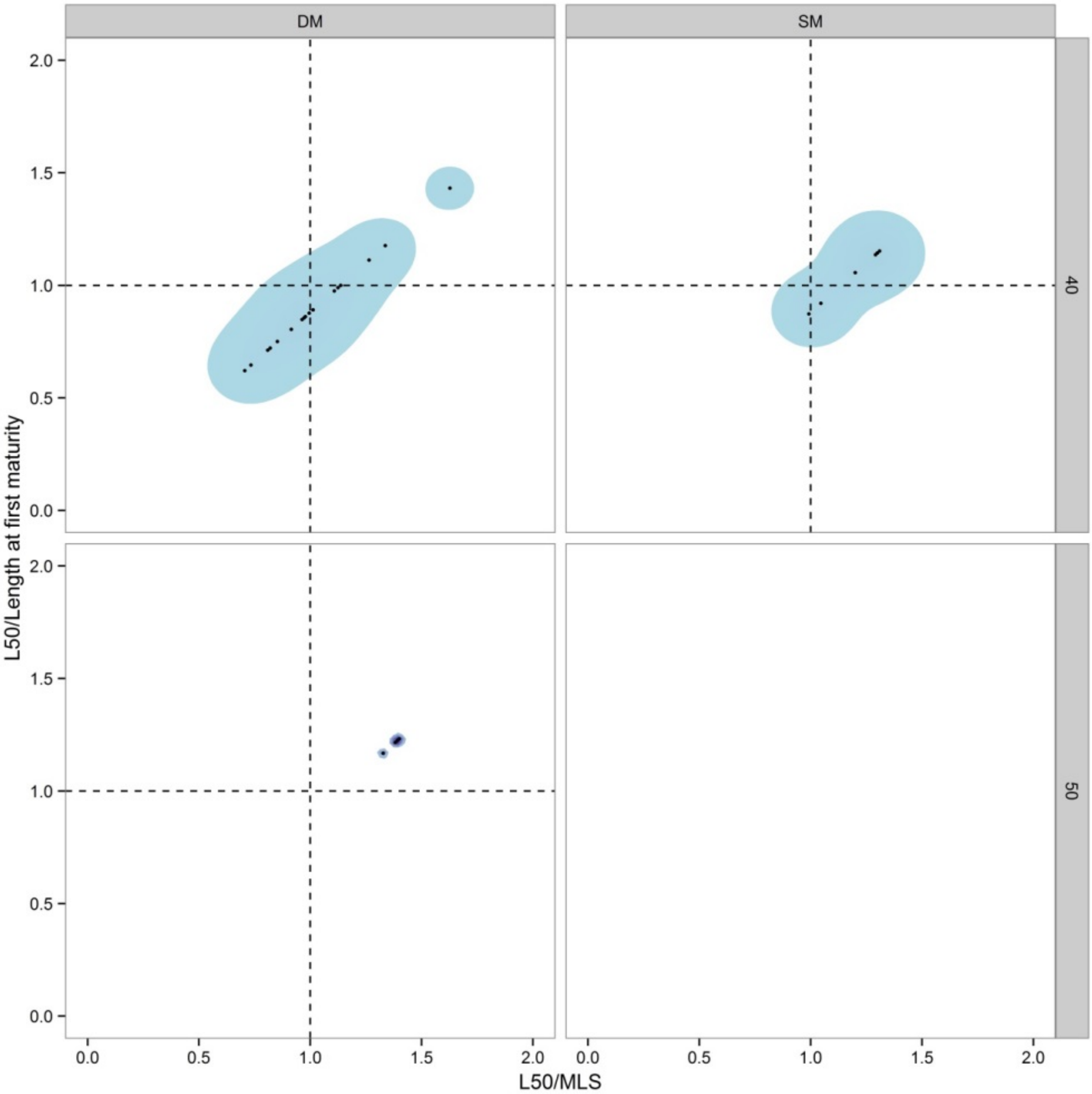


Figure 18. Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for *M. barbatus*.

Parapenaeus longirostris (Lucas, 1846)

Data were collected for eleven different GFCM GSAs. For diamond-mesh codends, L50%, SR and SF values increase with mesh size (Figure 19, Table 11). For square-mesh codend data were insufficient to explore the trends so the mean value was plotted as in previous cases. Furthermore, for DM codends, no significant relationship was found between selection parameters and number of meshes in codend circumference (Figure 20).

Table 11. Models describing the linear correlations between the L50(cm), SR(cm), SF and mesh size (mm) for DM codends for *P. longirostris*.

		Estimate	SE	p	R2
L50	intercept	0.09	0.23	ns	0.55
	slope	0.04	0.01	< 0.01	
SR	intercept	-0.29	0.37	ns	0.19
	slope	0.02	0.01	< 0.05	
SF	intercept	-1.71	1.09	ns	0.17
	slope	0.06	0.03	< 0.05	

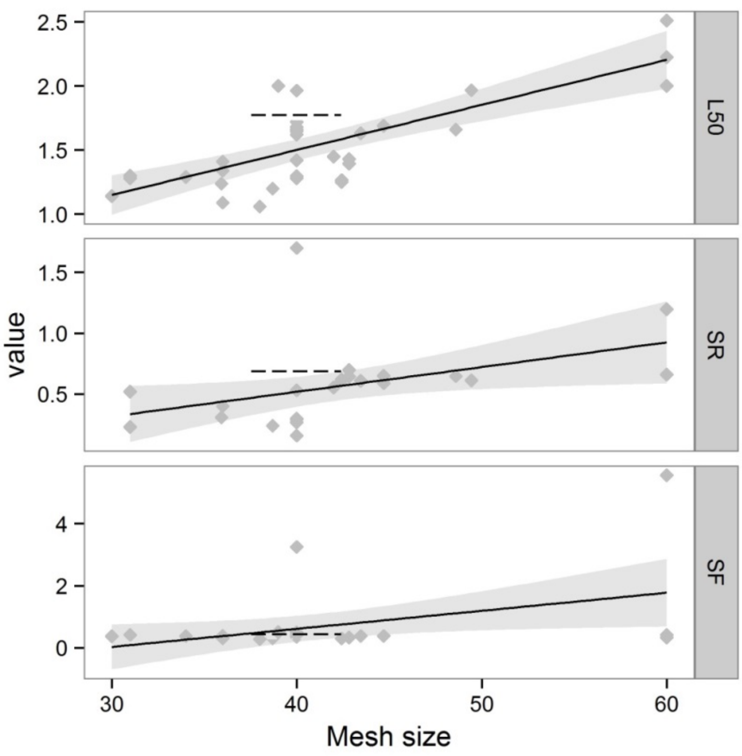


Figure 19. Relationship between selectivity parameters (L50% and SR) and mesh size for *P. longirostris*. Solid line represents DM codends, dashed line represents average value for SM codends.

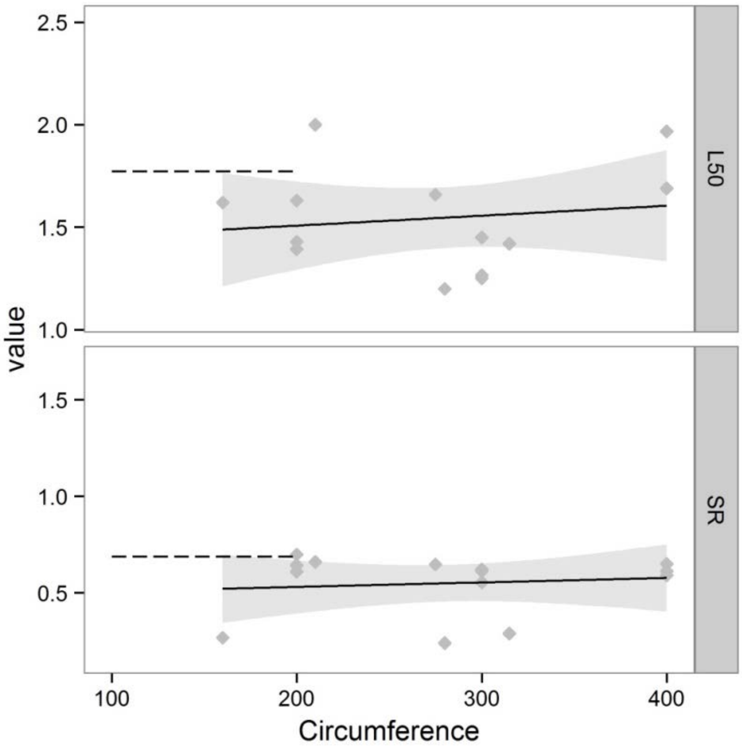


Figure 20. Relationship between selectivity parameters (L50% and SR) and codend circumference for *P. longirostris*. Solid line represents DM codends, dashed line represents average value for SM codends.

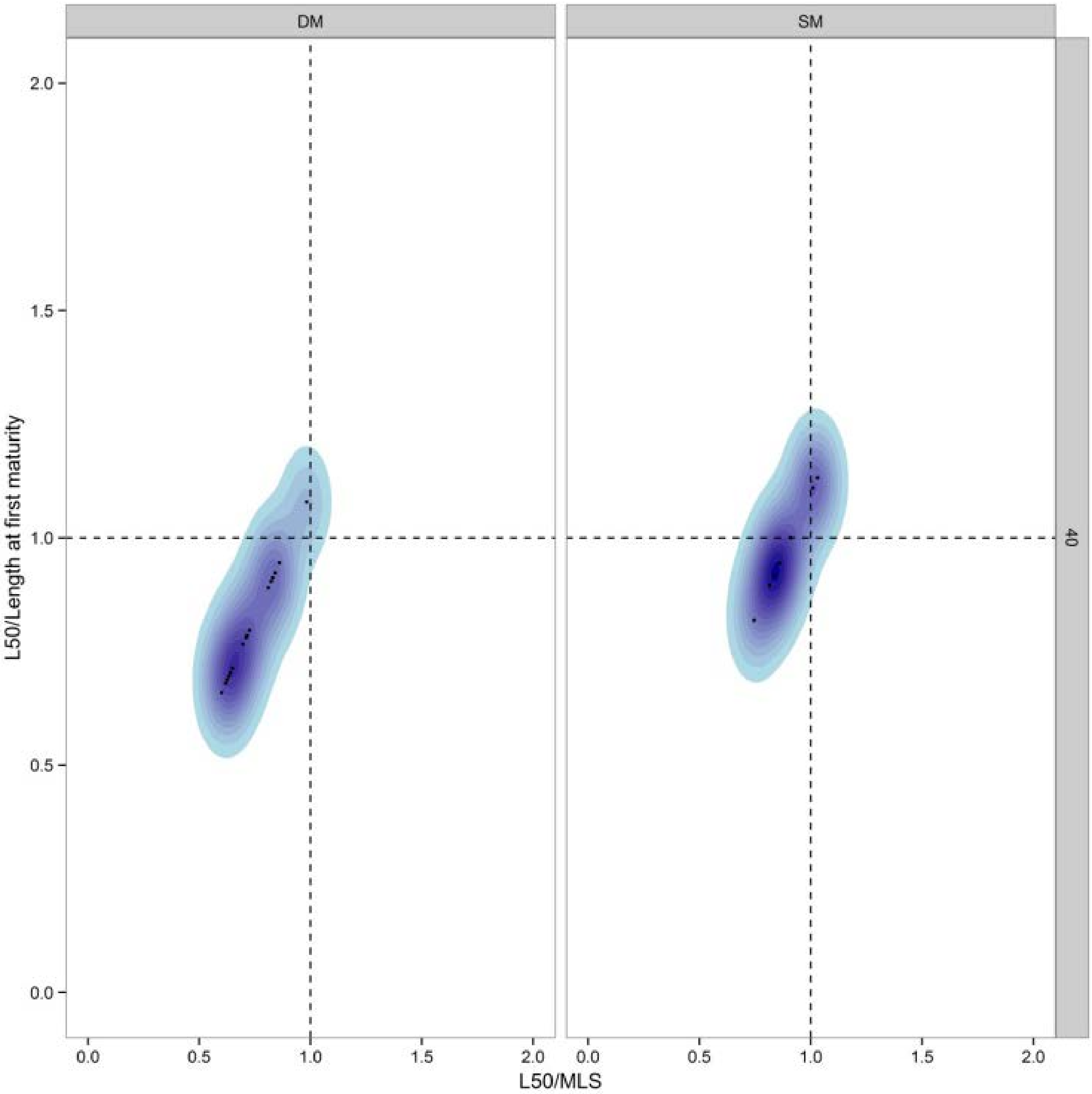


Figure 21. Trawl selectivity indicator for SM40 and DM40 codends for *P. longirostris*.

Nephrops norvegicus (Linnaeus, 1758)

Data were collected for five different GFCM GSAs. For diamond-mesh codends, there was no significant relationship between any of the selection factors and the technical codend parameters (mesh size and circumference) (Figure 22, Figure 23). For square-mesh codends, data were insufficient to explore the trends so the mean value was plotted as in previous cases. Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for *N. norvegicus* are shown on Figure 24. Coefficients of the models describing the linear correlations between the L50 (cm), SR (cm), SF and mesh size (mm) were not significant *(Sig. p=0.715* and *0.971,* for L50 and SR respectively*).*

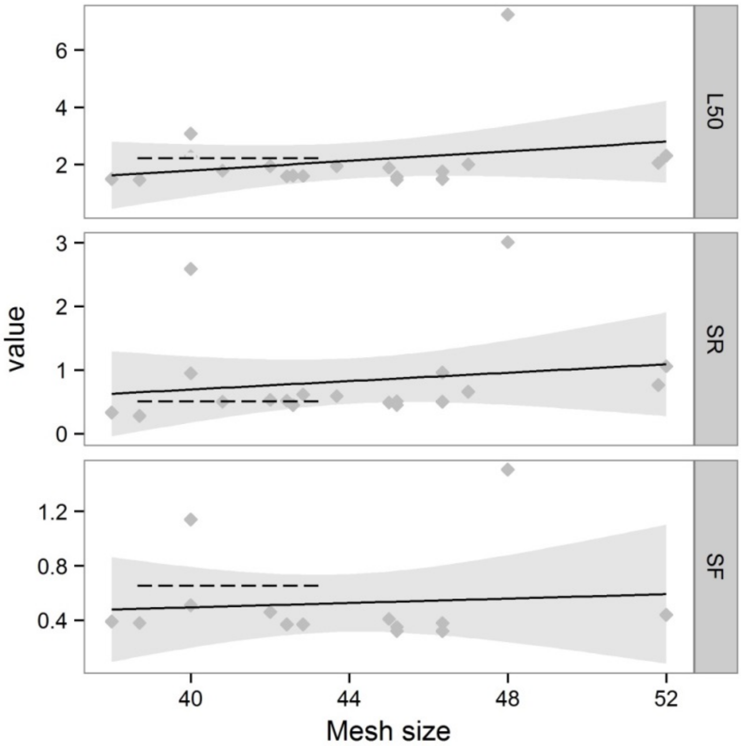


Figure 22. Relationship between selectivity parameters (L50% and SR) and mesh size for *N. norvegicus*. Solid line represents DM codends, dashed line represents average value for SM codends.

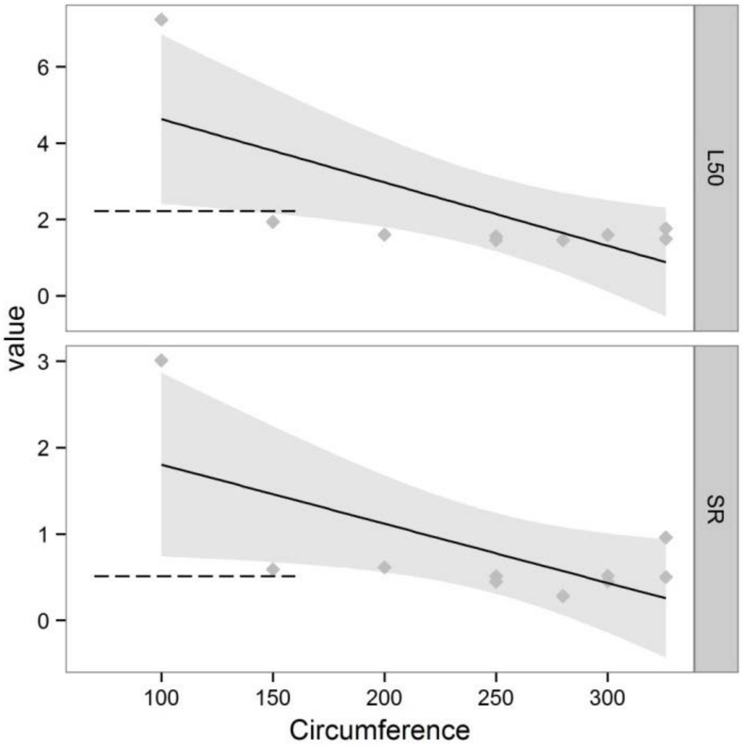


Figure 23. Relationship between selectivity parameters (L50% and SR) and codend circumference for *N. norvegicus*. Solid line represents DM codends, dashed line represents average value for SM codends.

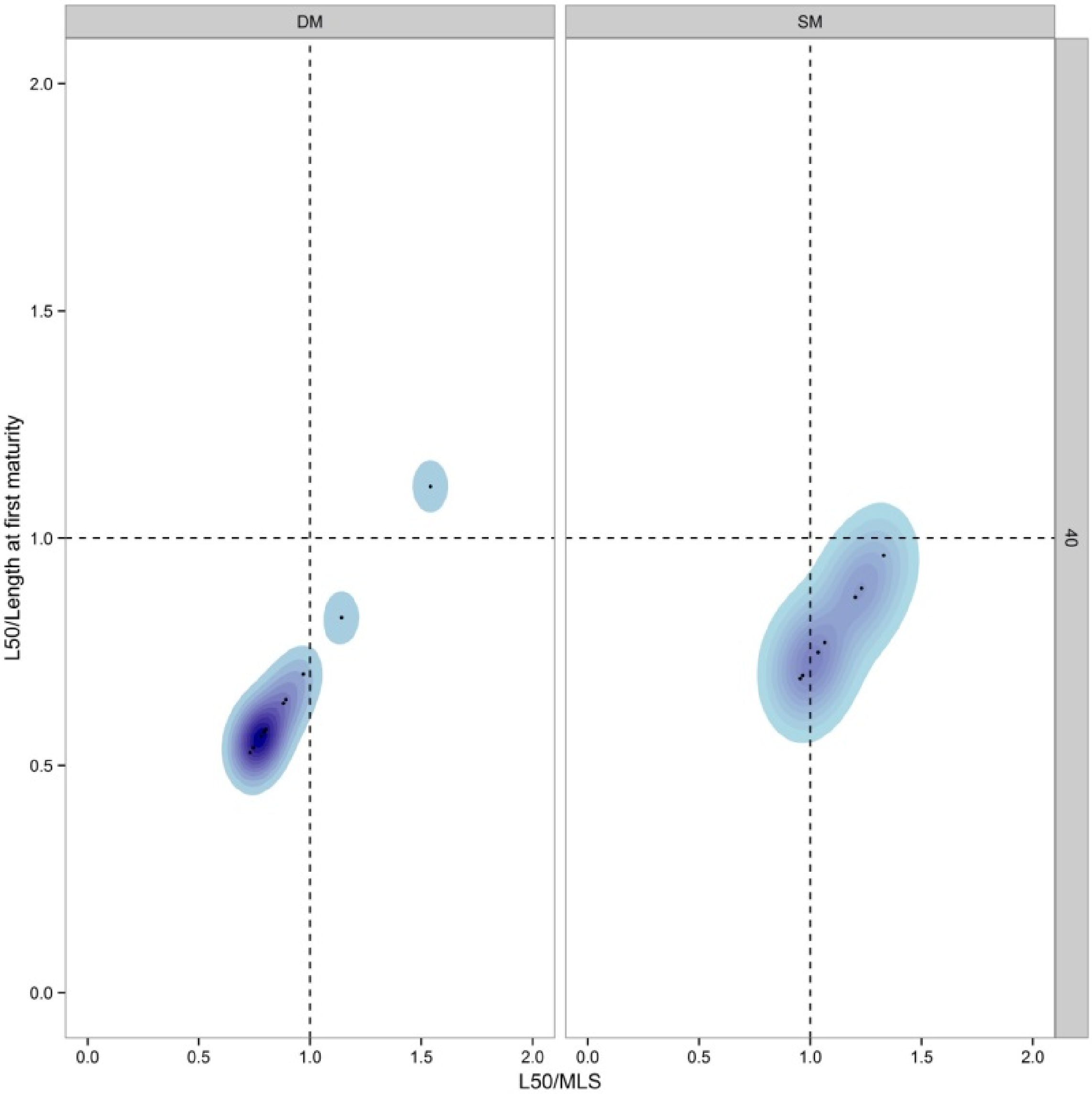


Figure 24. Trawl selectivity indicator graph for SM40, DM40 codends for *N. norvegicus*.

Aristeus antennatus (Risso, 1816)

Data were collected for four different GFCM GSAs. For diamond-mesh codends, L50% and SR values increase with mesh size while SF remains constant (Figure 25). For all other relationships, data were insufficient. Trawl selectivity indicator graphs comparing the selectivity of SM40, DM40 and DM50 codends for *A. antennatus* are shown on Figure 27.

Table 12. Models describing the linear correlations between the L50(cm), SR(cm) and mesh size (mm) for DM codends for *A. antennatus*.

		Estimate	SE	p	R2
L50	intercept	-0.02	0.29	ns	0.87
	slope	0.04	0.01	< 0.01	
SR	intercept	-1.24	0.58	ns	0.67
	slope	0.04	0.01	< 0.05	

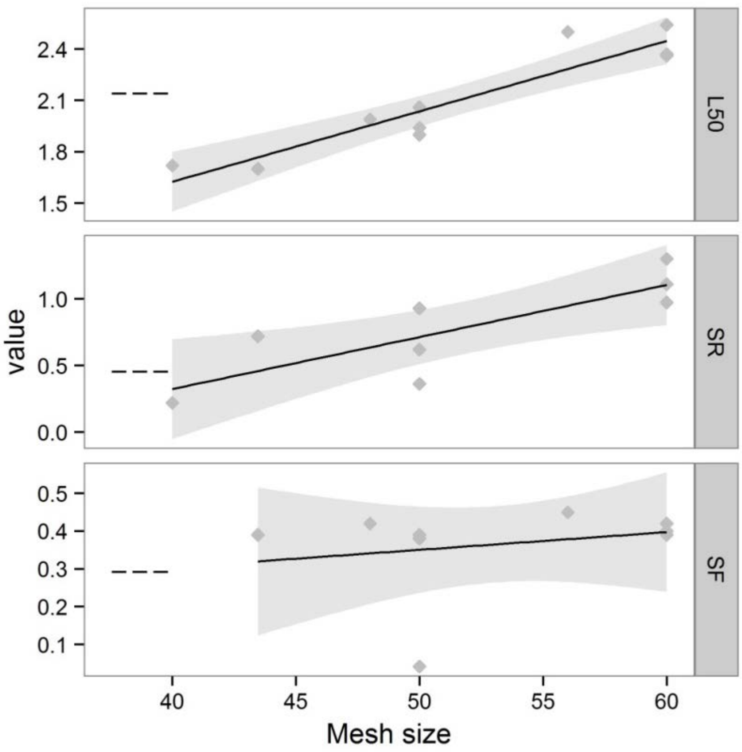


Figure 25. Relationship between selectivity parameters (L50% and SR) and mesh size for *A. antennatus*. Solid line represents DM codends, dashed line represents average value for SM codends.

Aristaeomorpha foliacea (Risso, 1827)

Data were collected for four different GFCM GSAs. For diamond-mesh codends, L50% and SR remained constant, while SF values decreased with mesh size (Figure 26). For all other relationships, data were insufficient. Trawl selectivity indicator graphs comparing the selectivity of SM40, DM40 and DM50 codends for *A. foliacea* are shown on Figure 27. Coefficients of the models describing the linear correlations between the L50 (cm), SR (cm), SF and mesh size (mm) were not significant *(Sig. p=0.988* and *0.389,* for L50 and SR respectively*)*.

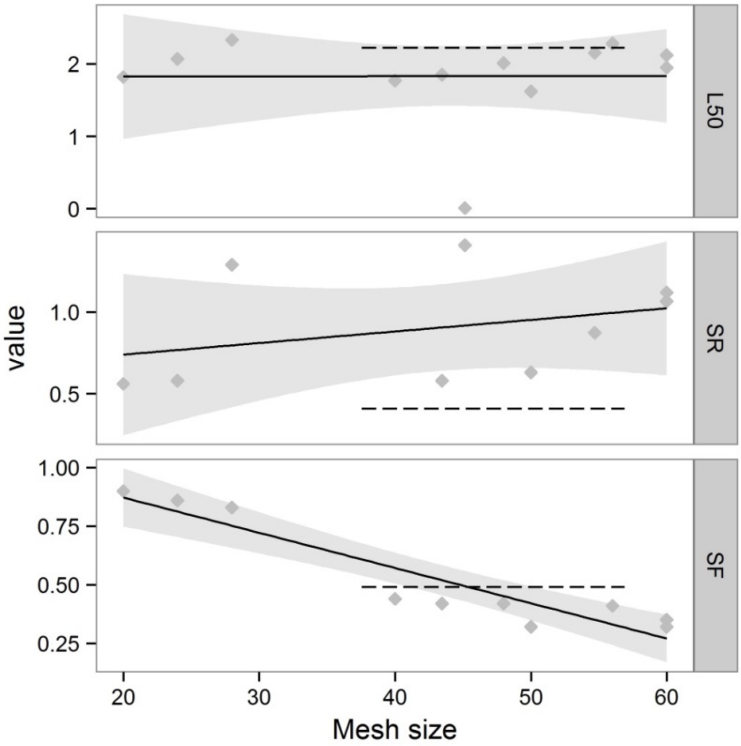


Figure 26. Relationship between selectivity parameters (L50% and SR) and mesh size for DM codends for *A. foliacea*. Solid line represents DM codends, dashed line represents average value for SM codends.

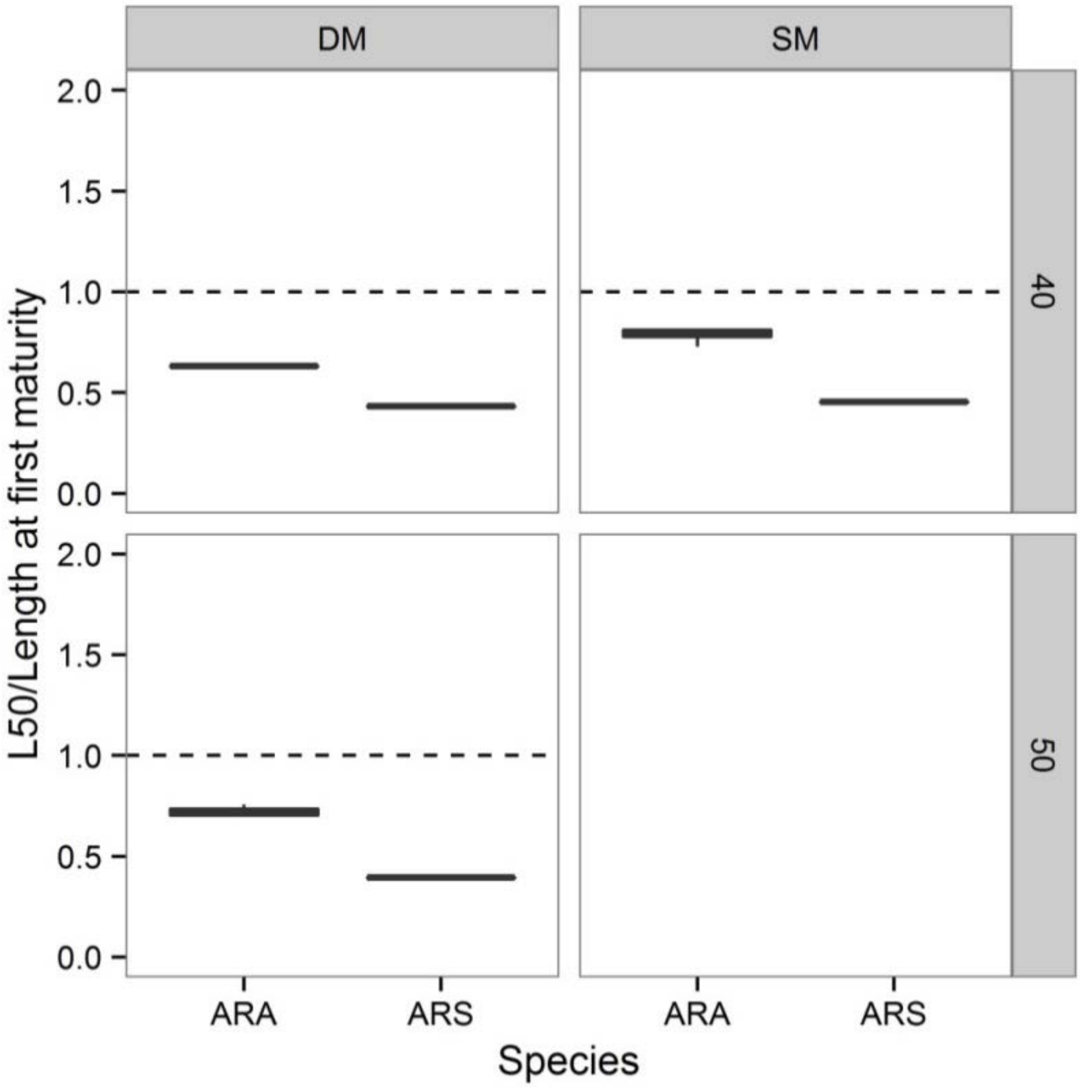


Figure 27. Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for *A. antennatus* (ARA) and *A. foliacea* (ARS).

All species

In multi-species fisheries such as demersal trawling in the Mediterranean, there is rarely a single minimum codend mesh size which is appropriate for all the species in the catch, due to differences in body shape and size at first maturity.

Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for all the species found in the literature (Figure 28) suggest that transition from DM40 to SM40 does not provide much better alternative compared to DM50 codends. From the graphs we can also see that most of the investigated species benefit when DM50 codends are used (points are mostly aggregated in the middle or in the upper right corner).

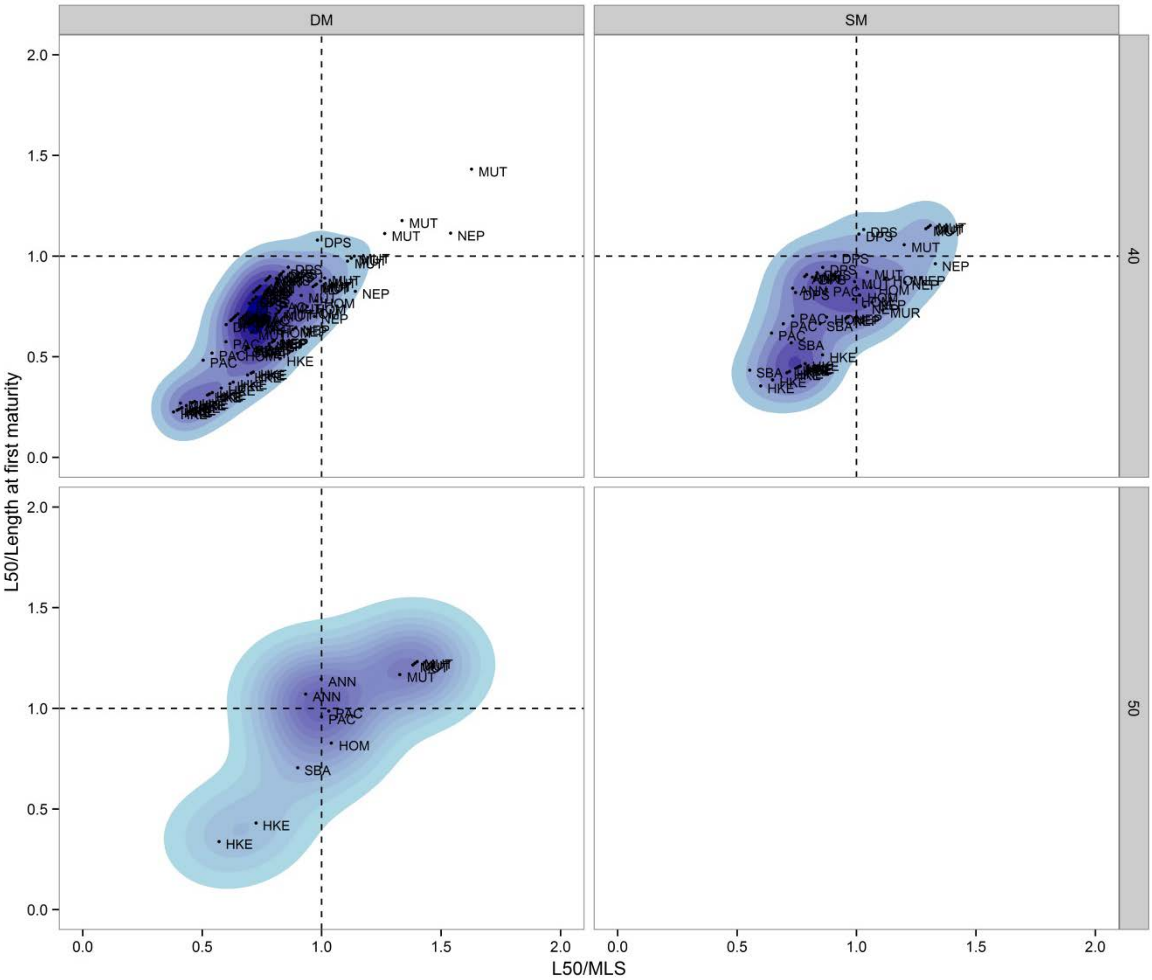


Figure 28. Trawl selectivity indicator graphs for SM40, DM40 and DM50 codends for all the species from the literature.

Discussion

The Annex III of the Mediterranean Regulation (Reg No 1967/06) sets Minimum Landing Sizes (MLS) for certain species. One of the goals of gear selectivity is to reduce the catches of individuals below the MLS, i.e. of individuals that cannot be legally landed. Towards this direction, we examined the effectiveness of selectivity in the Mediterranean through the trawl selectivity indicator graphs (Figure 12), by representing historical data of L50s in relation to MLS. However, in order for MLSs to be ecologically meaningful they need to approximate lengths at first maturity. This is also clearly stated in EU Reg. No 1380/2013 which seeks to replace MLS with Minimum Conservation Reference Size (MCRS) that take into account maturity of species. In our analysis, we also graphed L50s estimated in trawl selectivity studies in relation to length at first maturity. The data that we collected in order to construct the trawl selectivity indicator graphs provide a good opportunity to compare MLS and lengths at first maturity. This comparison is important in order to define optimal MCRS. Lengths at first maturity for the investigated DISCATCH species and average values are presented in Table 5.

For the majority of species, MLSs are well below the size at first maturity. Specifically for *Merluccius merluccius* length at first maturity (25-42.5 cm) was always bigger than MLS (18 cm) and the same was true for *Mullus surmuletus* (length at first maturity: 15-17.8 cm; MLS: 11 cm). For *Mullus barbatus* (length at first maturity: 10.5-15.2 cm) and *Trachurus spp.* (length at first maturity*:* 13.5-23.3 cm) only the minimum values of length at first maturity were below MLS, implying that most populations mature at sizes larger than MLS. Among the species considered, only *Parapenaeus longirostris* had a size at first maturity (1.82 cm) smaller than MLS (2 cm). From our data it is obvious that the existing MLSs are ecologically inefficient for sustainable management, in line with what reported in other studies in the Mediterranean (e.g., Stergiou *et al.* 2009) and that MCRS should be redefined for several species. In addition, low compliance even with the current MLSs is obvious in certain fisheries in the Mediterranean (e.g., Damalas and Vassilopoulou 2013) and this may further increase the problem of catching undersized individuals in the basin.

Beverton (1963) showed that most of the organisms escape from the trawl through the codend meshes, and this is probably the main reason why the majority of selectivity studies in Mediterranean were focused on increasing the codend mesh size in order to improve bottom trawls selectivity (Stewart 2002). It has been shown that accumulation of catch in diamond mesh codends results in distorted mesh geometry, thus reducing the selection area of the codend (Herrmann, 2005). Since only the meshes in front of the accumulated catch remain open, this is where the majority of the selection occurs (Pope et al., 1975; Herrmann, 2005). In order to prevent mesh distortion, Lök et al. (1997) shortened the lastridge rope, which resulted in 10% increase of L50 for some commercial species.

Some other studies tried to overcome this by increasing the codend circumference (Suuronen and Sardà, 2007) because this prolongs the time necessary for the catch to build up and distort the meshes. This effect was first noticed in the North Sea in the early nineties (Reeves et al., 1992). The first study of this kind in the Mediterranean conducted by Sala and Lucchetti (2010) did not show any effect of increased circumference on the codend selectivity, probably due to the small catch sizes. However, the second study performed by the same authors, where codend catches varied more, showed that changes in codend circumference significantly influence codend selectivity (Sala and Lucchetti, 2011). In this study, general relationship between circumference and L50 was significant only for HKE and MUT, while for all other species this effect was not evident. This is probably due to different behaviour and morphology of investigated species.

Another way of preventing mesh distortion is by changing mesh geometry from diamond to T90, square and hexagonal mesh. The use of 90° turned diamond mesh netting for trawl codends (T90) may be an alternative design which could potentially satisfy both fisheries management and the fishermen. A T90 codend can be considered to have size selective properties between those of a square mesh codend and a diamond mesh codend (Tokaç et al., 2014). Since there is only one study on T90 codends in the Mediterranean, no general trends were reported in this review. The first studies on the selectivity of the square mesh netting in Mediterranean were conducted in the nineties (Petrakis and Stergiou, 1997; Stergiou et al., 1997). As of July 1st 2008 in all EU Mediterranean waters it is forbidden to use towed nets with meshes smaller then 40mm square or 50 mm diamond (EC Reg. No 1967/2006).

This is the first time that square mesh is required by the regulation, which resulted in increased number of studies focused on this type of mesh. Unlike diamond mesh that closes under the weight of the catch, square mesh netting stays open for the duration of the tow (Eayrs, 2007). Many studies showed that square mesh is much more selective then the diamond mesh of the same size, at least for the species with round cross section (Petrakis and Stergiou, 1997; Guijarro and Massutí, 2006; Lucchetti, 2008; Sala et al., 2008). Recent studies from the Aegean Sea compared selectivity of 44 mm diamond, 40 mm square and 40 mm hexagonal meshes. The result showed that square mesh is significantly more selective then the other two for SQR, SQM and IAR.

Similar results were obtained by Aydın and Tosunoglu (2010) for HKE and GFB, but hexagonal was better for HOM. In this review, general relationships between different mesh sizes and selectivity parameters L50 and SR are given only for diamond mesh codends because for all other mesh types data were insufficient. Although many studies showed the benefit of using the square mesh instead of diamond mesh codends, the benefit of reducing discards and sorting time on deck, the inevitable short term economic losses usually discourage fishermen from using it. For example, Bahamon et al. (2006) estimated 12-33% short term economic losses for 40mm square mesh codends in shallow shelf fishing grounds in the Mediterranean, due to the escape of a high number of small species with relatively high commercial value.

In order to prevent the escape of highly valuable small species, a square mesh panel can be inserted in the diamond mesh codend. Only few studies on selective panels exist for the Mediterranean. Özbilgin et al. (2005) first showed how the use of square mesh panels can improve size selectivity for HKE and POD, what was also later found for MUT, ANN, PAC, NEP, DPS, WHB, GFB and BRF (Metin et al., 2005; Tokaç et al., 2009; 2010; Kaykac, 2010). Square mesh panels have been implemented in some non-Mediterranean EU fisheries, and so far it is known that optimal position and size of selection panel are crucial for proper performance (Suuronen and Sardà, 2007).

Sorting grids inserted in bottom trawls are also known to affect selectivity, but unlike selective panels they are used mostly to exclude large organisms. First research on grid selectivity in Mediterranean was performed by Sardà et al. (2004) who showed efficiency of grid with 20 mm bar spacing in reducing the number of undersized HKE in the catches. This was confirmed by Sardà et al. (2005), who performed similar study with the same grid bar spacing, but different sorting surface area. Sardà et al. (2006) compared selective grids with 15 and 20 mm bar spacing and found that the 20 mm grid is more effective, although optimal selection could be achieved only for a few species.

All above mentioned studies agreed that the use of grids can improve selectivity, but they can make the handling of the net more difficult. To overcome this a flexible grid was introduced (Loaec et al., 2006). The selective properties of flexible grid are similar to those of rigid grid but the handling of the net is much easier because it is possible to wind it on the net drum (Bahamon et al., 2007a; Massutí et al., 2009).

Grids can also be used to exclude larger organisms, and one of the most popular is TED (turtle excluder device). Atabey and Taskavak (2001) were the first to test the TED in the Turkish fishery, where they showed grid efficiency in excluding loggerhead, green sea turtle, jellyfish, sharks, and rays. Sala et al. (2011) investigated the effect of different TED designs and materials in bottom trawl fisheries, where they showed how the use of grid can reduce the debris and improve catch quality.

In conclusion, although there are many ways of improving selectivity of bottom trawls in the Mediterranean, there is not a single grid or minimum mesh size that is adequate for all species in this multi-species fishery.

Provide data on the codend geometry during fishing including how this affected by the amount of catch in the codend (Task 3.3)

This task calculates the geometry of codends used in the Mediterranean trawls fisheries. These include codends made of diamond and square mesh netting, and with different ranges of mesh size, twine diameter, number of meshes in circumference, number of meshes long and over a range of catch sizes.

In total the geometry of 24 codends have been calculated: 8 diamond-mesh demersal codends; 8 square mesh demersal codends; and 8 diamond pelagic codends. For each codend, the geometry is calculated with up to 26 different catch sizes. These geometries will be used by the FISHSELECT model to calculate the degree to which meshes are open during the fishing operation and to predict the corresponding codend selectivity in the Mediterranean trawls fisheries where these codends are used.

The codend is the rearmost part of trawl fishing net and the place where most selection takes place. In the DISCATCH project a model of codend selectivity will be used to predict the selectivity of the codends used in the Mediterranean trawl fisheries. In order to estimate codend selectivity it is necessary to know how open the codend meshes are during the fishing operation. If we know the overall geometry of the codend we can then calculate the lateral openness of each mesh along the codend. However, during a tow, as the catch size increases, the geometry of the codend also varies; hence we need to be able to calculate the codend geometry over the range of catch sizes we would expect to see during the fishing operation. In this deliverable the main objective is to calculate the codend geometry, at a range of catch sizes for each of the codends used in the Mediterranean trawls fisheries that are being investigated.

Methodology

Several means are available to calculate codend geometry: full scale observation at sea; small scale tests in flume tanks and numerical modelling. Each has its own advantages and drawbacks:

- full scale observation at sea give real information, but the observation area is generally very limited; it is impossible to see the whole structure at the same time, and these trials are very expensive;
- small scale tests in flume tanks give a lot of information, such as the behaviour of the structure in waves and in current. The main drawback is probably that the models used in tests are quite expensive, and this limits the number of tests that can be performed;
- numerical modelling can also give a lot of information, such as the tension in cables and netting twines, but generally certain assumptions have to be made regarding the behaviour of the structure and the hydrodynamic effects on catch and netting. Nevertheless they have been shown to be very accurate.

For the DISCATCH project, numerical modelling is the most suitable approach. It is able to take into account the large number of codends which have to be investigated and it is relatively inexpensive. The numerical approach used is the Finite Element Method (FEM).

This is a well-established engineering modelling methodology that has been used in many design and engineering contexts to predict the physical and mechanical characteristics of surfaces and structures. The numerical software package we apply here is one which has been specifically developed to predict the geometry and the forces acting on netting structures such as trawl fishing gears and codends.

Modelling the codend

The modelling is founded on the finite element method (FEM) model of the net based on a triangular element (Priour, 1999; 2013). The FEM model takes into account the inner twine tension, the drag force on the net due to the current, the pressure created by the fish catch in the codend, and the contact between knots of the netting, which limits the closure of meshes. The FEM model is able to describe all the net of the codend and the cable which closes the codend.

The net is modelled into triangular elements, whereas the cable, is modelled in linear elements (bars). Due to the high number of knots in the codend, the time required for the determination of the equilibrium position of each knot is generally extremely long. Thus, thanks to the FEM model, the triangular elements can cover a large number of meshes (Figure 29). The triangles are contiguous, which means that a vertex can belong to several triangles, and triangle boundaries are not necessarily parallel to the twines or to the diagonal meshes. Thus, the user is free to create the triangular elements. The refinement is easy: a triangular element can be divided into 3 triangles without any modification to the rest. Each vertex is linked to the net; thus, when the equilibrium position of each vertex is found, the equilibrium position of the net is also found.

All details of the method of numerical calculations based on twine tension, hydrodynamic drag, contact between knots, fish catch pressure, catch volume model, sum of forces and boundary conditions are reported in the Annex *D 0.2. Geometry of the codends.*

Discussion

Some of the codend geometries calculated using the FEM numerical model are presented in the Annex *D 0.2. Geometry of the codends.* Each figure demonstrates a particular feature of how the different design parameters affect the geometry of a codend and hence the lateral mesh openness and consequently the selective performance of a codend. All figures show the influence of catch size and how as the catch increases the diameter of the codend increases. The Annex *D 0.2. Geometry of the codends* (see Figure 4 in *D3.2.*) show how the number of meshes in circumference can affect the geometry and consequently the mesh openness will even when catch sizes may be similar. Similarly Figure 5-7 in the deliverable *D 0.2*, demonstrate how twine thickness, mesh size and mesh shape respectively influence codend geometry.

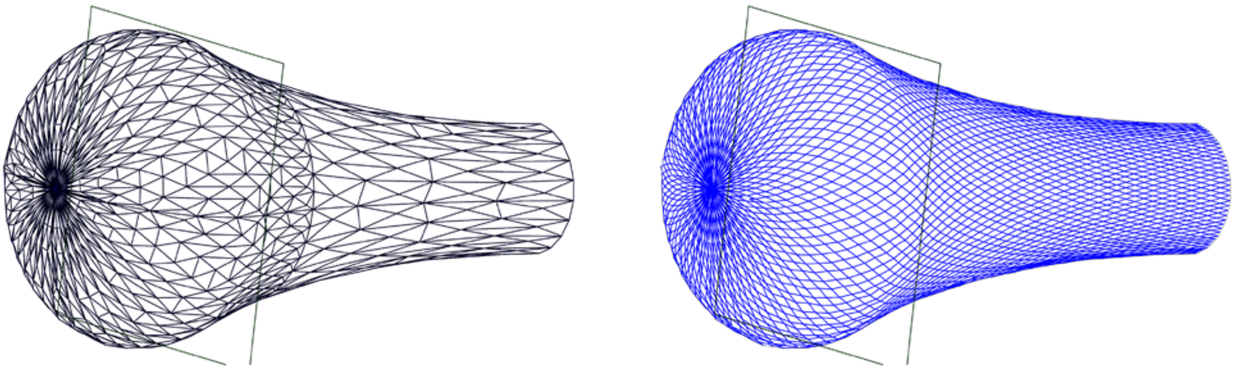


Figure 29. View of the model of codend. The net is split into contiguous triangles in the modelling. On top the triangular element are shown when on the bottom the twines are shown (only 1 on 10 twines is shown). This figure corresponds to p_d_ms_30_tt_10_ma_800 (see deliverable *D 0.2. Geometry of the codends*) and a catch of 5000 kg.

Run FISHSELECT simulations to predict size selectivity in different codends not tested at sea (Task 3.5)

Choice of simulation tool for simulating codend size selection in the DISCATCH project

PRESEMO is a codend size selection simulation model which has been developed to simulate size selection in diamond-mesh codend of fish species which can be described by one elliptical cross section. The model description for PRESEMO can be found in Herrmann (2005a). For haddock has PRESEMO successfully been applied to study various aspects of size selection in diamond-mesh codends: catch size (Herrmann 2005b), between haul variation in size selection (Herrmann and O'Neill, 2005), mesh size and number of meshes in codend circumference (O'Neill and Herrmann, 2007), twine thickness (Herrmann and O'Neill, 2006), codend round straps (Herrmann et al., 2006), T90 versus T0 (Herrmann et al., 2007).

Krag et al. (2011) later proved that the elliptical cross sectional description used for the PRESEMO simulation of haddock size selection in these studies was a very good approximation of haddock morphology being important for size selection in diamond-mesh codends. However this does not necessary imply that using the same kind of elliptical approximation is sufficient for simulating codend size selection of other species than haddock. So far PRESEMO have only one time before been applied to study size codend selection of other species than Haddock (Sala et al., 2006 2011) in a study on size selection of red mullet in diamond-mesh codends. Besides the limitation to model fish morphology of importance cross sectional shape by one elliptical cross section PRESEMO is only able to simulate size selection in diamond-mesh codends expect from square-mesh codends where it can be assumed that the meshes are all fully open.

In the DISCATCH project we needed to be able to simulate codend size selection of many different species both in diamond-, hexagonal- and square-mesh codends. However, during the work of preparing the data for performing the simulations of codend size selection using PRESEMO as original planned in the project proposal we became aware of several important limitations for the purpose for the use in the DISCATCH project:

i) The first part of the work for simulating size selection is to collect morphological data of relevance for codend size selection for the different species. During this process using the FISHSELECT toolbox (Herrmann et al., 2009; 2012) it became evident that for several species a more accurate cross section description could be obtained using other models than a perfect ellipse. This is something which PRESEMO cannot handle.

ii) Further for crustaceans like Norway Lobster and different shrimp species studies such as Frandsen et al. (2010) have demonstrated that more accurate estimates of codend size selection can be obtained by taking into account in the simulations that the species may make contact with the codend meshes in different ways. These are termed contact modes by Krag et al. (2014). PRESEMO can only handle simulations with one contact mode at the time.

iii) In addition from underwater recordings of square-mesh codends we became aware of that in several situations it is not valid to assume that all codend meshes are fully open during the fishing process. When simulatoing size selection in square-mesh codends, PRESEMO can only handle the situation where all meshes can be assumed to be fully open.

Based on realizing the limitations i) - iii) as described above we choose to base the simulations of codend size selection on the tool FISHSELECT instead of PRESEMO since FISHSELECT overcome all the limitations as described above with PRESEMO. FISHSELECT (Herrmann et al., 2009; 2012) is a more modern and more flexible size selection simulation tool than PRESEMO but has been developed by the same scientists.

In contrast to PRESEMO, FISHSELECT has been applied to simulate codend size selection of several different fish species: cod (Herrmann et al., 2009; Sistiaga et al., 2011), Haddock (Krag et al., 2011; Sistiaga et al., 2011), redfish (Herrmann et al., 2012; 2013a), Greenland Halibut (Herrmann et al., 2013b) covering species with very different cross sectional shape with some being very different from a perfect ellipse.

FISHSELECT includes more than 100 different parametric models for description of fish cross sectional shape and has also been shown to be able to simulate size selection of crustaceans (Frandsen et al., 2010) and of Krill (Krag et al., 2014). Further FISHSELECT has also been shown to be able to simulate size selection also of square-mesh codends (Krag et al., 2011) and of sorting grids (Herrmann et al., 2013a; 2013b; Sistiaga et al., 2011). Based on the above we have therefore chosen to use FISHSELECT for the codend size selection simulations instead of PRESEMO as originally planned.

Materials and methods

We used the FISHSELECT methodology (Herrmann et al., 2009) to investigate and predict the selectivity properties of multiple codend types for the Mediterranean. FISHSELECT is a methodology to assess the morphological conditions for different species of fish and crustaceans relevant in the process of mesh penetration in towed gears. It is based on a combination of laboratory experiments with freshly caught individuals, data collection, data analysis and computer simulation. The calculation of selectivity parameters for different codends are estimated by comparing the cross-sectional geometry of individual and the geometry of the mesh. The main tasks in FISHSELECT methodology are described below.

i. Data collection of the morphology: for each individuals of each species, length and weight are recorded. Cross sections that potentially could influence the ability of the species to penetrate meshes are measured by using a morphometer tool. Based on different geometrical shapes, the cross-section are automatically described by few parameters.
ii. Establishment of morphological relationship: the morphological parameters are linked to the length of the individuals by applying regression analysis. The output contains the fit statistics and the variance of the morphological parameters. This information is used to generate a virtual population of the same species having similar morphological characteristics. The between-individuals variation in the relationship among length and morphological parameters, will also be provided to the virtual population.
iii. Mesh list configuration: three different mesh geometries are considered: diamond-, square- and hexagonal-mesh. Different ranges of variation for both mesh size and mesh opening angle are combined to form the full mesh list investigated.
iv. Estimation of the basic mesh selectivity: data for the virtual population of fish and crustaceans and data for mesh of interest are combined to make a series of simulations using the established penetration model. The built-in functionality enables to estimate the basic selectivity properties (selection curve) for the selected meshes for the species being studied. For a specific mesh, it also enables a prediction of whether or not there is a reasonable balance between the selectivity proprieties of the mesh and the minimum landing size (MLS) for the species.

Thus, if information on the large scale population structure of a species is available for a particular fishery, the build-in functionality gives a first indicative prediction of the consequences on discard/loss of marketable fish, of using the mesh in combination of the chosen MLS.

Measurement and estimation of cross-section shapes

As detailed in the deliverable *D 0.3. Morphology data for species being investigated*, in FISHSELECT the morphological characteristics of each individual are defined by the shape of the cross-section (CS) of its body at different points. To determine the shape of the different CSs measured for each fish/crustacean, we used a mechanical sensing tool called Morphometer (see Herrmann et al., 2009). The shapes observed on the morphometer are transformed into digital image by using a flatbed scanner and were further analysed using an image analysis tool embedded in the FISHSELECT software.

The result of the image analysis function is a contour for each CS. To model these contour obtained for each CS, a variety of different geometrical shapes are tried. The CSs are chosen so that the points that could be critical for the fish to pass through the different selection devices were covered.

Mesh List

Three different mesh geometry have been considered: diamond-, square- and hexagonal-mesh. Different ranges of variation for both mesh size (MS) and opening angle (OA) are combined to form the full mesh list investigated. Considering the currently EC Reg. 1967/2006, which imposed different minimum mesh size (MMS) for demersal and pelagic fishery, we considered different ranges of variation of MS for demersal and pelagic species. Table 13 shows the complete ranges of meshe size and shape considered. Even if hexagonal-mesh is not currently adopted in Mediterranean trawl fisheries, such a shape represents a valid alternative to both diamond- and square-mesh. Sistiaga et al. (2011) demonstrated that the shape of a knotted diamond-mesh can be described by a hexagon. Moreover, as described by Krag et al. (2011), in a square-mesh codend the tension-less bars can be distorted by escaping fish during mesh penetration to form a hexagonal shape.

We used the FISHSELECT mesh definition function to define a list with different mesh shapes and sizes to use in the simulations. FISHSELECT models the different mesh geometries using parameters that refer to their geometrical shapes. In the diamond shape, the coefficient *c1* is the value of mesh size and *c2* is the opening angle. While in the hexagonal meshes, *c1* is the length of the shorter side bar, *c2* is the length of the longer side bar and *c3* is the opening angle, considered as the angle between two shorter side bars. In the mesh list, square-mesh represents a special case of the hexagonal-mesh shape with opening angle of 180°.

For square-mesh, mesh openness is defined as the circumferential distance between mesh bars to the mesh bar length. Thus, a fully opened square-mesh where the bars would be fully stretched would have an openness of 100 % and an opening angle of 90 degree.

While the mesh openness of a diamond-mesh is given by the ratio between the circumferential distance between the knots and the axial distance between the other two knots in the mesh. Thus, a diamond-mesh having an opening angle of 90 degree would have an openness of 100 %, which also represents a sort of square-mesh. Because the opening angle depends both on amount of catch and on the distance to the catch edge, for each mesh geometry, we considered different values of opening angle for each mesh size investigated.

Table 13. Ranges of variation in mesh size and opening angle both in the pelagic and demersal fisheries. Three mesh geometry are considered: diamond- (DM), square- (SM) and hexagonal-meshes (HEX). Variation of opening angle for DM and HEX follows steps of 5°and 30° degree respectively. square-mesh is considered a special case of the hexagonal-mesh when opening angle is 180° degree.

Type of fishery	Geometry	Length of mesh bar (mm)	Opening angle (°)	Total mesh
	DM	15-30	15°- 90°, step by 5°	256
Pelagic	SM	15-30	DM 90°; HEX 180°	
	HEX	7.5-15	30°- 180°, step by 30°	256
				Total = 512
	DM	30-60	15°- 90°, step by 5°	496
Demersal	SM	30-60	DM 90°; HEX 180°	
	HEX	15-30	30°- 180°, step by 30°	496
				Total = 992

Mesh penetration modelling

In order to test the ability of fish to penetrate a certain mesh, FISHSELECT needs to consider both the shape and the potential distortion of the mesh as well as the compression of the fish when it tries to escape. As explained above, fish could distort square-mesh to form a hexagonal shape during the escapement process. However, since the codend used today are often stiffer, we consider only the stiffness condition and then only the possibility of fish not being able to distort mesh bars at all, not even tensionless bar, for this reason we considered the hexagonal mesh shape as an independent codend design. The stiff mesh assumption is further supported by the result obtained by Hermann et al. (2009) where they found unrealistic selection parameter values obtained when applying the soft mesh model.

Regarding the ability of fishes to compress their body, FISHSELECT is able to include in the simulation either a single cross-section or a combination of several cross-section compression simultaneously. Compression is defined as the ability of the fish to deform its cross-section shape during the stiff mesh penetration. We did not consider the ability to compress their body or to deform the mesh.

In general, fish targeted by trawls have good swimming ability relative to the towing speed used in these fisheries. Several fish species also have been observed to orientate themselves in relation to the trawl netting during the capturing process e.g. Wardle (1993). In contrast to fish, smaller invertebrates such as shrimps and prawns tend to display a more limited response to stimuli from the trawl (Lochhead, 1961; Newland and Chapman, 1989). Therefore, the selectivity process for these species in trawls is expected to resemble a sieving process in which the individuals may meet the trawl netting with a more random orientation (in contrast to what has been observed for fish). Taking into account the previously considerations about the mobility of different species while they are in the codend, mesh penetration is initially applied for cross-section models CS1 and CS2 in fish species, we also considered CS3 for crustaceans. Based on the result obtained by Hermann et al. (2009), for fish species we assumed to consider both CS1 and CS2, while for crustaceans CS3 was never considered and depending on the species CS2 alone or a combination of CS1 and CS2 were the selected options.

The penetration process in stiffness conditions without body compression is described by Figure 30. In this scenario, the generic conditions that describes the penetration of a fish depends on both cross-section and mesh size. A fish can pass through the mesh if and only if the shape of the cross-section considered (represented by the inside curvature) is equal to the mesh shape, the individuals with cross-section shape smaller than the mesh shape pass through the mesh otherwise they are retained.

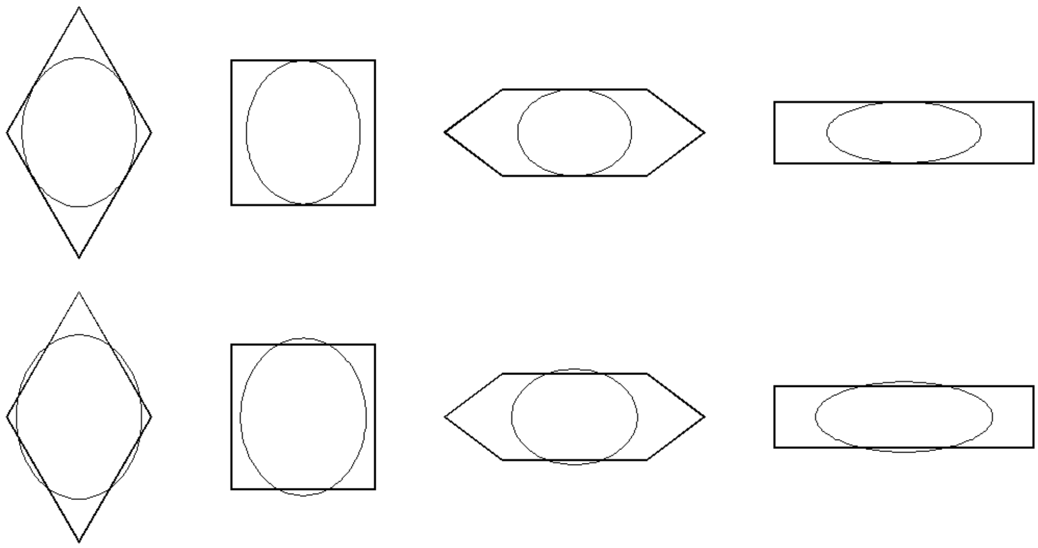


Figure 30. Mesh penetration process in stiffness condition without compression. Upper images represent the condition in which fish can pass through the meshes, the cross-section shape represented by the ellipse are at most of the same dimension of the mesh shape. The images below represent the condition in which the fish do not pass through the meshes, the cross-section shape are bigger than the mesh shape.

Simulation of mesh penetration and selectivity estimation

The FISHSELECT tool includes a flexible simulation model with different options to describing and identifying the conditions resulting in successful mesh penetration using data describing fish cross-section shapes and mesh geometry. The FISHSELECT functions simulate whether or not each of the 2000 virtually generated individuals pass through the defined meshes, this procedure leads to a simulation of the selection process in repeated hauls.

As input, these functions require: 1) a list of meshes with different opening angle values covering the full ranges of mesh shape present in the hauls (mesh list), and 2) a description of the total population of fish entering the codend (morphological data and virtual population). To examine the size selective potential of the considered codend designs we simulate the size selection of each species through the codend meshes considering the full range of opening angles for each mesh size.

We defined the basic selection property for a mesh panel as the selection property that take only the morphological condition for a mesh penetration into account. We consider the basic selective property of a codend as the length at which a fish has a 50% probability of being retained after entering the codend (L50) and selection range (SR: difference in length between the fish that has a 75% probability of retention and that with a 25% probability of retention).

The results of this procedure is a set of “coverd codend retention data” (Willeman et al., 1996) for each of the mesh defined. Each of these simulated retention dataset was then analysed as covered codend data assuming a standard *logit* selection curve described in (1) with parameters L50 and SR (Willeman et al., 1996):

$$r(l,L50,SR) = \frac{e^{\left(\frac{log(9)\cdot(l-L50)}{SR}\right)}}{1+e^{\left(\frac{log(9)\cdot(l-L50)}{SR}\right)}} \qquad (1)$$

This type of curve has often proved to be appropriate for modelling the length-dependent retention likelihood in diamond- and square-mesh codends for many fish species. The parameters estimation (L50 and SR) would follow a two-step procedure. The first step involves the estimation of L50 and SR and their covariance matrix for individuals hauls using the maximum likelihood estimation procedure. The second step follows the approach described by (Fryer, 1991) to estimate the mean selection parameters, where both the estimate parameters values and their covariance matrix are used, assuming that the parameters values are observation of a bivariate normal distribution. This method considers both the within- and between-haul variations in the parameters values. This analysis is conducted using the software SELNET (Hermann et al., 2012).

To test if the penetration model used in the simulation was appropriate, L50 of different mesh size have been plotted for different opening angle. The results are contrasted with bibliography data collected in the deliverable *Historical data size selectivity of species being investigated (D3.4).*

The basic selective propoerty of each mesh, were collected in a design guide, which are plots showing simulated L50 as isocurves for a range of mesh size versus mesh openings for each mesh type. The design guide can be used to identify the conditions required to obtain a specific and constant selection during a fishing process. Combinated with knowledge about the mesh configurations (type, size, and opening angle) in a specific codend, they indicate the expected range of selection parameters. Based on the best penetration model, design guides were produced to predict the basic selective property of the three mesh geometries investigated.

Guidelines for the design of size-selective mesh types

Fish species

The general guidelines proposed herein are based on the premise that fish size selection depends critically on two major technical parameters, mesh size and mesh opening angle. The data presented are therefore critical for management purposes, because they allow setting the desired selection parameter ranges based on the two key technical parameters. The guidelines consist of a set of isometric diagrams showing the isocurves of the selection parameters (L50 and SR) as a function of the mesh size and and of mesh opening angle. The guidelines provide information that can be used to design a trawl codend with improved fish size selection ability, which have the potential to be extended to all Mediterranean trawl fisheries.

A set of graphs for each fish species are presented as follows: the first two graphs show the L50 for different mesh size (mm) both for diamond- and hexagonal-meshes in respect to different opening angle (in degree). The circles represent the values of L50 from bibliography data, while clouds represent their density. For the hexagonal-meshes the circles come from experimental square-mesh experiments because when fish can deform tensionless square-mesh bars outwards they become hexagonal-like-meshes.

The last two graphs show the design guidelines for both diamond- and hexagonal-meshes, with the *iso*-L50 curves as function of mesh size (mm) and mesh opening (in degree). We therefore examined the effect of mesh opening using an optimal attack angle of cross-sectional areas. In this scenario, the diamond-mesh opening varied stepwise 5° from 15 to 90°, while the opening of hexagonal-mesh varied from 30 to 180°. Mesh openings of 90° and 180° correspond to square-meshes in the graph of diamond- and hexagonal-mesh, respectively.

The purpose of the diagrams is to show graphically the fish size selection potential of a mesh, thus providing useful information for its correct dimensioning with a view to minimising the proportion of retained undersize fish and crustaceans (< MCRS) and at the same time maximising efficiency in selecting the commercial sizes (≥ MCRS). The isometric diagrams were obtained using ad-hoc developed routines in R language (R Core Team, 2012).

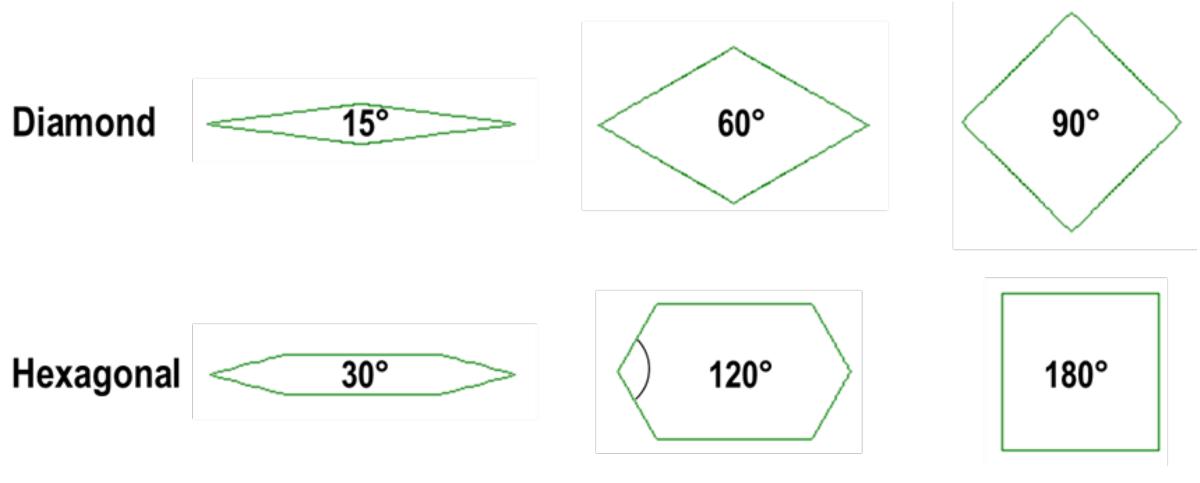


Figure 31. Illustration of the range of the mesh openings investigated both for diamond- and hexagonal-meshes for the guideline design of fish size-selective mesh.

Crustaceans

We explored the potential effect of the attack angle in the mesh opening for the specific mesh size investigated. The mesh shape was analysed in 5° steps of opening from 15 to 60° for diamond- and 10° for hexagonal-meshes from 30 to 120° (Figure 32).

In previous studies carried out using FISHSELECT to predict size selectivity for different species of fish, it was assumed that each individual is optimally orientated when attempting to pass through the meshes. However, we expect crustaceans to have a lower probability of meeting the meshes in the optimal orientation with optimal attack angle due to the relatively high towing speed compared to the size of the animal. Therefore, we run the simulation considering a random orientation of the crustaceans with a range of orientation 0-90° in steps of 30° (see Figure 33 for clarification).

We therefore cannot assume hexagonal-mesh as a sort of square-mesh and therefore we had to explored rectangular mesh shape instead, having considered that not all the codend meshes are fully squared. In such case, we stepwise analysed mesh opening in steps of 10% from 40 to 100%. Where the opening in % is the ratio between the mesh bar of a fully opened square-mesh and the other bar projected to a plan perpendicular to the towing direction.

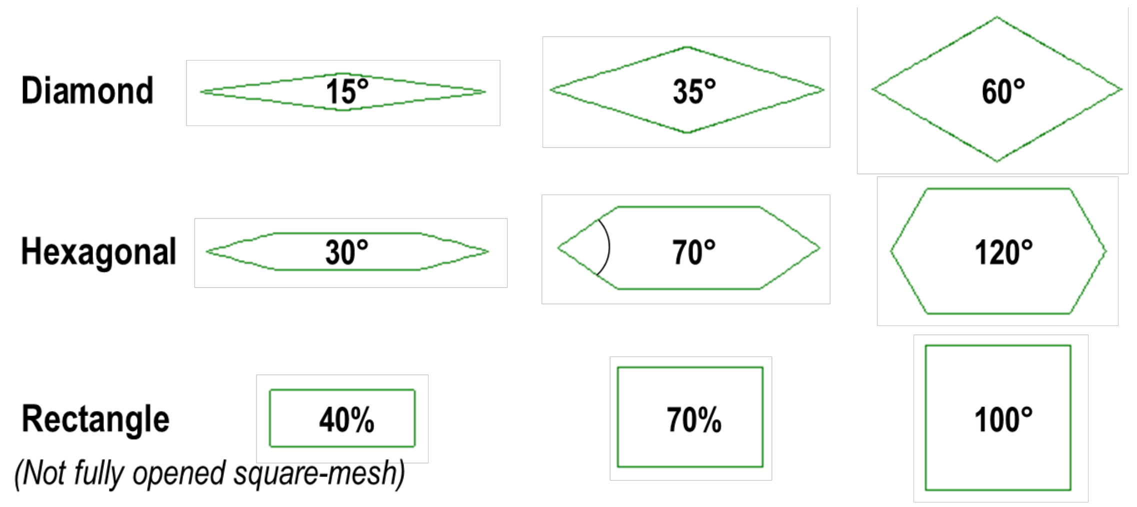


Figure 32. Illustration of the range of the mesh openings investigated both for diamond-, rectangle and hexagonal-meshes for the guideline design of crustacean size-selective mesh.

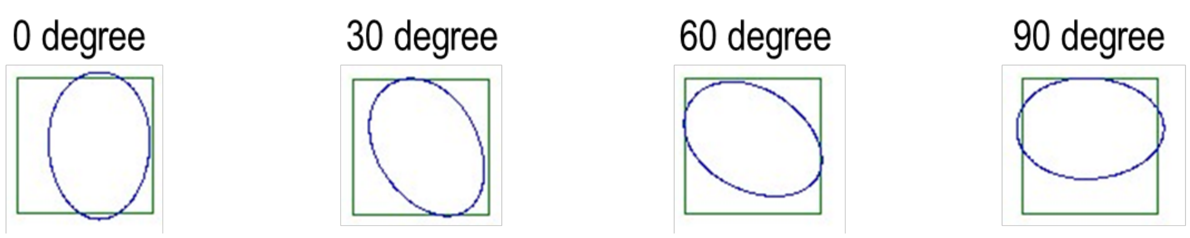
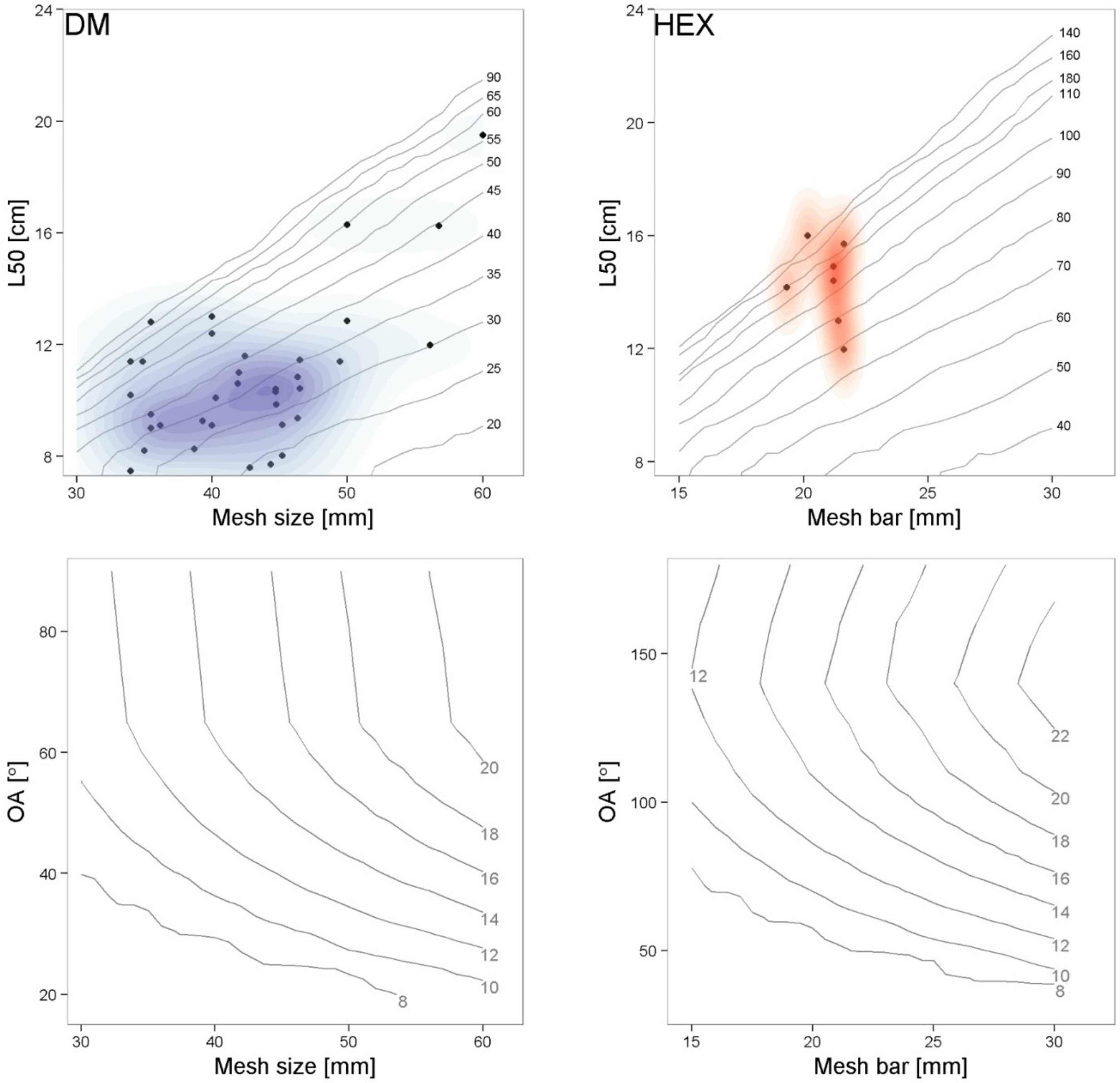


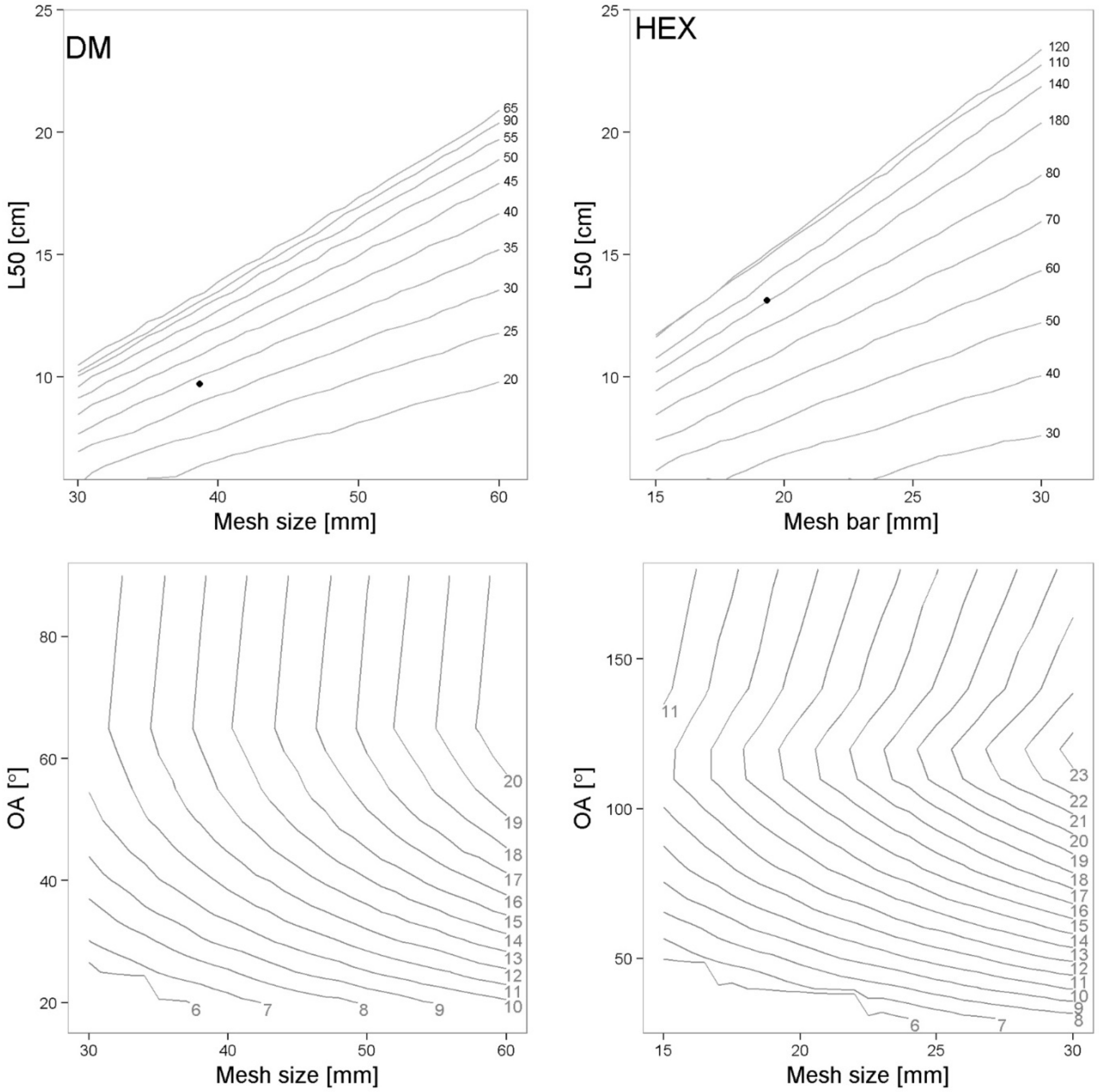
Figure 33. Illustration of potential effect of rotation of the cross section (or attack angle) in a fully opened square-mesh.

Demersal fish species

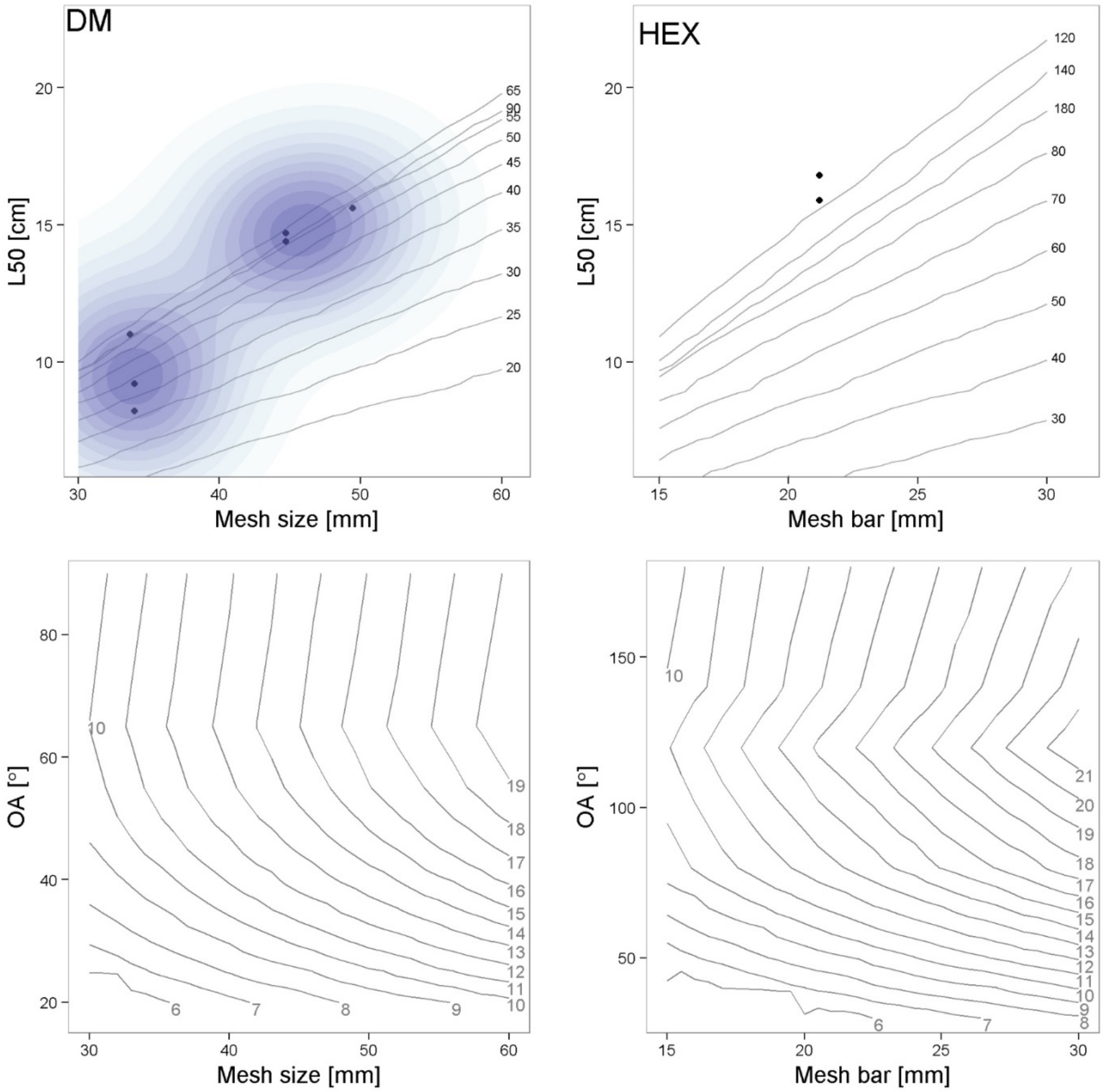
Hake (Merluccius merluccius)



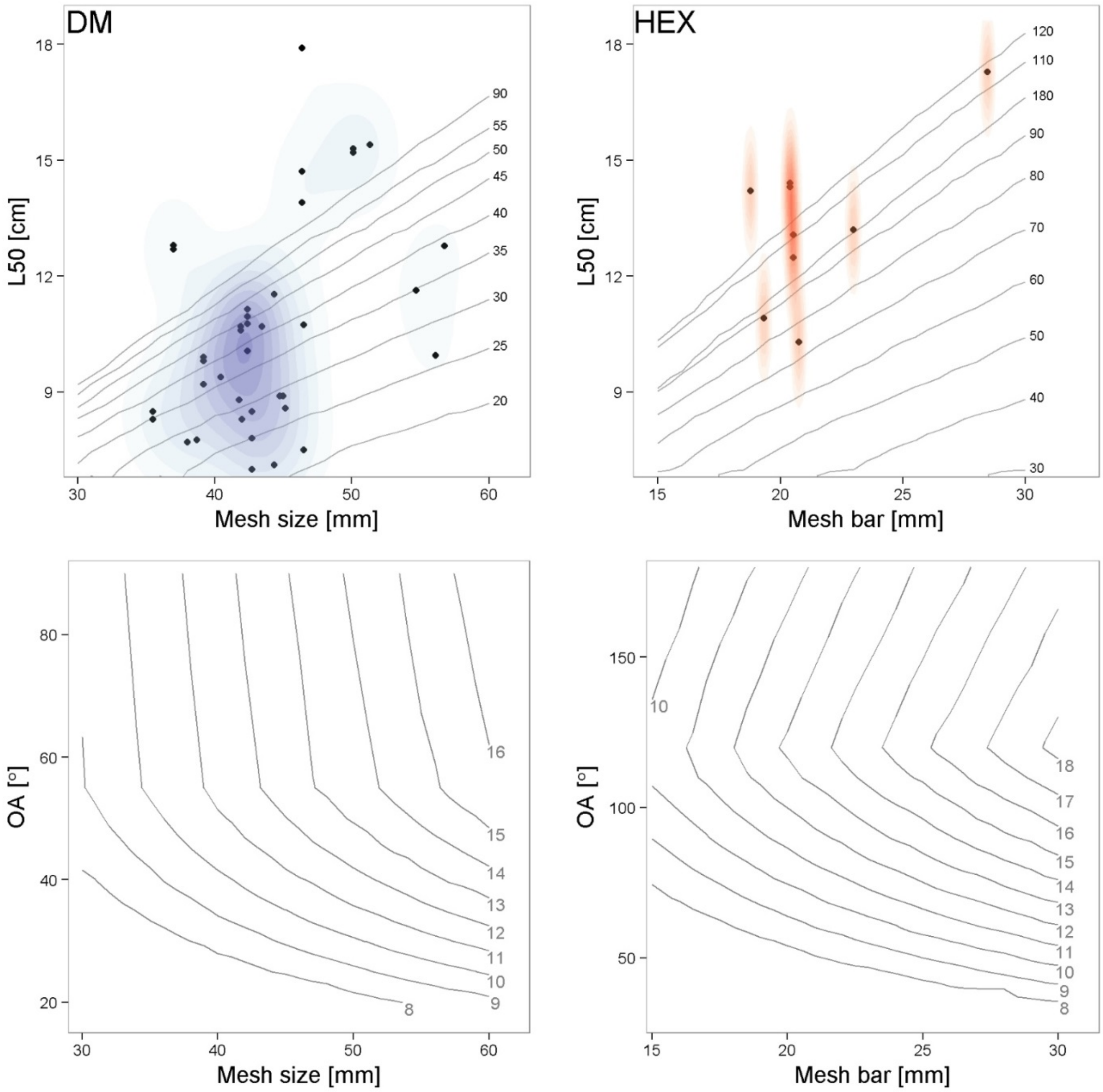
Mediterranean horse mackerel (Trachurus mediterraneus)



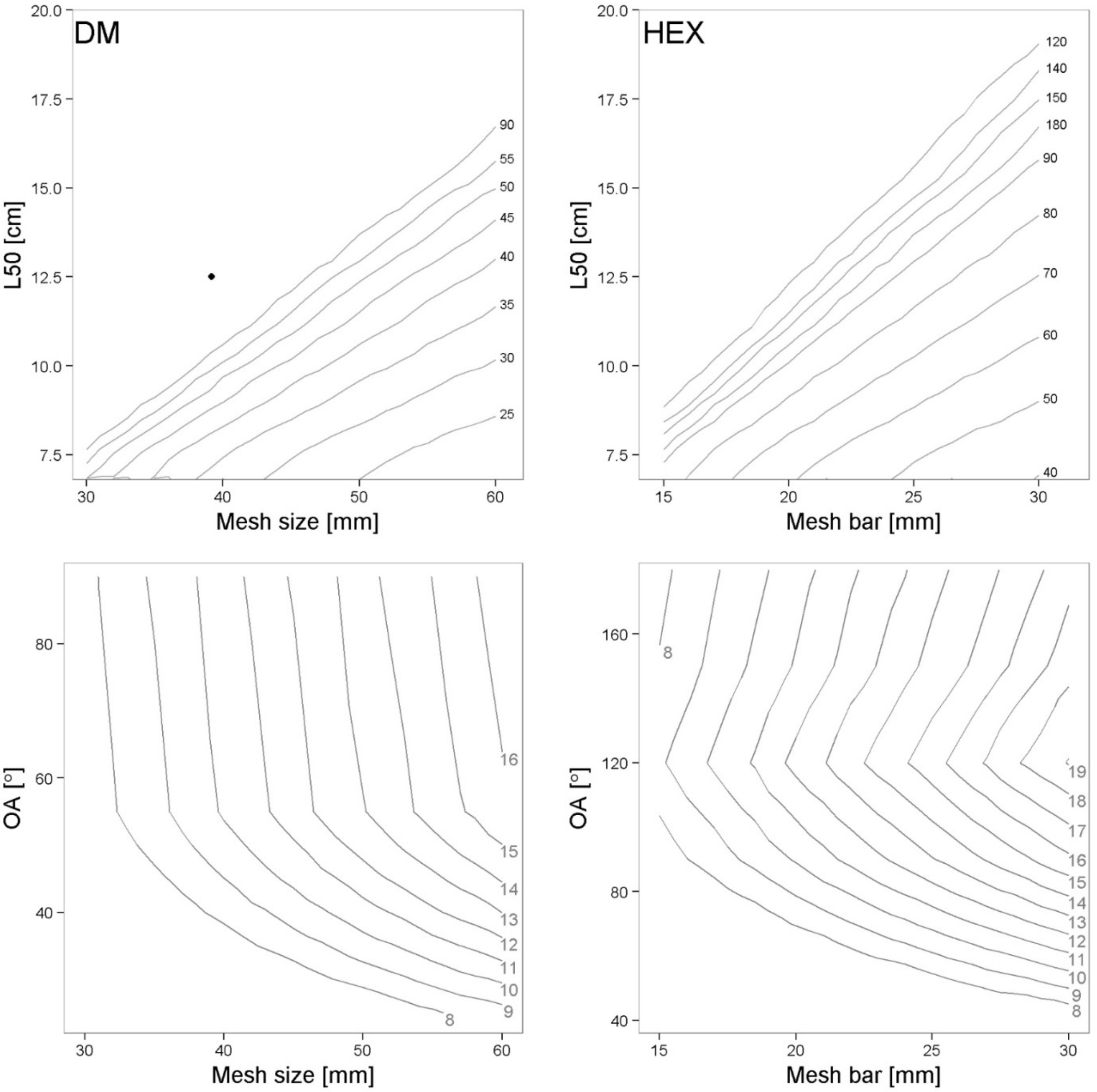
Atlantic horse mackerel (Trachurus trachurus)



Red mullet (Mullus barbatus)

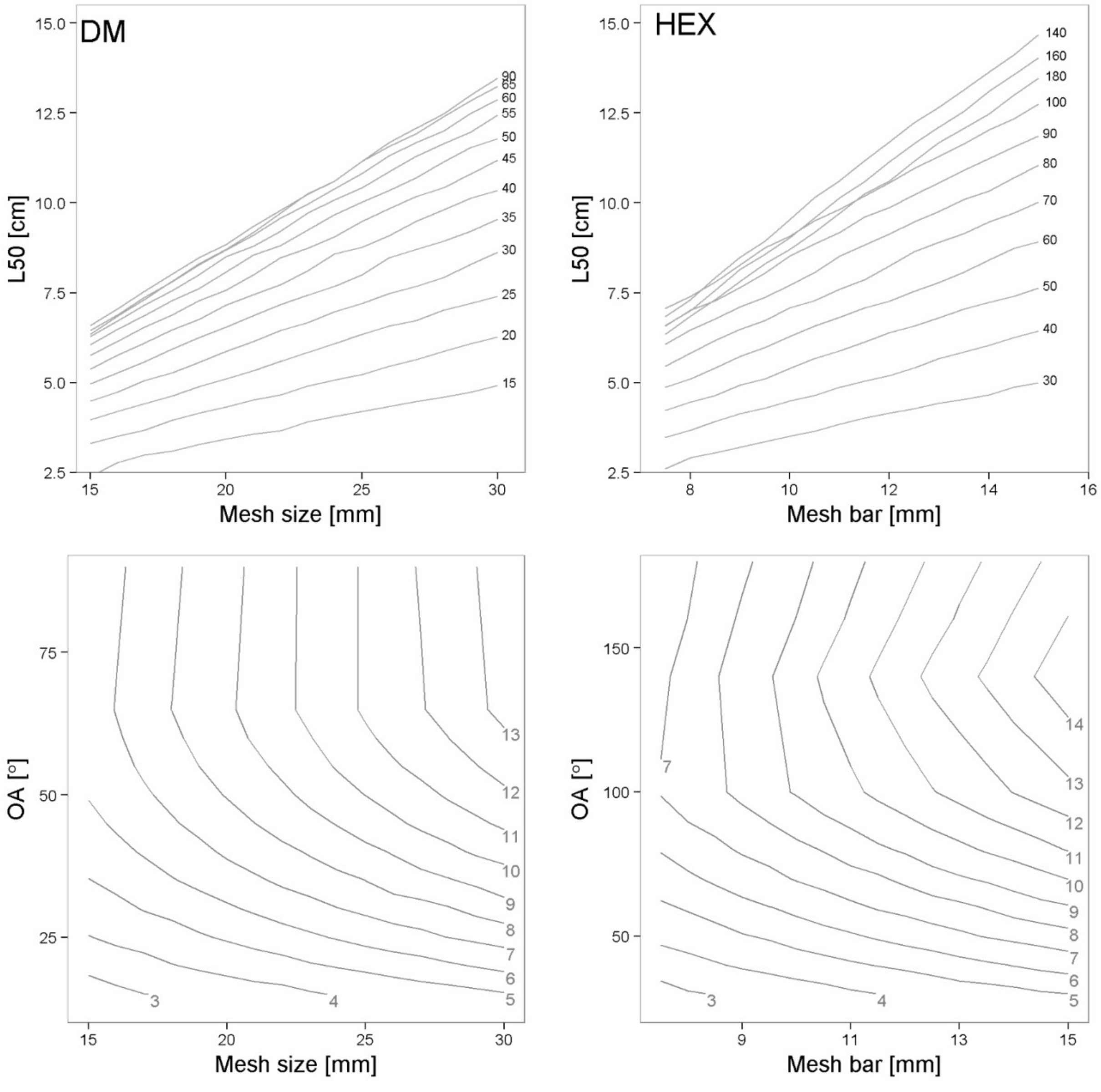


Striped red mullet (Mullus surmuletus)

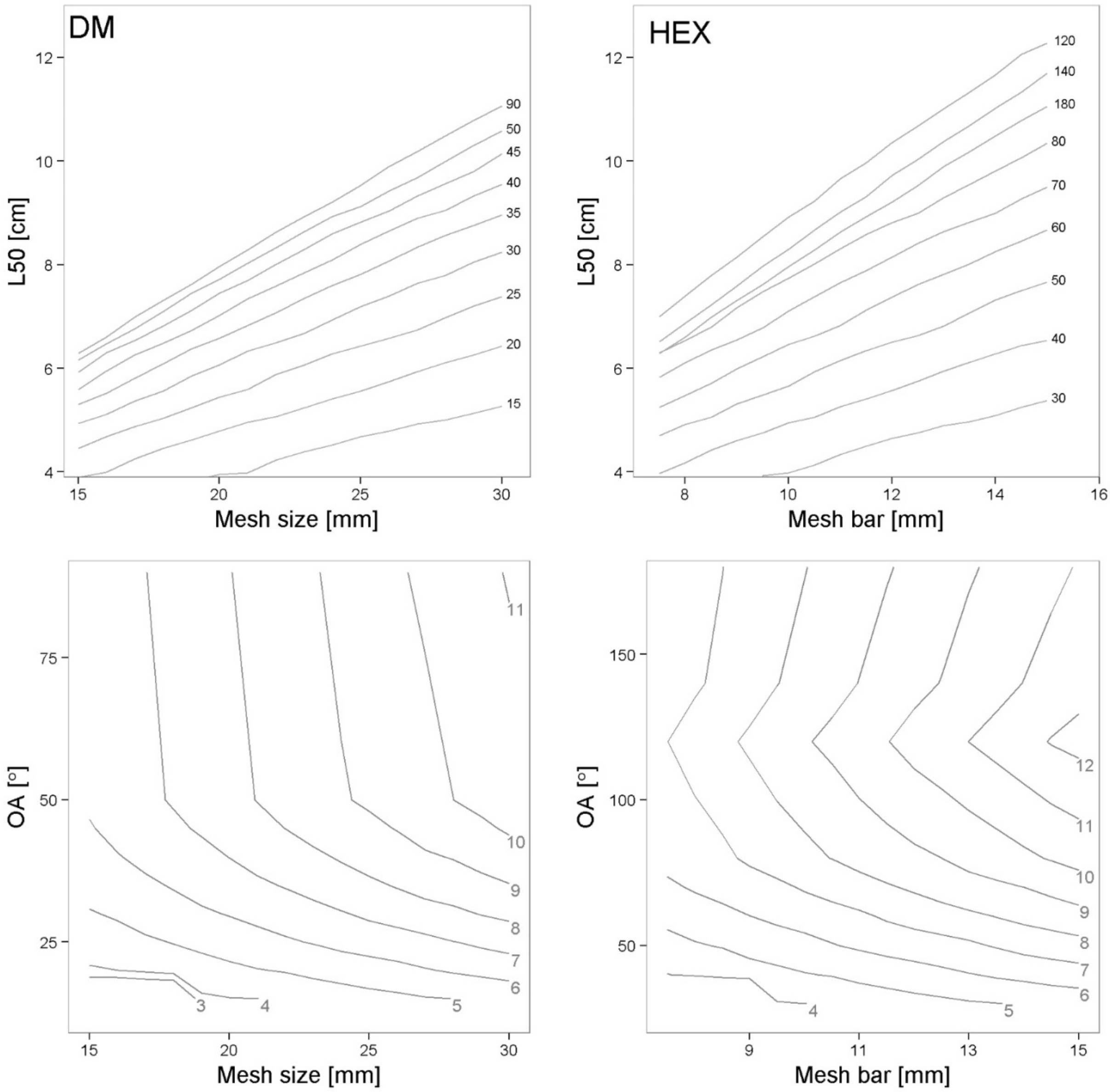


Pelagic fish species

European anchovy (Engraulis encrasicolus)



European pilchard (Sardina pilchardus)



Crustaceans

For each species, guidelines for the design of species size-selectivity have been developed for the three mesh shapes (Figure 34, Figure 36, Figure 38 and Figure 40): diamond- (DIA), rectangular (or square, REC) and hexagonal (HEX). Furthermore, in a second set of graphs (Figure 35, Figure 37, Figure 39 and Figure 41) experimentally obtained data are contrasted with the predicted selectivity models.

Giant red shrimp (Aristaeomorpha foliacea)

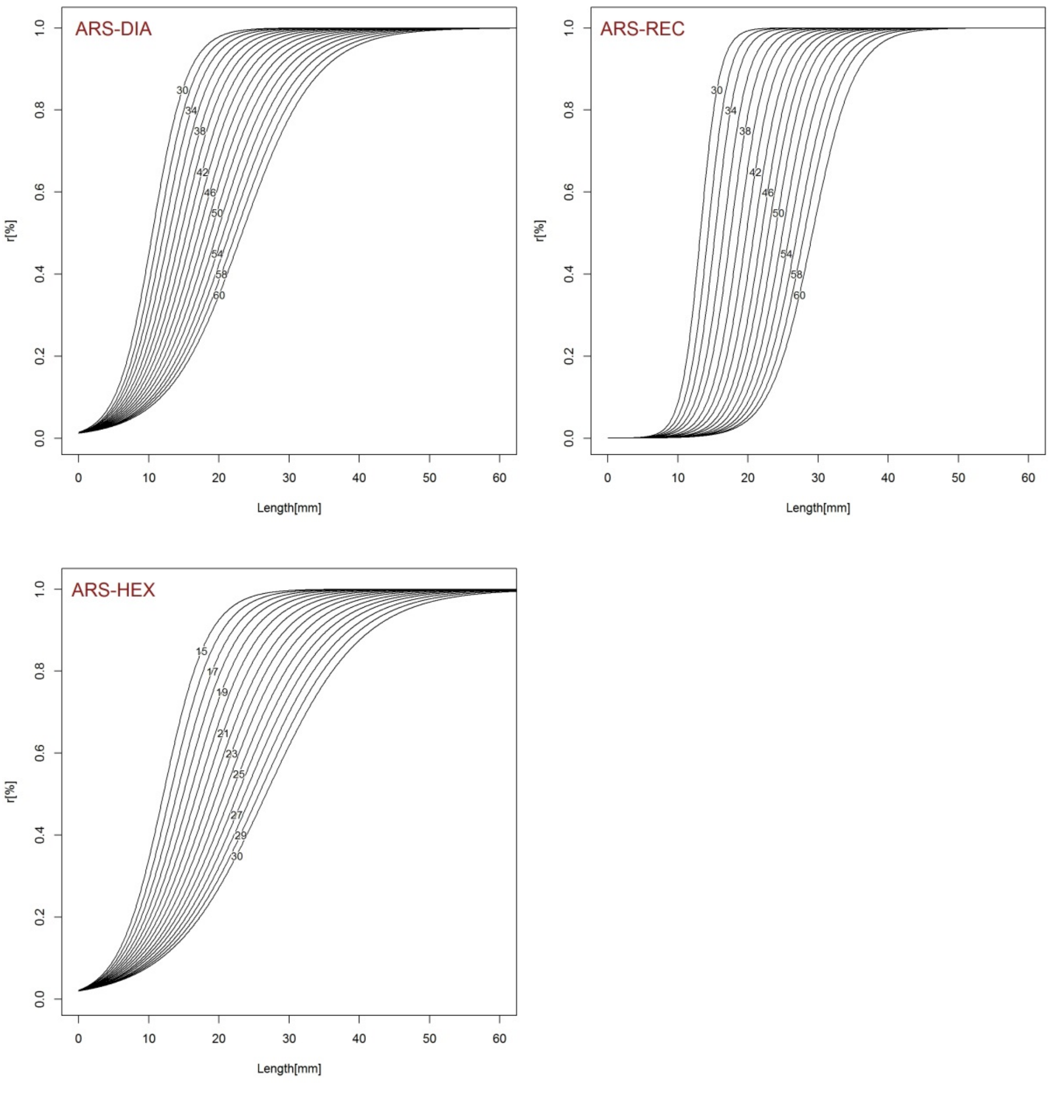


Figure 34. Selectivity guidelines with predicted selectivity of giant red shrimp *(Aristaeomorpha foliacea)* in different mesh sizes. Predictions are made from 30 to 60 mm meshes in steps of 1 mm assuming a similar distribution of mesh opening angle.

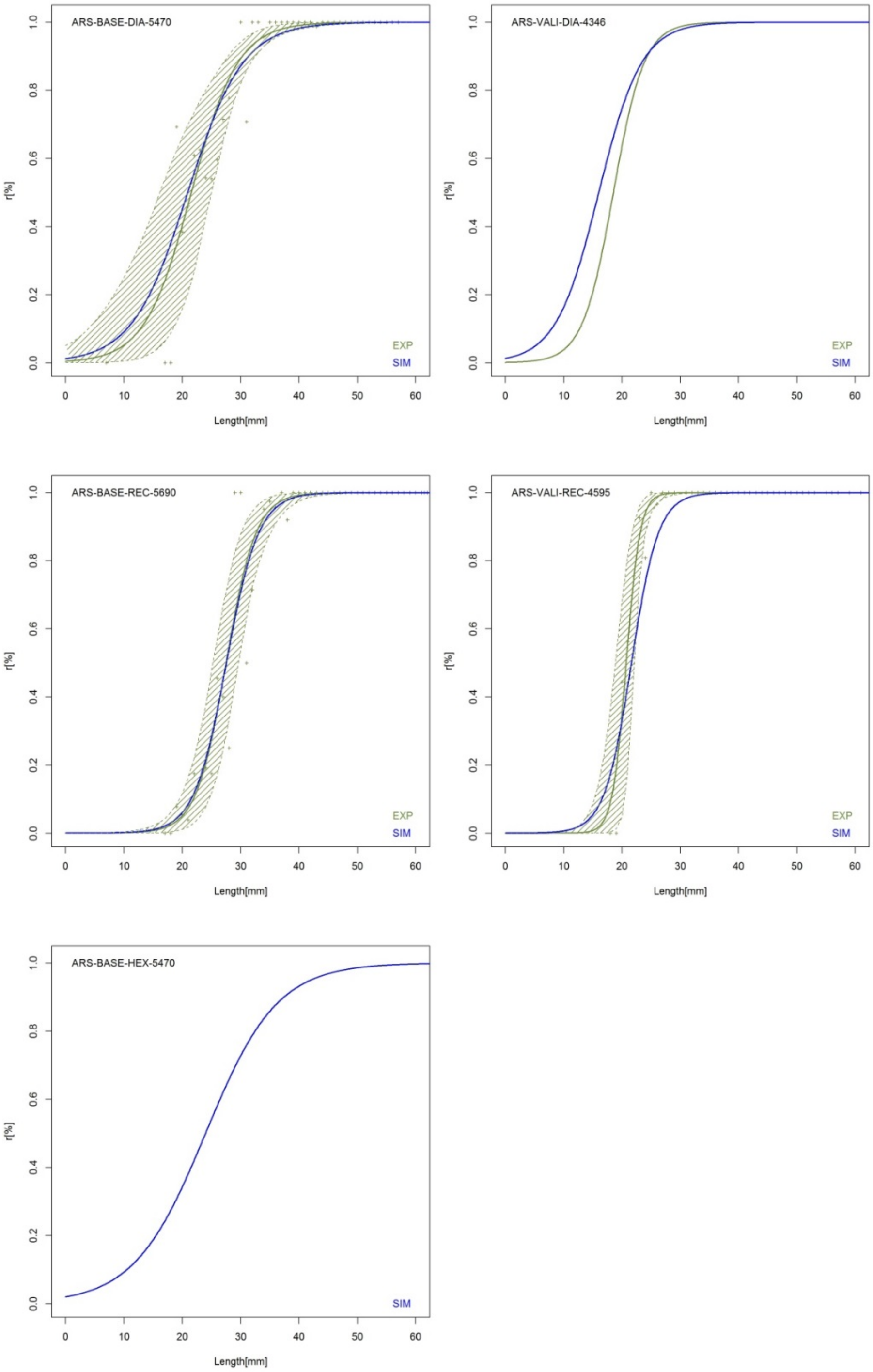
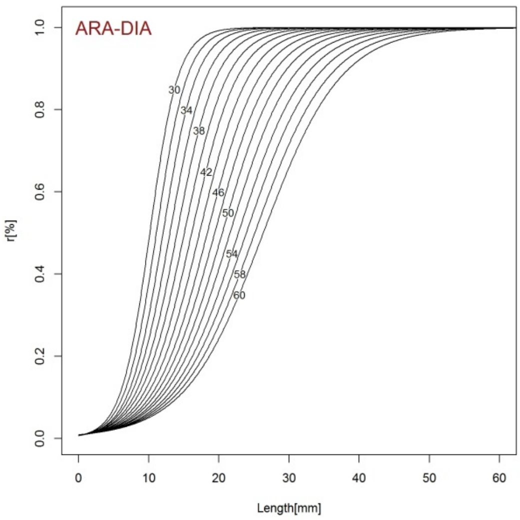
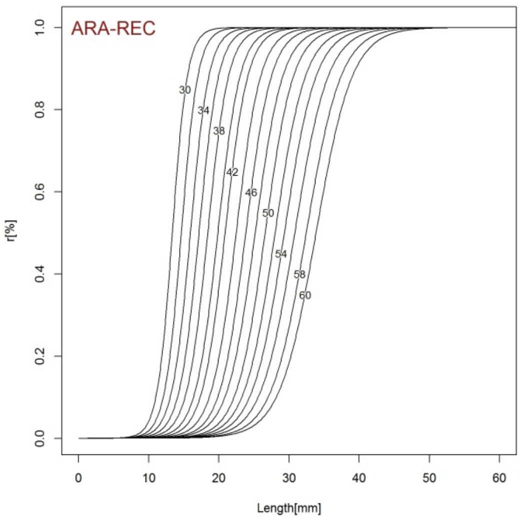


Figure 35. Giant red shrimp *(Aristaeomorpha foliacea):* experimentally obtained data (EXP, in green) contrasted with the predicted selectivity models (SIM, in blue).

Red shrimp (Aristeus antennatus)





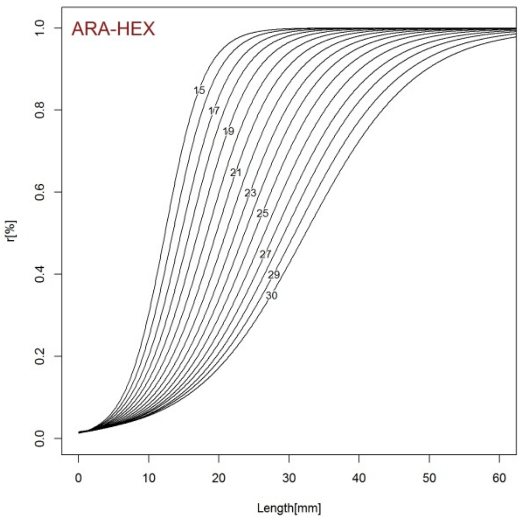


Figure 36. Selectivity guidelines with predicted selectivity of red shrimp *(Aristeus antennatus)* in different mesh sizes. Predictions are made from 30 to 60 mm meshes in steps of 1 mm assuming a similar distribution of mesh opening angle.

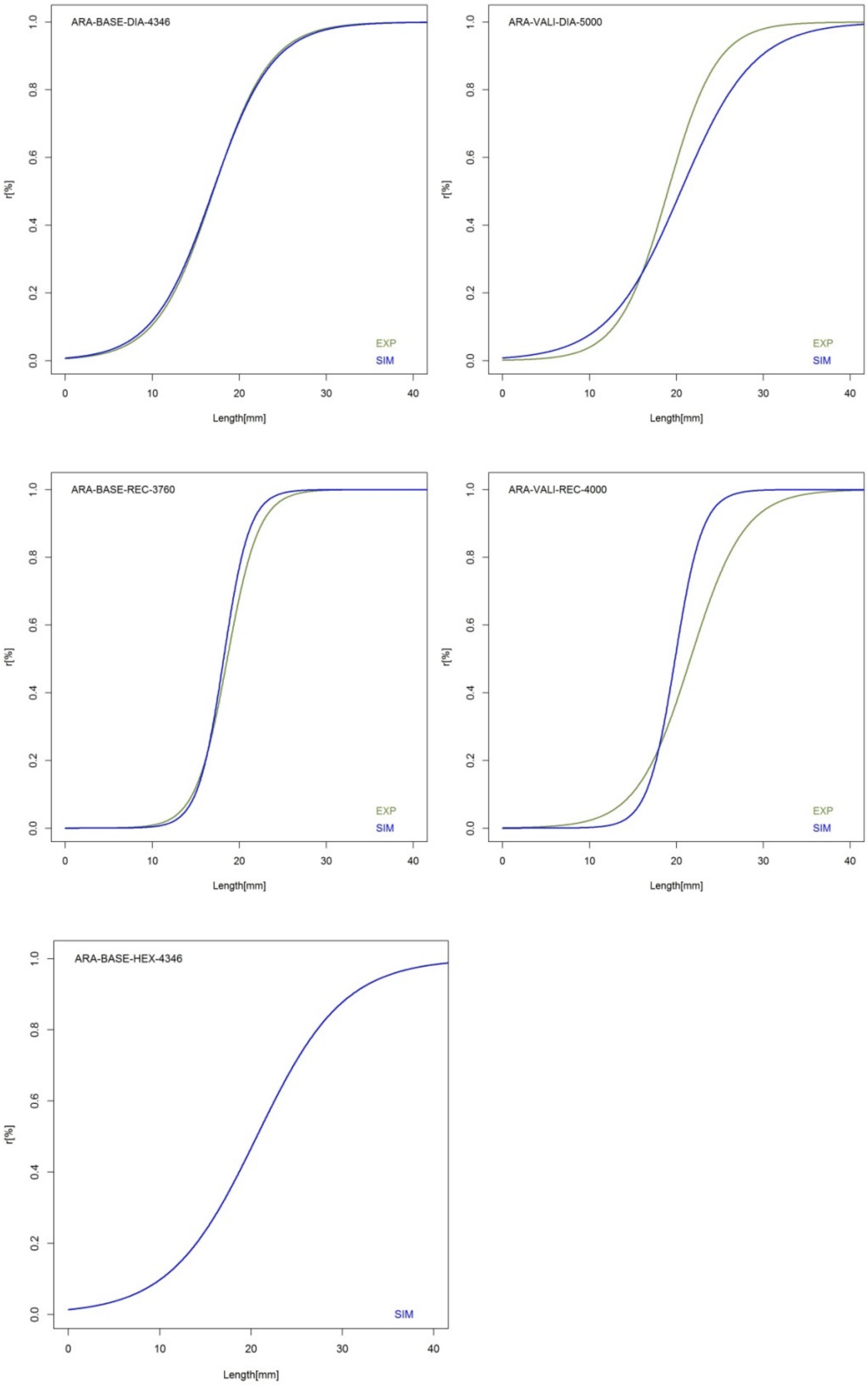


Figure 37. Red shrimp *(Aristeus antennatus):* experimentally obtained data (EXP, in green) contrasted with the predicted selectivity models (SIM, in blue).

Deep-water rose shrimp (Parapenaeus longirostris)

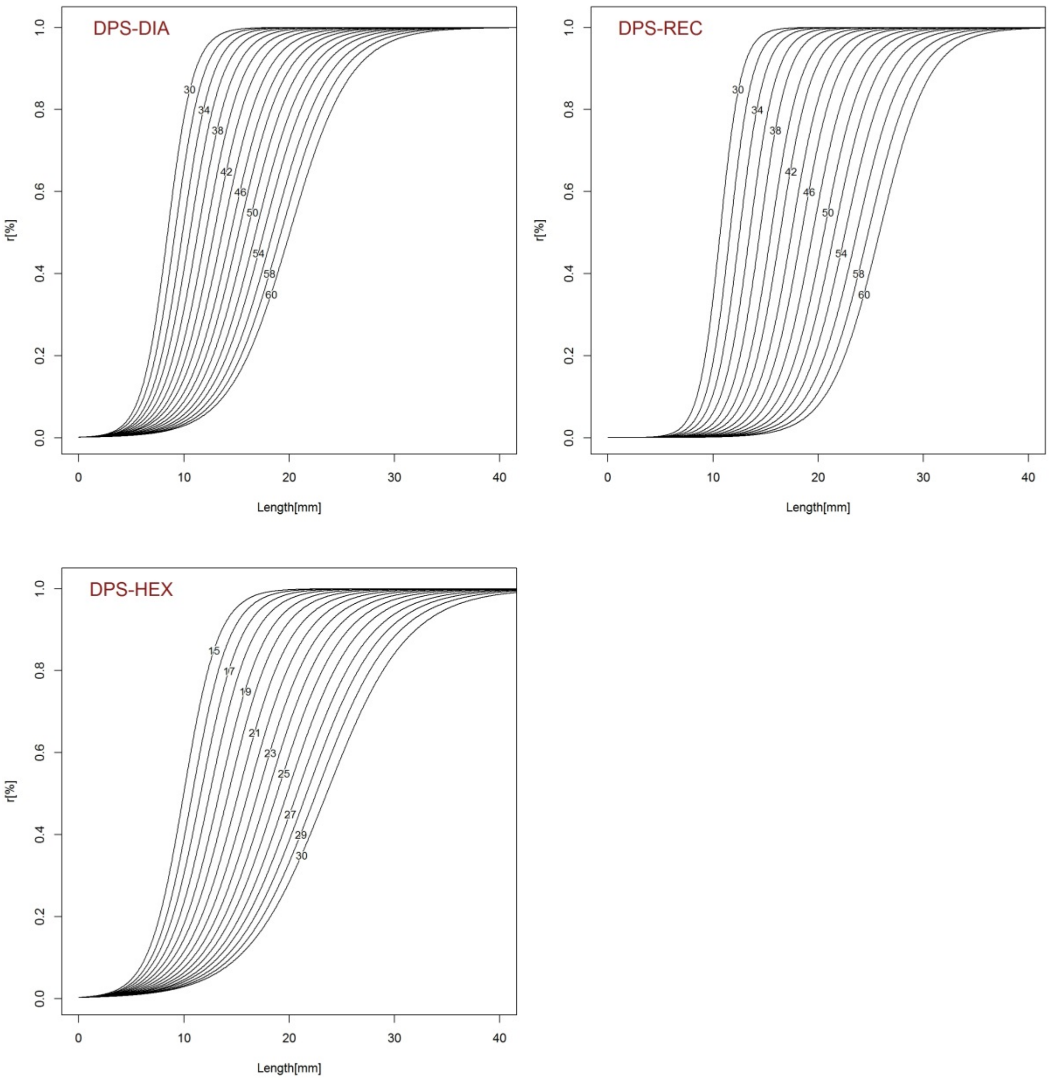


Figure 38. Selectivity guidelines with predicted selectivity of deep-water rose shrimp *(Parapenaeus longirostris)* in different mesh sizes. Predictions are made from 30 to 60 mm meshes in steps of 1 mm assuming a similar distribution of mesh opening angle.

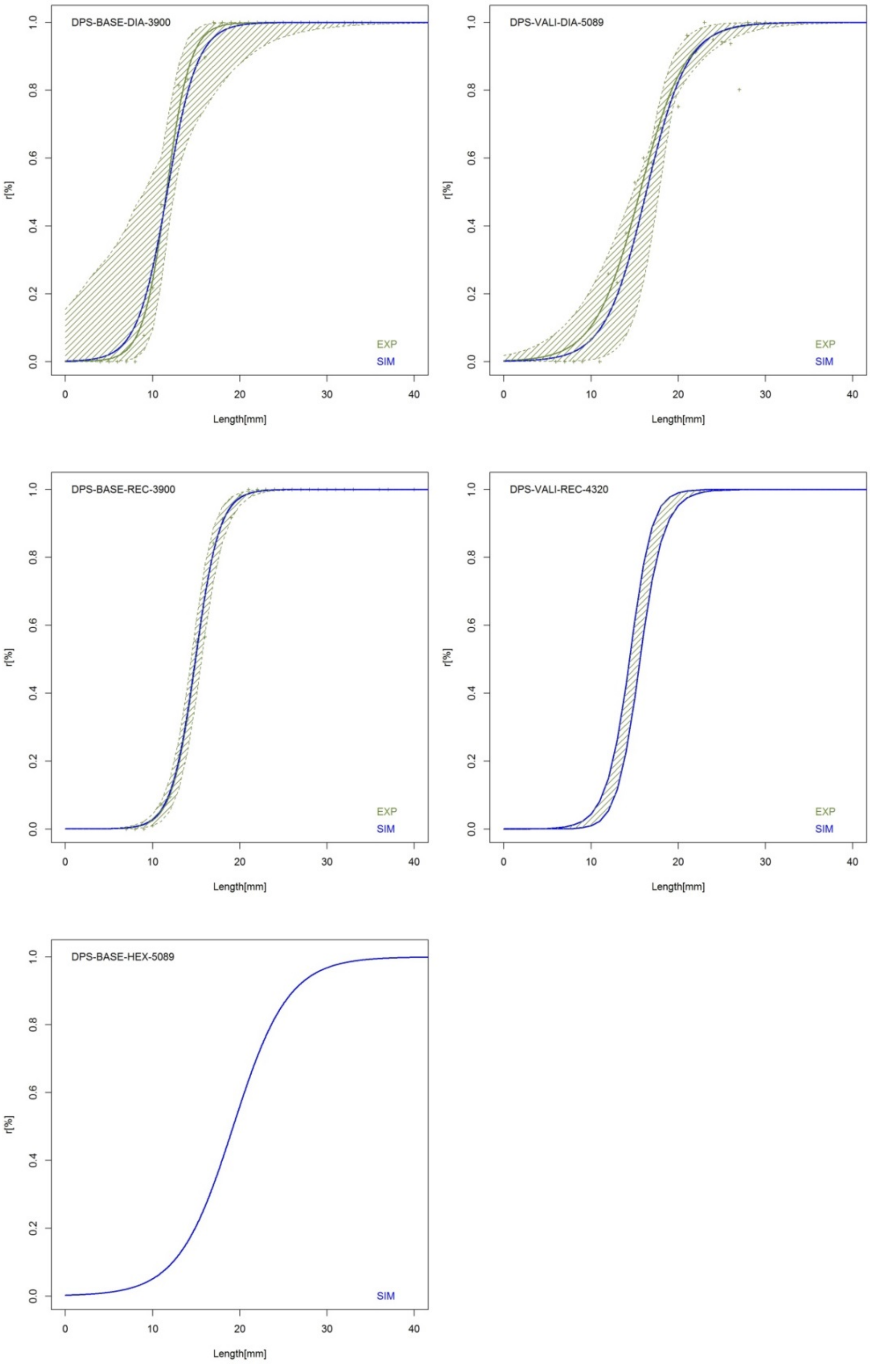


Figure 39. Deep-water rose shrimp *(Parapenaeus longirostris):* experimentally obtained data (EXP, in green) contrasted with the predicted selectivity models (SIM, in blue).

Norway lobster (Nephrops norvegicus)

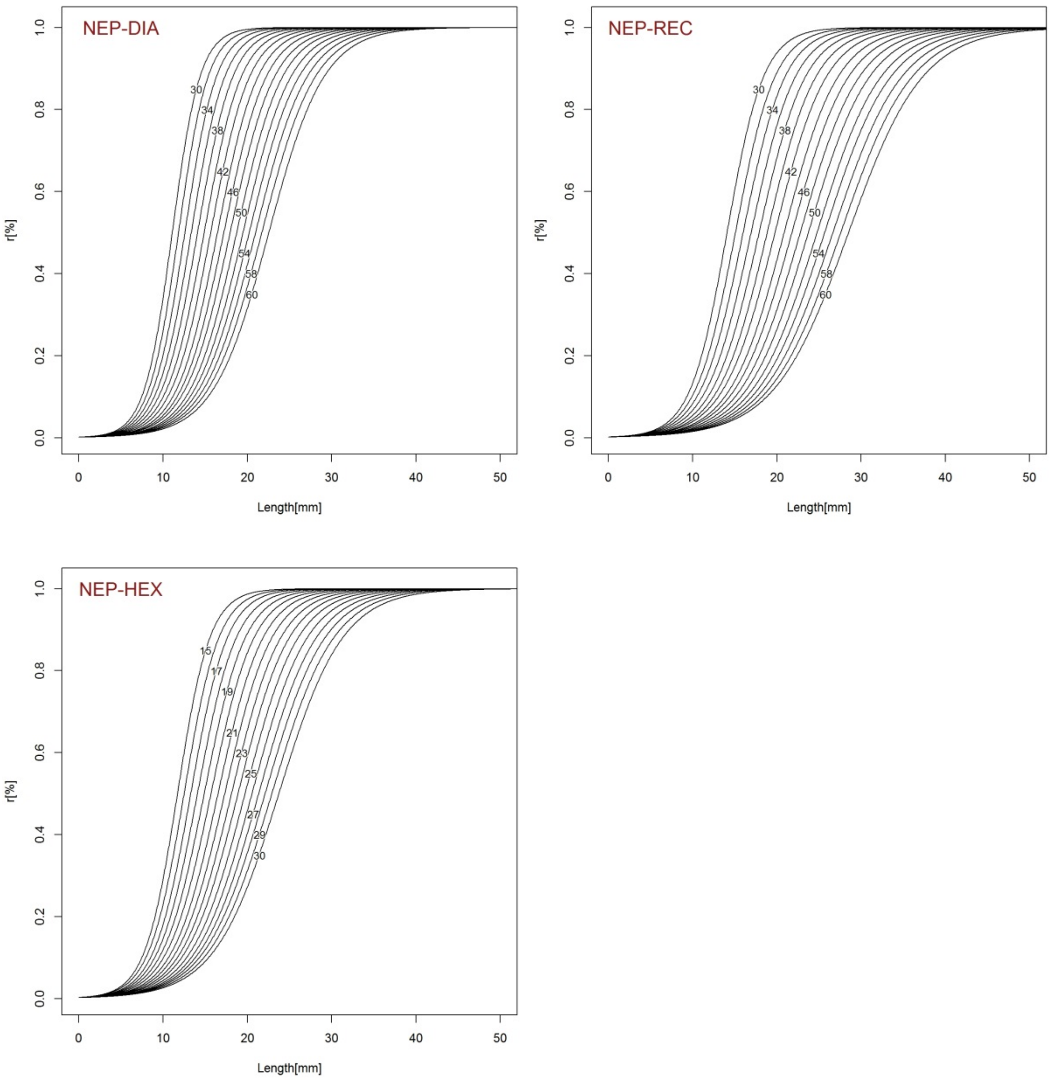


Figure 40. Selectivity guidelines with predicted selectivity of Norway lobster *(Nephrops norvegicus)* in different mesh sizes. Predictions are made from 30 to 60 mm meshes in steps of 1 mm assuming a similar distribution of mesh opening angle.

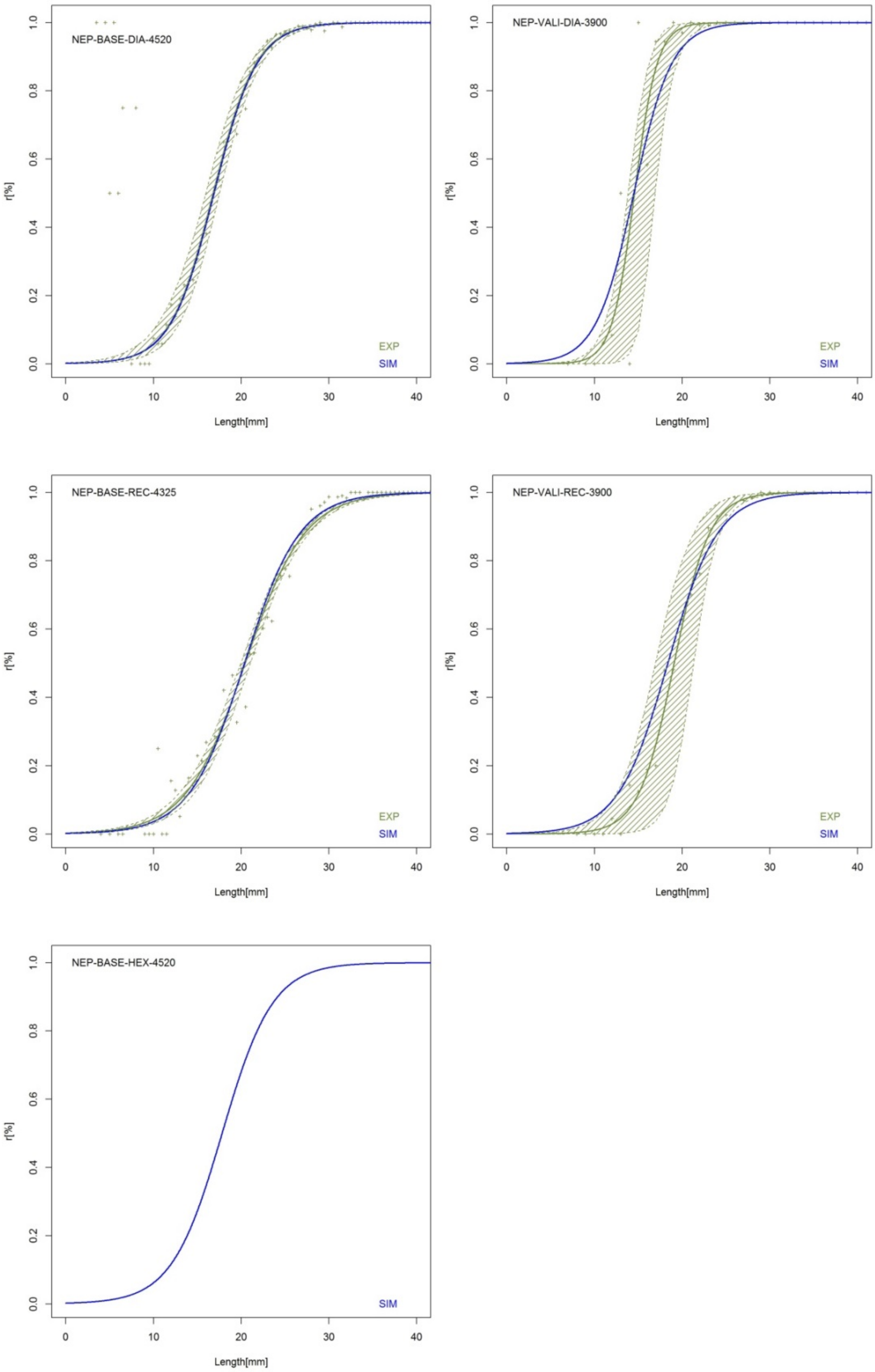


Figure 41. Norway lobster *(Nephrops norvegicus):* experimentally obtained data (EXP, in green) contrasted with the predicted selectivity models (SIM, in blue).

Experimental short pilot action at sea to complement the existing information on selectivity in the Spanish bottom trawl fishery (Task 3.6)

Introduction

During the last decade, several pilot projects were developed to improve the selectivity in the Spanish trawl fishery along the western Mediterranean. The effect of a change in the cod-end mesh size and shape, and the introduction of sorting grids in the extension piece of the net were studied (Bahamon *et al.*, 2006, 2007a, 2007b; Baro and Muñoz de los Reyes, 2007; García-Rodríguez and Fernández, 2005; Guijarro and Massutí, 2006; Massutí *et al.*, 2008, 2009a; Ordines *et al.*, 2006; Sardà *et al.*, 1993, 2005, 2006). The results of some of these pilot projects, jointly with other studies developed in other areas of the Mediterranean (e.g. Lucchetti, 2008; Petrakis and Stergiou, 1997; Stergiou *et al.*, 1997), were on the basis of the implementation of 40 mm square mesh cod-ends, adopted by the Council Regulation (EC) Nº 1967/2006, of 21 December 2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea.

However, new challenges have been raised in recent years, mainly directed at reducing ecological impacts and fuel consumption in order to increase both the environmental and economical sustainability of this fishery. This has generated innovative measures involving changes in the fishing operations and/or using more hydrodynamic bottom trawl gears and even mid-water doors not touching the seabed.

That is the case of the Balearic Islands and the Catalan coast, where experimental actions have been developed. More specifically, the *Instituto Español de Oceanografía* (IEO), responsible of this deliverable, has worked together with the fisheries sector and the fishing technologies industry in order to develop three different pilot projects based on the modification of the fishing operations and/or the trawl gear design.

The first one assessed the viability of changing the usual vessel operation, discontinuous work during five daily trips of 12-16 hours per week, to a continuous work during 46 hours per week (Massutí *et al.*, 2008). In the other two pilot projects, the traditional bottom doors were replaced by two types of doors: (i) bottom doors more hydrodynamic and lighter in one case (Massutí *et al.*, 2009b);and (ii) mid-water doors not touching the seabed in the other (Massutí *et al.*, 2011).

Additionally, in the former pilot project the bridles were shortened and the net was replaced by an experimental lighter net, with larger meshes and thinner twine in the wings and square (Massutí *et al.*, 2009). The cod-ends used in all these pilot projects were those established by the European legislation since 2008, being constructed of 40 mm square mesh of 3 mm twine thickness.

The results of these actions were very positive by reducing both fishing impact on the benthic ecosystem and fuel consumption, without significant reduction in yields of the main target species (Massutí *et al.*, 2011), and thus some bottom trawlers are already using these mid-water doors and probably the number of vessels using this type of doors will increase in the future.

However, the introduction of this type of doors could affect the gear selectivity, by increasing the catchability for nekto-benthic species. For that, within the framework of DISCATCH project, a short pilot action at sea has been developed in the Balearic Islands, trying to improve the selectivity of these bottom trawl gears using mid-water doors through the introduction of square mesh panels in the net.

Material and methods

Sampling experiment

A survey was conducted on the continental shelf and slope fishing grounds off Menorca (Balearic Islands, western Mediterranean), during one month (from middle September to middle October 2014), on board the commercial bottom trawler FV "Nueva Joven Josefina" (length 21 m; 44 grt; nominal engine power 150 hp), which habitually operates in the area. Two bottom trawl gears were employed (Figure 42 and Figure 43):

- A two-panel net of 30.5 m headline and 48 m footrope was used for operating on the gravel and sandy bottoms of the shallow continental shelf, between 50 and 100 m depth. The netting was of polyamide (PA) in the wings, belly and funnel, with a cod-end of polyethylene (PE). Last 3 m of this cod-end was of un-knotted *Dyneema* 48 mm square mesh of 3 mm twine thickness. This net was linked by 20 m PE and polypropylene (PP) legs (Ø42 mm) and 80 m steel and PP sweeps (Ø42) to Thyborøn type 15VFS doors, with a spreading force estimated of 562 kg (2.00 m^2 and 340 kg). These doors work at some meters above the bottom, with an angle of 27.6º and a resistance of 121 kg. The linking between the doors and the sweep were made by a steel warp (Ø15 mm) of 50 m length and chain ballast weighing 175 kg to ensure an optimal contact of sweeps and net to the bottom. These doors were linked to steel warp Ø16 mm.
- A four-panel net of 63 m headline and 54 m footrope was used for operating on muddy bottoms of the middle slope, between 500 and 800 m depth. The netting, cod-end and doors of this gear was the same than the previous one, with the only difference in the length of legs (40 m) and in the diameter (36 mm) and length (200 m) of sweeps.

Panels of un-knotted *Dyneema* 54 mm square mesh of 1.2 mm twine thickness were mounted to these nets: (i) one trapezoidal panel (7.4x4.0x12.0 m) of approximately 68.4 m^2 in the two-panel net, attached to the extension piece of the upper plan; and (ii) ten in the four-panel net, four rectangular panels (6.7x8.7, 6.6x6.0, 4.4x4.0 and 3.3x2.7 m) of approximately 124.69 m^2 (58.4, 40.1, 17.3 and 8.9 m^2, respectively) attached to the extension piece of the upper plan, and three rectangular panels (6.7X2.4, 6.6X0.8 and 1.7x0.4 m) of approximately 43.9 m^2 (16.1, 5.1 and 0.7 m^2, respectively).

Monitoring of fishing operations and data collection

Fishing operations (e.g. trawling speed, tow time) were performed within the routine activities of the bottom trawl fleet in the study area, working 12 hour per day (05:00-17:00) and 5 days per week (Monday-Friday). Usually, two trawls per day were performed, the first on the continental shelf, during the sunrise, and the second on the middle slope during daylight hours. During the four weeks survey, the alternate hauls method was followed to compare nets with and without panels, there after called EXP and TRA nets, respectively: (i) TRA nets were used during the first and third weeks; and (ii) EXP nets during the second and fourth weeks.

During the hauls, data on speed, position and depth of the vessel was recorded from the deck equipment (GPS and echo-sounders). After each haul, the crew and the scientific team sorted the catches in the cod-end according to taxonomic and commercial categories (landings and discards), and then the categories were counted and weighed separately. Total fish length (TL; cm), cephalopod mantle length (ML; cm) and crustacean carapace length (CL; mm) were measured for commercial species. The trawl monitoring ITI system was used to estimate the arrival and departure of the gear to the bottom, the distance between the doors and the vertical opening of the net. Fuel consumption was also estimated using a flow-meter installed at the engine power.

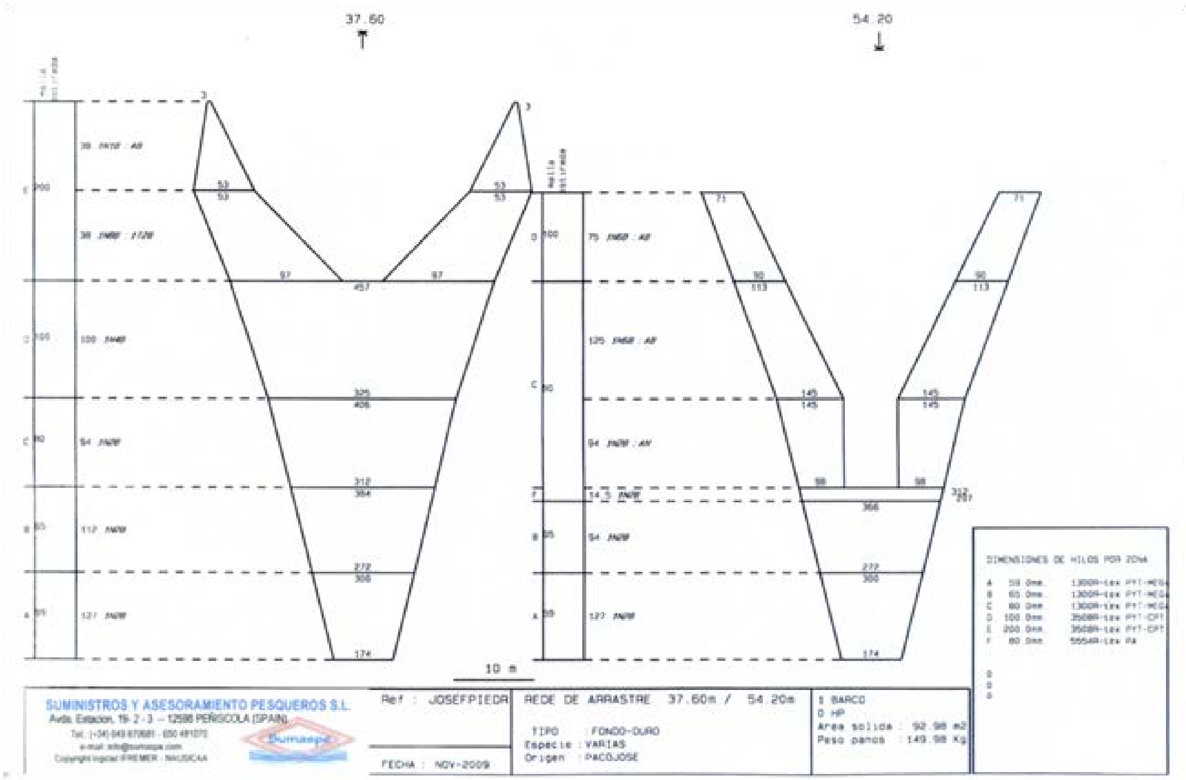


Figure 42. Schematic diagram of the commercial bottom trawl net used on the shallow shelf fishing grounds during the short pilot action developed off Menorca (Balearic Islands, western Mediterranean).

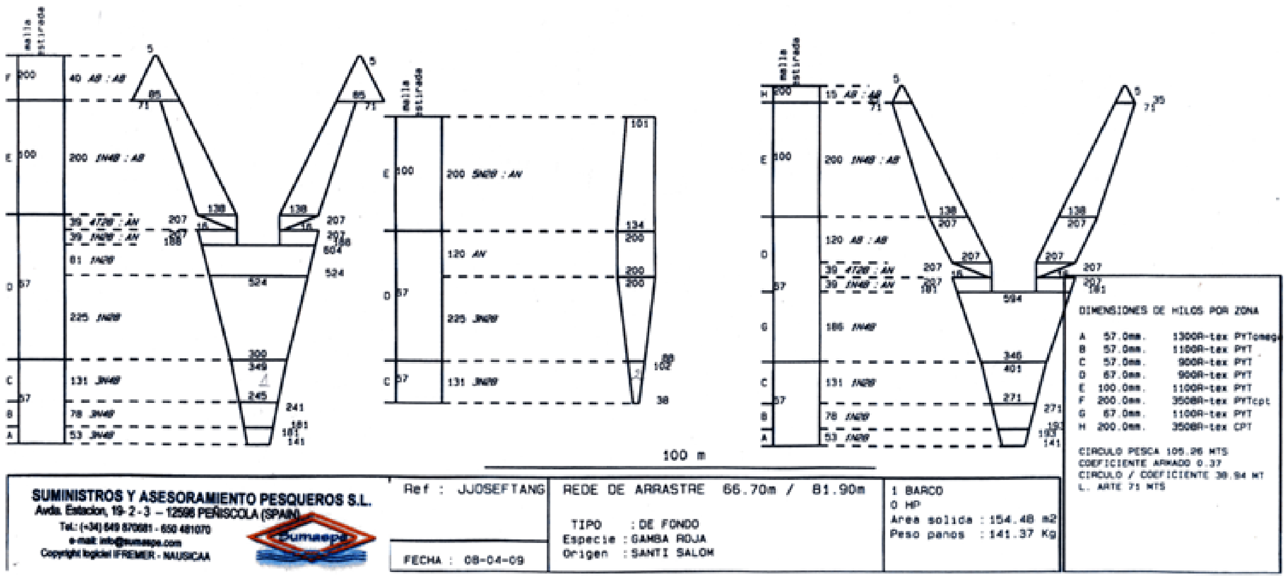


Figure 43. Schematic diagram of the commercial bottom trawl net used on the middle slope fishing grounds during the short pilot action developed off Menorca (Balearic Islands, western Mediterranean), within the framework of DISCATCH project.

Data analysis

Two different trawl gears were used in the shallow continental shelf and middle slope fishing grounds, with different type of bottoms, benthic communities and demersal resources assemblages (Massutí and Reñones, 2005; Acosta *et al.*, 2002). For that, the comparison of commercial yields, discards and size selectivity using TRA and EXP nets were made separately by depth stratum. A student t-test was applied to test differences in the composition of yields, in terms of abundance (n/h) and biomass (kg/h), between nets. Total yields, commercial yields and discards were compared for the whole catch and for the main species in each depth stratum. The composition of commercial catch (in terms of biomass; kg/h) and discards (in terms of abundance; n/h) was also estimated by taxonomic groups. Redundancy analysis (RDA) was used to investigate differences in catch composition between nets for the most important commercial species, in terms of biomass (kg/h), and for the most important discards, in terms of abundance (n/h). Monte Carlo free-distribution permutation based test was used to test the significance of the type of net (TRA *vs.* EXP). Species appearing in less than 15-20% of the hauls, depending on the bathymetric stratum, were omitted from the analysis. The length frequency distribution of the catches of the most important species from a commercial and/or ecological point of view was calculated by type of net, in terms of number of individuals by length class per hour. These length frequency distributions were compared between nets using the Kolmogorov-Smirnov test. Mean length of catches was estimated by gear type and a student t-test was applied to test for differences between them. Average distance between doors and the vertical opening of the net were estimated to compare differences in trawl geometry using TRA and EXP nets. Mean fuel consumption during the trawl, as well as the engine revolutions (rpm) and Kilowatt (kW), were also estimated to compare engine function conditions between nets.

Results

A total of 36 commercial trawl hauls were carried out from 15 September to 14 October 2014: (i) 16 hauls between 51 and 78 m depth, 6 using the traditional (TRA) net and 10 using the experimental (EXP) net; and (ii) 20 hauls between 592 and 693 m depth, 10 using TRA net and 10 using the EXP net. These hauls were developed on the fishing grounds exploited by the bottom trawl fleet of Maó (Menorca), both on the shallow shelf and the middle slope. The speed of the hauls developed on the shallow shelf was 2.7 knots and their duration ranged from 81 and 106 minutes, while these parameters in the middle slope were 2.1 knots and 216 and 407 minutes, respectively.

Catch composition

These 36 hauls yielded 4805 kg of total catch, 3082 kg on the shallow shelf (TRA: 1473 kg; 1609 EXP: kg) belonging to 86 species or taxonomic groups or marine litter, and 1723 kg on the middle slope (TRA: 946 kg; EX: 777 kg), belonging to 67 species or taxonomic groups or marine litter. On the shallow shelf, the most important species in the catches were algae (mainly red algae), echinoderms (mostly *Spatangus purpureus*), cephalopods (*Loligo vulgaris* and *Octopus vulgaris*), elasmobranchs (mostly *Scyliorhinus canicula* and *Raja* spp.) and the teleosts *Scorpaena* spp., *Chelidonichthys lastoviza, Trachurus* spp., *Trachinus draco*, *Serranus cabrilla*, *Spicara smaris*, *Zeus faber*, *Mullus surmuletus* and *Pagellus acarne*, among others. On the middle slope, the crustaceans *Aristeus antennatus Geryon longipes,* the fishes *Galeus melastomus*, *Phycis blennoides*, *Micromesistius poutassou* and the *cephalopods Todarodes sagittatus* and *Histioteuthis* spp. predominated in the catches.

On the shallow shelf, the commercial species or categories caught were comprised of 25 fishes and 4 cephalopods, which represented 75 and 25% of the landings, respectively, in terms of biomass, and 49 and 51% in terms of revenues. The target species/categories of the bottom trawl fishery in this depth stratum are *M. surmuletus*, *L. vulgaris*, *Scorpaena scrofa*, *O. vulgaris* and a mixed fish category called “Morralla”, mainly composed by *S. cabrilla*, *T. draco*, *Scorpaena notata* and *C. lastoviza*. On the middle slope, the commercial species caught were comprised of 6 decapod crustaceans, 11 fishes and 1 cephalopod, which represented 62, 26 and 12% of the landings, respectively, in terms of biomass, and 92, 7 and 1% in terms of revenues, respectively, being *A. antennatus* the target species. Other by-catch species/categories of the bottom trawl fishery in this depth stratum are the fishes *Phycis blennoides* and *Galeus melastomus*, the crab *Geryon longipes* and a mixed crustaceans category called “Gambussí”, mainly composed by species of the genus *Plesionika* and *Pasiphaea.*

Commercial yields and discards

In the shallow shelf, the comparison of fishing yields in terms of standardised biomass and abundance showed significant differences among nets for the total catch, commercial catches and discards. The biomass indices obtained with TRA net (164, 54 and 109 kg/h, for the total catch, commercial catches and discards respectively) were higher than those obtained with EXP net (102, 39 and 64 kg/h, respectively).

The abundance indices obtained with TRA net (792, 450 and 342 individuals/h, respectively) were also higher, but not statistically significant, than those obtained with EXP net (705, 373 and 332 individuals/h, respectively). Similar trends were also detected in the middle slope, where yields with TRA net were also higher, but not statistically significant, than those obtained with EXP net for total catch, commercial catches and discards. Especially for the standardised abundance, with mean values respectively of 473, 392 and 81 individuals/h with TRA net and 451, 374 and 77 individuals/h with EXP net.

The only significant differences were obtained at a species level, total catch and commercial catches of *P. blennoides* and *M. poutassou* with TRA net were higher than those obtained with EXP net. These differences were not detected for discards.

The catch composition showed similar results and trends, RDA analysis did not detected significant differences between nets. However, these models suggested a higher relation of some species with TRA net. In the shallow shelf, the biomass indices of commercial catches for *M. surmuletus*, *Trachurus* spp., *L. vulgaris* and “Mixed Fish” category with TRA net (1.0, 1.2, 10.6 and 12.3 kg/h, respectively) were higher than those obtained with EXP net (0.4, 0.6, 7.3 and 10.7 kg/h, respectively), being this relation marginally significant in the case of *M. surmuletus*. The abundance indices of discards for *S. smaris* and *S. scrofa* were higher with TRA net (3.1 and 3.4 individuals/h, respectively) than with EXP net (none and 1.7 individuals/h, respectively), being *S. smaris* only present in TRA net.

In the middle slope, the biomass indices of commercial catches for *Molva dypterigia*, *Helicolenus dactylopterus*, *M. poutassou*, *P. blennoides* and “Gambussí” were higher with TRA net (0.2, 0.04, 1.2, 1.5 and 0.7 kg/h, respectively) than with EXP net (0.1, 0.02, 0.5, 0.9 and 0.7 kg/h, respectively), being this relation significant in the case of *M. poutassou*, *Molva dypterigia* and *P. blennoides*.

The abundance indices of discards for *Lampanyctus crocodilus*, *Stomias boa* and *Lepidorhombus boscii* where higher with TRA net (11.7, 7.5 and 1.5 individuals/h, respectively) than with EXP net (2.0, 2.7 and 1.8 individuals/h, respectively), being this relation significant in the case of *L. crocodilus* and *S. boa*. By contrary, at this depth stratum, *A. antennatus* showed higher biomass index of commercial catches with EXP net (4.6 kg/h) than with TRA net (4.0 kg/h).

The comparison of discards by taxonomic/ecological groups also showed differences between types of net. In the shallow shelf, the average indices of discarded echinoids (mainly sea urchins) were higher with TRA net than with EXP net, both in terms of standardized biomass (32.0 and 6.8 kg/h, respectively) and abundance (168.1 and 64.3 n/h, respectively). In the middle slope, the average biomass indices of discarded meso-pelagic fishes and meso-pelagic crustaceans with TRA net (0.2 and 0.2 kg/h, respectively) were higher than those obtained with EXP net (0.04 and 0.02 kg/h, respectively). Similar results were obtained in the average abundance indices, those obtained with TRA net (12.2 and 7.0 n /h, respectively) were higher than with EXP net (2.4 and 1.0 n/h, respectively).

Size composition

None significant differences between types of net were detected in the length frequency distribution for any of the 15 analysed species (10 from the shallow shelf and 5 from the middle slope) but one species, *S. smaris*, showed significant differences in the mean size, with higher values with the EXP (17.2 cm) than with the TRA (15.5 cm). Aside from this, *Trachurus* spp., *R. clavata* and *Lophius piscatorius* also showed some variations between the mean size and length frequency distributions of the specimens captured with TRA (20.0, 76.2 and 40.1 cm TL, respectively) and EXP (18.3, 70.5 and 36.8 cm TL, respectively) nets. In *S. smaris*, the specimens <16 cm TL predominated in the catches with TRA net, while these small fishes were scarce in the catches with EXP net (Figure 53). By contrary, in *Trachurus* spp. the specimens <19 cm TL predominated in the catches with EXP net, while these small fishes were scarce in the catches with TRA net (Figure 51). Similarly, the percentage of small specimens of *R. clavata* (<65 cm TL) and *L. piscatorius* (<20 cm TL) in the catches with EXP net was clearly higher than those captured with TRA net (Figure 45 and Figure 50, respectively).

Discussion

The capture and discarding of below length at first maturity and minimum legal size are unwanted situations in any fishery. In this situation, more selective fishing gears are needed for the sustainable fisheries management. Although the implementation during recent years of square mesh in the cod-end has contributed to improve the selectivity of the Mediterranean bottom trawl fishery, it is necessary to progress in this issue to reduce discards and to solve the incongruence that still exist for some species between the minimum legal size, established by the European legislation, and the length of first capture with the legal minimum 40 mm square mesh cod-end in force (e.g. hake: 20 *vs.* 15 cm, respectively; Guijarro and Massutí, 2006). Most of the studies developed in the western Mediterranean have focussed on the cod-end mesh size and shape (e.g. Bahamon *et al.*, 2006, 2007a, Guijarro and Massutí, 2006; Ordines *et al.*, 2006; Sardà *et al.*, 1993, 2006), very few on the introduction sorting grids (Bahamon *et al.*, 2007b; Massutí *et al.*, 2009; Sardà *et al.*, 2004, 2005, 2006), but none has assessed the selectivity of bottom trawl with square mesh panels mounted in the upper plan of the net. Although the installation of square mesh windows has shown as a good technical measure to improve the selectivity of bottom trawls (e.g. Broadhurst, 2000; Kynoch *et al.*, 2008; 2009), and the serious concern about the poor selectivity of the Mediterranean bottom trawl fishery, in this area only four studies have assessed the effect of this escape panels. In Turkish waters of the Aegean Sea, Metin *et al.* (2205), Özbilgin *et al.* (2005) and Kaykaç (2010) tested the introducing of square panels in the upper part of the cod-end, while in the Tyrrhenian Sea Belcari and Viva (2005) tested the introducing of these panels in the upper part of the extension piece of the net, ahead the cod-end.

These studies reported a significant reduction of discards and by-catch of immature fish, and an increment of the length of first capture of the demersal target species (the fishes *Diplodus annularis*, *Pagellus erythrinus*, *Mullus barbatus*, *Merluccius merluccius*, *Trisopterus minutus capelanus* and *Micromesistius poutassou* and the decapod crustacean *Parapenaeus longirostris*). The results of the present short pilot action have shown few significant differences, both in fishing yields and discards, and suggested certain differences undetectable statistically, maybe due to the low number of samples available or the high variability among samples. Those differences that could be related to the improvement of bottom trawl selectivity through the installation of square mesh panels in the upper and lateral panels of the extension piece of the net, ahead the cod-end, can be due to demersal species with a more suitable body shape and/or swimming capability to escape through these windows. That could be the case of *Spicara smaris* in the shallow shelf and the fishes *Micromesistius poutassou*, *Molva dypterigia macrophthalma*, *Phycis blennoides*, *Lampanyctus crocodilus* and *Stomias boa* and the meso-pelagic crustaceans in the middle slope.

The reason for that these results are not so significant than those obtained in the previous studies that previously assessed the effect of the introduction of square mesh panels in the bottom trawl nets (Metin *et al.*, 2205; Özbilgin *et al.*, 2005; Kaykaç, 2010; Belcari and Viva, 2005) could be the characteristics of the nets in which the escape windows were installed. These studies used 40 mm diamond mesh cod-ends, while in our study a more selective 48 mm square mesh cod-ends were used. Moreover, the present pilot action was developed on board the F/V “Nueva Joven Josefina”, a bottom trawler that during last years has made continuous modifications in their gears trying to reduce the fuel consumption. These changes have brought the replacement of the traditional doors by mid-water doors not touching the seabed, the shortening of the bridles and the introduction of lighter netting, with larger meshes and thinner twine in the wings and square, which could have also improved the selectivity of the trawl net. In fact, the average fuel consumption during the bottom trawls developed on the middle slope was reduced from 49.5 to 47.3 l/h in a previous short pilot action that we developed during April 2011 in collaboration with this vessel to replace the doors (Massutí *et al.*, 2011), and three and half years ago the average fuel consumption have been reduced from 43 to 41.5 l/h.

In conclusion, the present short pilot action has shown that the installation of square mesh panels, in the upper part of the extension piece of the net, could be an appropriate and plausible measure to continue the improvement of the Mediterranean bottom trawl selectivity, specially maybe not at community level or even for the commercial species, but for other parts of the ecosystem. In this sense, is remarkable the significant differences detected in the discards of pelagic and meso-pelagic species. Moreover, it must be also considered the reduction of fuel consumption achieved, which can compensate the potential reduction of fishing yields at a short term, increasing both the environmental and economical sustainability of this fishery.

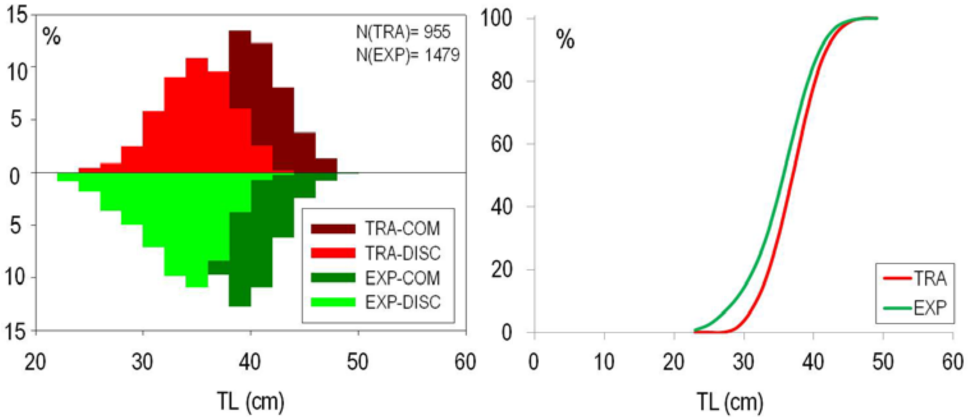


Figure 44. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Scyliorhinus canicula* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

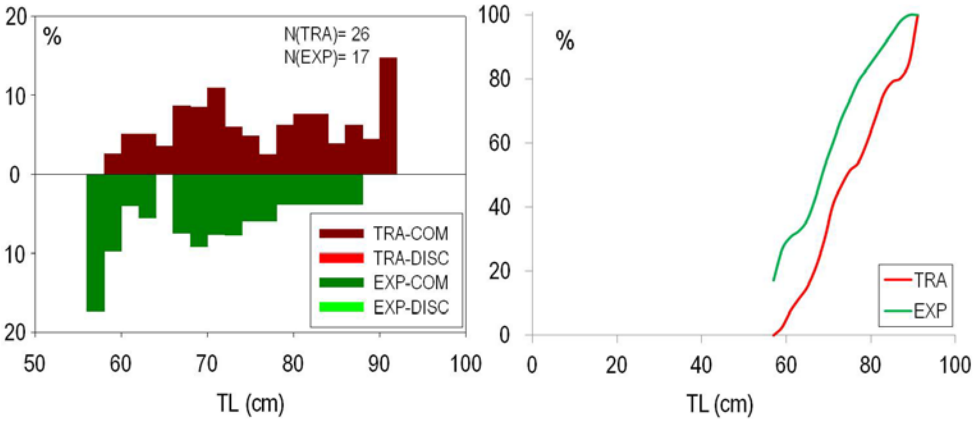


Figure 45. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Raja clavata* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

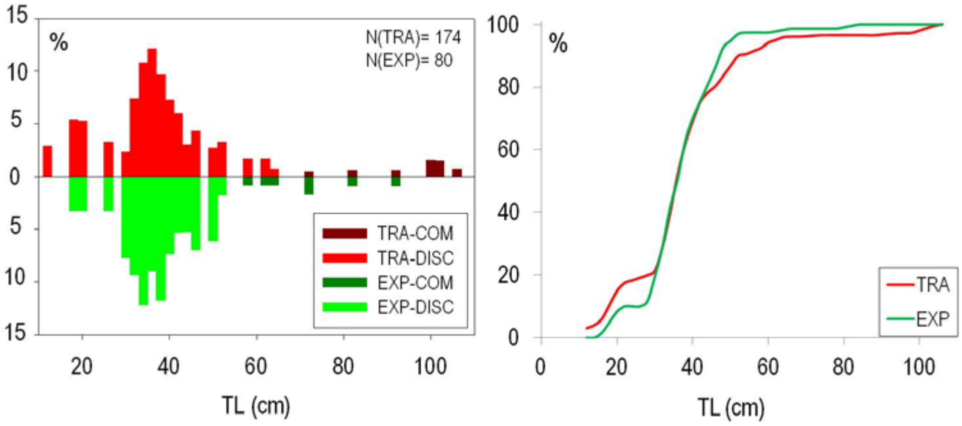


Figure 46. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Raja spp* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

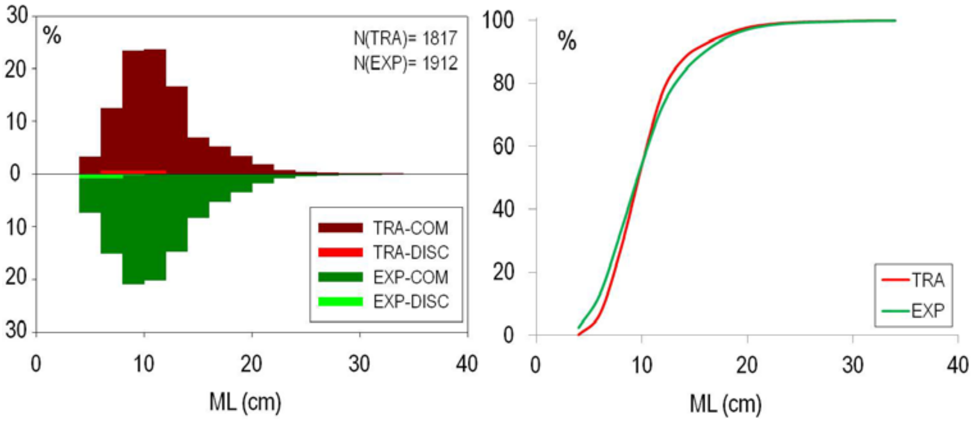


Figure 47. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Loligo vulgaris* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

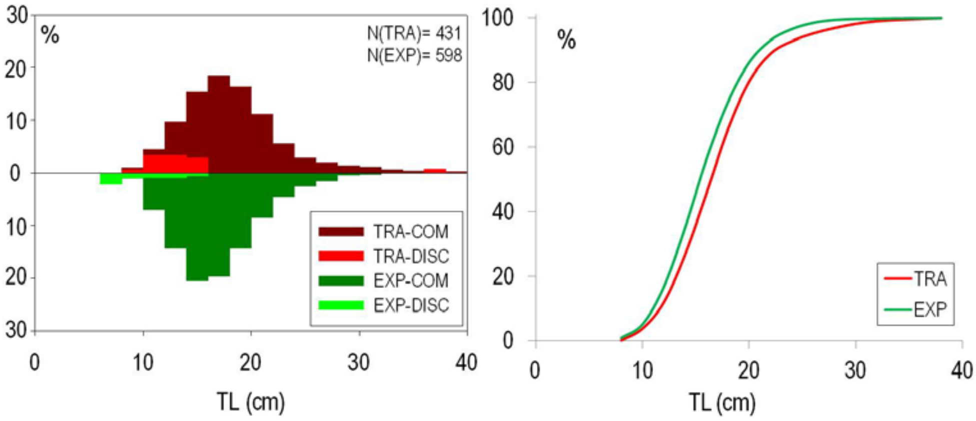


Figure 48. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Scorpaena scrofa* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

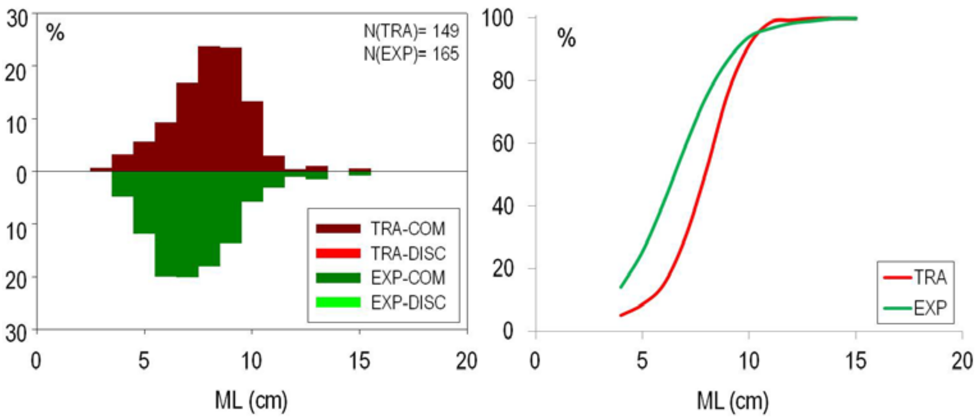


Figure 49. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Octopus vulgaris* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

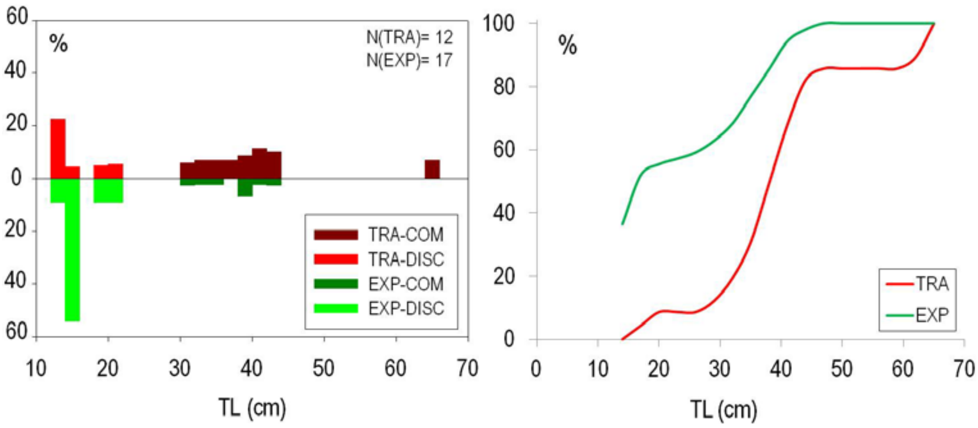


Figure 50. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Lophius piscatorius* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

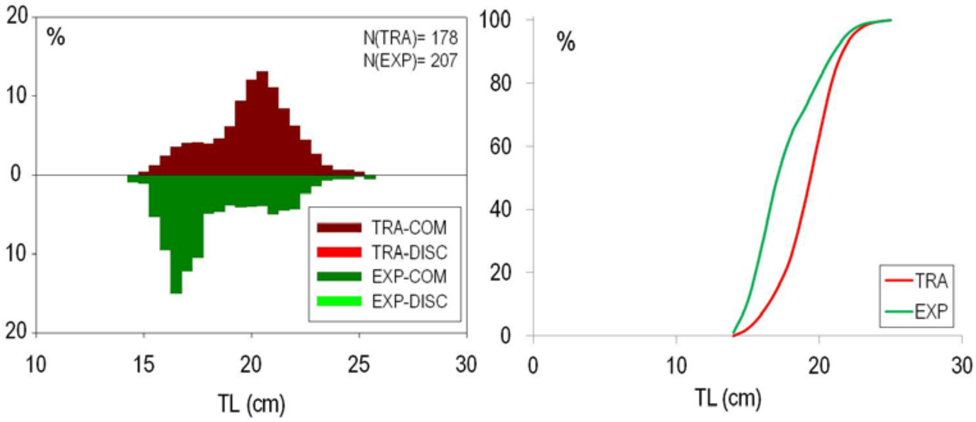


Figure 51. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Trachurus spp* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

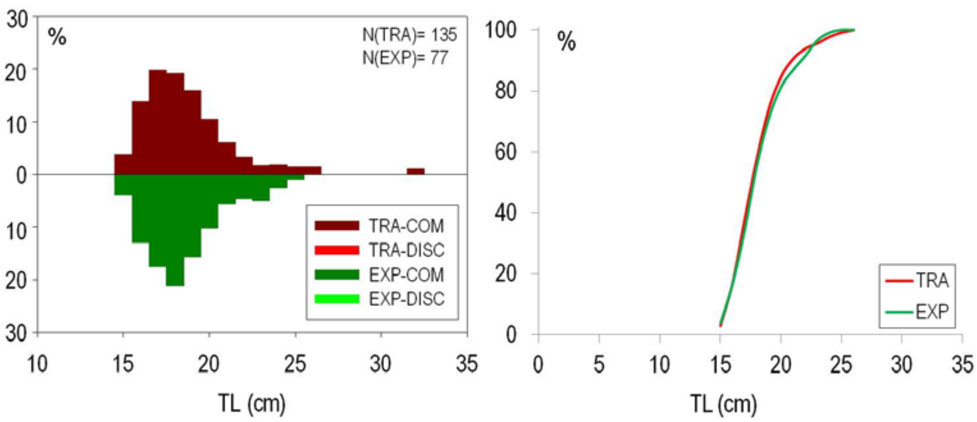


Figure 52. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Mullus surmuletus* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

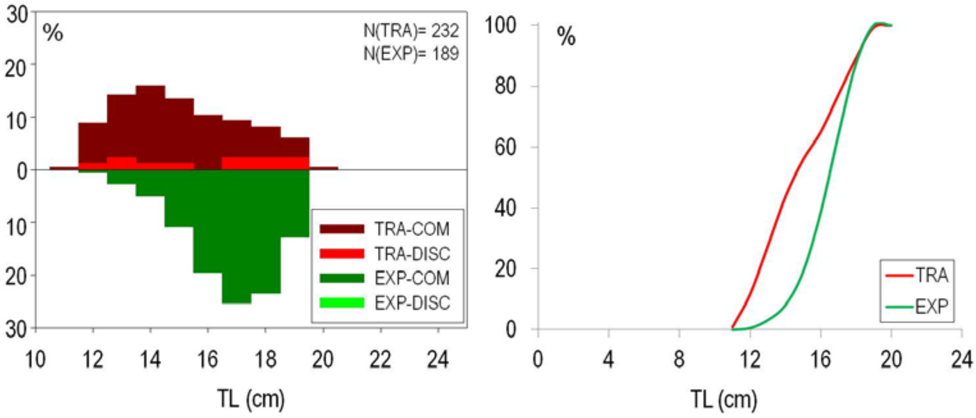


Figure 53. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Spicara smaris* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

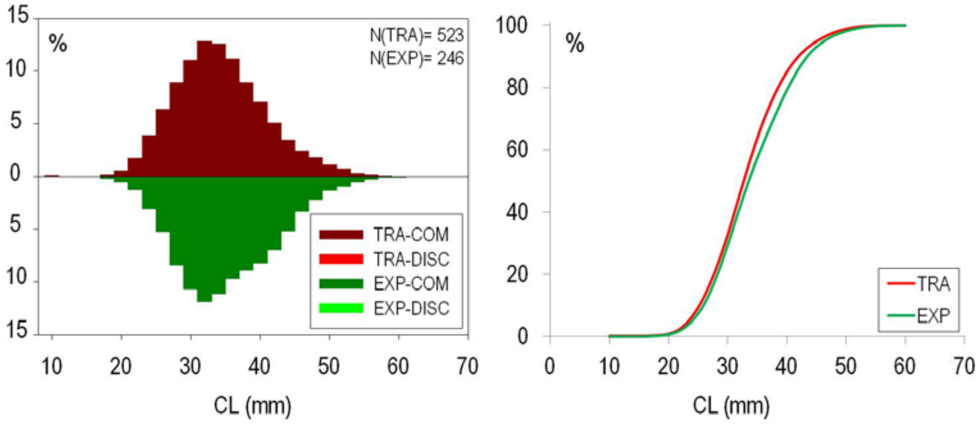


Figure 54. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Aristeus antennatus* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

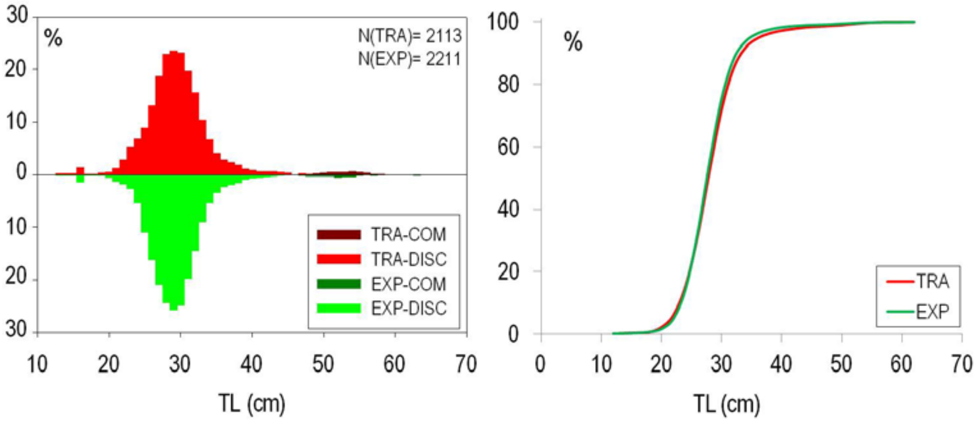


Figure 55. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Galeus melastomus* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

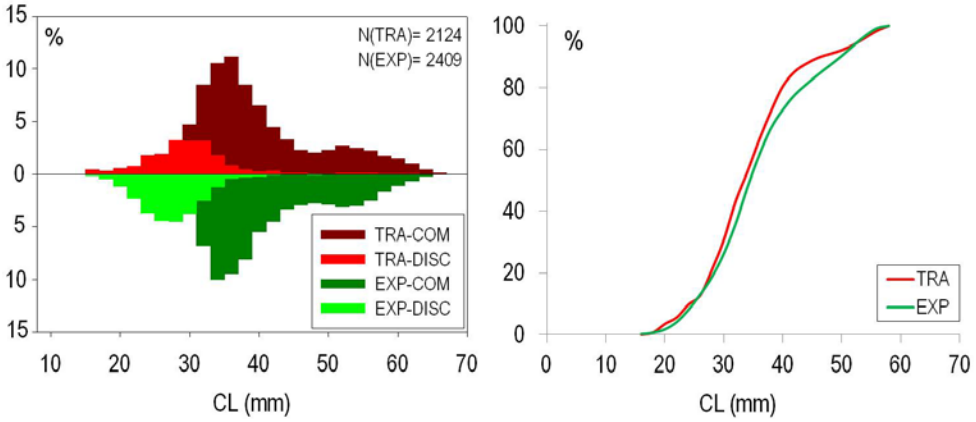


Figure 56. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Geryon longipes* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

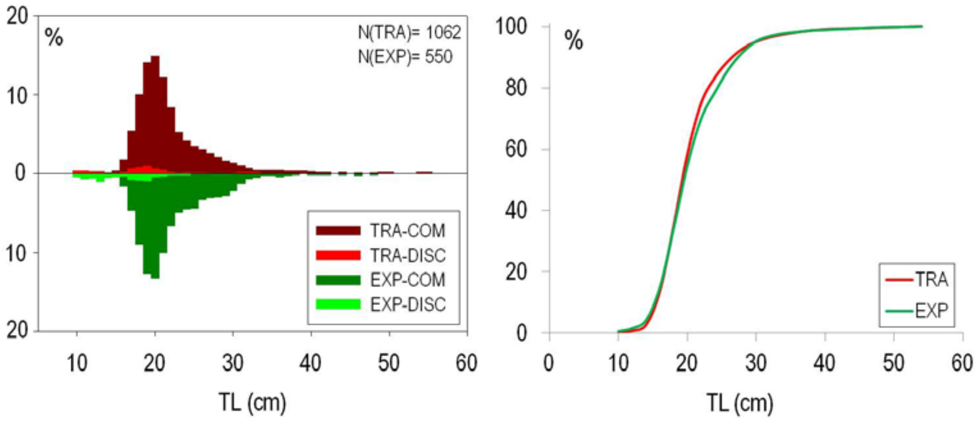


Figure 57. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Phycis blennoides* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

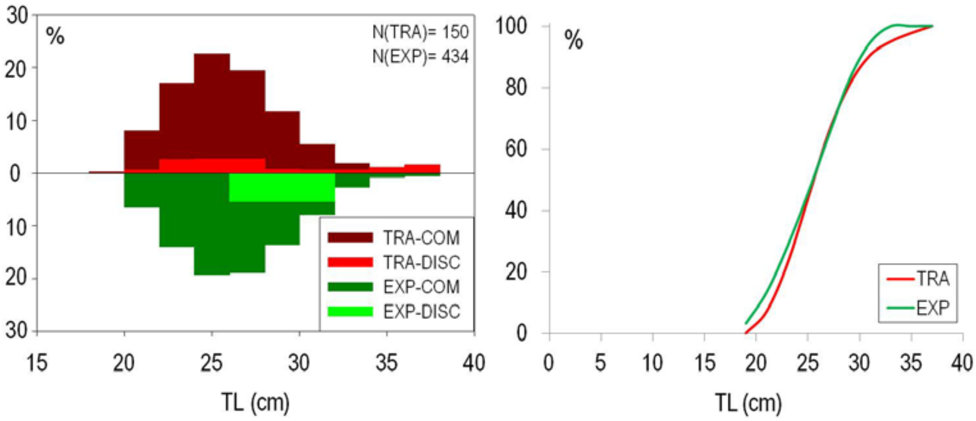


Figure 58. Length frequency distribution of commercial (COM) and discarded (DISC) catches of *Micromesistius poutassou* by type of net (TRA: traditional; EXP: experimental), and their cumulative percentage.

Experimental short pilot action at sea to complement the existing information on selectivity in the Greek bottom trawl fishery (Task 3.7)

Summary

A set of selectivity trials was conducted in the South Evoikos (GSA 22; Figure 59) to further examine the effect of the two commercial bottom trawl gears (40 mm square- and 50 mm diamond-mesh codends), which are currently in force in the Aegean Sea, on hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), horse mackerels (*Trachurus* spp.) and the deep water pink shrimp *(Parapenaeus longirostris)*.

The results indicate that the 40mm square mesh codend presents better selectivity properties than the 50 mm diamond mesh codend although it still allows about 18 % of the encountered undersized hake, about 7 % of undersized horse mackerel and about 9 % of undersized deep water pink shrimp to be caught. Further selectivity trials should be carried out incorporating more modifications on the nets such as sorting grids, separator panels and square mesh panels in the extension depending on the target species. These should be considered in combination with studies on the behaviour of the different species during capture to maximise their efficiency.

Figure 59. Map of trial area. Red transects indicate 40 mm SM codend hauls and yellow transects indicate 50 mm DM codend hauls.

Introduction

In Greece, the 40 mm square-mesh (SM) or 50 mm diamond-mesh (DM) codends have been recently implemented in bottom trawl fishery. Although information on the selectivity of the 40mm square codend in the Mediterranean is available in the literature, the experiments were primarily focused at comparing knotted and knotless square mesh (IMAS-Fish, 2007; Sala and Lucchetti, 2010) or were targeting different species (Bahamon *et al.*, 2006; Aydin *et al.*, 2011). Similarly, trials on the selectivity of the 50mm diamond mesh codend have been carried out in the Mediterranean (Sala and Lucchetti, 2011) but additional trials are required to further our knowledge on the selectivity properties of both gears in Mediterranean waters. The trials conducted within the auspices of the DISCATCH project aimed at that.

Experimental methods

Selectivity trials were undertaken on board FV *Takis-Mimis* (NX 411) during the period 14-17 September 2014 and the 'covered codend' method was employed. The covered codend method is routinely used for estimating the size selectivity of codends for towed fishing gears and has been extensively covered in the literature (Pope et al., 1975; Stewart and Robertson, 1985; Madsen and Holst, 2002; Millar, 2010). This method allows codend selectivity to be estimated directly because the cover will collect fish escaping the codend. The FV *Takis-Mimis* is a 1000 kW bottom trawler and for these trials she fished her normal nets, a typical design used on the Aegean Sea which is the standard rig configuration as conforming to the EC regulation No.1967/2006 for the Mediterranean Sea, fitted with the two test codends.

The 40mm (nominal) square mesh (SM) codend was an "Aggelidakis" codend with 200 meshes round and the 50mm (nominal) diamond-mesh (DM) codend was a "Deligiannis" codend with 340 meshes round. Both codends were made of 3mm single Polyamide (PA) multifilament twine thickness. The average mesh sizes prior to the trip were measured at 41.5 mm and 51.3 mm respectively. The extension had a fishing circle of 400 (nominal) meshes and was constructed from 2.55 mm single PA multifilament twine in both the top and bottom sheet. No ground gear was used and the foot rope was equipped with lead weights to keep the net on the bottom. The trawls were fished using 340kg steel "vee" type doors ("Portuguese 88s"; length 2.45 m, width 1.20 m). Scanmar units were used to monitor the geometry of the gear during fishing.

The towing duration was 60 minutes for all the hauls and the average towing speed was 2.8 kn, which was the vessels usual towing speed. Target species were hake, red mullet, horse mackerel, and deep water pink shrimp and thus fishing effort was directed towards these on the fishing grounds. The codend and the cover catches were separated onboard the vessel and all the target species were sorted from the bulk catch and measured to the nearest mm taking the total length. Sub-sampling occurred only when the number of individuals in a species exceeded 200 fish.

Due to the nature of the data the traditional two-step procedure for estimating mean selectivity for a set of hauls, i) estimation of the selectivity parameters of the individual hauls and their covariance matrix and ii) Fryer approach (1991), was not possible. Thus the approach used was similar to the ones described in Sistiaga *et al.* (2010), Eigaard *et al.* (2011), Hermann *et al.* (2012), Madsen *et al.* (2012) and Sala *et al.*(2015). This methodology, implemented in SELNET, circumvents the problem of underestimating the confidence limits for the average parameter values by double bootstrapping as described in Efron (1982) and Manly (1997) and takes into account both within-haul and between-haul variation. For each case analysed (species per codend) 1,000 bootstrap repetitions were conducted to estimate the 95% confidence limits. The results from the two gears for each species were plotted and compared to identify differences.

Results

During the trials a total of 22 valid hauls (11 per gear) were carried out. Fishing depths ranged from 68 to 258 m. A total of 274 kg from the 5 target species were caught with the 40 mm SM codend (47 % horse mackerels, 38 % red mullet, 9 % hake and 6 % deep water pink shrimp) and 175kg with the 50mm DM codend (45 % red mullet, 26 %

horse mackerels, 16% deep water pink shrimp and 13 % hake). Measurements for all fish species are in cm and in mm for deep water pink shrimp. A summary of the selectivity parameters and retention rates of the two test gears is presented in table 1 in the Annex *D 0.7.* .

Hake (Merluccius merluccius)

The 40 mm SM codend has a larger L50 from the 50mm DM codend ($L50_{40mm\,SM}$= 16.04 cm, SR= 2.27 cm; $L50_{50mm\,DM}$= 9.55 cm, SR= 7.75 cm; Figure 60). The retention by size, above MLS, for the 40 mm SM and 50 mm DM codends is about 48 % and 60 % respectively, whereas the retention by size below MLS is about 18.5 % and 31 % respectively. The total retention by weight is about 93 % for the 40 mm SM codend and about 97 % for the 50 mm DM codend. The size range of hake retained by the 40mm SM gear was 11-44 cm and 9-40 cm for the 50 mm DM gear.

Red Mullet (Mullus barbatus)

Although the retention by size, above Minimum Landing Size (MLS) is the same for the two test gears (76 %), the L50 of the 40 mm square mesh (SM) codend is larger than that of the 50 mm diamond mesh (DM) codend ($L50_{40mm\,SM}$= 13.31 cm, SR= 2.14 cm; $L50_{50mm\,DM}$= 11.69 cm, SR= 5.35 cm; Figure 61). Similarly the retention by size below MLS for both gears is below 1 %. The total retention by weight is about 86 % for the 40mm SM gear and about 82.5 % for the 50 mm DM gear. The size range of red mullet retained by the 40 mm SM gear was 11-29 cm and 9-24 cm for the 50 mm DM gear.

Horse Mackerel (Trachurus spp)

By combining the data from the two *Trachurus* species the L50s of the two test gears is $L50_{40mm\,SM}$= 14.83 cm, SR= 3.07 cm; $L50_{50mm\,DM}$= 13.67 cm, SR= 7.68 cm (Figure 62). The retention by size, above MLS, is 11.5 % and 18 % for the 40 mm and 50 mm respectively, whereas the retention by size below MLS is 13 % and 31 %. Total retention by weight for the two gears is about 35 % for the 40mm square mesh codend and 55 % for the 50 mm diamond mesh codend. The size range of horse mackerel retained by the 40 mm SM gear was 4-28 cm and 10-29 cm for the 50 mm DM gear.

Deep Water Pink Shrimp (Parapenaeus longirostris)

The 40 mm SM codend has a smaller L50 than the 50 mm DM codend ($L50_{40mm\,SM}$= 20.59 cm, SR= 4.55 cm; $L50_{50mm\,DM}$= 15.43 cm, SR= 5.55 cm; Figure 63). The retention by size, above MLS, for the 40 mm SM and 50 mm DM codends is about 9 % and 20 %, respectively. The retention of undersized shrimp is at 7 % and 37 % for the two gears. The total retention by weight is about 40 % for the 40 mm SM codend and about 71 % for the 50 mm DM codend. The size range of deep water pink shrimp retained by the 40 mm SM gear was 10-36 mm and 10-30 mm for the 50 mm DM gear.

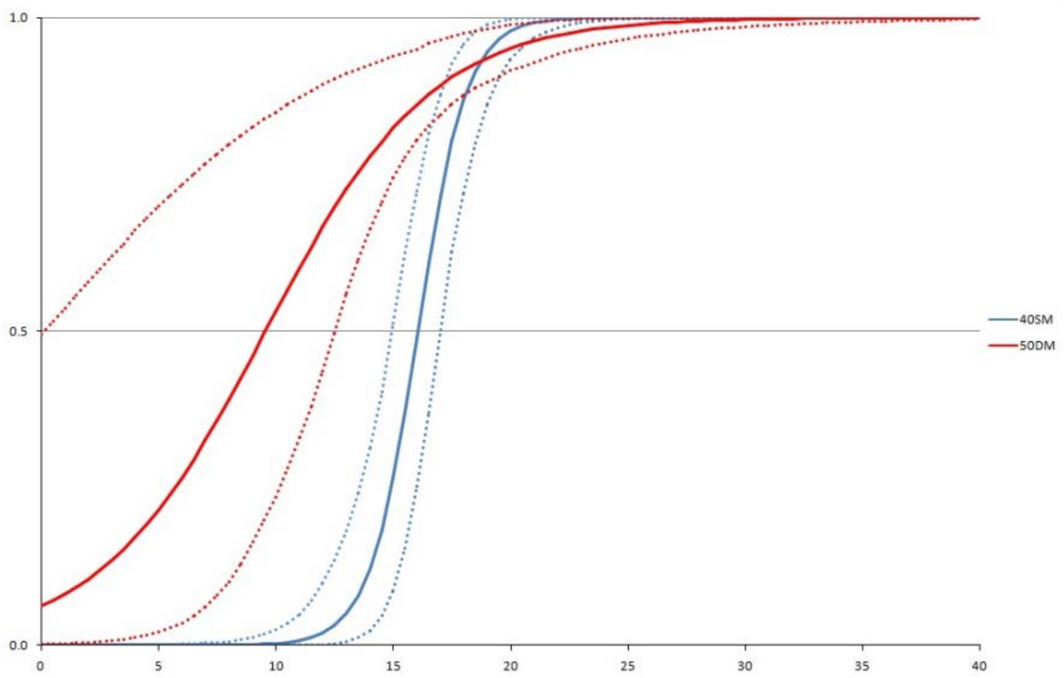


Figure 60. *Merluccius merluccius* mean selection curves for the two test gears. Dotted lines indicate confidence limits.

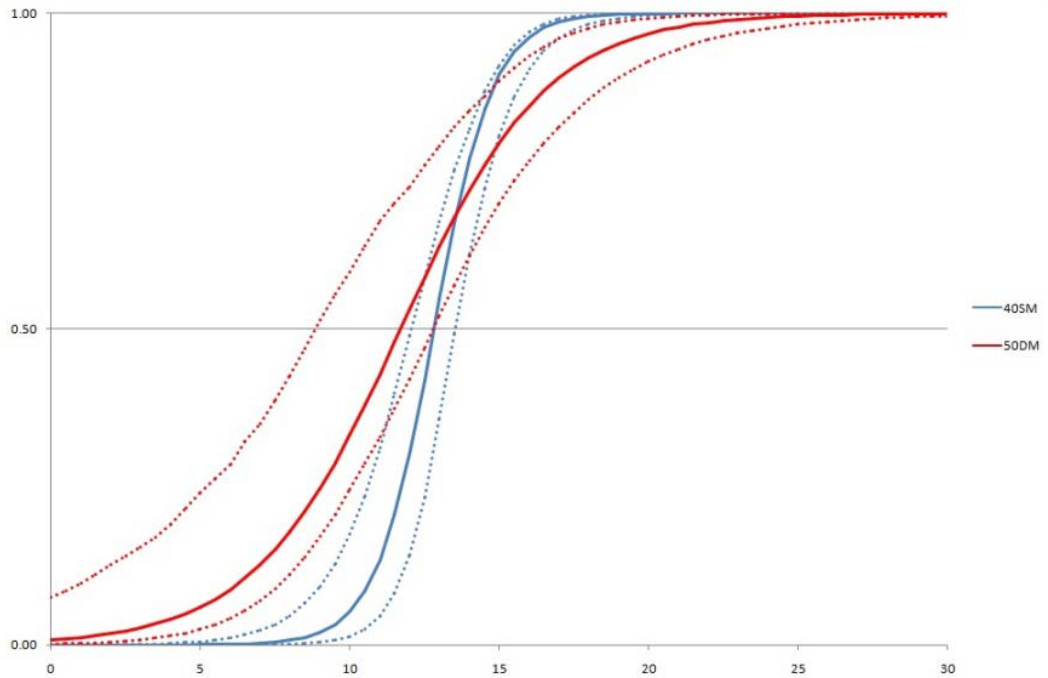


Figure 61. *Mullus barbatus* mean selection curves for the two test gears. Dotted lines indicate confidence limits.

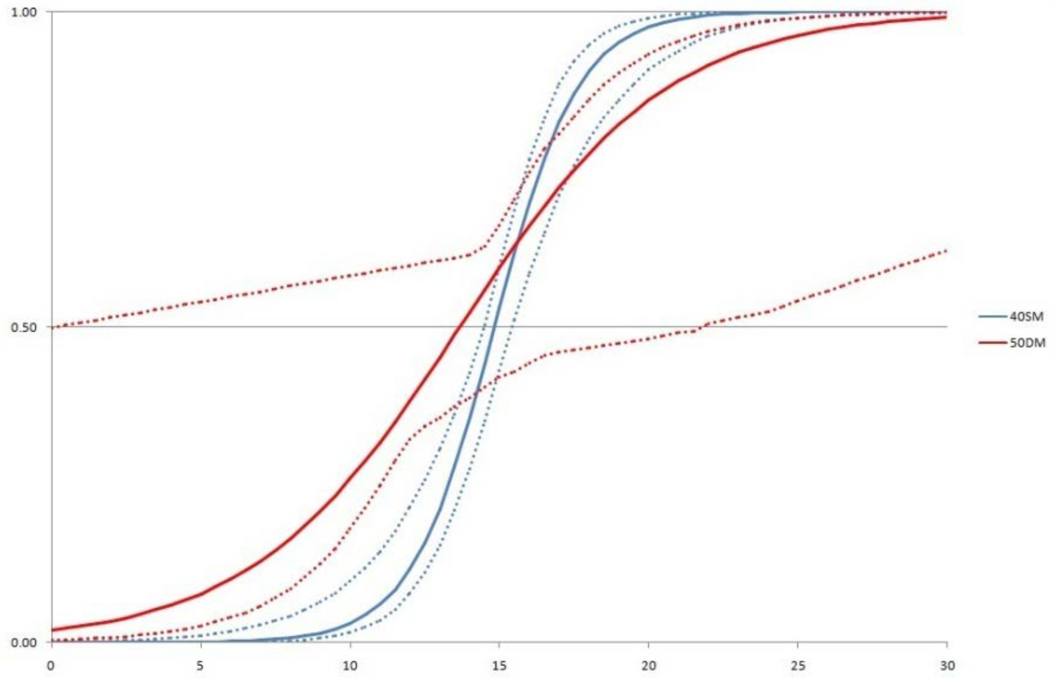


Figure 62. *Trachurus* spp. mean selection curves for the two test gears. Dotted lines indicate confidence limits

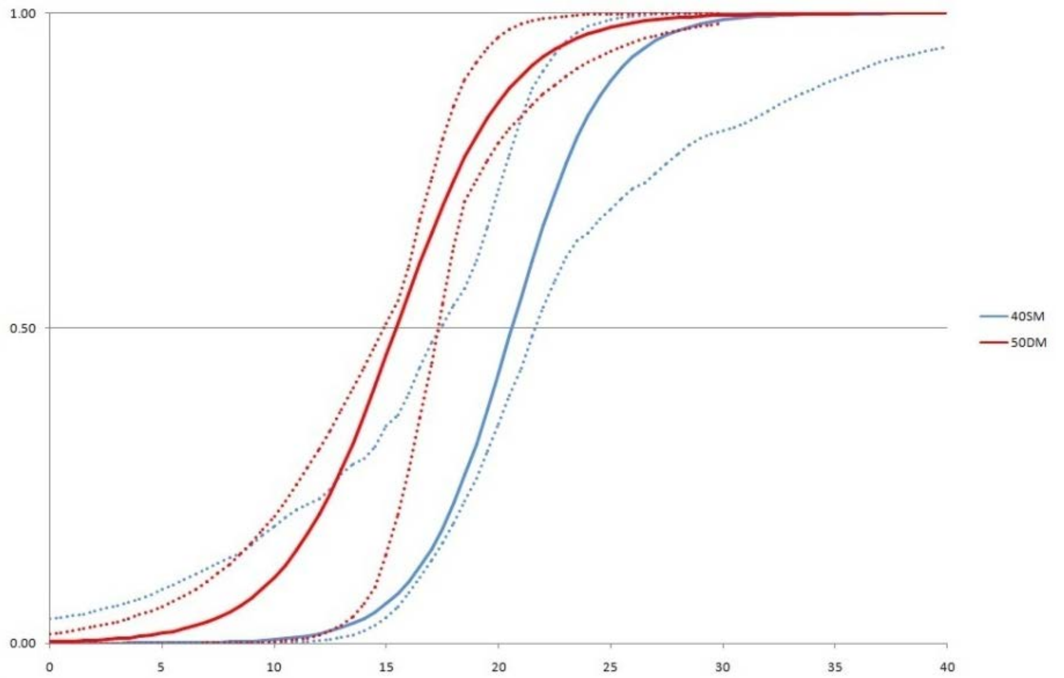


Figure 63. *Parapenaeus longirostris* mean selection curves for the two test gears. Dotted lines indicate confidence limits

Table 14. Direct estimate of the selectivity parameters for the two codends (40 mm SM and 50 mm DM) tested during the Aegean Sea trials. Mean values of the retention length at 50% (L50) and Selection Range (SR) are reported for MM: *M. merluccius* (European hake); MB: *M. barbatus* (red mullet); TT: *T. trachurus* (Atlantic horse mackerel); TM: *T. mediterraneus* (Mediterranean horse mackerel); TC: Trachurus spp (combined data); PL: *P. longirostris* (Deep water pink shrimp). SF: selection factor.

Species	Codend	L50 (cm)	SR (cm)	SF	α	β	Total retention by weight (%)	Number of fish retained above MLS (%)
MM	40 mm SM	16.24	2.57	0.41	3.2137	0.8552	93.27	99.28
	50 mm DM	12.91	5.11	0.26	3.0494	0.4302	96.95	97.32
MB	40 mm SM	12.34	2.90	0.31	2.0109	0.7569	86.12	78.77
	50 mm DM	10.89	5.04	0.22	1.7932	0.4362	82.45	80.48
TT	40 mm SM	15.37	2.36	0.38	-0.3473	0.9293	36.78	58.50
	50 mm DM	17.28	5.84	0.35	-0.859	0.3764	53.49	47.36
TM	40 mm SM	16.44	2.03	0.41	-1.5615	1.085	27.51	45.16
	50 mm DM	12.60	10.59	0.25	0.4977	0.2075	84.91	66.67
TC	40 mm SM	15.82	2.22	0.40	-0.8089	0.99	36.21	57.66
	50 mm DM	16.32	6.41	0.33	-0.4538	0.3426	54.58	48.07
PL	40 mm SM	2.12	3.97	0.53	-0.6816	0.5531	47.28	69.65
	50 mm DM	2.40	5.09	0.48	-1.7142	0.4317	71.14	91.27

Discussion

The selectivity slopes (from Figure 60 to Figure 63) of the 40 mm SM codend gear, apart from revealing larger L50s for this gear, are steeper than those of the 50 mm DM codend gear indicating that the 40 mm SM codend has better selection properties. By examining the results more closely this becomes more apparent. Table 1 (Appendix) contains a synopsis of the selectivity parameters for the two test gears. In more detail:

Both the 40 mm SM and the 50 mm DM codends have high retentions of *Merluccius merluccius* (about 66 % and 91 % respectively) but the 50 mm DM codend has also high retention of hake below MLS (about 31 %) in contrast to the 40 mm SM that retains about 18 % of undersized hake, making the 40 mm SM gear more preferable if hake is the target species in terms of discarding and conservation. In terms of weight both gears seem to retain similar amounts (40 mm SM, 93 %; 50mm DM, 97 %) but the 40 mm gear catch is composed from larger fish.

For *Mullus barbatus*, the 40 mm SM gear seems to perform similarly with the 50 mm DM gear, in terms of numbers retained (76 % in both cases) with the former having no retention below MLS and the latter around 0.2 %. The 40mm SM gear though is more preferable as it has a larger L50 than the 50 mm DM gear ($L50_{40mm\,SM}$= 13.31 cm; $L50_{50mm\,DM}$= 11.69 cm) allowing smaller individuals to contribute for a longer time in the stock as the size at first maturity is 11cm (Tsikliras and Stergiou, 2014). As expected in terms of weight the 40 mm SM gear has a slightly better retention (40 mm SM gear, 86 %; 50 mm DM, 82 %).

Atlantic horse mackerel, *Trachurus trachurus*, and Mediterranean horse mackerel, *Trachurus mediterraneus*, were combined as Trachurus spp. to allow for analysis due to the small numbers encountered. In line with the other fish species the 40 mm SM gear performs better for horse mackerels too retaining about 24 % of encountered horse mackerels of which 11.5 % were above MLS, whereas the 50 mm DM gear retained 49 % of which 18 % were above MLS. Similarly the L50 of the 50mm DM is smaller to that of the 40 mm SM gear ($L50_{40mm\,SM}$= 14.83 cm; $L50_{50mm\,DM}$= 18.67 cm) but further studies targeting horse mackerels need to be carried out to obtain more robust results.

For *P. longirostris*, although the 50 mm DM gear has higher retention (57 % of encountered) than the 40 mm SM gear (15% of encountered), it also has higher retention of undersized shrimp (37 %) in contrast to 7 % of the 40 mm SM gear. This is expected as the L50 of the 50 mm DM gear is below the 20 mm MLS ($L50_{50mm\,DM}$= 15.43 cm), whereas the L50 of the 40 mm SM gear is just above ($L50_{40mm\,SM}$= 20.59 cm). This is reflected to the retention by weight where the 50 mm DM codend retains 71 %, whereas the 40 mm SM retains about 40 %.

Overall the 40 mm square mesh codend presents better selectivity properties than the 50 mm diamond mesh codend and it performs well for red mullet and deep water pink shrimp but it still fails to produce L50s above MLS especially for hake and marginally for horse mackerels as fixed by the EC Reg. 1967/2006. The 50mm diamond mesh is unsuitable to meet the abovementioned EC regulation for hake, horse mackerels and deep water pink shrimp with L50s well below the MLS. It meets the EC regulation criteria for red mullet but it is still outperformed by the 40 mm SM gear in terms of L50.

In a mixed fisheries environment such as in the Mediterranean Sea, where different species grow at different rates, mature at different sizes and have different morphology, mesh size and shape that allows a certain size of one species to escape may not be appropriate for others. One way to overcome this problem is to try and separate the species and sizes before they are caught in the codend and become part of the catch. Therefore further selectivity studies should be carried out considering modifications that incorporate selectivity devices such as sorting grids, separator panels and square mesh panels on the extension or mouth of the trawl. As it has been shown in the literature (Main and Sangster, 1981, 1982a,b, 1983, 1984, 1985; Pingguo He, 2010), in order to maximise the efficiency of further selectivity trials it is fundamental that these should be done in conjunction with behavioural studies of each species during capture.

Validation sea trials on Italian semi-pelagic trawl fisheries in the Northern Adriatic Sea (Task 3.8)

Introduction

Anchovy (*Engraulis encrasicolus*) is one the most important commercial species of the Adriatic Sea. Italian fleet targeting small pelagics in the Adriatic Sea (GSA 17 and 18) is composed of 131 (around 66 couples) pelagic trawlers ("volante") mainly operating from Trieste to Ancona and about 44 "lampara" vessels (purse seiners with light) which operates mainly in the Central Adriatic Sea (Italian Ministry-IREPA Database, 2012).

Anchovy and Sardine (*Sardina pilchardus*) are the main target species of pelagic trawl in the Central-northern Adriatic sea. Other accompanying species with lower economical importance are also caught such as: Mediterranean horse mackerel (*Trachurus mediterraneus*), Atlantic horse mackerel (*Trachurus trachurus*), chub mackerel (*Scomber japonicus*), Atlantic mackerel (*Scomber scombrus*), and more rarely gilt sardine (*Sardinella aurita*). Most of the species caught by pelagic trawling have a Minimum Conservation Reference Size (MCRS, total length), established by the Council Regulation (EC) No 1967/2006.

SPECIES	MCRS
Anchovy (*Engraulis encrasicolus*)	9 cm
Sardine (*Sardina pilchardus*)	11 cm
Mediterranean horse mackerel (*Trachurus mediterraneus*)	15 cm
Atlantic horse mackerel (*Trachurus trachurus*)	15 cm
Chub mackerel (*Scomber japonicus*)	18 cm
Atlantic mackerel (*Scomber scombrus*)	18 cm

Therefore for these species the Regulation (EU) No 1380/2013 has fixed the landing obligation starting from the first of January 2015. The Italian legislation (yearly Ministry Decrees) regulates the activity of pelagic trawlers since 1988 closing fishing season during summer (about 30-45 days of closing season between July and September). Closing fishing season is not applied for the purse seiners. Fishing activity is also suspended during week-end. Nevertheless trends in anchovies landings decreased in the last years.

The minimum mesh size of pelagic trawl codends is fixed by Council Regulation (EC) No 1967/2006: "*For trawl nets targeting sardine and anchovy, where these species account for at least 80 % of the catch in live weight after sorting, the minimum mesh size shall be 20 mm*". Because the pelagic trawl target schooling fish, which by definition tend to relatively homogeneous groups, the gear is quite selective for species, but not necessarily in terms of size. Nevertheless knowledge on the selectivity performance of a semi-pelagic trawl targeting small pelagics are worldwide scarce. Thus improvement knowledge of trawl net selectivity is of prime importance.

In the traditional Italian pelagic trawls two boats tow one net. Each vessel tows one side of the net using two warps connected to bridles from the upper and lower wings at that side. Large weights (350 kg) are positioned on the bridle at the wing connection. The footrope is often weighted with chains. Pelagic trawl nets are made in knotted polyamide and have a vertical opening of about 10 m and horizontal opening of about 40 m.

Italian pelagic trawl is a trawl of outdated construction, as its basic design has not been changed since its beginning in 19th century. Schemes from that period show that its main features, with an exception of material used (previously natural material while today synthetic), are present even in trawls used nowadays. The need to avoid capture of undersized fish is obvious in multi-species and multi-size school catches and can only be achieved by substantial changes in the fishing techniques.

In fact, with conventional diamond mesh netting, both in bottom and in pelagic trawls, the meshes have a natural tendency to close-up once the netting comes under tension applied along the direction of tow making the escape of juveniles very difficult.

Moreover the performance and selectivity of pelagic trawling have been poorly investigated. Different solutions have been developed and implemented in recent years to improve the size and species selectivity of bottom trawl gear like the sorting grid and square mesh escape panels mounted on the codend or on the extension of the net. But these solution are not reliable in pelagic trawl. In order to identify suitable solutions to improve the selectivity of the pelagic trawling and evaluate of the potential offered by an appropriate net design optimisations, it is essential to know the catching process and how different species and sizes are enmeshes in the different netting panels of a pelagic trawl.

To achieve this goal a sea sampling was carried out with a single boat pelagic trawl onboard the research vessel Dallaporta. The main goal of this test was to better define the link between net section - mesh opening - size of enmeshed fish.

Material and methods

Sampling gear and performance

Sea trials were carried out onboard the Italian research vessel RV “G. Dallaporta” (810 kW at 1650 rpm; Length Over All 35.30 m and Gross Tonnage 285 GT; Figure 64) based in Ancona harbor, Adriatic sea, using a semi-pelagic single-boat trawl. The meshing experiment was carried out using a modified traditional Italian pelagic pair-trawling for a single boat trawling rigging (Figure 68 and Figure 69). Four different netting sections with different mesh opening (MO: stretched mesh opening: 15, 16.8, 22, 27.5 mm) were mounted on the extension piece of the net, in order to assess the possible meshing through the nettings (Figure 69 and Figure 70).

During all the sea trials, the behaviour of the trawls were constantly monitored in order to optimize the performances and to detect eventual inconvenience on the trawl behaviour. The front parts of this net are usually rigged with ropes, which herd the targeted fish inwards (Figure 65 and Figure 67). The horizontal opening is maintained by towing the net by 2- traditional bottom-doors. Pelagic trawl is towed at the appropriate level in the water column to intercept target shoal with gear depth being controlled by altering towing speed and/or warp length.

A fishing trip has been carried out in December 2014, using a partially modified pair trawl net, in order to identify the netting panels and meshes useful for the study of fish meshing. During all the hauls done, the SIMRAD PI50 system (Norway) was used to measure the gear performance: horizontal net opening (HNO, defined as upper net wing-end spread) and vertical net opening (VNO, defined as height of the headline centre above the seabed), and door spread (DS, defined as the distance between the two doors).

The instruments were linked by RS232/485 serial ports to a personal computer, which automatically control the data acquisition and provide the correct functioning of the system in real time through an appropriately developed Microsoft Visual Basic 6.0 program. The laptop recorded on the hard disk all the measurements made at a rate of every ten seconds. A set of measurements was recorded for every haul to be processed afterwards in the institute.

Figure 64. Research Vessel “G. Dallaporta” used for the sea trials.

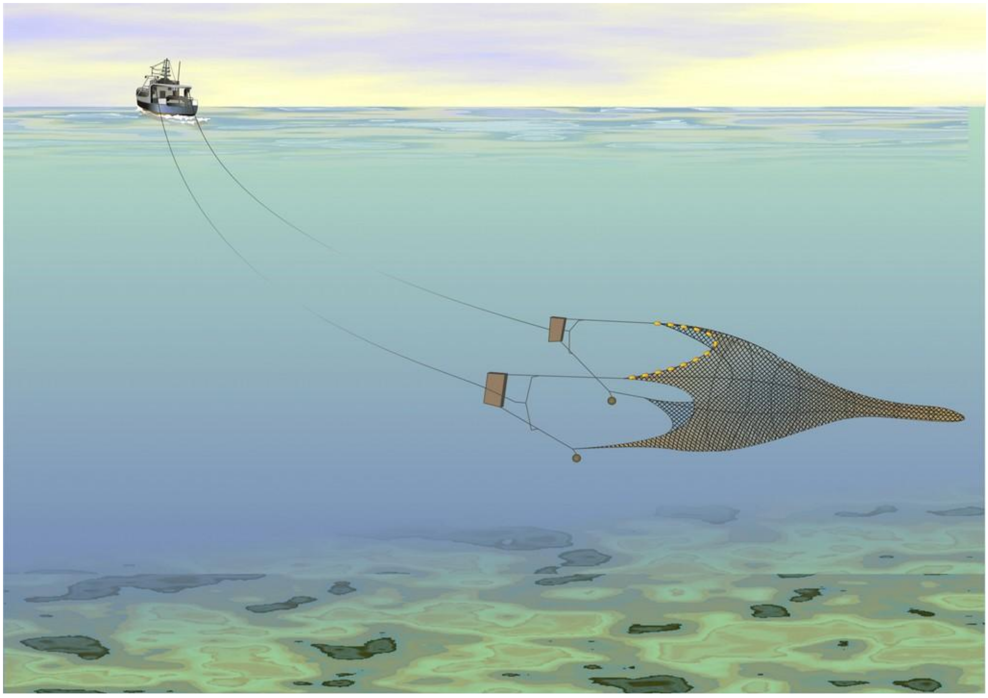


Figure 65. Scheme of the pelagic trawl used during the meshing experiment.

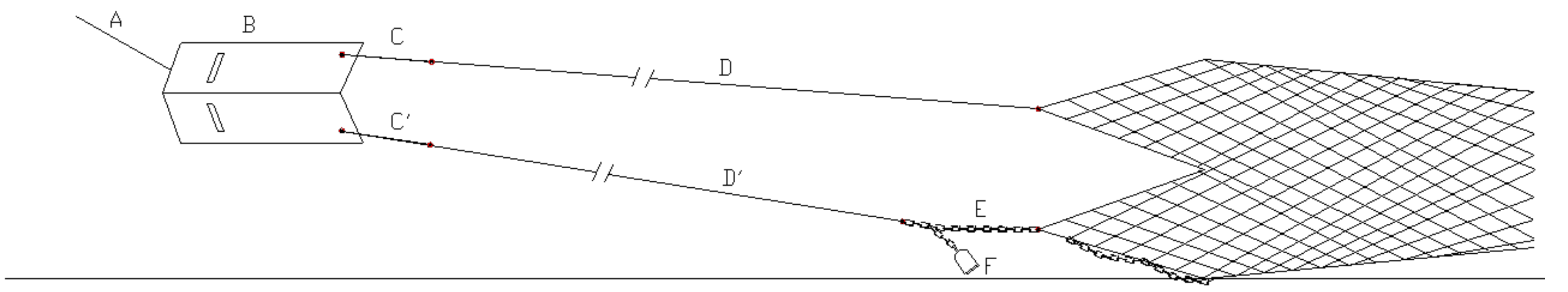
Catch analysis

Once the net was hauled onboard, each single specimen enmeshed in the different netting panels was taken and measured to the nearest 0.5 cm (total length (TL)). At the end of each haul the size frequency distributions of the main commercial species were calculated to the nearest 0.5 cm: total length (TL) for fish. Random subsamples were taken in case of abundant catches.

Analysis of the risk of meshing

Besides providing morphology data to run FISHSELECT (Frandsen et al., 2007; Herrmann et al., 2007; 2009; 2012; Krag et al., 2014) this information could be used to produce so called design guides which quantify the basic size selective properties of meshes of different shape and size for the species being investigated. Such design guides can be produced for any kind of mesh type and is a valuable tool for fisheries managers and gear designer. In addition it can be used to judge the risk for stickers (fish which due to the impossibility of going completely through, become enmeshed while trying to pass through the netting) in different parts of a trawl (Figure 66) when we have knowledge on the size structure entering the gear. Thus this can be applied to try to mitigate sticking problems by aiding gear design.

Figure 66. Sticking problems in the North Adriatic semi-pelagic fisheries.



Acronym	Name	Dimension/weight	Material
A	Towing Warp	Ø 15 mm	Stainless steel
B	Door "Grilli AR"	1.63 m x 1 m	Stainless steel
C	Upper Backstrop	6 m	Combined
C'	Lower Backstrop	6 m	Combined
D	Upper Bridle	50	Combined
D'	Lower Bridle	50	Combined
E	Regulation chain	4.5 m	Stainless steel
F	Clump weight	250 kg	Iron

Figure 67. Details of the single-boat net rigging.

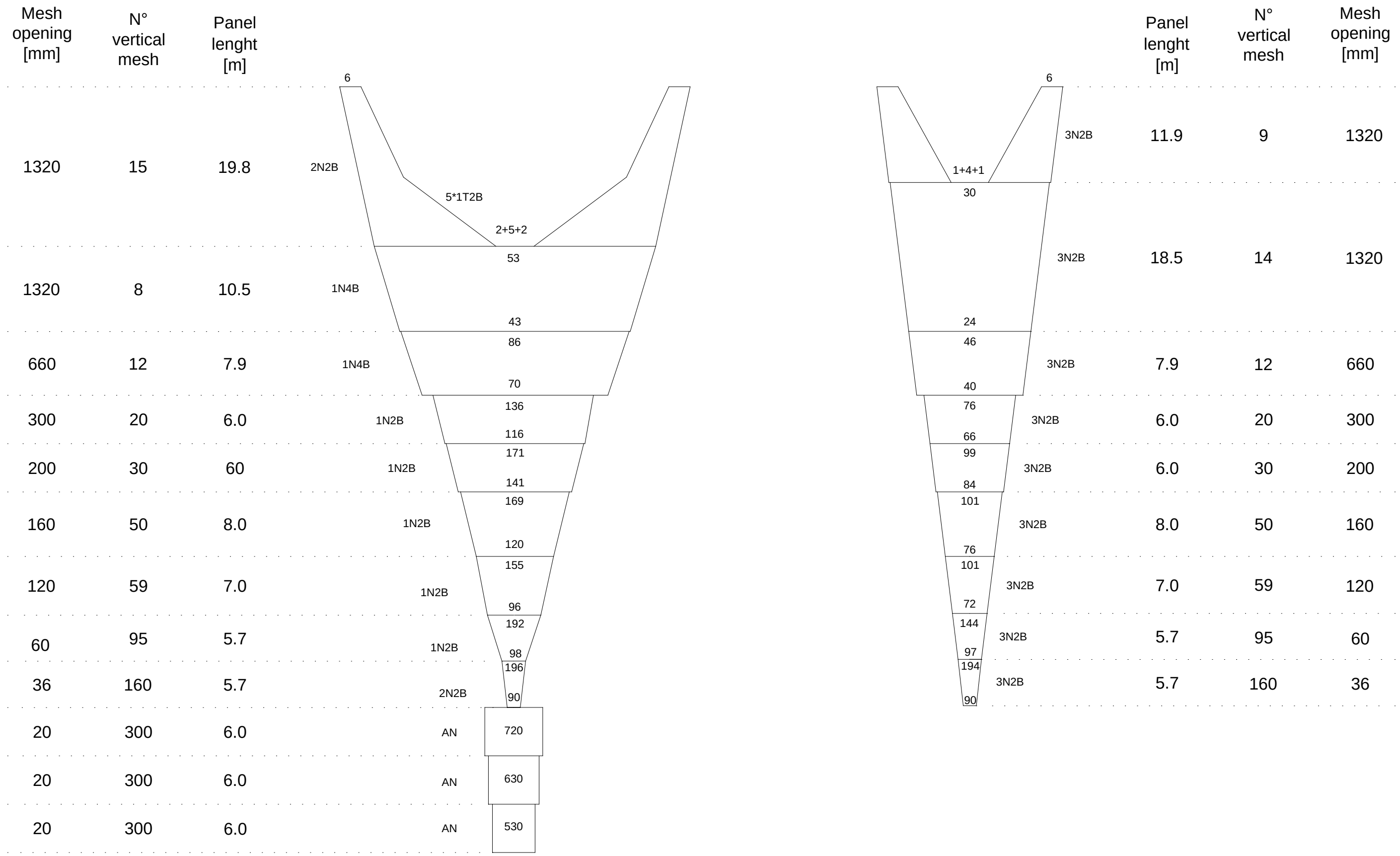


Figure 68. Original design of the single-boat pelagic trawl.

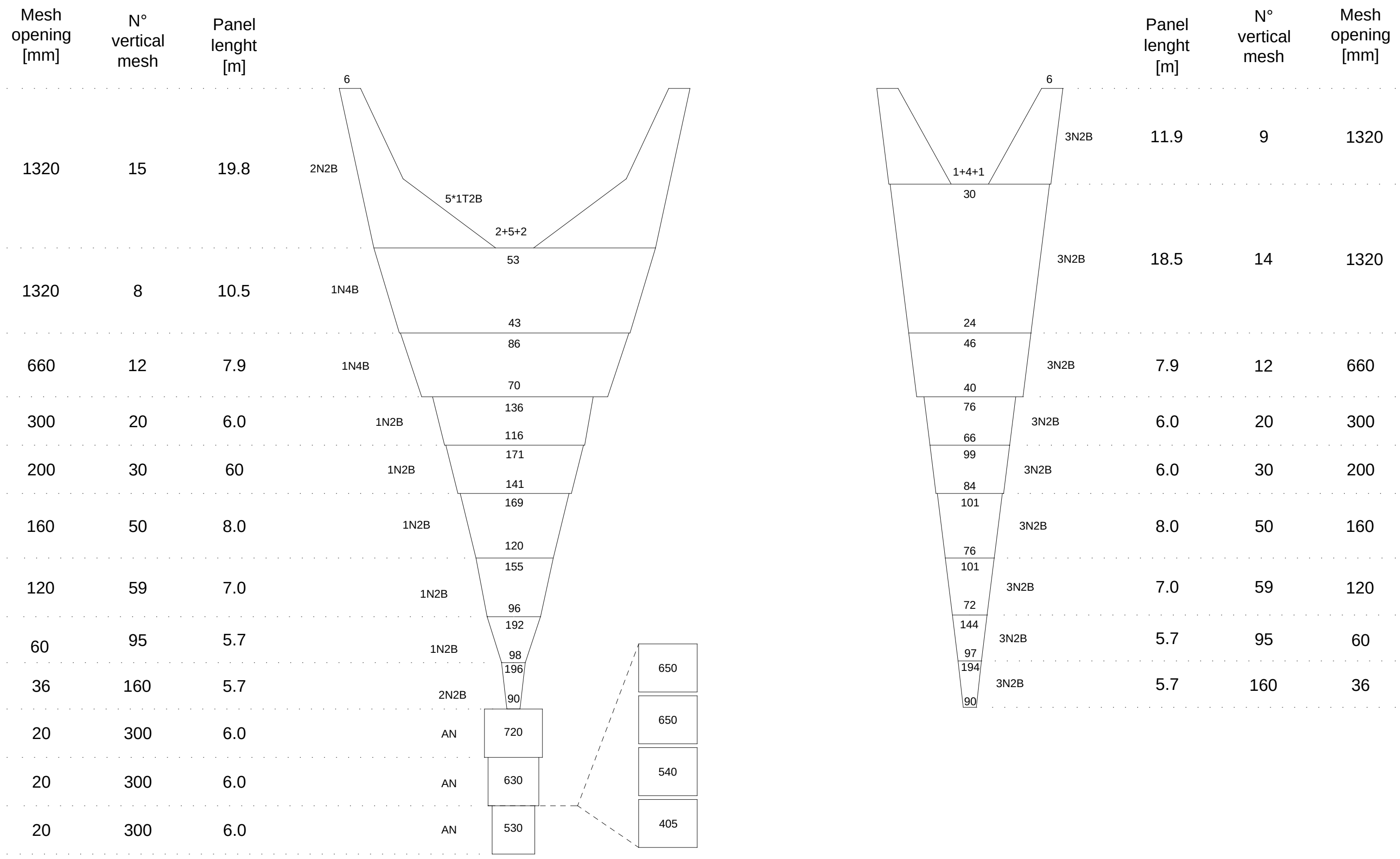
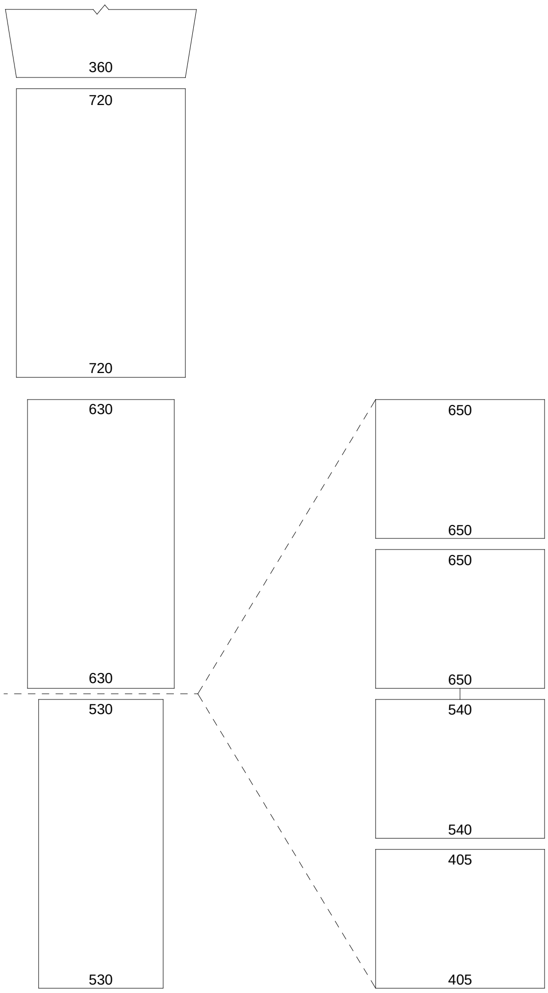


Figure 69. Modified design for the meshing experiment. The four netting sections have been inserted before the last netting piece of the codend.

Stretch mesh opening [mm]	Nominal mesh opening [mm]	N° vertical mesh	Panel lenght [m]	Rtex
36.0	36	-	-	1050
15.2	20	300	6.00	210/21
14.5	20	300	6.00	210/21
15.4	20	300	6.00	210/21



Rtex	Panel lenght [m]	N° vertical mesh	Nominal mesh opening [mm]	Stretch mesh opening [mm]
1050	3.00	176	17	15
1215	3.00	150	20	16.8
1050	3.00	125	24	22
____	2.50	86	29	27.5

Figure 70. Design and technical specifications of the codend of the net. The four nettings on the right have been mounted before the last codend netting piece as showed by the dashed line.

Results

Catch composition

Overall, 4 valid hauls were performed, to assess the catching process of a pelagic trawl. In order to minimise the variation of the environmental parameters, the hauls have taken place during daylight hours, at a time ensuring reliable weather conditions and at constant depth. Tow duration ranged from 27 to 40 minutes and towing speed was set at around 4.0 knots in accordance with the practices commonly employed in the semi-pelagic trawling in the Adriatic Sea. For most of the frequent species, the individuals caught in each haul were numbered and measured considering separately the codend and each panel with different mesh opening (MO) where fish was found entangled. During hauling of the net, the fish entangled or enmeshed in each netting panel was measured (total length) and weighted separately from the other netting panels.

Among all the species entered the net, only two species were entangled or gilled: anchovy and sardine. The cacth of anchovy and sardine below the MCRS is uncommon (Figure 71). In all tests only 0.19% of anchovy have been found entangled or enmeshed in the netting panel with 36 mm MO. This probably means that mesh opening below 36 mm MO are able to retain all anchovy entering the net. Conversly 0.03 % and 0.30% of anchovies were enmeshed respectively in the panels having 200 and 160 mm MO. This likely means that most of anchovies are able to escape from these type of meshes. On average 4.50 % of all anchovies caught have been found gilled or enmeshed in the 65 mm MO netting panel, with a bulk of 9.71% in the third haul and a modal class at 8 cm TL. This percentage reduced to 1.83% in the panel with 120 mm MO, where a modal class equal to 12 cm TL was detected (Figure 72).

Concerning *S. pilchardus*, the percentage of entangled or enmeshed fish was always really low in all panels: on average, the higher percentage (1.69%) was detected in the netting panel having 120 mm MO (modal class 13 cm TL), followed by the 65 mm MO (0.38%, modal classes at 6 and 13 cm TL), 160 mm MO (0.20%, modal class 13 cm TL) and 36 mm MO (0.10%; Figure 72).

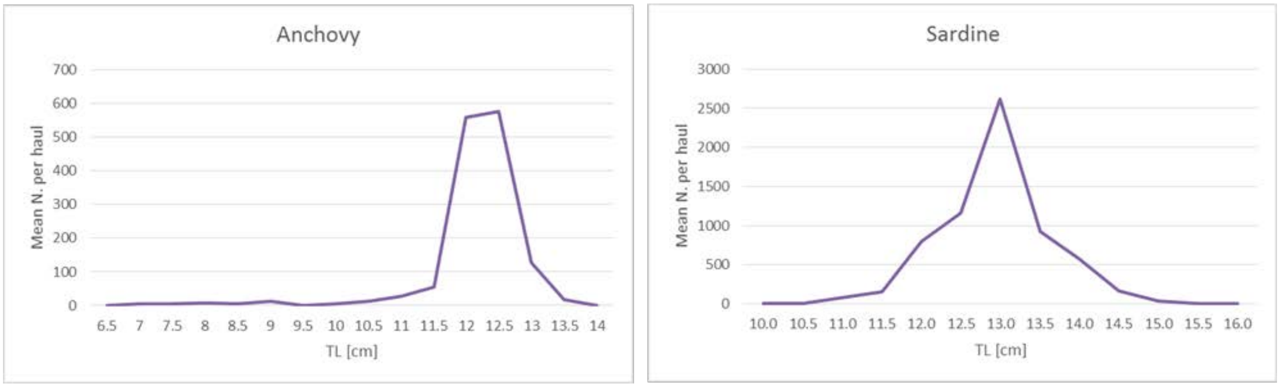


Figure 71. Mean number of anchovies and sardines obtained in the codend catch.

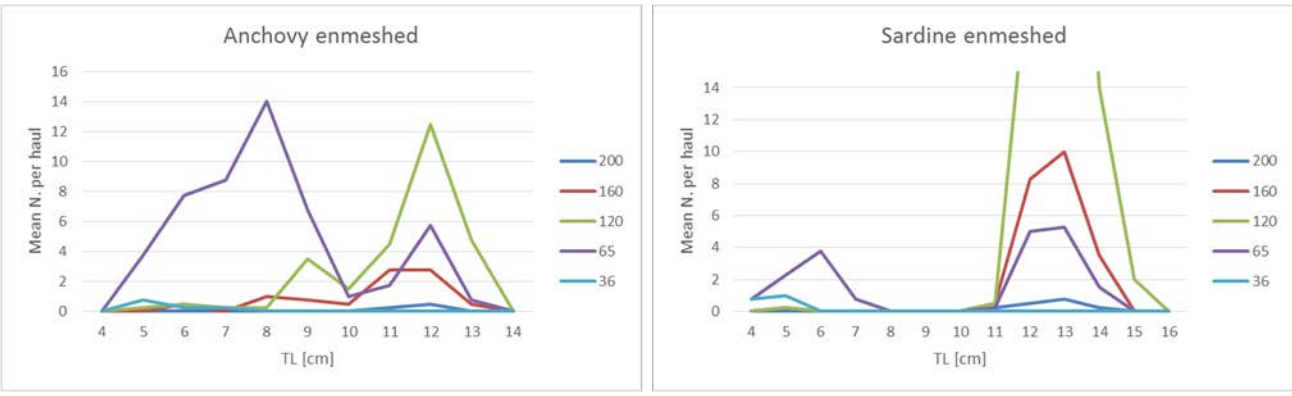


Figure 72. Mean number of anchovies and sardines enmeshed in each haul in the different panels (200, 160, 120, 65, 36).

Risk of meshing

For a fish population of anchovies with a total fish length ranging from 11 to 14 cm, as in the case of the population fished during the sea trials, the FISHSELECT analysis shows that a high and serious sticking problem might be evident with meshes of around 30 mm and an opening angle of around 50-60° (Figure 73). For the catched anchovies population we did not encountered any relevant sticking problem neither in the codend nor in the previous trawl panels. In Figure 74, it is reported the FISHSELECT simulation analysis comparing the fished anchovies population with the risk of meshing (i.e. lengths ranging between L05 and L95). Practically there is not evident overlapping between the range of risk of meshing and the catched anchovies.

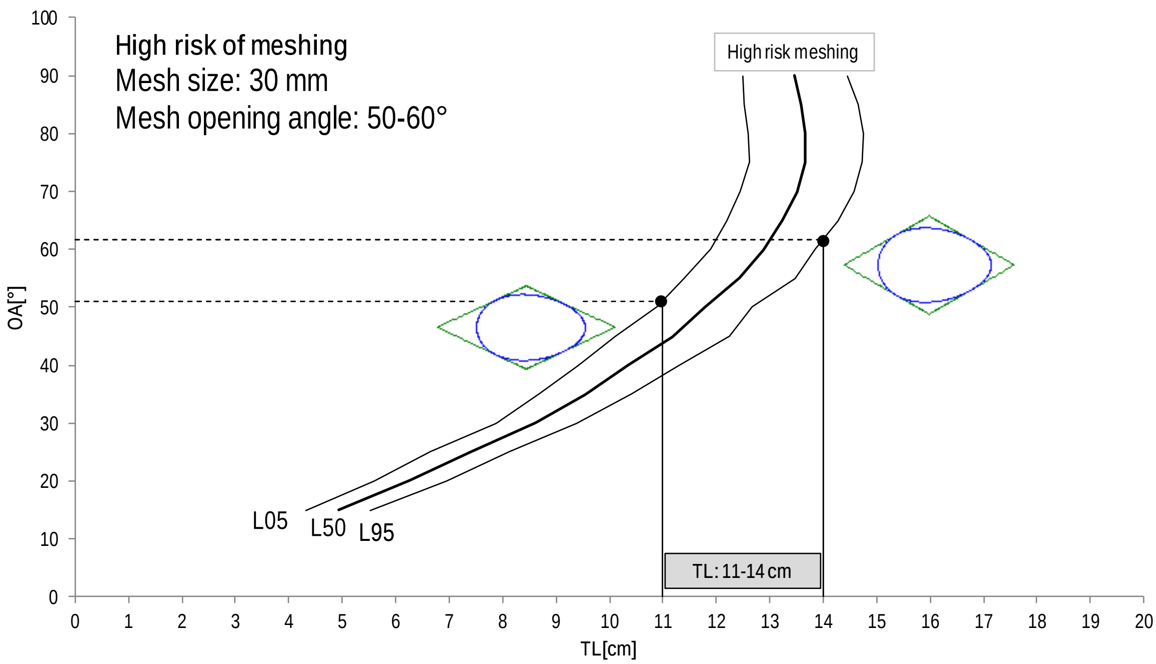


Figure 73. FISHSELECT analysis of risk of meshing for anchovies. L05, L50 and L95: retention length at 5, 50 and 95 %; OA: mesh opening angle; TL: total fish length.

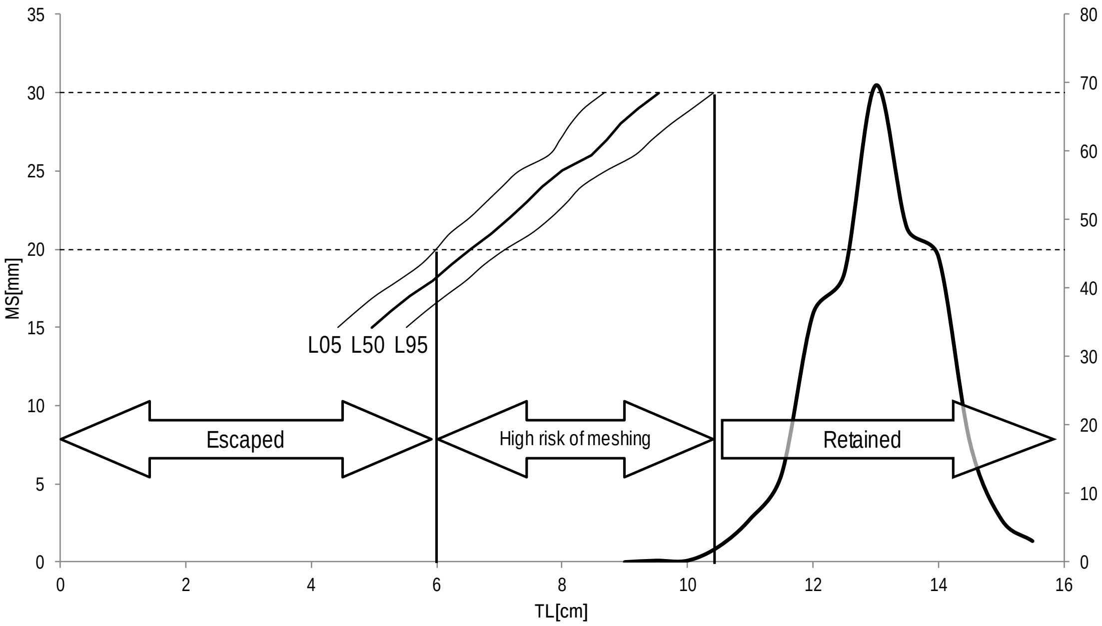


Figure 74. FISHSELECT analysis of risk of meshing for anchovies comparded to fished anchovies population (thick curve). L05, L50 and L95: retention length at 5, 50 and 95 %; MS: mesh size; TL: total fish length.

Conclusions

The results obtained during the cruise for studying the effect of design and rigging optimisations on trawl selection show that:

- The catch of *E. encrasicouls* and *S. pilchardus* is really low (below 1%)
- in the catching process of a semi-pelagic trawl, the enmeshing or entangling of the main target species (anchovy and sardine) is really low;
- on average 4.50 % of all *E. encrasicolus* caught have been found gilled or enmeshed in the 65 mm MO netting panel, with a bulk of 9.71% in the third haul;
- the modal class of anchovy enmeshed in the panel with 65 mm MO was 8 cm TL;
- concerning *S. pilchardus*, the percentage of entangled or enmeshed fish was always really low in all panels: on average, the higher percentage (1.69%) was detected in the netting panel having 120 mm MO;
- the modal class of sardine enmeshed in the panel with 120 mm MO was 13 cm TL;
- the mesh opening seems to be one of the main parameters affecting the possibility of small pelagic species escapement; it seems that almost all the fish can be retained in netting having mesh openings below 36 mm;
- the mesh opening is not the unique parameter affecting selectivity; in fact, the diamond meshed of the semi-pelagic were always highly stretched, so that enmeshed anchovies and sardines can even be found in the netting panel with 160 mm of mesh opening. Therefore the hanging ratio, consequently the mesh opening angle, is an important parameter in the mesh selection process.

Quantifying, modelling catch and discard composition in trawl net fisheries (WP4)

Introduction

The work under WP4 consists of two tasks. The Task 4.1 is based on simulation modelling at population level using the BEMTOOL bioeconomic platform (MAREA) to predict the consequences of different harvesting pattern based on gear mesh change on population, production and economic indicators. The task 4.2 is based on an ecosystem approach using the trophic modelling tool "Ecopath with Ecosim (EwE)".

Three case studies have been implemented: on the demersal fishery of GSA 18 (south Adriatic), in GSA22 (Aegean Sea) and on GSA16 (Strait of Sicily). As reported in Deliverable 2.4.1 of LANDMED project (2015), the results of the selectivity study confirmed the lack of size selectivity for the mid-water trawling and purse seiners; for these two gears the increases in selectivity is very difficult to achieve. The use of large meshes in the codend has been tested in the Chioggia harbor (Veneto Administrative Region, northern Adriatic, unpublished results) with results not satisfactory. In fact, if large meshes are used in the codend of pelagic trawl, there could be the possibility that the anchovies entering the codend can be gilled or enmeshed. For this reason, simulations have been carried out only for demersal fisheries case studies of Table 1 in WP 3, as for demersal species gear selectivity can be considered a technical measure able to contribute at improving the exploitation pattern of the affected stocks. For the case study in GSA 22 the two approaches BEMTOOL and EwE are applied in a complementary way, i.e. the outputs of the bioeconomic population model in terms of fishing mortality by fleet and species for the different harvesting scenarios are used in the ecosystem model to design the scenarios in respect to the reference scenario (gear mesh size 40D). The specific objective of Task 4.2 of DISCATCH was to investigate ecosystem effects of improved trawl selectivity in the NAS.

BEMTOOL simulation approach (Task 4.1)

BEMTOOL is an integrated bio-economic simulation model incorporating 6 operational modules (Biological, Pressure, Economic, Behavioural, Policy/Harvest Rules and Multi-Criteria Decision Analysis) characterized by components communicating by means of relationships and equations. BEMTOOL has been conceived as a platform, where several tools (already existing models) and functions (chosen from the selected models and adjusted to the BEMTOOL objectives) allow to simulate the effects of management measures and/or harvesting strategies in the short, medium and long-term, considering that the management of Mediterranean fisheries is generally based upon input control systems (e.g. fishing effort limitations, mesh size restrictions, closed season). The biological tools included in BEMTOOL are:

- XSA (Darby C.D. and Flatman S., 1994);
- SURBA (Needle C.L. , 2003);
- VIT (Lleonart, J.; Salat, J. 1997);
- ALADYM (Lembo et al., 2009 and Spedicato et al., 2010);
- FLR scripts for short and medium term forecast developed during the SGMED working groups 2010-2011;

Several socio-economic functions are implemented of BEMTOOL according to the following models:

- BIRDMOD (Lembo, 2005; Accadia and Spagnolo, 2006);
- MEFISTO (Lleonart et al., 2003; Maynou et al., 2006; Merino et al., 2007; Silvestri and Maynou, 2009);
- FISHRENT (Salz et al, 2011)
- BEMMFISH (Guillen et al, 2004).

BEMTOOL follows a multi-fleet and multiple species approach simulating, on a fine time scale, the effects of a number of management trajectories on stocks and fisheries. The model accounts for length/age-specific selection effects, discards, economic and social performances, effects of compliance with landing obligation and reference points. The implementation of decision modelling (Multicriteria Decision Analysis and Multi-attribute utility theory) allows that stakeholder perception is encompassed to weight model-based indicators and rank different management strategies. A wide set of biological, pressure and economic indicators is the default output of BEMTOOL.

BEMTOOL simulation approach has been used within DISCATCH project with the aim to forecast the effect of different mesh sizes/shapes scenario on the commercial yields and discards rates, as well as to assess the different performances of selected technical measures. In particular the ALADYM simulation model has been applied to simulate the fish population and the selectivity impact.

Recently some BEMTOOL characteristics have been upgraded with new features during the LANDMED and SEDAF projects within the MAREA framework (tender MARE/2009/05 LOT 1 Mediterranean http://www.mareaproject.net), taking into account issues related to the landing obligation. Thus DISCATCH project benefited of some BEMTOOL improvements. These regards some technicalities, as the program installation, and methodological expansions as the introduction of uncertainty (process error) implemented in the model following Monte Carlo paradigm, that is allowing a risk evaluation in terms of biological sustainability of the different management strategies also at the light of the economic performances.

Considering the DISCATCH context the most relevant changes regard the selectivity and discard modelling. Besides the already available selectivity models (classical ogive, deselection ogive, normal, log-normal, bi-normal and two-sided) to simulate the fleet behaviour, the possibility to model the selectivity according to an external vector (by age/length) has been added, as well as the possibility of modelling the destiny of individuals escaped along the selection process. Regarding discards, the new features added are: the possibility to model the discard according to an external vector in addition to a reverse ogive, which was already present in a previous version of the model, and the possibility to model the destiny of discarded individuals, if relevant information is available or reasonable assumptions can be made.

The biological and pressure input to be entered in BEMTOOL model have been derived from the relevant assessment of the case study species, where the needed stock and pressure parameters/data are available. The endorsed assessments have been preferred; where endorsed stock assessments were not available, *ad hoc* assessments have been carried out. Useful feedback has been provided by the case studies developed in the LANDMED (2015) and SEDAF projects (2015). Results from tasks 3.2 (experimental size selectivity data/parameters) and 3.5 (size selectivity data/parameters are derived by a simulation process) of DISCATCH have been used to parameterize the pressure module of the model. The input for the socioeconomic component of the model have been mainly derived from SEDAF project (MAREA Framework).

The implementation of different selectivity scenarios for trawlers have been carried and compared with the 'status quo', represented for trawlers by the a codend with a 40D mesh size. The simulations have been conducted by fleet and the effects, in terms of population, production and economic indicators estimated to 2020.

Material and methods

For the case study on the demersal fishery of GSA 18 (south Adriatic), 10 fleet segments have been considered:

- ITA_DTS_0612 (Italian trawlers from 6 to 12 m);
- ITA_DTS_1218 (Italian trawlers from 12 m to 18);
- ITA_DTS_1824_2440 (Italian trawlers from 18 m to 40);
- ITA_HOK_1218 (Italian longlines from 12 to 18 m);

- ITA_PGP_0006_0612 (Italian polyvalent passive gears from 0 to 12 m);
- ALB_DTS_1224 (Albanian trawlers from 12 to 24 m);
- MNE_DFN_0012 (Montenegrin drift and/or fixed netters from 0 to 12 m);
- MNE_DTS_0612 (Montenegrin trawlers from 6 to 12 m);
- MNE_DTS_1224 (Montenegrin trawlers from 12 to 24 m);
- MNE_HOK_0012 (Montenegrin longlines from 0 to 12 m).

The species considered in the GSA 18 case study are *M. merluccius*, *M. barbatus*, *P. longirostris* and *N. norvegicus*. For trawlers the change in mesh size (from 40D mm to 50D mm) in 2011 according to the EU regulation (EC 1967/06) has been assumed. Stock parameters were gathered from the most updated stock assessment, while transversal and economic parameters were the same as those used in the SEDAF project (MAREA Framework). In GSA 18, for status quo scenario a diamond mesh of size 50 mm have been assumed and then compared to:

- a square mesh of size 50 mm;
- hexagonal mesh of size 50 mm.

The selectivity of the other gears remained unchanged in the projections. For GSA 22 demersal case study, 4 fleet segments have been considered:

- OTB1224 (trawlers from 12 to 24 m);
- OTB2440 (trawlers from 24 to 40 m);
- PG0012 (polyvalent passive gears from 00 to 12 m);
- PG1224 (polyvalent passive gears from 12 to 24 m).

The species considered in the GSA 22 case study are *M. merluccius*, *M. barbatus*, *P. longirostris* and *T. trachurus*. Being the stock assessments and the data updated to 2006, the simulations have been performed on artificial populations (assumed at steady state), simulated according to an average of the three years of data available (2004-2006). In GSA 22, for status quo scenario a diamond mesh of size 40 mm has been assumed and then compared to:

- a diamond mesh of size 50 mm;
- a square mesh of size 50 mm;
- hexagonal mesh of size 50 mm.

The selectivity of the other gears remained unchanged in the projections. For GSA 16 demersal case study, 2 fleet segments have been considered:

- OTBunder24 (trawlers up to 24 m);
- OTBover24 (trawlers grater than 24 m)

The species considered in the GSA 16 case study are *P. longirostris*, *M. merluccius* and *A. foliacea*. For trawlers the change in mesh size (from 40 mm to 50 mm) in 2011 according to the EU regulation (EC 1967/06) has been assumed. In GSA 16, for status quo scenario a diamond mesh of size 50 mm have been assumed and then compared to:

- a square mesh of size 50 mm;
- hexagonal mesh of size 50 mm.

The selectivity of the other gears remained unchanged in the projections. Exhaustive information on inputs are reported in the deliverable 4.1

Results

The results of simulations showed that the 50S mesh would allow to obtain the highest level in SSB for all the stocks under consideration. For *M. merluccius* and *M. barbatus* the difference between status quo (diamond 50 mm) and hexagonal mesh of size 50 mm cannot be much appreciated, because the corresponding SL50% are very similar (respectively 11.74 cm and 12 cm for *M. merluccius* and 8.8 cm and 9 cm for *M. barbatus*). For *N. norvegicus* and for *P. longirostris* it is more evident that the highest value of SSB is associated to the square mesh and then to the hexagonal mesh, while the diamond one is the mesh that would give the worse performance (Figure 75).

In GSA 22 a similar behavior is shown by the 4 stocks under consideration for the 4 simulated selectivity scenarios. For this case study the effect of the different meshes is more appreciable, because artificial populations have been used (not affected by historical effects like change in mesh size, recruitment, fishing mortality, etc.) (Figure 76).

The effect of the different selectivity scenarios on the catch (overall and by fleet segment) show diverse consequences depending on the species life history traits, the geographical area and the historical trend affected the population. In GSA 18 for all the stocks the strongest decrease in catches in the first year of projection (2015) has been observed for the square mesh scenario, in respect to the hexagonal and the diamond mesh scenarios. Nevertheless, the results showed that the square mesh is the selectivity scenario that in the medium term would allow to obtain the highest increase in catches (Figure 77 and Figure 78).
The same behavior is shown by the stocks of case study GSA 22: the decrease in catch of *M. merluccius* in 2015 is less evident in the graph than for M. barbatus, because of the scale; in relative terms the *M. merluccius* overall catch increases of the 36% from 2015 to 2021, while the M. barbatus of 62%.

On the stocks targeted also by gears different from trawlers (*M. barbatus* and *M. merluccius*, caught also by polyvalent and passive gears) there is a benefit for the gears other than trawlers of the change of selectivity applied on trawlers. In Figure 79 the example of GSA 18 is shown, where the benefit of polyvalent and passive gears due to the increase of mesh size applied to trawlers from 2015 (first year of application of the measure) is apparent. A similar behavior has been observed in GSA 22.

The effect of the different selectivity scenarios on the mean length in catches of trawlers and of the other gears has been explored: Figure 80 shows that while mean length of trawlers catches of T. trachurus in GSA 22 increases according to the different selectivity scenarios (the highest values is shown by square mesh) from 2015, the mean length of the catches of the polyvalent and passive gears decreases in 2015, because of the availability of the smallest individuals, no more caught by trawlers. Then, the mean length in catches of the polyvalent and passive gears increases too reaching the same level of status quo scenario for diamond and hexagonal mesh. The square mesh would allow obtaining a mean length higher than the status quo scenario from 2017 for trawlers, polyvalent and passive gears.

An example of the effect on discard volume is demonstrated for *M. barbatus* stock in GSA 18. The square mesh scenario gives the lowest amount of discard (practically null), in respect to the hexagonal mesh (the effect 25 tons) and the status quo scenario (about 46 tons). The effect of different selectivity scenarios on the discard volume and discard ratio has been explored on *T. trachurus* of GSA 22, where the status quo scenario corresponds to the diamond mesh of size 40 mm: the landing of trawlers shows, as for *M. barbatus* in GSA 18, a decrease in 2015 and then an improvement. This improvement is the highest for square mesh of 50 mm and lower for the hexagonal and diamond mesh of 50 mm (but higher of status quo scenario). The discard amount (only due to trawlers) shows a decrease in 2015 for all the scenarios except for status quo.

The plateau reached by the diamond and hexagonal mesh of size 50 mm from 2017 has a similar level of status quo scenario; only the square mesh of size 50 mm in 2017 reaches a discard amount much lower than the status quo. This is more clear after having a look to the discard ratio of trawlers (Discard/Catch) that shows a decrease for all the scenarios except for status quo; this decrease is more important for square mesh of size 50 mm.

From 2016 the discard ratio reaches a plateau that is lower for square mesh scenario and higher for diamond (50 mm) and hexagonal scenarios (very similar SL50%: respectively 11.3 cm and 11.9 cm). Worth to note in GSA22

The grater benefit of the 50S mesh size on the overall landings and revenues is shown in Figure 83 accounting for uncertainty. The effect of the different selectivity scenarios on the socio-economic indicators has been also evaluated: in Figure 84 an example for GSA 18 referred to the revenues and the average wage of a trawler fleet segment and of a longlines fleet segment is reported. The revenues of trawlers, following the landing trend, showed a decrease in 2015 and then an increase that is higher for the square mesh scenario, lower for hexagonal and the lowest for diamond mesh. The revenues of longlines fleet segment benefit of the decrease in trawlers revenues of 2015; after 2015, the square mesh produces the highest revenues, while the lowest is given by the diamond mesh (status quo). The same trend is observed for the average wage.

Extended results are reported in deliverable *D 0.3. Outputs of the BEMTOOL simulations, in the short and medium-long terms, for each combination GSA/scenario*.

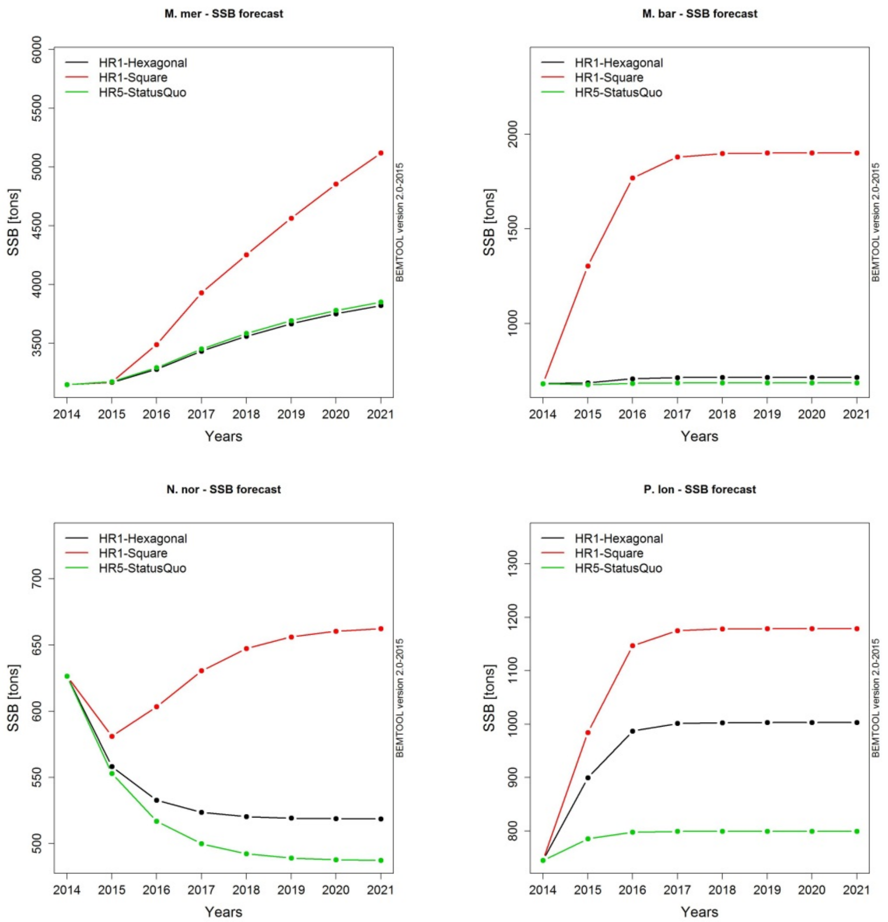


Figure 75. Effect of the different selectivity scenarios on the SSB of the 4 stocks under considerations in GSA 18 demersal case study.

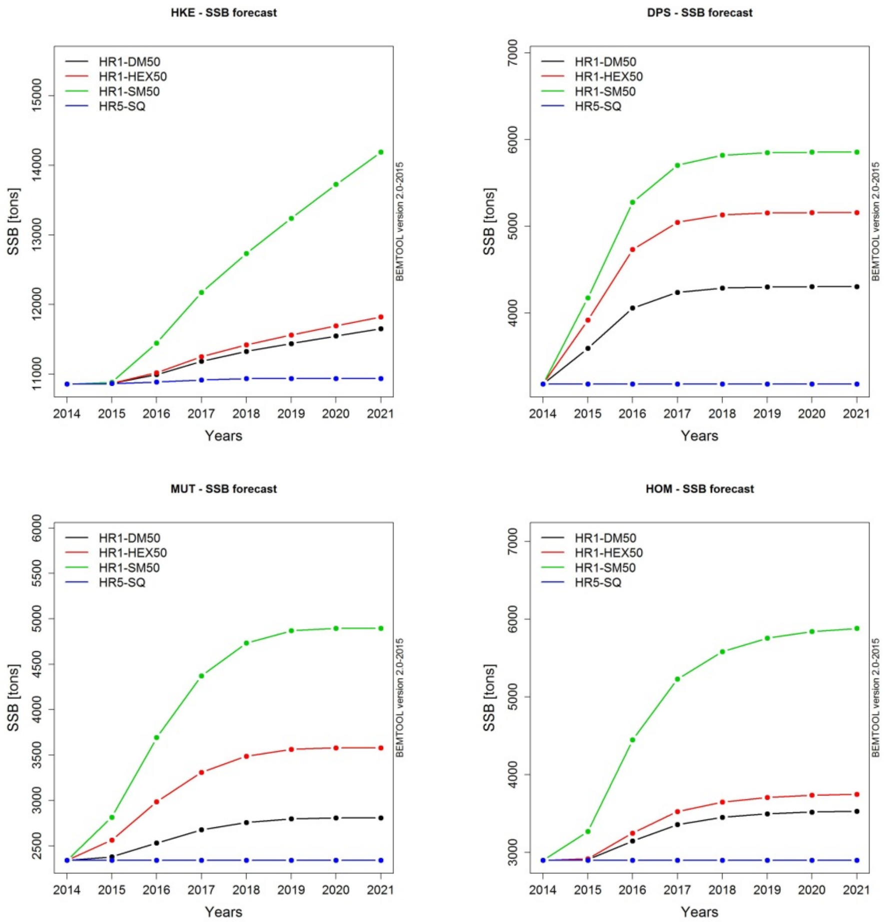


Figure 76. Effect of the different selectivity scenarios on the SSB of the 4 stocks under considerations in GSA 22 demersal case study.

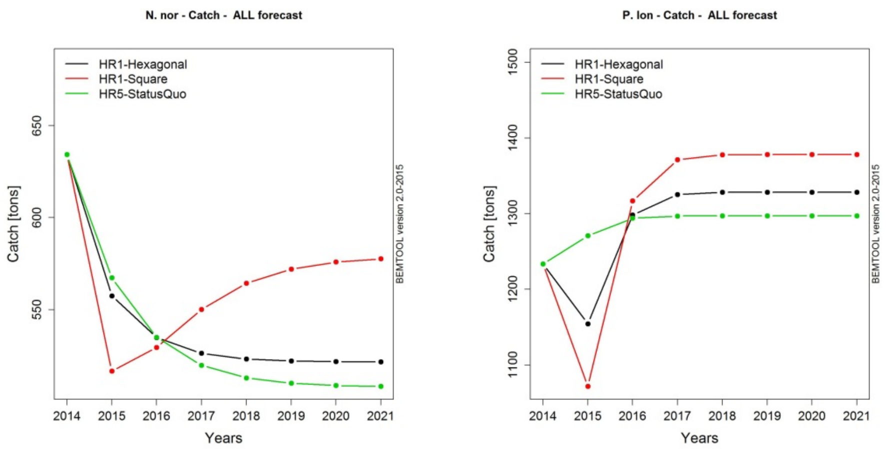


Figure 77. Effect of the different selectivity scenarios on the overall catch of the *N. norvegicus* and *P. longirostris* in GSA 18 demersal case study.

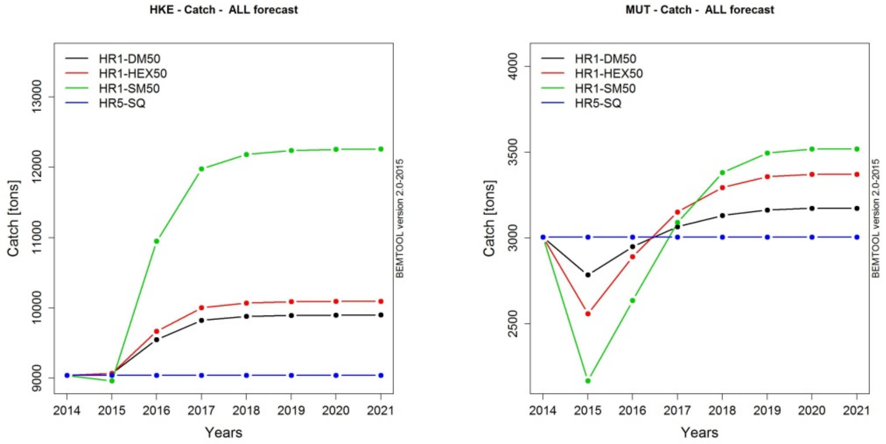


Figure 78. Effect of the different selectivity scenarios on the overall catch of the *N. norvegicus* and *P. longirostris* in GSA 18 demersal case study.

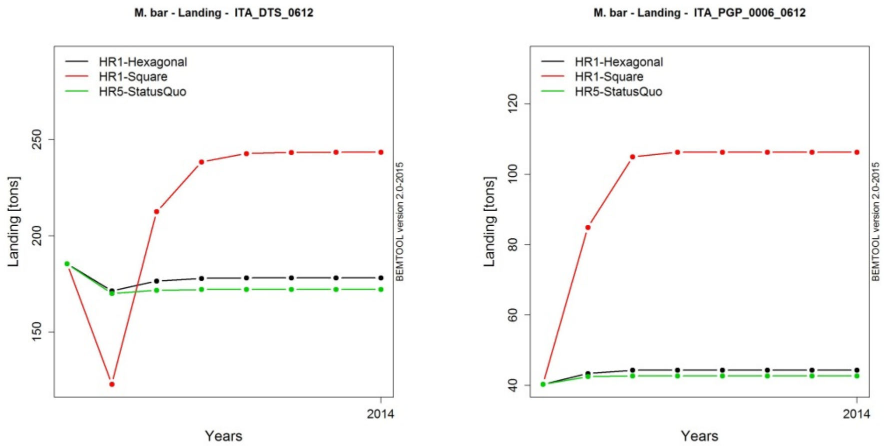


Figure 79. Effect of the different selectivity scenarios on the Catch of M. barbatus on trawlers and polyvalent passive gears in GSA 18 demersal case study.

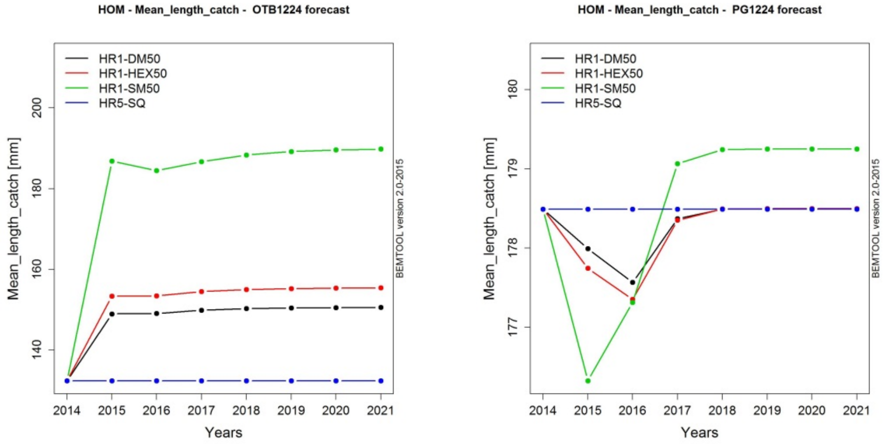


Figure 80. Effect of the different selectivity scenarios on the mean length in the catch of T. trachurus on trawlers and polyvalent passive gears in GSA 22 demersal case study.

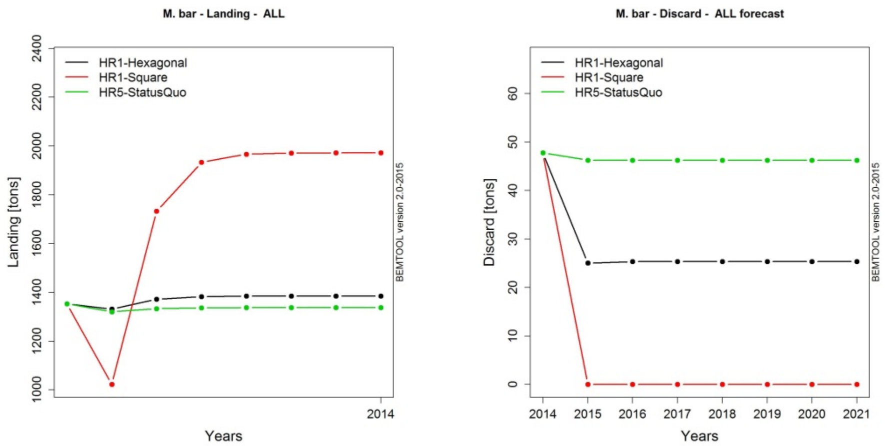


Figure 81. Effect of the different selectivity scenarios on the Landing and discard of the M. barbatus in GSA 18 demersal case study.

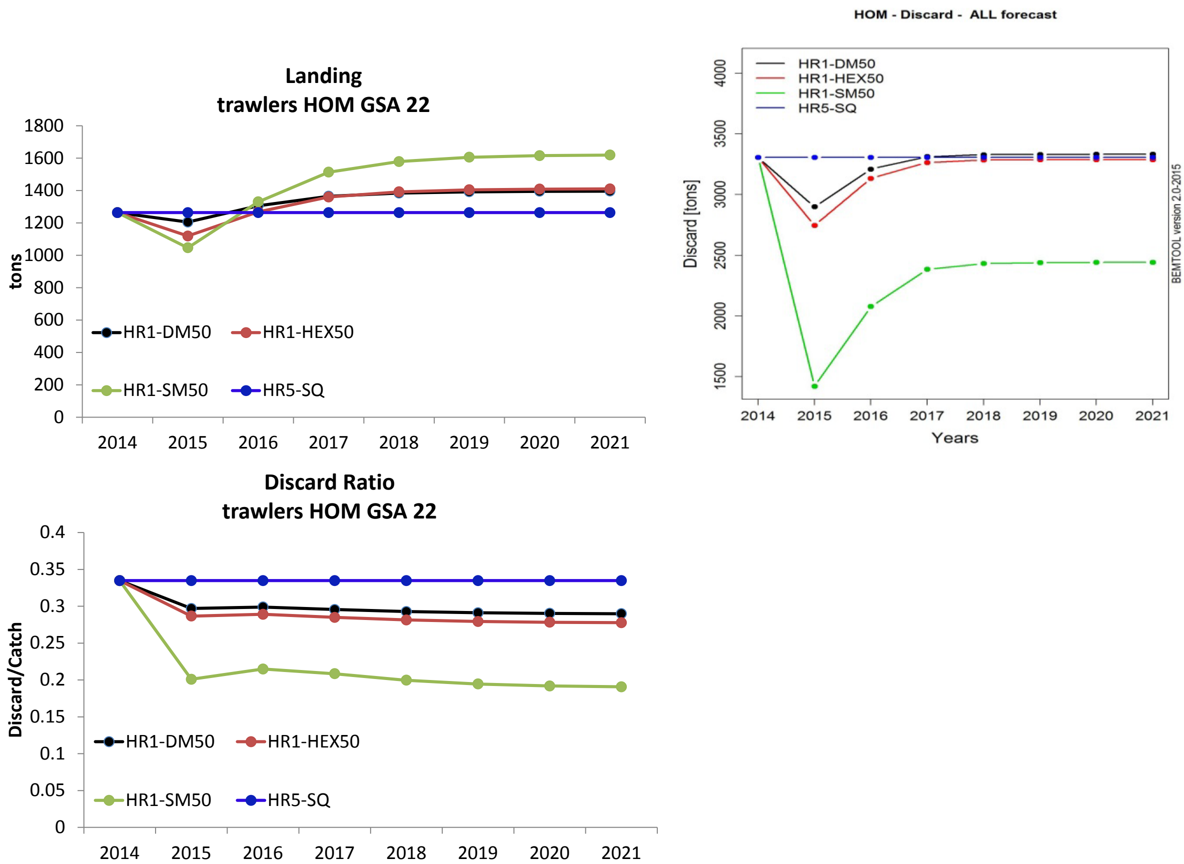


Figure 82. Effect of the different selectivity scenarios on the trawlers landing, discard and discard ratio (D/C) of T. trachurus in GSA 22 demersal case study.

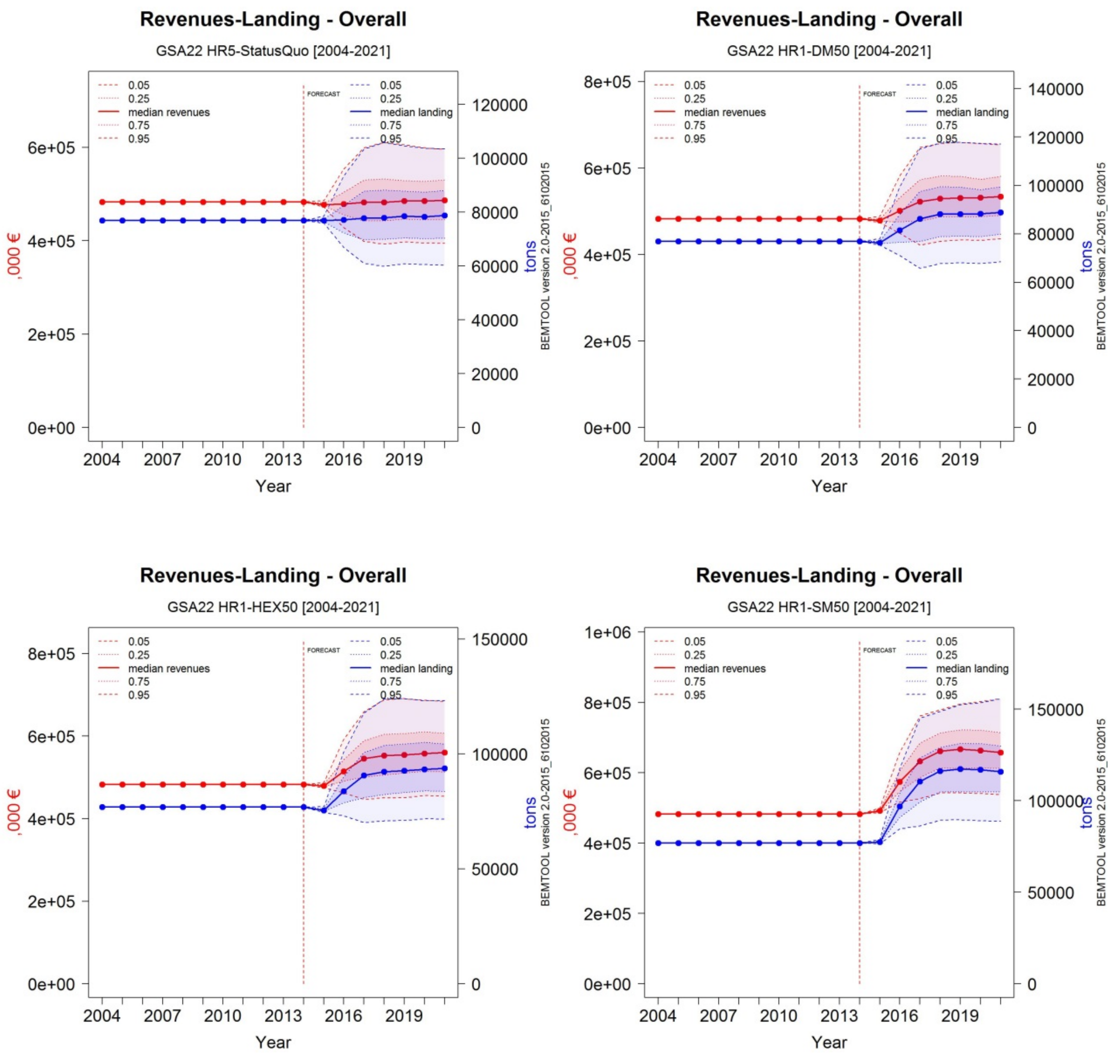


Figure 83. Effect of the different selectivity scenarios on the trawlers total landing and revenues accounting for uncertainty.

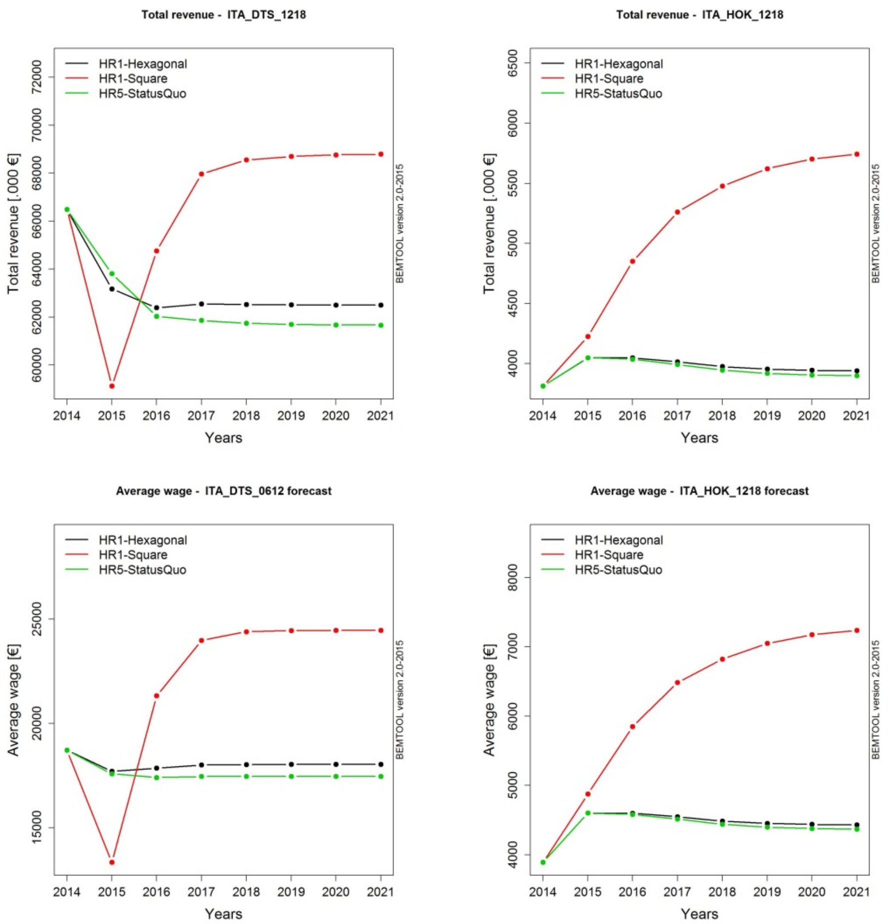


Figure 84. Effect of the different selectivity scenarios on the trawlers and polyvalent gears total revenues and average wage in GSA 18 demersal case study.

Conclusions

The BEMTOOL simulations allowed to explore the effects of different selectivity scenarios on the relevant indicators. In particular, the focus was on SSB, overall catch, landing, discard, discard ratio, mean length in catches, revenues and average wage indicators. The main findings of BEMTOOL can be summarized as follows.

- The 40D mesh represents the configuration producing the smaller level in SSB respect to the other configurations, while the 50S mesh size corresponds to the highest improvement in SSB;
- In the medium term the 50S mesh allows to obtain the highest catches, while the 40D the lowest;
- In the short and medium term the 50S mesh allows to obtain the lowest discard amount and discard ratio, while the 40D mesh the highest;
- The increase in mesh size of trawlers determines an improvement of the catches also of the other gears, because the smaller individuals left by the trawlers are left to growth and are then available to them, thus can be caught at higher sizes by all the gears (trawlers and not);

- The 40D mesh represents the configuration producing the smaller mean length in catches respect to the other configurations, while the 50S mesh size corresponds to the highest mean length, that in turns could implies more valuable products ;
- The 40D mesh represents the scenario producing the lowest revenues and average wage, while the square scenario corresponds to the highest ones;
- For all the points the hexagonal mesh gives intermediate results.

Ecopath with *Ecosim* approach (Task 4.2)

Ecosystem modelling integrates available information to study direct and indirect trophic interactions among ecosystem compartments, including fishing activities and the environment. It is therefore a useful tool for fisheries management (Christensen and Walters 2004). The broad use of the trophic modelling tool "Ecopath with Ecosim (EwE)" (Christensen and Walters 2004; Coll *et al.* 2009) has contributed to complement previous knowledge of the structure and functioning of marine ecosystems and has enabled the proposal of reference limits and exploitation indicators based on meta-analysis of models' results (e.g., Christensen, 1995; Libralato *et al.*, 2008).

The North Aegean Sea (NAS) is one of the most productive areas in the Eastern Mediterranean (Bosc *et al.*, 2004) mainly due to the influence of nutrient rich Black Sea water input. This area is one of the main fishing grounds for Greece (Papaconstantinou, 2005). In Task 4.2 of DISCATCH project we used as basis an EwE model for the NAS (Tsagarakis *et al.*, 2010) developed to describe the food web in the mid 2000s and we updated it in order to construct a model for a previous period (early 1990s). This is urged by the need to tune feeding interactions using time series of fisheries and survey data so as to upgrade it to a basic and effective tool that may allow the investigation of policy options towards an ecosystem-based management of fisheries in the North Aegean Sea. The specific objective of Task 4.2 of DSICATCH was to investigate ecosystem effects of improved trawl selectivity in the NAS.

The Ecopath with Ecosim approach (EwE) (Christensen and Walters, 2004) version 6 was used to describe the N. Aegean ecosystem. Trophic interactions among functional groups (composed of single species, group of species sharing similar ecological features or different developmental stages of species) are described by a set of linear equations, each ensuring that total mortality of a group does not exceed its production (mass balance). The usual information per group needed to parameterize the model includes (i) the biomass in weight, (ii) the production per unit of biomass (iii) the consumption per unit of biomass (iv) the unassimilated proportion of food (v) the diet composition of predator (vi) landings and (vii) discards in weight.

Flows of the N. Aegean model were expressed as $t \cdot km^{-2} \cdot yr^{-1}$ and biomasses were expressed as $t \cdot km^{-2}$ of wet weight. The model area is defined by the 20 m and 300 m isobaths (Figure 85) covering 8374 km^2 in total. This is mainly the area where trawlers, purse seiners and the biggest fraction of artisanal fleets operate.

The model is based on the previously developed Ecopath model in the area for the period 2003-2006 (Tsagarakis *et al.*, 2010). This model was adjusted to input data from the early 1990s (mainly 1991-1993), averaging data from separate years. The 1990s model has 40 FGs (38 living FGs, and two detritus FGs) with a slightly modified structure in comparison to the 2003-2006 model. Input data for the 1990s model included bottom trawl surveys (Bertrand *et al.*, 2002; Labropoulou and Papaconstantinou, 2004), fisheries (El.Stat., 2011) and discards (Anon, 2008) data and other sources of information described in detail in Tsagarakis *et al.* (2010). The swept-area method was used to estimate biomass for benthic and demersal species. For each species, production and consumption values were retrieved from the literature (Froese and Pauly, 2014) or estimated based on empirical equations, while for multispecies functional groups (FG) these values were weighted with the relative biomass of each species in the FG. Input for diet composition was also based on a literature review.

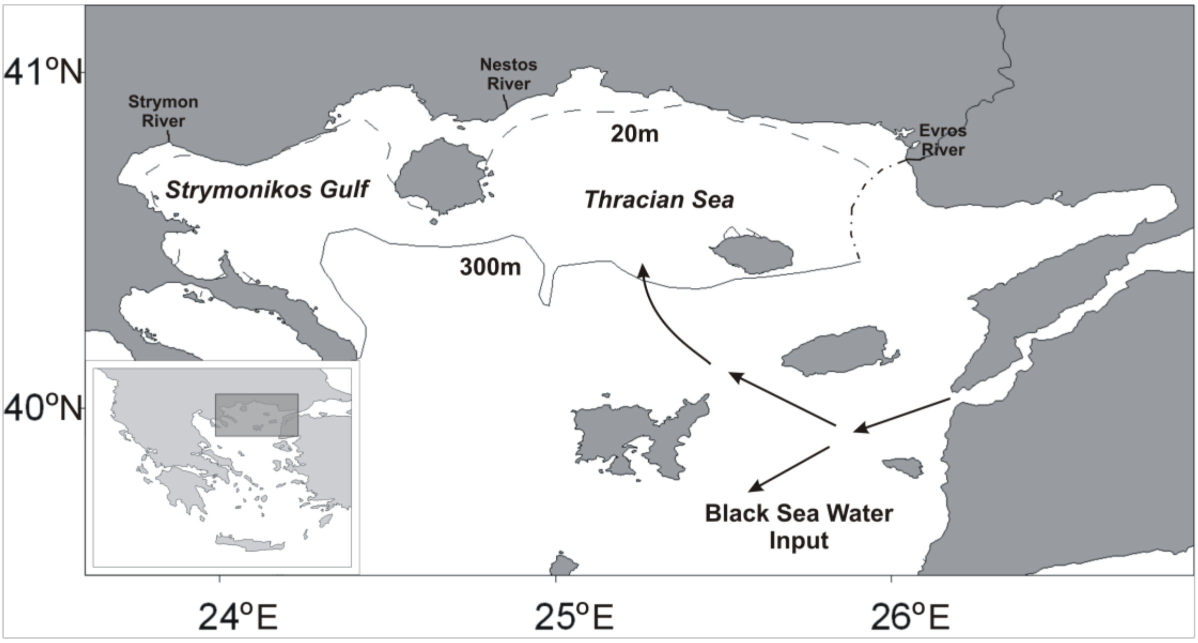


Figure 85. North Aegean Sea (Strymonikos Gulf and Thracian Sea). Isobaths of 20m and 300m which define the model area are shown, as well as the most important rivers of the area. Arrows indicate the direction of Black Sea Water Input.

Five fishing fleets were considered in the model: (1) bottom trawls, (2) purse seines, (3) static artisanal nets (gill and trammel nets), (4) longlines and troll baits (targeting European hake and large pelagic fish) and (5) pots targeting cephalopod species (octopuses and cuttlefish). Bottom trawls and purse seines constitute the industrial fishery while the rest belong to the artisanal fishery in the area. Species-specific and fleet-specific discards to marketable ratios were estimated using data collected by observers on board commercial boats in the area (Anon., 2008) and applied to estimate the amount of discards generated on an annual basis. To achieve mass-balance we corrected some of our inputs mainly concerning (a) the diet matrix, especially for groups for which information was not coming from the modelled area, and (b) biomasses, especially for groups for which sampling method is known to produce an underestimation. The functional groups and the values of the input parameters of the resulting (balanced) Ecopath model are summarized in Table 15.

In a next step, we developed Ecosim, the time dynamic simulation of the initial parameters of the base Ecopath model. This is done through a series of coupled differential equations derived from the Ecopath master equation. Dynamic trophic relationships (consumption rates) follow the 'foraging arena' concept, where biomasses are divided into vulnerable and invulnerable components (Walters *et al.*, 1997), and it is the transfer rate (*v; vulnerability*) between these two components that determines if control is top-down (i.e., Lotka-Volterra), bottom-up (i.e., donor-driven), or of an intermediate type (Christensen *et al.*, 2008).

Ecosim was developed feeding the model with data for the period 1993-2010. The larger the calibration period (time series) the better the calibration of the model and this was the reason why we constructed an Ecopath period for a decade before (1990s) the existing model (2000s; Tsagarakis et al., 2010). We constructed biomass time series (1993-2008 with some missing years) for fish, decapod and cephalopod functional groups using data from bottom trawl (Bertrand *et al.*, 2002) and acoustic (Machias *et al.*, 2007) surveys in the area as well as from stock assessments (STECF 2009).

Table 15. Functional groups and basic parameters of the Ecopath model. P= production; B= biomass; Q = consumption; U= unassimilated food EE = Ecotrophic efficiency; TL = Trophic level; L= landings; D= Discards.

	Group name	TL	B (t/km²)	P/B	Q/B	EE	U/Q	P/Q	L	D
1	Phytoplankton	1.00	4.57	117.30	0.00	0.69				
2	Microzooplankton	2.05	0.48	258.85	776.54	0.71	0.40	0.33		
3	Mesozooplankton	2.33	2.79	29.19	87.55	0.81	0.40	0.33		
4	Macrozooplankton	2.92	0.33	21.07	53.17	0.92	0.20	0.40		
5	Jelatinous plankton	3.03	2.48	4.84	12.09	0.20	0.20	0.40		
6	Suprabenthos	2.21	1.11	7.32	54.40	0.98	0.30	0.13		
7	Polychaetes	2.09	5.33	1.63	12.46	0.96	0.60	0.13		
8	Shrimps	3.04	0.40	3.18	7.52	0.97	0.20	0.42	0.024	0.001
9	Crabs	2.92	0.27	2.57	4.94	0.96	0.20	0.52	0.002	0.002
10	Norway lobster	3.02	0.05	1.32	4.76	0.67	0.20	0.28	0.026	0.000
11	Bivalves & gastropods	2.05	3.78	1.15	3.27	0.98	0.43	0.35	0.001	0.000
12	Benthic invert. (no crustacea)	2.05	4.93	1.15	3.27	0.98	0.43	0.35		
13	Benthic cephalopods	3.49	0.28	2.68	5.50	0.93	0.13	0.49	0.134	0.005
14	Benthopelagic cephalopods	4.13	0.11	2.86	22.15	0.92	0.39	0.13	0.039	0.003
15	Mullets	2.75	0.10	1.80	7.08	0.89	0.20	0.25	0.070	0.001
16	Anglerfish	4.34	0.08	0.90	4.20	0.47	0.20	0.22	0.011	0.001
17	Flatfishes	3.48	0.18	1.60	8.26	0.91	0.20	0.19	0.055	0.015
18	Blue whiting	3.77	0.15	1.10	7.41	0.99	0.20	0.15	0.021	0.006
19	Other gadiforms	3.65	0.13	1.10	7.41	0.94	0.20	0.15	0.025	0.006
20	Hake	4.27	0.29	0.75	4.13	0.92	0.20	0.18	0.083	0.005
21	Demersal Fish 1	3.36	0.18	1.55	7.48	0.93	0.20	0.21	0.062	0.018
22	Demersal Fish 2	4.29	0.18	1.49	5.15	0.88	0.20	0.29	0.093	0.025
23	Demersal Fish 3	3.30	0.39	1.71	8.39	0.87	0.20	0.20	0.062	0.038
24	Demersal Fish 4	3.10	0.18	2.22	9.00	0.87	0.20	0.25	0.055	0.018
25	Benthopeagic Fish	3.55	0.24	1.90	9.27	0.95	0.30	0.21		
26	Picarels and Bogue	3.34	0.20	1.69	7.49	0.87	0.20	0.23	0.115	0.021
27	Sharks	3.57	0.10	0.58	5.16	0.63	0.20	0.11	0.007	0.006
28	Rays & skates	3.94	0.06	0.88	4.07	0.72	0.20	0.21	0.012	0.006
29	Anchovy	3.34	1.66	1.52	6.37	0.99	0.30	0.24	0.391	0.184
30	Sardine	3.31	0.91	1.28	10.42	0.99	0.30	0.12	0.396	0.128
31	Horse mackerel	3.46	0.23	1.13	7.59	0.96	0.20	0.15	0.106	0.036
32	Mackerel	3.70	0.29	1.03	5.84	0.99	0.20	0.18	0.201	0.002
33	Other Small pelagic fishes	3.35	0.49	0.83	6.54	0.93	0.30	0.13	0.026	0.016
34	Medium pelagic fish	4.36	0.18	0.61	3.24	0.70	0.20	0.19	0.077	0.000
35	Large pelagic fishes	4.53	0.07	0.34	2.24	0.98	0.20	0.15	0.021	0.001
36	Loggerhead turtle	2.95	0.02	0.16	2.68	0.06	0.20	0.06		0.000
37	Sea birds	3.10	0.00	4.78	111.61	0.01	0.20	0.04		
38	Dolphins	4.57	0.01	0.08	13.81	0.26	0.20	0.01		0.000
39	Detritus	1.00	31.44			0.52				
40	Discards	1.00				0.76				
	Total								2.116	0.545

For time series of total catches (1993-2009) we used i) landings information from the Hellenic Statistical Service (El.Stat., 2011) and ii) gear specific discard ratios for each species from DCR/DCF (Anon., 2008) to estimate discards based on landings. For fishing effort information (1993-2010) we used total both DCR/DCF (Anon., 2008) and the Hellenic Statistical Service (El.Stat., 2011) sources. Relative values compared to the starting year of the model (1993) were used for biomass and effort time series while absolute values were used for total catches. The calibration of the model was a four-step approach after loading the time series (Coll et al., 2008):

i) We searched for an environmental anomaly using the software routine's and we applied it to force the primary producer (phytoplankton) of the model.
ii) We used the software's routine to identify the most sensitive trophic interactions (predator/prey specific vulnerabilities *v*)
iii) We estimated vulnerabilities *v* of these pairs based on biomass time series. Higher weight was set for the most reliable time series. The appropriate vulnerabilities are estimated based on the minimization of Sum of Squares between observed (time series) and predicted model outputs, as a goodness of fit criterion.
iv) Steps (ii) and (iii) above were repeated several times to reach satisfactory model outputs.

The fit of time series was very satisfactory for some groups (e.g., shrimps, hake, benthopelagic species, sardine, horse mackerels) and less for others (e.g., benthic cephalopods, demersal fish 3) (Figure 86). This fully developed, calibrated EwE model was then used to simulate scenarios of improved bottom trawl selectivity in the Aegean Sea. Four selectivity scenarios were set based on the outcomes of BEMTOOL simulations. These included (i) a reference scenario with 40mm Diamond (40D) mesh which was applied in the area at least until 2010, (ii) a 50mm Diamond (50D) mesh, which is stated in the the EC Reg. 1967/2006, and two mesh configurations with improved selectivity (iii) 50mm Square (50S) and (iv) 50mm Hexagonal (50H). The BEMTOOL outputs included estimated fishing mortalities for Hake, Deep-water pink shrimp, Red mullet and Horse mackerels for GSA 22 under the aforementioned scenarios. For the EwE scenarios the relative fishing mortalities (Fs) in respect to the reference scenario (40D) from BEMTOOL outputs were used as inputs (Table 16).

Table 16. Percentage of fishing mortality (F) for each selectivity scenario (50D, 50S, 50H) in relation to the reference one (40D).

	F in relation to 40D		
Species	50D	50S	50H
Hake	95.8%	94.7%	95.8%
Red mullet	94.3%	75.9%	88.2%
Deep-water pink shrimp	98.6%	93.8%	93.6%
Horse mackerel	94.4%	80.2%	94.2%

These modified Fs were applied for the four previously mentioned species/FGs while no changes in fishing effort was applied to other functional groups (FGs) despite that selectivity is expected to be changing for these as well. The EwE scenarios were simulated for the period 2011-2020 when constant fishing effort was assumed and no environmental forcing was applied. Trends in ecosystem indices for the four scenarios are shown in Figure 87. These indices have been widely used to explore the exploitation status of an ecosystem: *Total Catch* is a direct measure of the effect on the fisheries; *Catch/Biomass* ratio scales this effect in relation to overall biomass in the ecosystem; *mean Trophic Level of the catch* shows the position of the catch in the food web and when decreasing may be an indication of depletion of high trophic level species or of high contribution of mid trophic level species to the catch; *Fisheries in Balance (FiB) index* is a trophodynamic index showing whether fisheries are balanced (the index should decline only when catches do not increase as much as expected given a shift in targeting to lower trophic groups that have higher rates of production of sustainability of the fisheries).

Three out of four ecosystem indices (with the exception of mean trophic level of the catch) that were explored showed positive responses to simulated improved selectivity. As expected - since it was the scenario with the overall larger reduction in fishing effort - higher values were predicted for the 50S scenario. The two remaining scenarios of improved selectivity, 50D and 50H showed very similar responses, slightly improved compared to the reference scenario (40D). Responses were better in the long term (2020) compared to the first five years of the simulations (2015).

In the 50S scenario, Total catch and Catch/Biomass increased by 7.8% and 6.55% respectively in 2020 while in 2015 these increased only by 2.02% and 1.33%. More profound increases were estimated for the FiB index. In general, the ecosystem wide exploitation status showed improving trends as evidenced by the FiB index, the Total Catch and the Catch/Biomass ratio while at the same time ecosystem function and structure didn't seem to change substantially. The changes in predicted biomass and yield for the four FGs that Fs were modified to simulate changes in selectivity are not only due to direct impact of the fisheries (reduction in fishing mortality) but also due to indirect complex feeding interactions.

For example, shrimps show decreasing trends (at least in the short term) (Table 17) under improved selectivity despite the relaxation in fishing mortality. This can be attributed to the fact that they constitute an important prey not only for hake which is directly impacted by the scenarios but also for other FGs which benefit through cascading effects. Again, in most cases larger changes were observed for the 50S scenario. Hake biomass increases by 3% after five years of simulations and by >7% after ten years with 50S mesh, while this increase only reaches ~3% in 2020 with 50S and 50H meshes (Table 17).

This increase seems to be limited by competition with other FGs that share similar preys (e.g. Anglerfish, Demersal Fish 2, Rays and Skates) and which also indirectly benefit from improved selectivity. Red mullets don't show any particular increases since the positive effects of reduced F are counterbalanced by negative effects caused by increases in predators' biomasses. The most obvious positive effects are for horse mackerels which may even double their biomass after 10 years of application of 50S mesh; for this FG the direct positive effects caused by the substantial reduction in F are not limited by predation or competition. On the contrary, competition is reduced due to decrease in the biomass of small pelagic fish (anchovy, sardine, other small pelagics) while effects of predation are mixed because some of their predators are increasing and others are decreasing.

The effect on yields was negative for all four species except horse mackerels whose population increase was large enough to overcome the decrease in F (Table 18). However, these decreases would probably not cause problems in the fishing sector because i) it is the smaller individuals (of lower or no commercial value) that escape under improved selectivity, ii) the decreases are low for some species (e.g. hake), iii) they seem to recover or even reverse (increase) in the long term and finally iv) because the yield of other species increases (Table 18).

Overall, total biomass increases -depending on the scenario- by 0.5-2% and by 0.9-3.9% after five and ten years of simulations respectively (Table 17). The increase in total yield is higher and reaches 2-7.8% in the long term (Table 18). Improved selectivity seems to affect the whole spectrum of the food web, mid and high trophic level FGs but also pelagic and demersal/benthic ones. This is because of the complexity of the food web and the benthic pelagic coupling described in the NAS (Tsagarakis et al., 2010) and the Mediterranean in general (Coll and Libralato, 2012). The FGs that seem to benefit more are the higher and top predators (e.g., Large pelagic fishes, Dolphins, Hake, Anglerfish, Demersal Fish 2) while the biomasses of prey FGs (e.g., Demersal Fish 1, Demersal Fish 3, Benthopelagic Fish, Picarels and Bogue, Anchovy, Sardine, Other Small pelagic fishes) decrease in most cases.

The NAS EwE model simulates responses of FGs/species to improved trawl selectivity by taking into account not only the decrease in Fs (which was used to set up the scenarios) but also trophic interactions, i.e. predation, prey availability and competition among ecosystem components. At the FG/species level, such models do not intend to replace stock assessment models which take into account more detailed information such as age structure of the population, catch at age, detailed fishing effort etc and can more realistically represent population dynamics, but can simulate indirect multispecies responses such as trophic cascades.

These interactions are the reason why even though improved selectivity was simulated for only four FGs, responses were evident for all the food web components. As a result, improved selectivity didn't seem to benefit much certain species but contributed to spread the positive effects to other FGs through a bottom-up procedure. Among the scenarios, the 50S mesh configuration had the best response on the food web and most ecosystem components. 50S and 50H scenarios showed similar results but only slightly improved compared to the reference one (40D). For all scenarios improvements were more obvious in the long term (after a decade). It seems that the ecosystem as a whole and its components could benefit from improvements in selectivity but benefits may not be evidenced immediately. At this point it should be also noted that results would probably be even better if improved selectivities were simulated for additional FGs/species other than the four ones explored here, however this was not possible in the framework of DISCATCH.

Table 17. Short (2015) and long (2010) term relative (%) predicted changes in biomasses for high trophic level FGs under different selectivity simulations (50D, 50S, 50H) compared to the reference scenario (40D). Differences >|5%| between reference and the other scenarios are indicated in shaded cells (red for negative and green for positive changes). The FGs for which fishing mortality was changed to simulate improved selectivity are indicated in bold.

		2015			2020		
FG#	FG	50D	50S	50H	50D	50S	50H
8	**Shrimps**	-2.39%	-6.46%	-2.63%	1.06%	4.86%	1.07%
9	Crabs	0.39%	1.33%	0.40%	0.22%	0.80%	0.21%
10	Norway lobster	-1.36%	-4.26%	-1.43%	-1.21%	-3.25%	-1.27%
11	Bivalves & gastropods	0.16%	0.58%	0.17%	0.18%	0.71%	0.18%
12	Benthic invert. (no crustacea)	0.21%	0.75%	0.23%	0.18%	0.68%	0.18%
13	Benthic cephalopods	0.12%	0.31%	0.10%	-0.07%	-0.30%	-0.09%
14	Benthopelagic cephalopods	0.59%	4.19%	0.70%	1.20%	8.02%	1.35%
15	**Mullets**	0.27%	1.30%	1.24%	0.17%	0.86%	1.27%
16	Anglerfish	1.39%	5.40%	1.53%	2.01%	9.12%	2.17%
17	Flatfishes	-1.28%	-4.58%	-1.30%	-1.83%	-6.85%	-1.87%
18	Blue whiting	-4.32%	-15.10%	-4.61%	-7.15%	-24.55%	-7.59%
19	Other gadiforms	-2.61%	-9.28%	-2.70%	-1.63%	-5.92%	-1.70%
20	**Hake**	1.86%	3.08%	1.87%	2.90%	7.18%	2.94%
21	DemeFish1	-2.03%	-8.02%	-2.11%	-3.25%	-13.07%	-3.38%
22	DemeFish2	-0.23%	1.44%	-0.15%	0.43%	4.74%	0.56%
23	DemeFish3	-0.80%	-2.91%	-0.85%	-0.71%	-3.03%	-0.75%
24	DemeFish4	0.44%	1.39%	0.46%	0.19%	0.45%	0.20%
25	BepeFish	-3.42%	-13.04%	-3.57%	-5.81%	-21.75%	-6.01%
26	Picarels and Bogue	-0.80%	-3.28%	-0.83%	-1.36%	-5.96%	-1.42%
27	Sharks	-0.64%	-1.73%	-0.61%	-0.31%	-0.03%	-0.26%
28	Rays & skates	0.11%	1.23%	0.29%	0.56%	3.52%	0.76%
29	Anchovy	-0.54%	-1.89%	-0.56%	-0.70%	-3.60%	-0.73%
30	Sardine	-0.17%	-1.19%	-0.19%	-0.23%	-2.67%	-0.26%
31	**Horse mackerel**	13.16%	53.31%	13.72%	23.98%	102.81%	25.03%
32	Mackerel	-1.88%	-6.54%	-1.96%	-4.14%	-14.38%	-4.32%
33	Other Small pelagic fishes	-1.63%	-6.20%	-1.70%	-3.59%	-14.62%	-3.74%
34	Medium pelagic fish	-0.57%	-1.39%	-0.55%	-1.48%	-5.20%	-1.48%
35	Large pelagic fishes	0.76%	3.37%	0.80%	2.43%	11.17%	2.55%
36	Loggerhead turtle	0.56%	2.18%	0.58%	1.76%	7.42%	1.83%
37	Sea birds	3.58%	15.66%	3.74%	6.62%	30.03%	6.92%
38	Dolphins	0.34%	1.33%	0.35%	1.21%	5.06%	1.26%
	Total	0.47%	2.02%	0.49%	0.90%	3.88%	0.95%

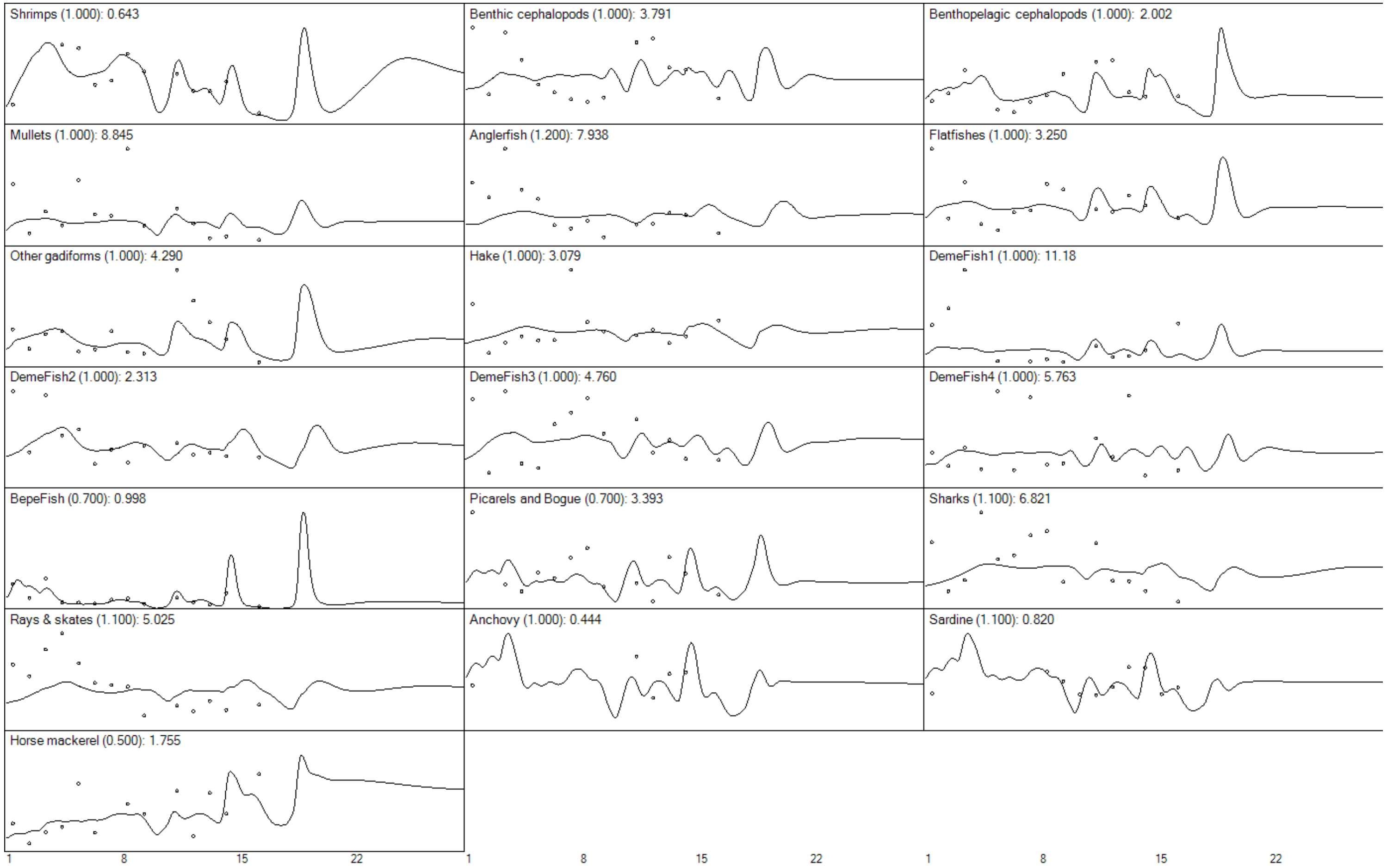


Figure 86. Fit of model predictions (lines) to biomass time series (dots) for the functional groups used to calibrate the Ecosim model. The numbers in parentheses show the weight given to that particular time series and the ones outside the parentheses indicate the Sum of Squares.

Table 18. Short (2015) and long (2010) term relative (%) predicted changes in yield for commerciall FGs under different selectivity simulations (50D, 50S, 50H) compared to the reference scenario (40D). Differences >|5%| between reference and the other scenarios are indicated in shaded cells (red for negative and green for positive changes). The FGs for which fishing mortality was changed to simulate improved selectivity are indicated in bold.

		2015			2020		
FG#	FG	50D	50S	50H	50D	50S	50H
8	**Shrimps**	-3.79%	-12.25%	-8.89%	-0.40%	-1.62%	-5.43%
9	Crabs	0.39%	1.33%	0.40%	0.22%	0.80%	0.21%
10	Norway lobster	-1.36%	-4.26%	-1.43%	-1.21%	-3.25%	-1.27%
11	Bivalves & gastropods	0.16%	0.58%	0.17%	0.18%	0.71%	0.18%
13	Benthic cephalopods	0.12%	0.31%	0.10%	-0.07%	-0.30%	-0.09%
14	Benthopelagic cephalopods	0.59%	4.19%	0.70%	1.20%	8.02%	1.35%
15	**Mullets**	-5.45%	-23.16%	-10.74%	-5.54%	-23.49%	-10.71%
16	Anglerfish	1.39%	5.40%	1.53%	2.01%	9.12%	2.17%
17	Flatfishes	-1.28%	-4.58%	-1.30%	-1.83%	-6.85%	-1.87%
18	Blue whiting	-4.32%	-15.10%	-4.61%	-7.15%	-24.55%	-7.59%
19	Other gadiforms	-2.61%	-9.28%	-2.70%	-1.63%	-5.92%	-1.70%
20	**Hake**	-2.44%	-2.44%	-2.38%	-1.44%	1.44%	-1.35%
21	DemeFish1	-2.03%	-8.02%	-2.11%	-3.25%	-13.07%	-3.38%
22	DemeFish2	-0.23%	1.44%	-0.15%	0.43%	4.74%	0.56%
23	DemeFish3	-0.80%	-2.91%	-0.85%	-0.71%	-3.03%	-0.75%
24	DemeFish4	0.44%	1.39%	0.46%	0.19%	0.45%	0.20%
26	Picarels and Bogue	-0.80%	-3.28%	-0.83%	-1.36%	-5.96%	-1.42%
27	Sharks	-0.64%	-1.73%	-0.61%	-0.31%	-0.03%	-0.26%
28	Rays & skates	0.11%	1.23%	0.29%	0.56%	3.52%	0.76%
29	Anchovy	-0.54%	-1.89%	-0.56%	-0.70%	-3.60%	-0.73%
30	Sardine	-0.17%	-1.19%	-0.19%	-0.23%	-2.67%	-0.26%
31	**Horse mackerel**	6.81%	22.99%	7.08%	17.02%	62.70%	17.72%
32	Mackerel	-1.88%	-6.54%	-1.96%	-4.14%	-14.38%	-4.32%
33	Other Small pelagic fishes	-1.63%	-6.20%	-1.70%	-3.59%	-14.62%	-3.74%
34	Medium pelagic fish	-0.57%	-1.39%	-0.55%	-1.48%	-5.20%	-1.48%
35	Large pelagic fishes	0.76%	3.37%	0.80%	2.43%	11.17%	2.55%
	Total	0.60%	2.02%	0.40%	2.13%	7.80%	1.98%

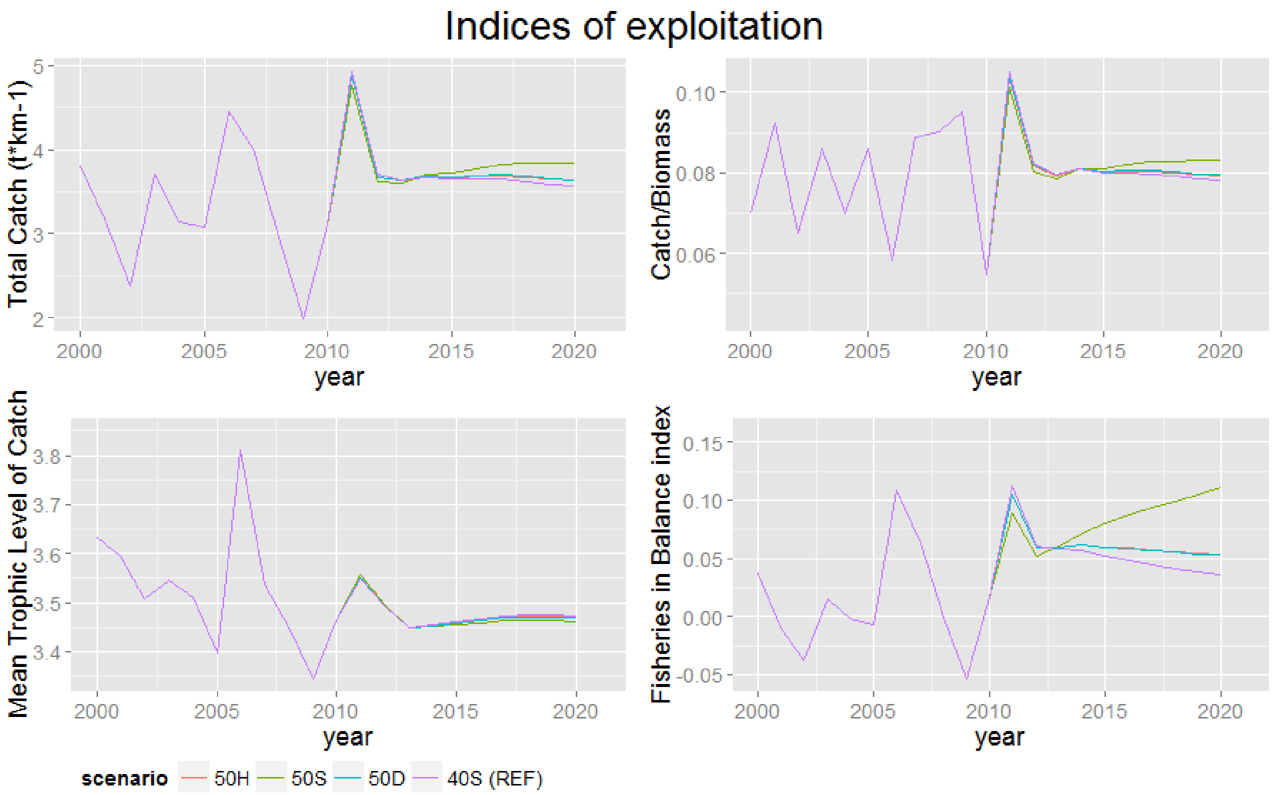


Figure 87. Trends in indices of exploitation of the North Aegean Sea under different selectivity simulations. Different selectivities were assumed for the period after 2011.

Framework and synthesis (WP5)

WP5 aims to collect, homogenize, integrate and analyse the information obtained in the other WPs. The main outcome has been to synthesize the results obtained and to deliver reliable advices for the discards management issue in the demersal and pelagic Mediterranean fisheries. WP5 included the following main tasks:

- Task 5.1. Approach for synthesizing assessments on discards produced at area and trawl fisheries level in the Mediterranean
- Task 5.2. Factors and processes affecting the selection properties and discard of the Mediterranean demersal and pelagic trawling
- Task 5.3. Synopsis of the technical options for the discard reduction in the Mediterranean demersal and pelagic trawl fisheries

The specific objectives of WP5 have been:

- to synthesize by area and trawl fisheries catch and discard amounts and composition;
- to link discard patterns with reasons for discarding and particularly market driven fishers' incentives;
- to provide a synthetic overview of common potential recommendations for mitigation of unwanted bycatches in the Mediterranean demersal and pelagic trawl fisheries;
- to present the main findings of the project in a set of comprehensive conclusions and advices with wide applicability.

Approach for synthesizing assessments on discards produced at area and trawl fisheries level in the Mediterranean (Task 5.1)

An evaluation of national discard programs has been provided, identifying all potential loopholes in methodology. Countries and Sub Geographical Areas (GSAs) where the onboard programmes have been established from 2003 onwards have been reported in Figure 88. Sampling programmes have been set in about 70% of the Mediterranean GSA, although the number of countries involved is around 30% of those concerned. In the Mediterranean Sea, no report or analysis of the adequacy of sampling frame observers onboard and discard data assessment exists.

The Mediterranean onboard programmes seem to have low levels of bias in the sampling protocols, with the higher level of risk of bias linked to low sampling coverage and landing and effort statistics. This may increase the uncertainty and decrease the precision of discards estimates. The source of bias of vessel selection is present in all sampling programmes, since the selection of vessels is opportunistic, depending also on the refusal of vessels, which is not recorded. Data on the regional and interregional level and métier level could be problematic for fleets that split their effort between regions and/or different metiers.

Risk of bias may also exist in species reported as groups; however these groups concern few species with overall low catches. Another minor source of bias could be the presence of observers on board, that may influence the behaviour of fishermen (choice of the fishing areas, the duration of trips, discards sorting behaviour etc.). Species identification does not seem to be an important source of bias since efforts are held to increase the adequacy of observers on board through training courses and identification keys. The main method for estimating fisheries statistics (including discards) and biological parameters is named “design- based methods” in which survey weights are derived from the inclusion probabilities of the samples and available auxiliary information (landings or effort).

The Mediterranean countries have developed the management rules for common data exchange, that it will be hosted by GFCM (General Fisheries Commission for the Mediterranean Sea). Data ex-change format matrices could have advisable similar variables stocked in the different countries. It is although necessary to consider the particularities of the Mediterranean organization, such as those mentioned at the Regional Coordination Meeting for the Mediterranean and Black Sea in 2013, regarding that Mediterranean countries have not developed tools to build common Fishframe data exchange matrices.

Understanding reasons for and factors affecting discarding (e.g., Rochet and Trenkel 2005, Feekings et al. 2012) is an important step towards the management of the discards issue and currently, the mitigation of discards is a major concern to conservation bodies and the wider public (Catchpole and Gray 2010). The level of discards changes if the fishery is directed at homogeneous or mixed fishing grounds (Eliasen and Christensen (2012). There are also seasonal and interannual variations in fisheries discards (Moranta et al, 2000; Tsagarakis et al., 2014), some others discards variations are related to the cycles of life of the species (Tsagarakis et al., 2014), depth (Machias et al., 2001; Sánchez et al., 2004; Mallol, 2005) or differences in the composition of the catch and relative biomass of target species (Tsagarakis et al., 2014).

Many EU fisheries have put in place measures such as minimum mesh sizes, effort regulations including spatio-temporal fishery closures, days at sea quotas, daily hour restrictions, and landing quotas (STECF, 2008), in an effort to mitigate capture of unwanted species/sizes. However solutions to by-catch/discards need to be designed for specific fisheries and may differ between regions of the world (Hall and Mainprize 2005, Johnsen and Eliasen 2011), especially given the varying incentives for discarding.

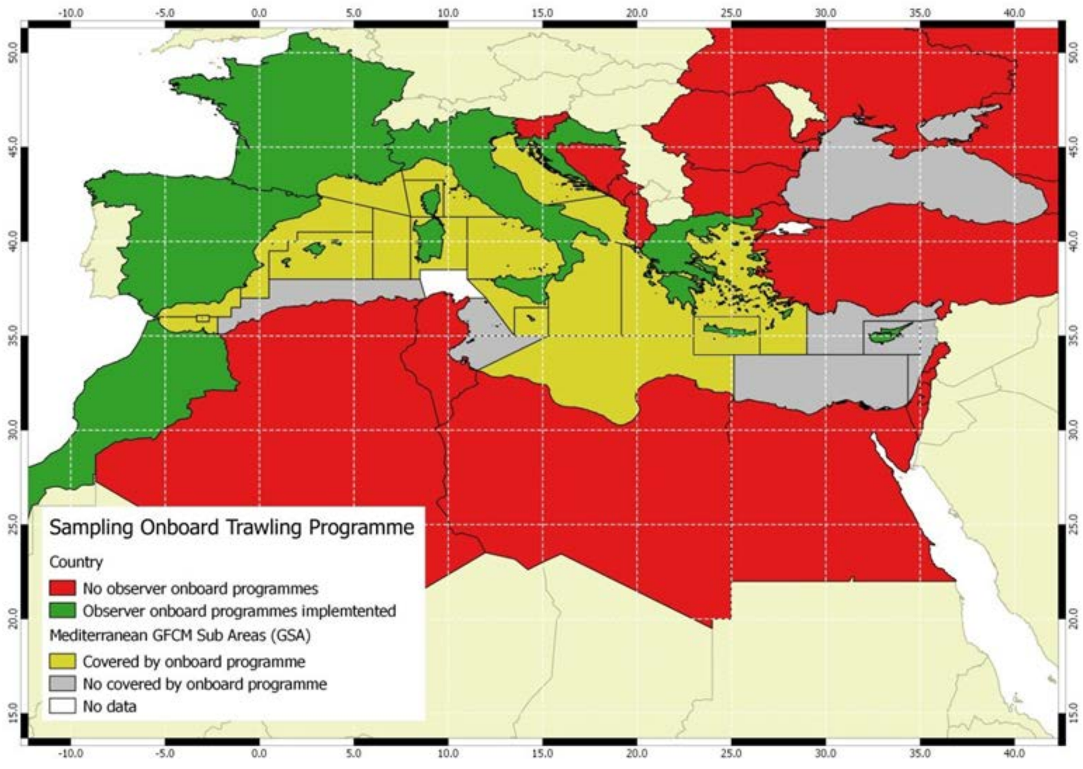


Figure 88. Mediterranean GCFM Sub Areas where observer onboard programmes are implemented.

The multi-species/multi-gear nature of the Mediterranean fisheries result in highly varying fisheries geographically and among the different fishing gears in terms of catches, target species, sorting practices and composition of discards (STECF/SGRN, 2006). Technical specifications of fishing gears and other legal constraints also affect discards composition and quantities. In addition, the use of marine resources highly depends on economic and cultural characteristics which regulate needs, demands and species prices (Rochet and Trenkel, 2005). Of the 300 species caught in the Mediterranean, only around 10% are consistently marketed and 30% are occasionally retained (depending on the sizes and market demands) whereas up to 60% are always discarded (Bellido et al., 2014).

Different technical and environmental factors that influence discard rates have been summarized and their spatio-temporal pattern has been described. Discarding is affected by numerous reasons and the decision to discard is usually a complex outcome of several factors which is difficult to disentangle. Natural conditions are represented by sea weather, sea bottoms, depth, etc., whereas structural conditions by species composition, abundance and size structure of the catch. Fishing depth has been greatly related to patterns in discarding, obviously due to varying catch composition and the relative biomass of target species in the different depth strata. The availability of resources, sometimes affected by the status of the stocks, has been shown to affect fluctuations of market demands and associate discarding practices in several cases in the Mediterranean Sea. These suggest that by-catch can be an important supplemental income for fishers and discarding practices are altered (discards are reduced) when the availability of fishery resources or access to them is limited.

Increased discarding of some species has been reported during their reproductive period when they migrate to shallow areas accessible to small scale fisheries. Seasonal patterns in discarding have been observed in several fisheries (Moranta et al., 2000, Castriota et al., 2001) and they are possibly related to species life cycles and/or changes in distribution grounds. Generally there is a much lower discard level in fisheries targeting fish in schools than in fisheries targeting species in a mixed environment in regard species, size and year classes. Similarly, discarded quantities were positively correlated with hourly yields (Vassilopoulou and Haralabous, 2010) and discards rates increased with total catch (Stergiou et al. 1998, D'Onghia et al. 2003) in other Mediterranean trawl fisheries. Moreover, fishers' attitude, approaches practiced and experience have been also shown to affect discards.

Nutritional habits of the community affect fishing and discarding practices. At small scale, some species may be marketable only in some areas according to the level of familiarization of the consumer. At larger scale, discards ratios for trawls are generally lower in the eastern and southern basin (Tsagarakis et al., 2014). Community welfare affects resource use of the fisheries catch (Tsagarakis et al., 2014).

Technical measures and especially those referring to gear selectivity affect the composition of the catch and subsequently discarding. However, it should be noted that even if EU provisions on the codend mesh size and shape are respected and adopted, the abovementioned meshes (40 mm square or 50 mm diamond) are not perfectly selective so that the catch of undersized specimens might be important, especially in number of individuals rather than in weight.

Mediterranean discards include species of low or no commercial value as well as damaged and/or small sized individuals of commercial species. Market demands rather than fish size (legal reason) determines what is discarded in Mediterranean fisheries. Moreover, economic value of the catch is not fixed and fluctuates according to market demands. Natural conditions (e.g. depth, productivity, substrate type) which are very dynamic and variable, mainly affect species composition, size and structure of the catch. Community influence mainly refers to fishing strategies (haul and trip duration, sorting practices, etc), while state (and. regulations) influence include the effect of management measures and technical characteristics (Table 19).

In the Mediterranean, as in several other areas, market seems to be the most influential factor which determines what is discarded or not, even in contrast to legal constrains. In the multi-species Mediterranean trawl fishery marketable by-catch may constitute an important supplemental source of income, especially when abundance of target species is low.

In addition, a market for specimens below Minimum Landing Size (MLS) is apparent in several cases. Moreover, geographical differences, apart from the effect of natural conditions, seem to be related to socio-cultural characteristics such as community welfare, nutritional habits and familiarization with some species, which affect market demands.

Mediterranean discards ratios highly fluctuate geographically, seasonally and interannually. Moreover, there are large-scale geographic and regional differences in discarding practices. This concern discards both at the fishery and at the species level. Several characteristics of the fisheries in the Mediterranean Sea affect discarding patterns: (i) trawl fishing is essentially multispecies, (ii) there is a great diversity of species in the catch including, the fraction of by-catch that consists of both species which are marketable (according to market demands) and not, and (iii) there are no overquota discards and MLS is the only management measure directly affecting discarding behaviour (Caddy et al., 2009).

As in worldwide, Mediterranean bottom trawling (OTB) produces the bulk of discards (Figure 90) and this is the reason why most studies focus on trawling activities (Hall et al., 2000; Tsagarakis et al., 2014). Most of this information comes from EU Mediterranean countries, especially Spain, Italy, Croatia and Greece while four non EU countries (Turkey, Egypt, Israel, Syria) are also represented.

Figure 90 summarizes the estimated discards ratios and discarded quantities per fishing gear in the Mediterranean Sea. Trawls are responsible for the bulk of discards in the Mediterranean notwithstanding their relatively low contribution (15%) in total landings. Dredges produce substantial amounts of discards due to their high discards ratio. Midwater trawls, static nets, and to a lesser extent, purse seiners, despite their lower discards rates, may still produce large amounts of discarded quantities, since they are responsible for the majority of landings.

Table 19. Factors affecting discards in the Mediterranean, following the categorization by Eliasen and Christensen (2012). Effect of the discard category factor on the amount of the discard in Italian trawl fisheries is also shown: High (H), Medium (M) and Low (L) influence on the discard amount.

		Shelf Bottom trawl	*Deep bottom trawl*
Natural conditions influence	Species composition, abundance and size structure of the catch	H	M
	Availability of the resource	H	H
	Life cycles of species	H	M
	Biological Invasions	L	L
	Environmental factors (depth, seabed, productivity, etc.)	M	M
Community influence	Soak time, haul duration	H	L
	Sorting practices	H	L
State and regulation influence	Technical measures (gear selectivity)	H	L
	Spatio-temporal closures	L	L
	MLS	M	M
	Inspection by the authorities	L	L
Market influence	Low or no economic value	H	H
	Resource use related to socio-economic factors	H	H
	Storage capacity of the vessel and sorting capacity of the crew	H	L

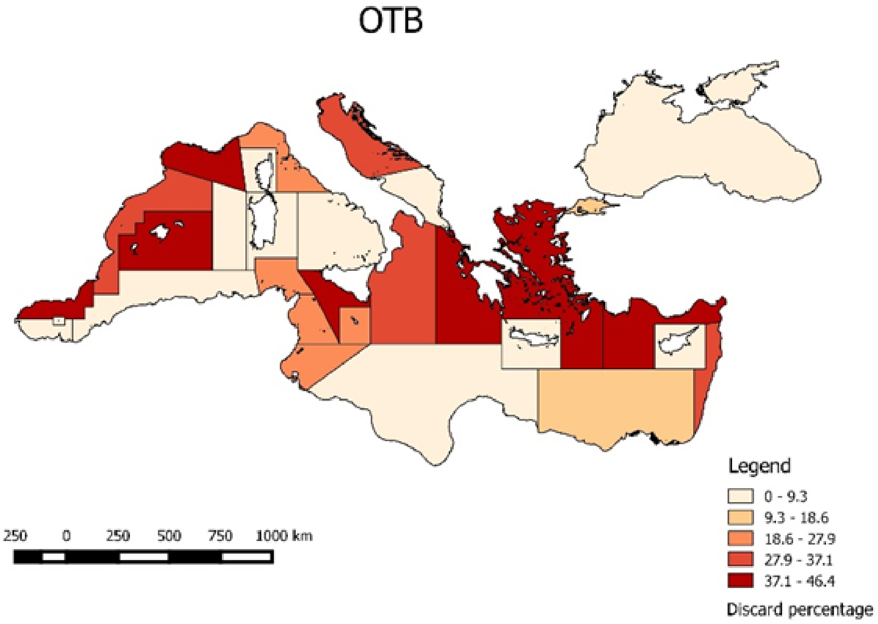


Figure 89. Average Demersal Otter Trawl (OTB) discard percentage obtained from Literature review in each GSA.

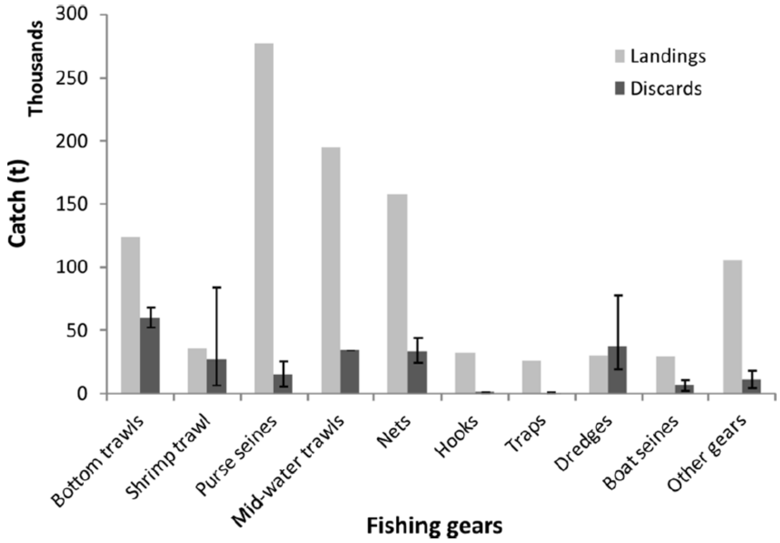


Figure 90. Graphical representation of landed and estimated discarded quantities with their standard errors in the Mediterranean Sea for year 2006.

The available information on discards in the EU small pelagic Mediterranean fisheries is still rather scarce and scattered. However, the data available show that the gears targeting small pelagic fish (mainly purse seines, pelagic trawls) are highly selective in terms of species composition and total discards of the small pelagics fisheries are generally low. The percentage of fish below MCRS and thus subjected to the landing obligation provisions are generally lower than 5% of the total catch (Sartor, 2014). As it concerns Rapido trawling (TBB), data are only available for the GSA 17 and GSA 9, where these gears are used. Owing to the characteristics of the catching process of these gears, the percentage of discards is always high, especially for Rapido trawling targeting flat fish such as the common sole (*Solea solea*).

Discards at species level show great differences and fluctuations. These fluctuations are influenced by ecological and biological factors (catch composition, length frequencies of the populations) as well as by economic and socio-cultural traits which eventually affect market demands. As compared to other regions, discarding in the Mediterranean Sea occurred at lower levels, and landings rates of specific species (e.g., hake, red mullet, red shrimps) largely exceeded those of discards, except for bogue (Uhlmann et al., 2014). Moreover, a great amount of the by-catch is commercialized since numerous by-catch species are occasionally landed, reducing the discarded quantities to lower levels. For example, in the strait of Sicily, for 1 kg of targeted shrimps 9.6 kg of by-catch were produced but 4.4 kg of these were commercialized (Castriota et al., 2001). Discarding practices strictly depend on the selective properties of fishing gears. In the Mediterranean Sea most of selectivity studies focus on bottom trawling and mainly on the following species: *Merluccius merluccius, Mullus barbatus, Parapenaeus longirostris, Pagellus erythrinus, Nephrops norvegicus* and *Diplodus annularis*.

A review of the selective properties of trawl gears has been carried out. Although mesh size and mesh configuration (diamond and square) are considered as the most important factors influencing trawl selectivity, other factors that are known to influence trawl selectivity, such as codend circumference, weight of the catch at the end of the haul or twine thickness. The results showed that the increase in mesh size generally positively affected parameters L50 and SR for *M. merluccius, M. barbatus, P. longirostris* and *A. foliacea*, while the same was not evident for *N. norvegicus* and *A. anntenatus*. Increase in circumference on the other hand generally showed decrease in L50 values only for *M. merluccius* and *M. barbatus*. In contrast, SR values were not affected by the change in circumference for any of the analysed species. Trawl selectivity indicator graphs (Figure 12) were created which enabled instantaneous evaluation of the performances of three most commonly used codends in Mediterranean (40 mm diamond and square mesh codend, and 50 mm diamond mesh codends), by determining whether certain codend is catching mature or immature individuals, below or above MLS. The results of the analysis showed that for the majority of analysed species 50 mm diamond mesh codend performed the best. According to the results, *M. barbatus* showed the smallest discrepancy between the MLS and L50 and length at first maturity (LMF), while the biggest discrepancy was observed for *M. merluccius*. As already noted by some authors, the MLS of species commonly caught in Mediterranean trawl fisheries are not harmonised with the species length at first maturity (Stergiou et al., 2009), indicating that most of the species that are caught are not allowed to spawn at least once in their life time (Figure 28).

In conclusion, the main results achieved in task 5.1 showed that the complexity of the fishing activity in the Mediterranean basin is influenced by many factors: multi-target species, the geographical peculiarities, the multi-gear use, the seasonality etc. The low level of discarding of MLS-regulated species in certain Mediterranean trawl fisheries may be a consequence of a quota-independent management system of demersal trawl fisheries and, even more importantly, a consequence of low compliance by fishermen and weak control and enforcement in certain areas. Anyway, the existing MLSs are ecologically inefficient for sustainable management and that MCRS should be redefined for several species. Generally, market demands rather than fish size (legal reason) determines what is discarded.

Factors and processes affecting the selection properties and discard of the Mediterranean demersal and pelagic trawling (Task 5.2)

In Task 5.2, the framework affecting discard factors described in the MariFish project BADMINTON (Eliasen and Christensen, 2012) has been reviewed. Successively, it has been presented to the project's stakeholders to be further developed/adapted in order to enable recording trawl fishers' perceptions through targeted events organized under WP6 (Table 20)

Experts across countries and fleets identify economic drivers "*price differential*" and "n*o market for potentially commercial species*" as influential drivers. The same holds for vessel's "*limited storage/freezer/processing capacity*", "*physical characteristics*", "*stock structure/availability*" and fishing gear related driver. Less influential or of no effect are considered "*weather conditions*" in the case of Spain and Italy, "*vessel size and power*", "*distance of fishing grounds to markets*", "*economic crisis affected demand*" in the case of Italy and Greece and general view across fishers that others are also discarding in all three cases. Differences in experts' estimations are noticed for example with regard to spatio-temporal closures, general view across fishers that discarding is not an issue of concern, the "*cost of investment in improved gear*". Regarding differences across types of fleets it is observed for example that haul and trip duration in the case of Italy are less influential for deep bottom trawlers, while "*fisher's experience*" is more influential for self-bottom trawling compared to the other types of the Italian fleet.

The main results achieved in task 5.2 demonstrated the synergistic effect in the decision-making process of discarding affected by economic, regulatory and environmental/natural factors, as well as individual characteristics related to the fisher, fishing operations and vessel. Stakeholder engagement showed that cost compensation, commercialising species caught in a sustainable manner and overall economic incentives have been seen positively as potential interventions. Main stakeholder concerns have been expressed about providing discards to the fishmeal industry and aquaculture, needed facilities and infrastructure and control/fines, which are already strict. Moreover, according to stakeholders' point of view, the option to land discards and the re-use for other purposes than human consumption, might stimulate fishermen to catch more fish.

Synopsis of the technical options for the discard reduction in the Mediterranean demersal and pelagic trawl fisheries (Task 5.3)

The review carried out during DISCATCH project (WP1 and WP2) highlights that discard amount fluctuates among fisheries and areas, usually from <20 % to 70 %, due to a biological, technical, environmental, legal and socio-economic factors. Species specific discards ratios in the Mediterranean are low for target species and usually higher for species that constitute commercial by-catch, but discard ratios of a given species, either target or non-target, are likely to fluctuate within a fishery, across seasons, years and regions.

Approaches contributing to discards mitigation in the Mediterranean mainly comprise technical measures, which are related to improvement of selectivity and/or avoidance of potential hot spots of discards. The latter mainly involves spatio-temporal closures for protecting species at certain stages of their life history (e.g., protection of juvenile nursery areas, or adult spawning grounds). At present the Council Regulations (CE No 1967/2006) established a combination of technical regulation, including gear modifications and gear restrictions, fishing effort limitations, seasonal and spatial area closures and management regulations such as minimum landing legal sizes.

Table 20. Trawl fishers' drivers of discarding decision-making in Mediterranean demersal and pelagic trawling (marine experts' review). SB: continental shelf bottom trawling; DB: Deep-sea bottom trawling; PT: Pelagic trawling.

Category of Drivers	Drivers	IT	IT	IT	GR	SP
		SB	DB	PT	DB	SB/DB
Economic	Price differential	X	X	X	X	X
	No market for potentially commercial species	X	X	X	X	X
	Economic crisis has affected demand	(X)	(X)	0	(X)	X
	Damaged fish	X	(X)	(X)	(X)	X
	Costs related to sorting/freezing/catch preservation	X	X	X	(X)	0
	Cost of investment in improved gear	(X)	(X)	(X)	X	X
"Social"/group behaviour	General view (fishers) that discarding is not an issue of concern	0	0	0	X	X
	General view (fishers) that others are also discarding	0	0	0	(X)	0
Individual characteristics						
Fishing operations	Trip duration affects discarding	X	(X)	X	(X)	X
	Haul duration affects discarding	X	(X)	X	X	X
	Distance of fishing grounds to markets affects discarding	(X)	(X)	(X)	(X)	X
Vessel	Limited storage/freezer/processing capacity	X	X	X	X	X
	Vessel size and power (LOA, KW/HP)	0	0	0	(X)	X
	Non availability of technology on board (scanmars, fish finders/sonars, trawl eye)	X	(X)	(X)	X	X
Fisher	Fisher's experience	X	(X)	(X)	X	X
	Whether skipper is owner of the vessel and/or has other related businesses (e.g., fishmonger)	0	0	0	X	*
Environmental/natural	Weather conditions	(X)	(X)	(X)	X	(X)
	Physical characteristics	X	X	X	X	X
	Stock structure/availability	X	X	X	X	X
Regulatory	Minimum conservation reference size	X	X	X	(X)	X
	Spatio-temporal closures, restrictions of fishing effort	(X)	(X)	(X)	X	X
	Fishing gear insufficiently selective to avoid bycatch	X	X	X	X	X
	Level of enforcement/probability of prosecution	X	X	X	(X)	X

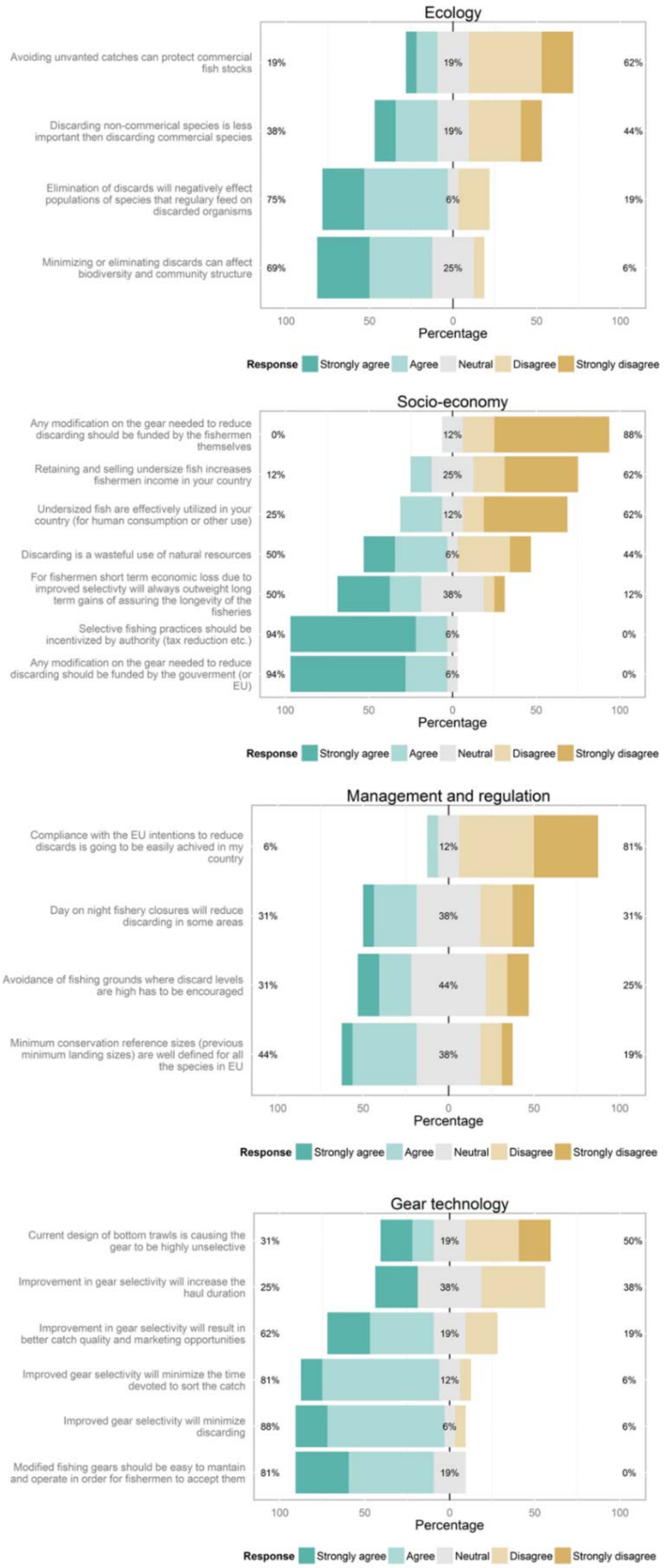


Figure 91. Graphical representation of the stakeholder’s responses on the different issues.

Stakeholder perspective has been evaluated during stakeholder events (Split, 9th October 2014 and Madrid, 11th June 2015). The stakeholders answered a questionnaire on the discards issue and landing obligation provision. The main goal was to gain knowledge on their perception regarding the discards in the Mediterranean and mitigation measures that can deal with this issue. The results are summarized in Figure 91 and Table 21.

By considering the whole set of questions and ranking them (Table 1) it is possible to see that there is not a clear trend of the topics that stakeholders consider as having a paramount importance. However is it possible to infer some useful remarks. The costs to shift from the traditional to more selective gears is the most important topic for stakeholders, who consider any modification of the gear needed to reduce discarding should be funded by the national authorities or by the EU. Stakeholders seem to be not available to pay for more selective gears; on the other hand they also consider that retaining and selling undersize fish shall not increase their income, mainly because the undersized fish products are not effectively utilized.

Another important result is that stakeholders consider the current design of bottom trawl gears as highly unselective and they seem to be well aware of the potential positive effects of improving selective form an ecological (discards reduction, positive effects on the biodiversity) as well as technological (better catch quality and marketing opportunities, reduction of time devoted to sorting the catch etc.) point of view.

Overall, the stakeholders do not consider the discards ban implemented in the framework of EU Reg. No 1380/2013 as a proper management measure to improve the status of the commercial stocks since there is uncertainty on the long term gains and mostly because they consider that the retaining and selling of undersized fish will not increase their income and finally because the compliance with the EU provision will not easily be achieved.

Table 21. Ranking of the different questions according to each topic. 1: totally agree; 5: totally disagree.

Topic	Question	Rank
4.7	Selective fishing practices should be incentivized by authority (tax reduction etc.)	1.31
4.5	Any modification of the gear needed to reduce discarding should be funded by the government (or EU)	1.37
2.6	Modified fishing gears should be easy to maintain and operate in order for fishers to accept them	1.88
2.2	Improved gear selectivity will minimize discarding	2.00
1.1	Minimizing or eliminating discards can affect biodiversity and community structure	2.06
2.3	Improved gear selectivity will minimize the time devoted to sorting the catch	2.12
1.3	Elimination of discards will negatively affect populations of species that habitually feed on discarded organisms	2.19
2.4	Improvement in gear selectivity will result in better catch quality and marketing opportunities	2.31
4.4	For fishers, short term economic loss due to improved selectivity will always outweigh the long term gains of assuring the longevity of the fisheries	2.37
3.4	Minimum conservation reference sizes (previous minimum landing sizes) are well defined for all the species in EU	2.75
2.5	Improvement in gear selectivity will increase the haul duration	2.87
4.1	Discarding is a wasteful use of natural resources	2.87
3.2	Avoidance of fishing grounds where discard levels are high has to be encouraged	2.94
1.2	Discarding non-commercial species is less important than discarding commercial species	3.06
3.3	Day or night fishery closures will reduce discarding in some areas	3.06
2.1	Current design of bottom trawl gear is causing it to be highly unselective	3.19
1.4	Avoiding unwanted catches can protect commercial fish stocks	3.56
4.2	Undersized fish products are effectively utilized in your country (for human consumption or other uses)	3.87
4.3	Retaining and selling undersize fish increases fishers' income in your country	3.94
3.1	Compliance with the EU intentions to reduce discards is going to be easily achieved in my country	4.12
4.6	Any modification of the gear needed to reduce discarding should be funded by the fishers themselves	4.56

The second stakeholders meeting of the DISCATCH project took place on the 11th June, at the Ministry for Agriculture and Environment in Madrid (Spain). The methodology used was the participatory approach. It requires that stakeholders, i.e. fishermen and ship-owners associations, environmental organizations, labour organizations and other sectors are enabled to express their qualitative and quantitative perception of the current situation being aware of the conceptual basis of the European scientific evaluation framework, the role of indicators, the information they are able to convey.

The survey was based upon two scenarios (n°1 and n°2) which aimed to understand how stakeholders perceive the alternative management options, how they rank the importance of the economic, social and biological factors affecting the fishery and what level of utility they assign to the different biologic, economic and social indicators.

The Scenario n°1 was structured to understand how stakeholders regard the framework used at the EU level and the evaluation of the economic/biological consequences. The survey was carried out according to the following conceptual framework. First, the common objective is defined: to contribute to the sustainable fishery management. Then, the main components are identified: the ecological state (safe level of reproductive potential, conservation of abundance and biodiversity and preservation of the size structure of the fish); the impact/pressure (monitoring the mortality, the fishing intensity and the reduction of discards); the economic component (maximize revenue and improve cost efficiency).

Among the objectives of a sustainable fisheries management, pertaining to the ecological state component, the higher preference was expressed by stakeholders for “maintaining a safe level of reproductive potential” (38%). As regards the pressure/impact component, the higher preference was expressed for “monitoring the fishing intensity” and “monitoring the mortality” (36%). The evaluation of objectives related to the economic state component showed a slight higher preference for “improve the cost efficiency” (52%) in respect to “maximize the revenue” (48%). In general, these results are indicative of a fair awareness of the stakeholders that the potential reproductive level should be secured by checking the mortality and/or fishing intensity. It is also worth noting that the cost efficiency is considered essential/preeminent to maximize revenue (Figure 92).

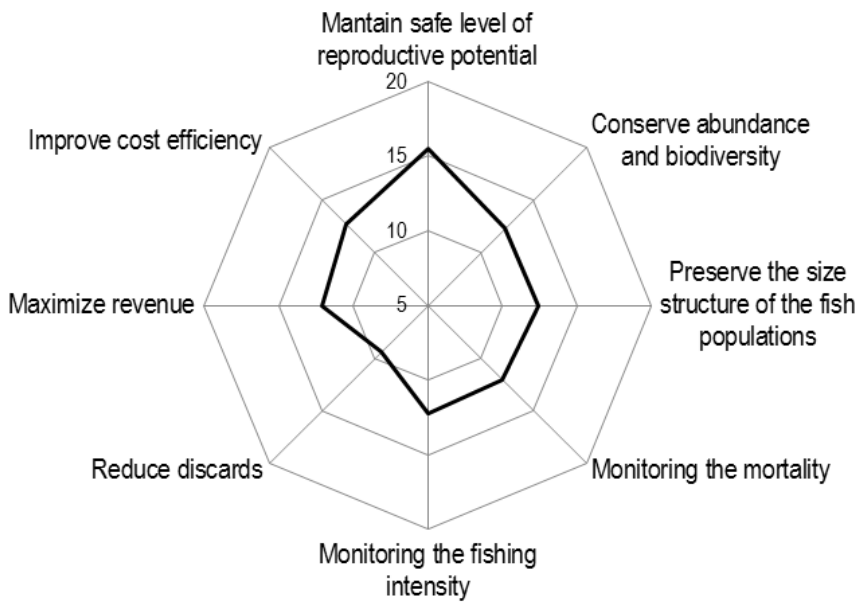


Figure 92. Stakeholders’ insights regarding the importance (in %) of the different objectives of a sustainable fishery management in the long term.

As regards the stakeholder perception of the effectiveness of the ecological indicators to track the objectives, higher rank was attributed to “mean size of the spawners”. Among the pressure/impact indicators, higher preference was expressed for “fishing mortality at the MSY of a mix of target species”. Among the economic indicators, the stakeholders gave their preference to “revenue” in comparison to “production”, which is a sign of awareness that the increase in production does not necessarily turns into increased revenue, and to “fuel costs” in comparison to “crew costs”. Stakeholders’ perception of the effectiveness of the indicators (all together) has been reported in Figure 93.

The objective of the Scenario n°2 was focused on understanding the perception that stakeholders have regarding the potential effects of decisions derived by the implementation of a pool of management measures, given a set of defined ecological, economic and social criteria/factors. Among the different management strategies (scenarios) to achieve a sustainable fishery management in the long term, the “fleet withdrawal” (scraping) is considered the worst option by the stakeholders. Very low position in the standings gets “keep the status quo”, while the “measures combination” is considered as the best option to achieve a sustainable fishery management in the long term (Figure 94).

Looking into the effects from the management strategies, the higher expectation is for the maintenance of the occupation levels (number of workers). After that, stakeholders express the same expectation for all the following effects “optimize revenue”, “maintain a safe level of the reproductive potential of target species (SSB)”, “maintain a safe structure of spawner population (mean length of spawners)” and “optimize costs” (Figure 95).

The past and present situation and also future possibilities of the management measures affecting discard amounts in the Mediterranean sea were evaluated using SWOT analysis technique (Henricks, 1999; Houben et al., 1999), taking into account the stakeholders’ perspective. This study explores constraints and opportunities of management measures addressed to reduce discard. Inputs used in the present SWOT analysis were collected during the two SH meetings (Split, 2014 and Madrid, 2015) held during DISCATCH project.

Stakeholders’ knowledge and insights generated essential inputs in terms of the conceptualization and potential implementation of an innovative system for fisheries. The SWOT analysis (Table 22) revealed that the combination of the management measures described before can guarantee the main ecological and socio-economic goals in a sustainable fisheries framework. Anyway, the main constraints regard the creation of meaningful and agreed incentives to adopt selective fishing practices. In this sense, stakeholders would not consider moving forward beyond the current status quo without adequate incentives.

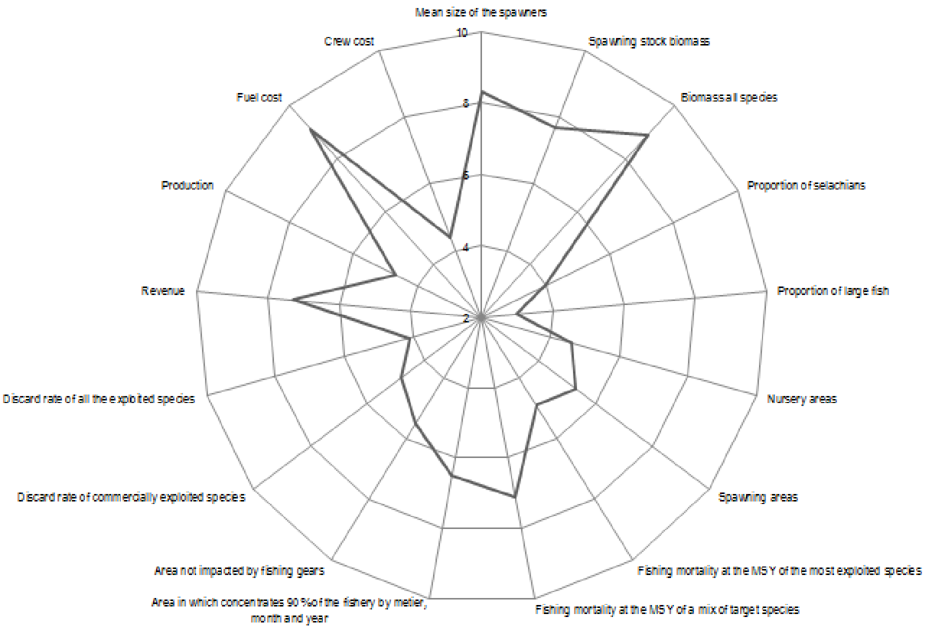


Figure 93. Stakeholders' perception of the effectiveness (in %) of the indicators to track the objectives.

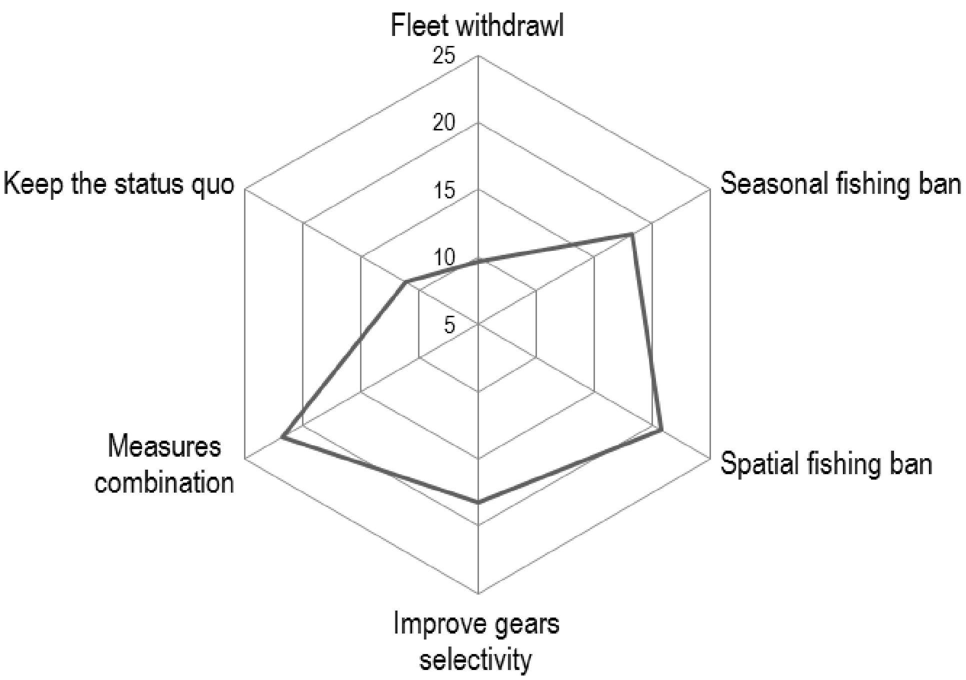


Figure 94. Stakeholders' perception of the importance (in %) of the different management strategies to achieve a sustainable fishery management in the long term.

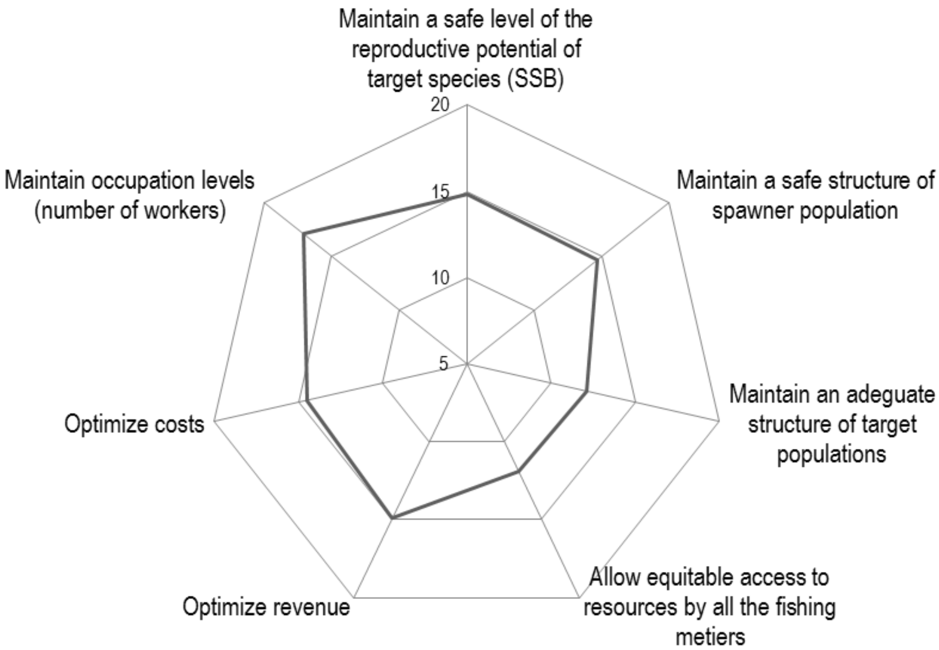


Figure 95. Main effects expected (in %) by the stakeholders, following the application of the management strategies to achieve a sustainable fishery management in the long term.

Table 22. SWOT analysis of the management measures to reduce discard.

STRENGHTS	Protection of nursery and spawning areas Improved gear selectivity Control of fishing effort	OPPORTUNITIES	Conservation of safe level of reproductive potential Preservation of the size structure of the target fish stock Improvement of cost efficiency
WEAKNESS	Subsidising for selective fishing practices Low compliance Destination of discard	THREATS	Negative effect on benthic population which habitually feed on discarded organisms Illegal market

Establishment of stakeholders' platform and project information management (WP6)

Objectives

The overall objectives of WP 6 are:

1) the coordination and facilitation of the consultation between the project partners and the relevant stakeholders;
2) the organization of two stakeholder meetings;
3) the collection of stakeholders feedback in reply to the questionnaires developed according to the MCDA methodologies;
4) the dissemination of the project results.

Description of work

The consortium partners who represent considerable expertise in the fishery science (research institutes) and a range of key stakeholders, particularly fishermen, organized in a multi stakeholder platform (MEDAC, *Mediterranean Advisory Council*) have interacted in this project to make sure scientific findings were grounded with real and up-to-date knowledge of what happens at sea, such as the one fishermen have. The multi stakeholder platform to ensure interaction with all relevant stakeholders in the fishery sector has been established through the organization of a more interactive website used to inform and get feedback from stakeholders. In addition, the organization of two large multi stakeholder events ensured the interaction between stakeholders and scientists at the beginning using a survey with a questionnaire and at the end of the project using Multi-Criteria Decision Analysis (MCDA) techniques to address and finally consent on complex issues among many participants, with different background, knowledge and, sometimes, conflicting objectives or preferences. Bottlenecks, challenges, and solutions or mitigation strategies were presented at the stakeholder events based upon state-of-the-art of knowledge for the sector.

Internal communication and dissemination (Task 6.1)

Updated project information and results from WPs 1, 2, 3, 4 and 5 were made available through the new MEDAC web site. The platform helped facilitating the discussion by providing stakeholders with preliminary information and results and at the same time it helped collecting feedback information from them. The fluxes of information and knowledge to stakeholders were ensured through the web site, by mean of login and personal password through which they were able to download information and upload comments on the most relevant topics of the project . Final project results and information will be disseminated to MEDAC stakeholders and general public by uploading a general summary and overview of the Project activities using MEDAC web site.

Collaborative planning of stakeholder events (Task 6.2)

Each of the two stakeholder event was planned in terms of logistics, participant recruitment and outcomes in collaboration with relevant WP leaders. Special attention was paid to the number of participants, their representativeness and the language of communication. Support to ensure participation, quality of deliberations, convergence of different areas of knowledge, and feedback processes was ensured. The agendas of both events included plenary presentations by experts of each WP followed by panel discussions involving stakeholders and working groups for drafting action plans, after a procedure of identifying topics of priority. Document, synthesizing discussions and outcomes of each stakeholder event was delivered. Reports included transcripts of all outputs produced at each event for circulation to participants as well as action lists and conclusions at the closing of each of the stakeholder events.

The stakeholders attending the meeting that was held in Split (October 2014) answered a questionnaire on the discards issue and landing obligation provision. The main goal was to gain knowledge on their perception regarding discards in the Mediterranean and mitigation measures that can address this issue. Stakeholders are aware that bottom trawl gears are unselective; they have a clear perception of the potential positive effects of improving selectivity from an ecological as well as technological point of view. However, they considered the costs to shift from traditional to more selective gears as one of the most important topic. Thus, they believe any modification of the gear, aiming at reducing discards, should be funded by the national or EU authorities. Furthermore, they also believed that retaining and selling undersized fish shall not increase their income. On the other hand, they also stated that avoiding unwanted catches cannot protect commercial species. Overall, the stakeholders do not consider the discards ban implemented in the framework of EU Reg. No 1380/2013 as a proper management measure to improve the status of the commercial stocks.

MCDA survey among stakeholders (Task 6.3)

The participatory management is a working method of paramount importance because is based on the principles of knowledge sharing and accountability to address the sustainable development of the fishery sector. The industry-science cooperation could ensure more coherent information and a progressive implementation of an EA, by enhancing the stakeholder awareness of the evaluation process and by incorporating their knowledge into research-based advice.

The first objective of the task 6.3 is to test the stakeholder perception of the European scientific evaluation framework, and in particular on how they recognize the importance of indicators to monitor the stocks, the ecosystem and the fishery sector.

The second objective of task 6.3 is to study how stakeholders perceive the potential effects of key issues for the economic and environmental sustainability, such as avoiding by-catches and reducing discards, improving ecosystem state and yield in the long-terms, facing possible losses in the short-terms, changes of gears and economic impacts, changes/loosing local seafood traditions/habits, etc. At the MEDAC meeting held in Madrid on June 11 a two-scenarios survey was carried out, at pilot scale, in order to promote a participatory role of the stakeholders in the management process. Twelve stakeholders answered anonymously to a questionnaire.

The first scenario was carried out using the AHP method, while the second one by using the NSFDSS method. Among the objectives of a sustainable fisheries management, pertaining to the ecological state component, the higher preferences was expressed by stakeholders for “maintain a safe level of reproductive potential” (38%). As regards the pressure/impact component, the higher preferences was expressed for “monitoring the fishing intensity” and “monitoring the mortality” (36%). The evaluation of objectives related to the economic state component showed a slight higher preference for “improve the cost efficiency” (52%) in respect to “maximize the revenue” (48%). In general, these results are indicative of a fair awareness of the stakeholders that the potential reproductive level should be secured by checking the mortality and / or fishing intensity. It is also worth noting that the cost efficiency is considered essential / preeminent to maximize revenue.

As regards the stakeholder perception of the effectiveness of the ecological indicators to track the objectives, higher rank was attributed to “mean size of the spawners”. Among the pressure/impact indicators, higher preference was expressed for “fishing mortality at the MSY of a mix of target species”. Among the economic indicators, the stakeholders gave their preference to “revenue” in comparison to “production”, which is a sign of awareness that the increase in production does not necessarily turns into increased revenue, and to “fuel costs” in comparison to “crew costs”. Among the different management strategies (scenarios) to achieve a sustainable fishery management in the long term, the “fleet withdrawal” (scraping) is considered the worst option by the stakeholders. Very low position in the standings gets “keep the status quo”, while the “measures combination” is considered as the best option to achieve a sustainable fishery management in the long term.

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List of Annexes

Review and analysis of scientific papers and technical reports on discards quantities, composition, practices and mitigation tools in the Mediterranean (WP1)

D 0.1. Review on fishery discards from Mediterranean demersal and pelagic trawl fisheries with particular reference on processes adopted for sampling and analysis

D 0.2. Review on factors, reasons and mitigation measures associated with fishery discards from Mediterranean trawl fisheries

D 0.3. Draft paper for a peer-reviewed journal on the existing knowledge of fishery discards, the associated factors and reasons, and the implemented management tools

Data Collection Framework analysis (WP2)

D 0.1. A review document on assessment of Mediterranean fishery monitoring programmes and implementation, focusing particularly in discards and bycatch issues

D 0.2. Draft paper for a peer-reviewed journal on GAM multivariate analysis and other advanced statistics to identify drivers of discards and bycatch in selected Mediterranean European fisheries

D 0.3. Bayesian spatial modelling of discards and by catches

Predicting commercial yields, discards rates and selectivity by towed gears from fishing gear characteristics (WP3)

D 0.1. Characteristics of investigated codends

D 0.2. Geometry of the codends

D 0.3. Morphology data for species being investigated

D 0.4. Historical data size selectivity of species being investigated

D 0.5. and D 0.6. Simulated size selectivity of the different codends and behavioral models for species being investigated

D 0.7. New selectivity data for Spanish bottom trawl nets (GSA05) with square mesh panels of thinner, lighter and wider netting without knots in the upper plan

D 0.8. Experimental short pilot action at sea to complement the existing information on selectivity in the Greek bottom trawl fishery (*version revised*)

D 0.9. New selectivity data for the existing pelagic pair trawl (Northern Adriatic Sea) with and without integrating selective devices

Quantifying, modelling catch and discard composition in trawl net fisheries (WP4)

D 0.1. Parameterization of the different GSAs/scenarios for the BEMTOOL simulations

D 0.2. Parameterization of EwE models based on outcomes of WP 1, WP 2, WP 3 and WP 4

D 0.3. Outputs of the BEMTOOL simulations, in the short and medium-long terms, for each combination GSA/scenario

D 0.4. Outputs of Ecopath with Ecosim simulations

D 0.5. Draft paper for a peer-reviewed journal on the effects of different bottom trawl selectivities on the ecosystem components and fishery resources, studied using the EwE methodology

Framework and synthesis

D 0.1. A working document on the Mediterranean demersal and pelagic trawl fisheries by gear and area

D 0.2. A working document on factors affecting the selective behaviour related to discarding

D 0.3. Report on the management options for the discard reduction

Establishment of stakeholders' platform and project information management (WP6)

D 0.1. Report on the results of the 1° stakeholders event

D 0.2. Report on the MCDA methodology and survey activities

D 0.3. Report on the results of the 2° stakeholders event