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Deliverable No. 4.3

DiscardLess

Strategies for the gradual elimination of discards in European fisheries

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D4.3

Decision support tool for fishers incorporating information from tasks 4.1, 4.2 and information on unwanted catches derived from scientific data.

(Month 36)

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Revision Control

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Report Highlights (Main results)

- The main highlight is the series of analysis making use of survey, observer and official landings data to provide maps that can be used to allow fishermen to choose where and when to fish to best avoid unwanted catches
- Guidance is offered on avoidance of choke species, fish below Minimum Conservation Reference Size, as well as where these are in low abundance while desired catch may be in high abundance
- Maps of where discarding occurs the most, and how species are discarded together or not can help provide further guidance on the avoidance of discards
- The economic implications of some of these strategies are also presented allowing fishermen to potentially maximise revenue while avoiding unwanted catch
- In some cases, the information has been packaged in flexible and interactive web based apps that allow fishermen to use the information in their own way.

The methods/approaches followed:

- The main methods used were a range of modelling and mapping tools.
- The models were principally statistical to allow us to see how species distributed in space and time, and where different species could be found (and discarded) together or not.
- The main output results were a series of maps for all the key elements; where particular catch proportions could be found, where discarding of a given species was generally low, where two or more species were discarded together etc.
- The outputs in some cases were packaged in web based apps, this approach can be used for all the output map information for the fishermen to choose how to use, combine and present the information

How these results can be used and by who?

- The principle target of the outputs are the fishermen in their routine activities
- The availability of maps showing where different species, size classes (above and below MCRS), and discards can be found represent the key results.
- Our concept is that the maps can help fishermen find desired catches, and avoid unwanted ones. The web based apps then allow them to do this in their own way and approach.

Policy Recommendations

- This work is not primarily focused on policy. The main users would be fishermen, however, one policy implication would be to consider ways to introduce the flexibility in management needed to make this approach work most optimally

Executive Summary

The main aim of this deliverable was to provide fishermen with the detailed knowledge that can come from using scientific data to illustrate the spatial and temporal distributions of the fish, the catches, and the discards. We set out to use the many data and models now available to scientists to potentially assist fishers in making their strategic choices, including fine-scale real-time mapping of catches and activity data, discards hotspots, juveniles surveys etc. The aim was for Decision Support Tools (DST) to be provided to e.g. assess the role of "choke" species at the local scale. The role of the scientist here is as an advisor to the fishers, on where and when they might fish to reduce "choke" problems, and avoid unwanted catches.

No single approach was possible across all the case studies, and indeed was probably not desirable, as each case study had its own specific challenges. These arose from a combination of how the fish were distributed i.e. in discreet areas, or widely spread, and on the nature of the LO challenge, e.g. avoidance of particular species or size classes, and the limitations in fishing imposed by geography and other legislation drivers.

Many of the analyses presented here have also been developed into bespoke Decision Support Tools, mainly involving web based apps to help fishermen understand and use the results and particularly maps of catch and discard distributions. DST can take many forms. At their simplest, these can represent maps of where fish are found (from surveys), and caught and discarded (from observers). However, more detailed analyses can be used to analyse spatial patterns and their variation, how discards and catches of numbers of species co-occur in space or time, or not. The information can also be represented in an interactive form using web based apps. But the DST process can also be simply the provision of important understandings about discarding and its drivers, e.g. quota management rules, or about the interaction of economic profitability with discarding – is it economically better to NOT discard? We present examples of all these types of Decision Support information in the report. These cover case studies from the Baltic, through western waters to the Mediterranean. They cover many different metiers and fleets, from single to multi-species, using a wide variety of gears. Perhaps the key message is that we can identify many different approaches that could help reduce or even eliminate discarding, but they all tend to be specific to local conditions. It should be possible to export the approaches to other fisheries, but in broad terms rather than the specifics. Essentially, the causes of discarding are common, but the solutions tend to be local and specific.

Some of the elements brought together here have been submitted or published in the peer reviewed press, while others represent recently completed work. **Chapters 1 & 2** report on an analysis approach developed by IFREMER and that has been applied to combined discard observer data from **IFREMER & MI, for the Celtic Sea case study**. In **Chapter 1**, the analysis was designed to highlight where different species were being discarded either together or in isolation. The initial approach is statistical, and looks for clusters that can be discriminated from each other. In Chapter 1, we looked at the results for the combined data from Ireland and France, and then at what the differences were between emergent clusters for the two countries. We also compared the spatial patterns of discard clusters to landings clusters. This asks the question can we predict discards on the basis of the spatial structure of the landings. While some discard clusters corresponded well to landings clusters this was more unusual than cases where no obvious common pattern was found. So high landings of a species may not predicate high discards of that species.

We also looked more closely at the Irish cluster patterns alone in **Chapter 2** to find out if this would provide useful information for Irish fishermen, working under specific quota arrangements and often with unique metiers. In this case we also looked at clustering of discards for fish that were either above or below MCRS. The second step was to look for discard clusters that were also clustered spatially. Many of the clusters could be seen scattered across the Celtic Sea, but some such as >MCRS megrim discards were aggregated in the south, while > MCRS hake discards were concentrated in the Nephrops fishery areas. Hake discards < MCRS were in similar locations to the adults, but <MCRS megrim discards were concentrated in one small part of the adult discard area.

In **chapter 3** by **IFREMER for the English Channel case study**, the analysis makes use of landings and VMS data to help fishermen define the spatial distribution of the species or sizes of fish that they would wish to avoid, or indeed to concentrate upon. The work is focused on the development of a web based app that fishermen can use interactively to choose their precise area of operation. This may be to avoid catching <MCRS fish, or to avoid excessive catches of a "choke species". This type of app has been developed as a Decision Support Tool (DST) in a number of the case studies reported in this Deliverable. Fishermen can then define a maximum or minimum proportion of a given species in the landings that he is willing to accept depending on the objective i.e. avoiding or targeting the species. The time scale over which the maps are presented can also be controlled, either for a year, quarter or month.

A likely side-effect of introducing the landing obligation of the 2013 Common Fisheries Policy into mixed fisheries is the occurrence of the "choke species" problem. When discarding no longer is an option, leasing quota or changing fishing practices remain important tools to avoid choke species. In **Chapter 4 (DTU-Aqua in the North Sea case study)**, the scale and tactics linked to using avoidance behaviour to reduce choke species is investigated by analysing the fishing behaviour of a single demersal trawler in the North Sea. Analysis combined qualitative information collected through interviews with the vessel owner and skipper, along with quantitative analysis on fisheries data. From the interviews, saithe and cod were identified as potential choke species and subsequent analysis focused on these two species. The analysis of catch and quota composition showed that cod would choke the fishery early if no catch-quota balancing options were available, resulting in a 87% reduction in revenue, while saithe could choke the fishery later, resulting in a 43% reduction in revenue. Avoidance behaviour was difficult to detect from fisheries data, which was explained by avoidance primarily taking place through very fine-scale tactical choices rather than large displacements. Catch composition showed that saithe is distributed more patchily than cod, with most hauls containing small amounts of saithe and a few hauls containing large amounts. This chapter shows the choke species problem seen from the perspective of an individual fisher and highlights the amount of real-time tactical decisions and trade-offs that need to be made when operating in mixed-fisheries. It also illustrates how solutions and mitigation can be very local and specific, and this will probably more often be the case than we can identify global or generic mitigation.

Generally fisheries science and management advice use both scientific (e.g. observers and surveys) and commercially derived data (e.g. landings and VMS) to estimate the distribution and abundance of marine species.

In **Chapter 5, (DTU-Aqua in the North Sea case study),** the emphasis is on a new type of commercial data with high resolution and coverage that has not previously used for scientific purposes. While currently used datasets include the total weight by species on per hauls basis, the new data, primarily developed for traceability purposes, also include the commercial size class for the species landed, recorded directly by fishers on a haul-by-haul basis. Thus, this dataset has the potential to provide knowledge on landed fish with as high spatio-temporal resolution as when coupling logbooks and sales slips but with the addition of detailed knowledge on the size distribution. This chapter describes the coverage and completeness of the dataset, and explores the reliability of the data available. It is concluded that the main limitation here is the small number of fishing vessels covered by the dataset, but that the data from those vessels are accurate, detailed and reliable. There is therefore, clear scope to develop this type of data across more vessels. This type of data could provide knowledge on detailed spatial patterns of fishing effort and commercial species distributions as well as serve as a reference fleet. Because these vessels provide direct observations at the haul level it could also be used for analysis at a vessel or métier level, for instance on catchability, spatial selectivity, seasonal patterns or to compare and verify outcomes of spatial fishery models.

The uses for survey and observer data in helping fishermen to determine where and when to fish is illustrated with an example from the **Balearics case study by IEO** in **Chapter 6**. The surveys were used to model the spatial patterns of species abundance for the main commercial species. The observer data were then used to provide a temporal dimension to this, and looked at both the catch make up, and the discarding practices. The results from this were a series of maps of species distribution, above and below MCRS, species overlaps, fishing grounds, discard hotspots etc. This was then all brought together in an on-line tool where fishermen could access: maps, from both surveys and observer data; biological data such as length distributions, maturity etc., by species and fishing ground; and discarding patterns. This type of DST is now being developed in other case study areas e.g. English Channel and the Celtic Sea.

Chapter 7 by MI in the Celtic Sea case study, explores a different aspect of discarding behaviour that could help understand and reduce drivers for discarding. In most countries quotas are assigned on an annual basis, and it has long been speculated that discarding would tend to increase towards the end of the year as quota runs out. In Ireland, quota is assigned on a monthly basis. This allowed us to examine what happens with discarding as quota is exhausted 12 times a year, as opposed to once, as in most jurisdictions. The study focused on the mixed demersal fishery, and on the key species of cod, haddock and whiting. Cod and haddock represent strong choke problems. The "Challenge" trials reported in D4.2 showed that the boats studied were choking on cod and haddock with 4 days in the month. The findings showed that there was little evidence of an increase in cod or haddock discarding as the month progressed, presumably as they had no available quota over most of each month. However, whiting, which had a much less restrictive TAC, did show an increase towards the end of the month. What this suggests is that increased flexibility in when a TAC can be used, might help reduce the overall discarding bulk in some fisheries, and particularly whiting in the Celtic Sea.

In **Chapter 8 (MI, IFREMER & CEFAS in the Celtic Sea case study),** we present the results from a detailed analysis of observer data from Ireland, France and the UK used as an ensemble of the catches taken in the Celtic Sea. The analysis focuses on mapping hot spots of CPUE, and catch proportion for three key species; cod, haddock and whiting, and over and under MCRS. The analysis can be extended to any species, both commercial and non-commercial. The maps are based on consistent observations of particular catch rates, so only those locations where one would consistently (over 5 years) see high or low levels for these categories. The data are then interpolated to provide regional coverage. The maps are then drawn together into a web based app, where the fishermen can choose the species (or size class) of interest, and then map CPUE or catch proportion at the selected level of intensity. They can also map a number of species or sizes together on one map, and change the levels to show, to help choose likely places to avoid or find particular species or sizes. The app represents a DST for fishermen. We plan to incorporate additional species, as well as discarding hotspots. The app is a prototype, and we plan to develop the approach working with individual fishermen to best fit it to their needs, and engage them in trying out the approach.

The main thrust for **Chapter 9** by **IFREMER in the Celtic Sea case study**, is to find an appropriate way to map discard observer data to help fishermen choose where and when to fish, to reduce the capture of unwanted fish. Such spatio-temporal reallocations of fishing effort are part of adaptation strategies that could help mitigate the impact of the landing obligation. If the primary objective is to reduce discards while maintaining commercial catches, maps of landings and discards can provide fishers with insights on appropriate fishing grounds and/or periods. When using on-board observer programme data to explore spatial and/or temporal patterns of landings and discards, one common problem is the non-random spatial distribution of the data. To overcome this issue, a non-parametric mapping method based on nested grids was developed using the French on-board observer data. The method relies on an iterative process of cell division where the size of the cells varies according to the number of observations. Landings and discards are then estimated in each grid cell. Two contrasting fishing métiers, trawlers and netters, are examined to illustrate the advantages and issues of the nested grid method, and discuss how it can be applied to any fishing métier. Spatial reallocation strategies could be found for the trawling métier, but not for the netting one. Accurate effort data are required to verify that the on-board observed data spatial coverage is sufficient to produce meaningful maps. A potential application of this study is to create an atlas of landings and discards for each métier observed by on-board observer programmes.

The objective of the study presented in **Chapter 10** (**IFREMER in the English Channel case study)** was to analyse, at fine scale, the annual, seasonal and spatial distributions of several species in the Eastern English Channel (EEC). Data from scientific surveys are not available for all times of the year, but do provide consistent yearly and spatially resolved abundance indices. On-board commercial data do cover the whole year, but generally provide a biased perception of stock abundance. The combination of scientific and commercial catches per unit of effort (CPUEs), standardized using a delta-generalized linear model, allowed us to infer spatial and monthly dynamics of fish distributions in the EEC, which could be compared with previous knowledge on their life cycles. Considering the scientific survey as a repository, the degree of reliability of commercial CPUEs was assessed with survey-based distribution using the Local Index of Collocation. Large scale information was in agreement with literature, especially for cuttlefish. Fine scale consistency between survey and commercial data was significant for half of the 19 tested species (e.g. whiting, cod). For the other species (e.g. plaice, thornback ray), the results were inconclusive, mainly owing to poor commercial data coverage and/or to particular aspects of the species biology. The approach allowed a more representative mapping of the spatial temporal abundance distribution pattern of a number of species throughout the year. The information can then be used in both targeting, and avoidance in the context of the LO.

Chapter 11 (DTU-Aqua, North Sea case study) focuses on the use of Remote Electronic Monitoring (REM) with CCTV which is often considered as a potential tool to ensure compliance with fishing regulations. Since 2008 several trials have been conducted in the European Union on the use of REM with CCTV, often in the context of the landing obligation. One of the largest and longest running European trials was the 2010 to 2016 Cod Catch Quota Management trial (CCQM) in Denmark. This paper reviews the methods and experiences gained from this trial, with focus on the last two years where criteria for video audits were expanded and major technical developments took place. The cost-effectiveness and potential of REM for compliance, management and scientific purposes is discussed. The present study demonstrates that REM is capable of high precision detection of non-compliance with a discard ban and that developments in the transmission of REM data allowed for a smoother and more reliable Monitoring, Control and Surveillance (MRS) system. Although further developments are needed, especially within the field of automated image analysis, we conclude that REM is one of the few feasible tools where fisheries information and compliance can be ensured under a landing obligation.

In **Chapter 12 (UAZ-IMAR, Azores case study)** species Distribution Models of 15 species of deep-water sharks and rays were developed based on survey data for the Azores case study. Deep-sea sharks, even if only occasionally taken as bycatch of the deep-water longline fisheries in the Azores, could rapidly choke the fisheries of this Portuguese outermost region, as many of those species are currently under a TAC 0. Maps predicting occurence by species and combined occurence of all species at the range of the whole Azores EEZ were developed to help fishers identify areas they should avoid to limit the risks of catching those species. Composite maps combining the distribution of the main shark species caught by the bottom longliners on one side, and by the deep-water drifting longliners on the other side were created to better highlight for those two specific groups of fishers the main areas to be avoided. This information was completed by fine-scale information on shark spatial and vertical movements derived from acoustic telemetry data from 2 species: kitefin shark *Dalatias licha*, and bluntnose sixgill shark *Hexanchus griseus*. Telemetry data help identify potential essential habitats for those species. Our study highlights that areas to avoid fishing and limits in fishing depths at some time of the day could be promising mitigation measures for some species of deep-water elasmobranchs but not for all.

Chapter 13 (NAYS, Eastern Mediterranean case study) examines the scientists story in the context of the operation of the LO in the Mediterranean, and where no TACs are operated. This is quite a different situation to most of the other case studies as discarding is not driven by quota restrictions at all, and no choke species effect is in play. The study concludes that the LO and the effort based management scheme in the Mediterranean are incompatible.

Chapter 1. International landings and discards analysis in the Celtic sea demersal mixed fisheries.

By: Marianne Robert & Lionel Pawlowski - IFREMER, and Julia Calderwood & David Reid - Marine Institute

Celtic Sea case study

Introduction

In response to the recent CFP reform and more especially its article 15 focusing on the landing obligation (LO), strategy and tactics for minimising unwanted catches need to be deployed by the fishing industry. In that process, scientists are trying to identify, using various sources of data and approaches, the best locations, times and practices to avoid unwanted fish.

The Celtic Sea area is a region that extends from the shelf area west of Scotland down to the western Channel south of England. The variety of habitats in the Celtic Sea accommodates a diverse range of fish, crustacean and cephalopod species that support a wide variety of fisheries targeting different species assemblages from pelagic to demersal. Despite pelagic trawling being responsible for more landings than any other gear types in the Celtic Sea this fishery only accounts for a small fraction of the total fishing effort in this area. In this study we are only considering the demersal fisheries to gain a full understanding of the fisheries that mainly operate in this ecoregion. These fisheries consist of several fleets mainly comprising of bottom trawlers, but also including beam trawlers, gillnetters and longlines, using different métiers and targeting different species assemblages throughout the year. The main species caught are angler fish (*Lophius piscatorius* & *budegassa*), hake (*Merluccius merluccius*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and Norway lobster (*Nephrops norvegicus*). Two areas are important in terms of landings, south of Ireland (especially statistical rectangle 31E3) and south Cornwall in area VIIe (especially statistical rectangle 28E5).

The mixed nature of these fisheries leads to high discard ratios, especially in the mixed demersal trawl fishery where many species occupy similar habitats and display similar behaviours making it difficult to selectively fish for individual species. The most discarded quota species in the Celtic Sea include whiting (*Merlangius merlangus*), Atlantic mackerel (*Scomber scombrus*), hake (*Merluccius merluccius*), plaice (*Pleuronectes platessa*) and Norway lobster (*Nephrops norvegicus*). The demersal landings (in volume) are mainly made by bottom trawlers although there has been an increase in the landings made by gillnetters and longliners in the last couple of years. Commercial landings are highly structured in space, and the Celtic sea is characterised by several type of mixed fisheries. The bottom trawlers are fishing on a mix of demersal species and mainly land species% subject to TACs including hake, haddock, whiting and anglerfish in the Central part of the Celtic sea and in the Channel. Area VIIe is characterized by a high diversity of gear including beamer (UK) and gillnetter implying diversity of landed species with the predominance of the other groups (which correspond to bivalves such as scallops and cephalopods mainly) and some gadoids patches south of Cornwall. Longliners and gillnetters target hake and monkfish along the continental slope.

It is essential to account for this multi-species dimension when analysis discards avoidance strategies to mitigate the adverse impact of full implementation of the landing obligation. Homogeneous spatial species assemblages of landings had been identified in the Celtic sea using integrating Vessel Monitoring Systems (VMS) and logbook data for France data on one side (Mateo et al 2017), and Irish data on the other side (Gerritsen & Lordan, 2011). The following step is therefore to identify is there are also homogeneous spatial species assemblages in discards. Such analysis would inform on some global patterns in discards composition but would also provide interesting information at fine spatial scale. Landings and discards clusters maps would then be confronted to investigate the link between landings and discards profile at some spatial scales. This analysis will be performed i) on national data to identify their specificities, as both countries have different dedicated fleets and TAC limitations constraints and ii) at international level (both data aggregated) to identified more global patterns and issues. In fine, results and maps need be discussed with fishermen to see if they can be useful in defining potential spatio-temporal fishing strategies to avoid unwanted discards.

Methods

Data compilation

Irish and French catches were extracted from national observer at sea data bases in ICES division 7b-k between 2010 and 2014. Sampled landings and discards are raised up to total at the haul level to provide weight discarded and landed by species. Data at fishing operation level were aggregated to a grid of 0.05° longitude*0.05°latitude (which corresponds to 3'*3'). French and Irish data were then combined to provide the first international landings and discards analysis in the area.

Data analysis

Multispecies maps

The objective of the analysis was to identify and describe areas with similar landings and discards profiles, using a combined set of multivariate methods (principal component analysis (PCA), hierarchical classification), as defined in Mateo et al 2017.

In the context of the landing obligation, analysis was carried out for species subjected to Total allowable Catches (TAC). The remaining species were grouped in the category "others". The TAC species in the area are : *Aphanopus carbo, Brosme brosme , Caproidae ,Coryphaenoides rupestris , Lepidorhombus spp., Lophiidae, Melanogrammus aeglefinus , Merlangius merlangus,Merluccius merluccius, Micromesistius poutassou, Molva dypterygia, Molva molva , Nephrops norvegicus , Pleuronectes platessa, Pollachius pollachius , Pollachius virens , Rajiformes , Clupea harengus, Scomber scombrus, Solea spp , Gadus morhua ,Sprattus sprattus , Squalus acanthias*. Large pelagic species, *Thunnus thynnus* and *Xiphias gladius*, were removed from the analysis. The other small pelagic TAC species were kept as they can contribute significantly to by catch and discards of the demersal fleets.

The sum of the retained landings and discards in weights per species in each grid cell (over the period 2010–2014) were converted into proportions. A centred and normed PCA was applied to this matrix. The statistical individuals (in rows) were the grid cells (3'*3' squares) and the variables (in columns) were the species. PCA reduces the dimensionality of data and identifies the main recurring species combinations that explain the greatest variation (Legendre and Legendre, 2012). Subsequent application of hierarchical cluster analysis (HCA) identifies groups of cells with similar species composition, using the first 10 components accumulating 40-60% of the explained inertia in the PCA (Deporte et al., 2012). The last components of the PCA were removed to keep down random fluctuations, thus improving the partitioning and homogeneity between and among classes (Legendre and Legendre, 2012).

A distance matrix was constructed by calculating the Euclidean distance between the cells in the selected components space. HCA was applied to this matrix, using Ward's minimum variance method, which consists in minimizing the total within-cluster variance. The most appropriate number of clusters (k) was chosen using the "elbow criterion", which looks at the percentage of variance explained as a function of the number of clusters. The spatial clusters were described according to the relative abundance for each species in clusters.

Spatial link between landings and discards species profiles

Observer at sea data allow to investigate the link between landings and discards species profile on a coherent spatial and temporal scale as both information are collected at the haul level.

The link between landings and discards species composition in each grid cell was identified by looking if cells attribute to one cluster in the landings analysis belongs to the same cluster in analysis based on discard data or if there are spread in various clusters.

Analyses were performed using R.3.1.1 (http://www.R-project.org/) and various packages such as (ade4 and mapplots).

Results

Given the abundant amount of information, the result section gives headlines and some example as illustration. More details on PCA/HCA analysis and cluster compositions are provided in the supplementary material. Analysis were also performed on a border range of species (species accounting for 90% in weight). The results of this extra analysis are reported in the supplementary and not presented herein. Results of species composition landings clusters are not presented as already presented in Mateo et al 2017 and Gerritsen et al 2012 (see also supplementary).

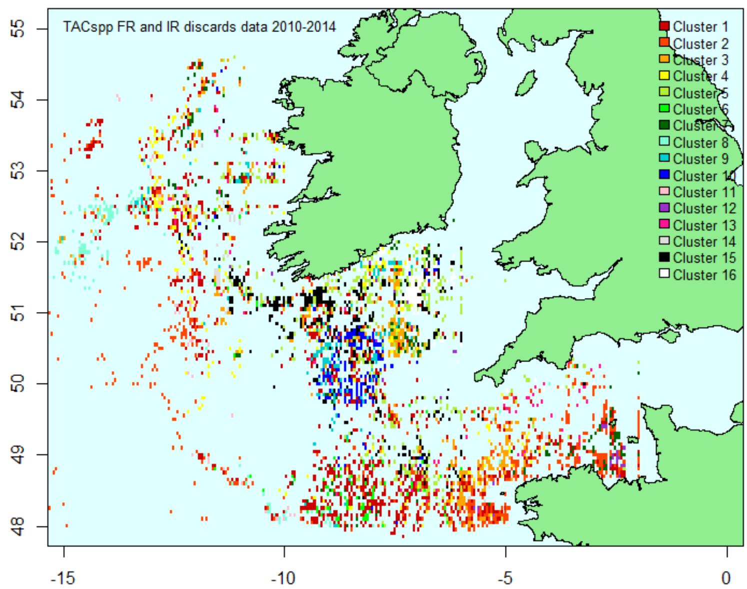
At the international level

Spatial pattern in discards species assemblages

Figure 1 illustrates the strong spatial structure in discards species assemblages based on the 28 species under TAC in ICES area VIIb-k. The relative abundance for each species in clusters (Table 1) can be used to identify species discards hotspots but also to understand the multi species components of discards in demersal fisheries. Indeed, even if some species dominate in certain cluster, most of them are made of a large number of species.

Cluster 16 in black shows a hotspot of whiting discards in a restricted area in VIIg. In these cells, discards of haddocks and herring are also observed (Figure 3 and Table 1). Discards of cods are dominant in two clusters (cluster 15 and cluster 3) along with haddock in the central Celtic sea and south Ireland on one side and with hake and ling in the Irish Sea, central Celtic sea and in division VIIb on the other side. These three clusters illustrate the strong technical interaction occurring in these highly mixed fisheries, with strong proportion of both discard of whiting, haddock and cod in the same location. Discards of nephrops are restricted to the nephrops habitat and fishing ground (cluster 12, figure 3 and table 1) and associated to discard of dogfish. Clusters 1 and 2 are composed of many species with no dominance except by the other group (non TAC species).

A very restrictive number of cells characterized cluster 12 (in dark orchid) which is characterized by a relatively high proportion of discards of flatfish mainly sole and plaice along the northern Britany coast and in the Central Celtic Sea. The main area seems to concentrate discards of rajaiidae (cluster 7 in dark green): the western channel, a restricted area in the central Celtic sea and some areas in division VIIb.



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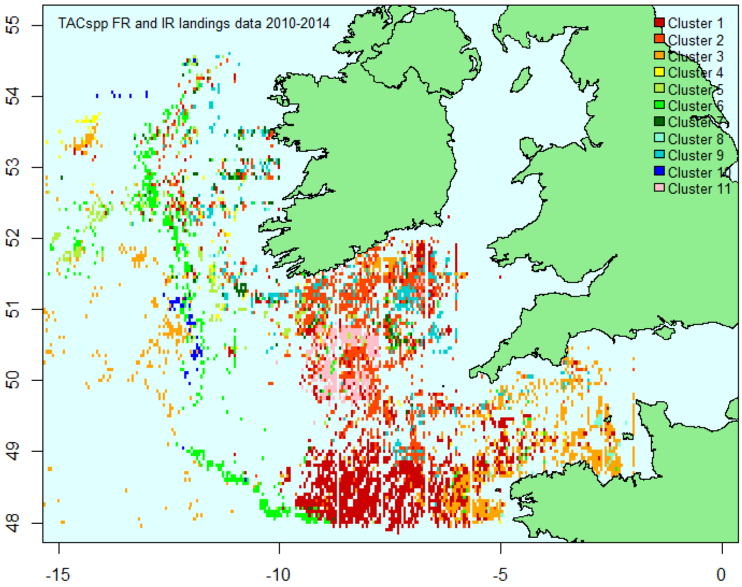

Figure 1. Clusters maps of international discards (top) and landings (bottom). The same colour code was assigned to each 3'*3' square belonging to the same cluster. Species selection: TAC species.

Table 1. The relative abundance for each species in clusters. TAC species and international data set

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Aphanopus.carbo	0,001	0,000	0,000	0,003	0,000	0,000	0,000	0,018	0,000	0,000	0,978	0,000	0,000	0,000	0,000	0,000
Brosme.brosme	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,998	0,000	0,000	0,000	0,000	0,000	0,002	0,000
Caproidae	0,044	0,001	0,002	0,014	0,009	0,808	0,003	0,014	0,026	0,031	0,007	0,000	0,007	0,005	0,027	0,001
Clupea.harengus	0,007	0,003	0,003	0,001	0,099	0,001	0,004	0,001	0,028	0,023	0,000	0,009	0,030	0,000	0,023	0,767
Coryphaenoides.rupestris	0,009	0,000	0,005	0,011	0,000	0,002	0,000	0,011	0,008	0,000	0,951	0,000	0,000	0,000	0,001	0,000
Gadus.morhua	0,028	0,002	0,188	0,016	0,049	0,007	0,012	0,012	0,064	0,106	0,000	0,032	0,007	0,027	0,379	0,071
Lepidorhombus.spp	0,061	0,002	0,035	0,071	0,036	0,056	0,037	0,095	0,390	0,081	0,047	0,025	0,022	0,001	0,028	0,014
Lophiidae	0,036	0,006	0,081	0,438	0,036	0,026	0,019	0,013	0,071	0,035	0,147	0,049	0,007	0,003	0,022	0,012
Melanogrammus.aeglefinus	0,038	0,001	0,048	0,031	0,166	0,042	0,035	0,005	0,040	0,065	0,000	0,037	0,033	0,008	0,299	0,151
Merlangius.merlangus	0,014	0,002	0,021	0,007	0,115	0,011	0,014	0,008	0,017	0,030	0,000	0,062	0,056	0,003	0,085	0,555
Merluccius.merluccius	0,037	0,001	0,187	0,061	0,027	0,006	0,015	0,127	0,095	0,057	0,039	0,017	0,011	0,223	0,074	0,024
Micromesistius.poutassou	0,022	0,002	0,030	0,009	0,008	0,005	0,005	0,712	0,071	0,050	0,017	0,008	0,011	0,000	0,020	0,029
Molva.dypterygia	0,009	0,001	0,001	0,002	0,000	0,004	0,000	0,840	0,005	0,000	0,138	0,000	0,000	0,000	0,000	0,000
Molva.molva	0,011	0,001	0,565	0,050	0,024	0,013	0,049	0,024	0,062	0,006	0,006	0,012	0,005	0,118	0,037	0,017
Nephrops.norvegicus	0,008	0,000	0,004	0,002	0,002	0,000	0,000	0,001	0,037	0,896	0,000	0,029	0,000	0,000	0,011	0,009
OTH	0,103	0,141	0,055	0,052	0,068	0,043	0,048	0,090	0,049	0,042	0,085	0,067	0,051	0,035	0,031	0,039
Pleuronectes.platessa	0,009	0,001	0,012	0,015	0,158	0,004	0,030	0,001	0,030	0,010	0,000	0,619	0,012	0,003	0,039	0,059
Pollachius.pollachius	0,010	0,001	0,105	0,006	0,001	0,000	0,001	0,001	0,002	0,000	0,000	0,009	0,000	0,860	0,003	0,000
Pollachius.virens	0,001	0,000	0,010	0,004	0,001	0,008	0,001	0,002	0,006	0,001	0,000	0,000	0,000	0,964	0,002	0,000
Rajiformes	0,045	0,005	0,085	0,023	0,040	0,049	0,494	0,006	0,065	0,013	0,008	0,116	0,020	0,003	0,012	0,016
Scomber.scombrus	0,024	0,003	0,021	0,006	0,009	0,020	0,006	0,003	0,013	0,004	0,012	0,004	0,802	0,048	0,006	0,020
Solea.spp	0,013	0,001	0,001	0,002	0,021	0,000	0,005	0,000	0,000	0,008	0,000	0,928	0,012	0,000	0,001	0,007
Sprattus.sprattus	0,004	0,000	0,001	0,000	0,005	0,000	0,000	0,001	0,007	0,000	0,000	0,000	0,949	0,000	0,002	0,031
Squalus.acanthias	0,013	0,000	0,008	0,008	0,007	0,007	0,008	0,003	0,055	0,835	0,000	0,000	0,012	0,014	0,021	0,010

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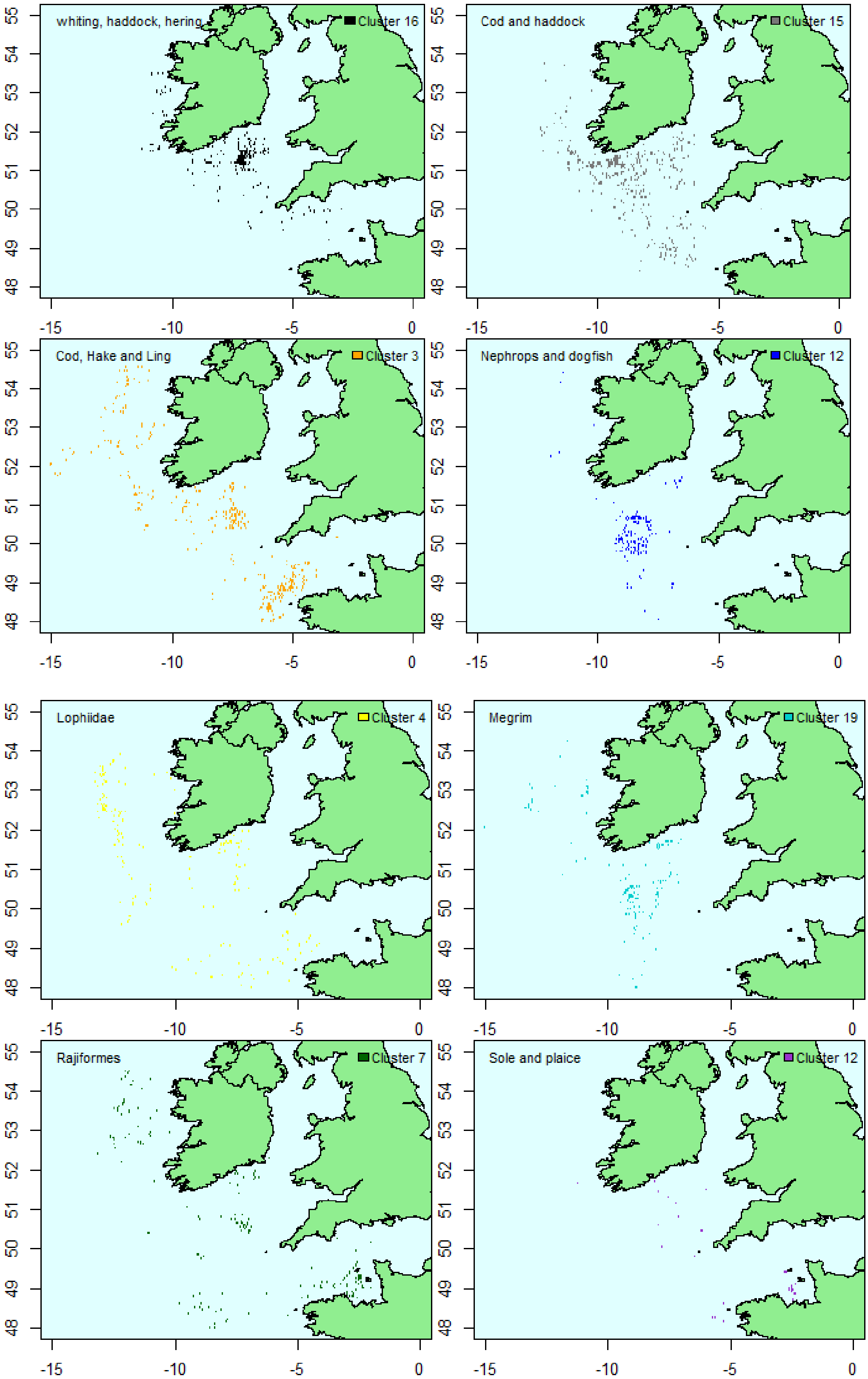


Figure 2. Detailed cluster maps based on French and Irish data a) b) c) and d)

It is not easy to compare the two maps as spatial coverage of discard observation is much smaller than landings dataset. However, when looking at both landings and discards clusters maps (Figure

1) one can spot similarities and discrepancies. For example, landings profile in the south division VIIh seems relatively homogeneous (one majority cluster, cluster 1 in red), while it hosts a diversity of discards clusters. On the contrary, well define feature in landings maps in the central Celtic sea can also be found on the discards maps.

The pie plots in Figure 3 help in quantifying the link between landings and discards species profile by expressing how cells of the same cluster in landings are clustered in terms of discards. On the general trend, we can say that there is weak to medium spatial correlation between landings and discards clusters. No perfect match were found, the best situation is found where around 50% of the 3'*3' cells of the same cluster based on landings data are grouped in the same cluster of discards, the remaining cells are spread in various discards clusters. This is the case for 35% of the landings cluster. For four clusters, the dominant species are consistent between landings discards cluster meaning that there is a clear spatial link between landings and discards. One can mention landing cluster 4 and discard cluster 14 both characterized by important proportion of Pollack and saithe; cluster 10 and discard clusters 11 both characterized by important proportion of ling; landing cluster 11 and discard cluster 10 both characterized by important proportion of nephrops and cods and landings cluster 9 and discard cluster 15 and 16 both characterized by whiting and haddock (with little amount of cod). Another interesting feature is than many clusters of landings (cluster 10, 3, 1, 7 and 8) have important number cell gathered in discards cluster characterized by the dominance of the other groups (Non Tac species, discard cluster 1 and 2).

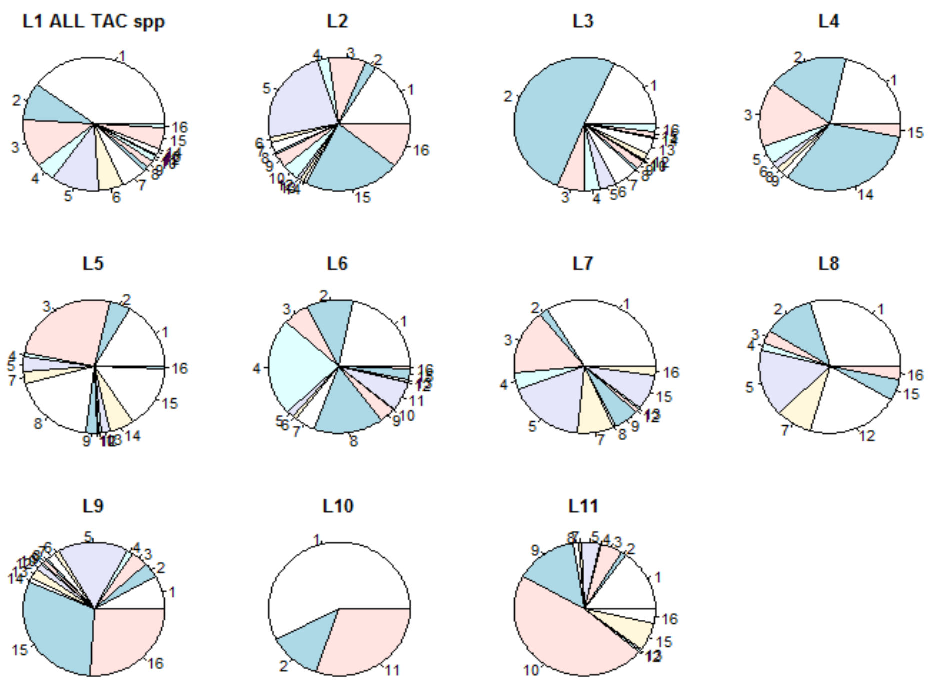
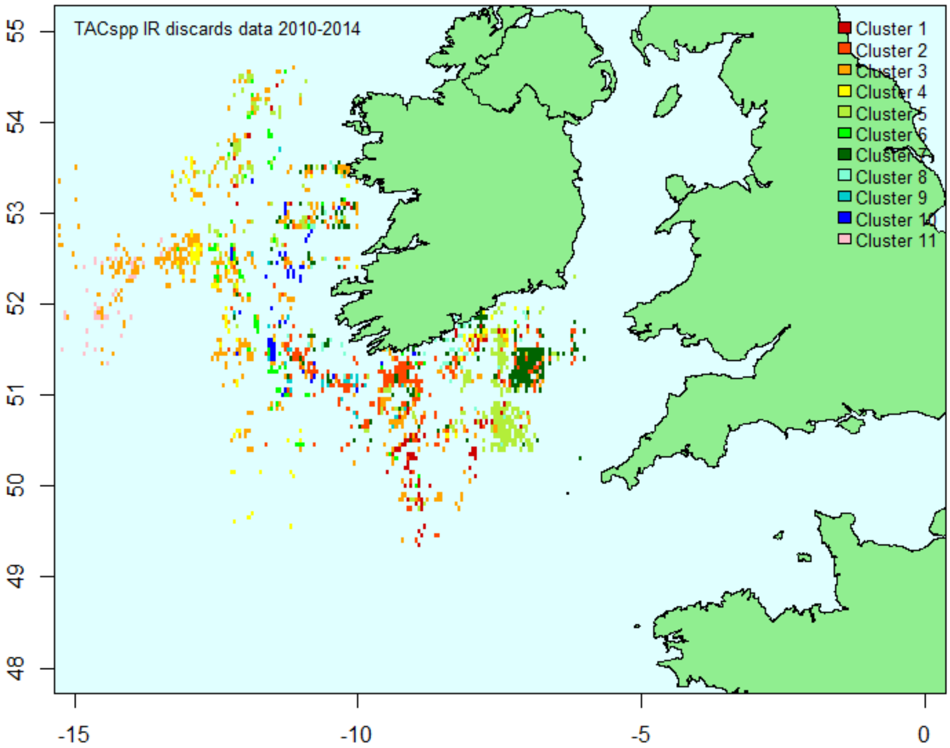


Figure 3. Pie plots illustrating how the cells locate in the same cluster of landings are classified in terms of discards. TAC species and international data set

At the national level

Spatial pattern in discards species assemblages



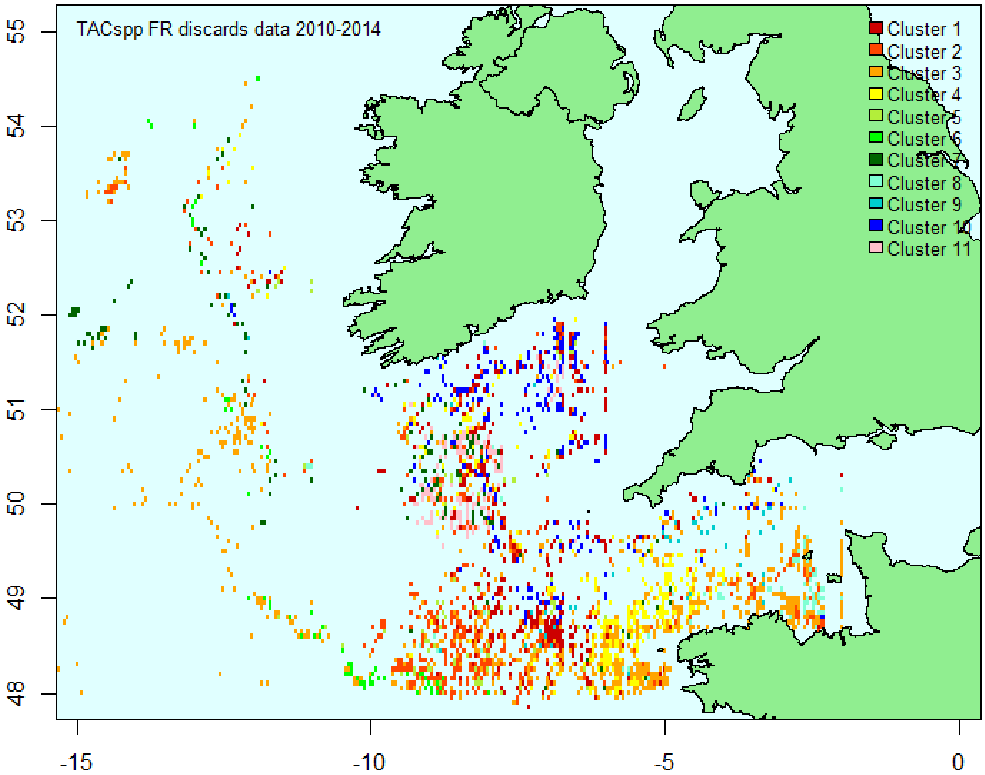


Figure 4. Clusters maps of Irish discards (top) and French discards (bottom). The same colour code was assigned to each 3'*3' square belonging to the same cluster. TAC species

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When analysis the two data set separately, there is relatively little spatial overlap between the French and Irish discard maps, except in the central Celtic sea and along the slope in west of Ireland (Figure 4). The Irish fleets do not visit the south VIIg while the French fleets is fishing less in VIIb. Detailed description of species composition in each cluster per country can be found in the supplementary materiel. More surprisingly, on the overlapping area of the central part of the Celtic sea, differences in spatial distribution of clusters are also observed.

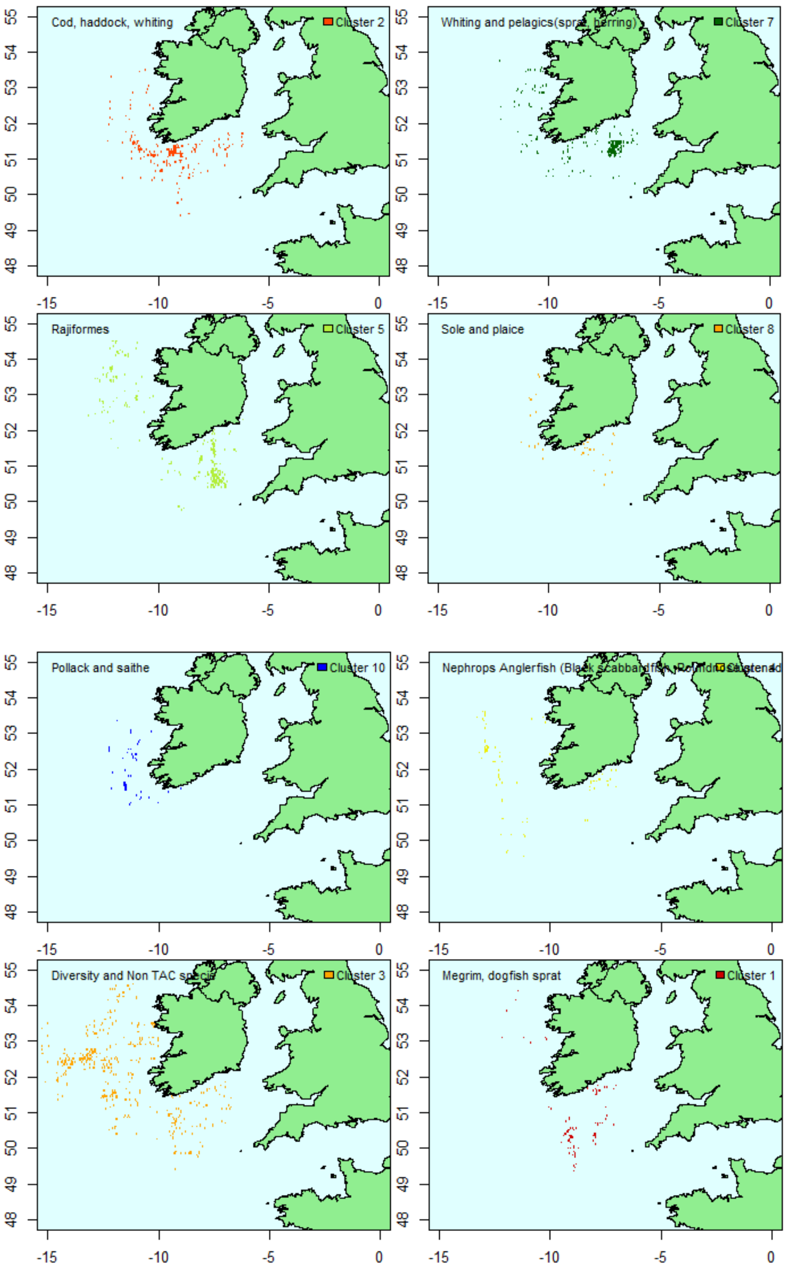

Figure 5. Detailed cluster maps based on Irish data a) b) c) and d)

Irish data show three distinct discard patches on the south coast comprising whiting and pelagics (sprat and mackerel, in dark green cluster 7, figure 4 and 5), rays in light green (cluster 5) and cod, haddock whiting in orange-red (cluster 2). In the same area, these patches are less clear on the French discards maps although cluster 10 is characterized by the main gadoids species (cod,

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haddock, and writing) and plaice (figure 4 and 6). The French map reports important discards of nephrops , megrim and cod 50°N/-9°O (cluster 11, pink) and associated discards of haddock and whiting in area VIIh (cluster 1, figure 4 and6). Discards in the channel and south VIIh seems to be very diverse with cluster 2, 3 and 4 not characterized by megrim and anglerfish, non TAC species and ling, Pollack and cod respectively.

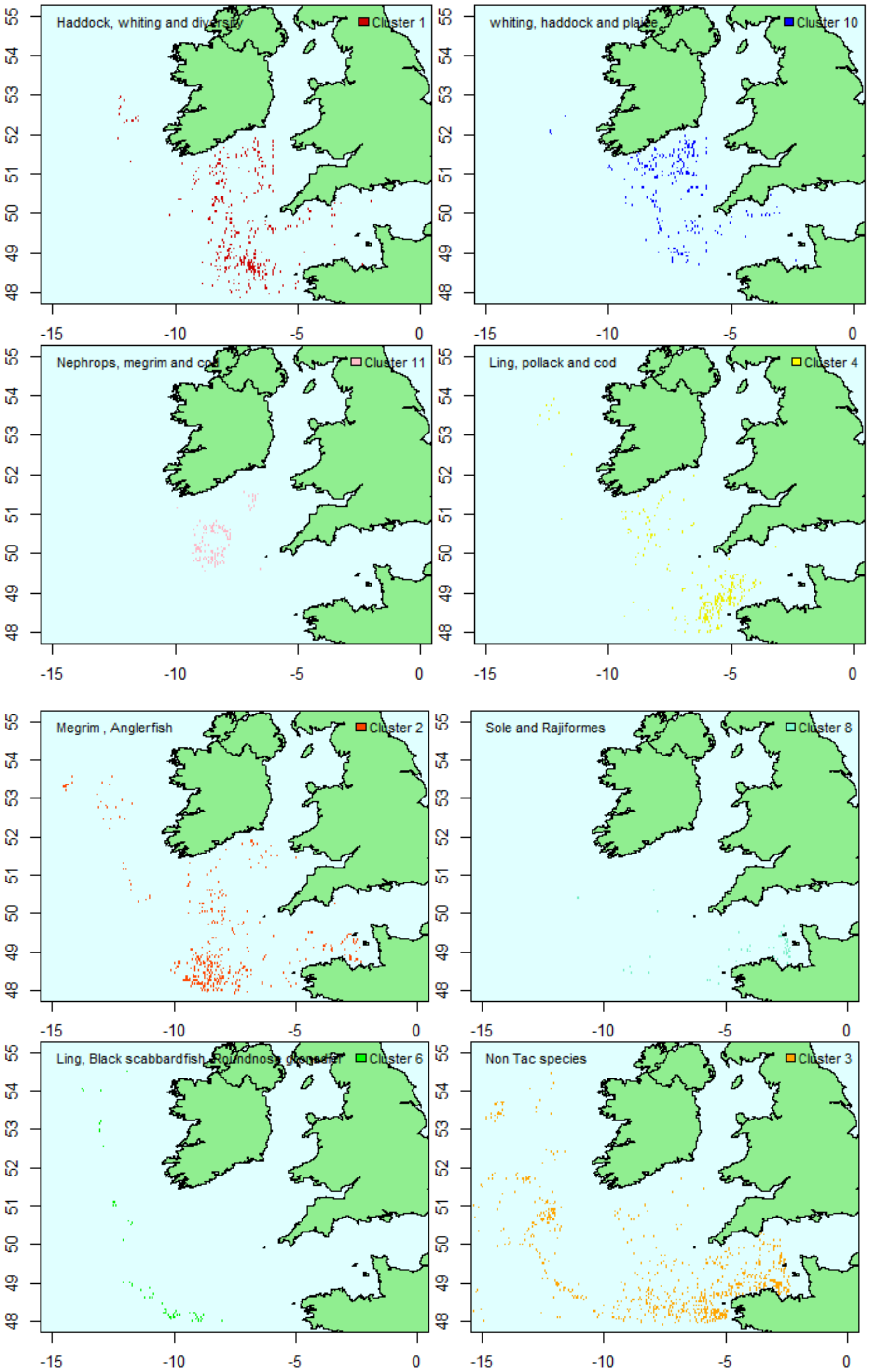

Figure 6. Detailed cluster maps based on French data a) b) c) and d)

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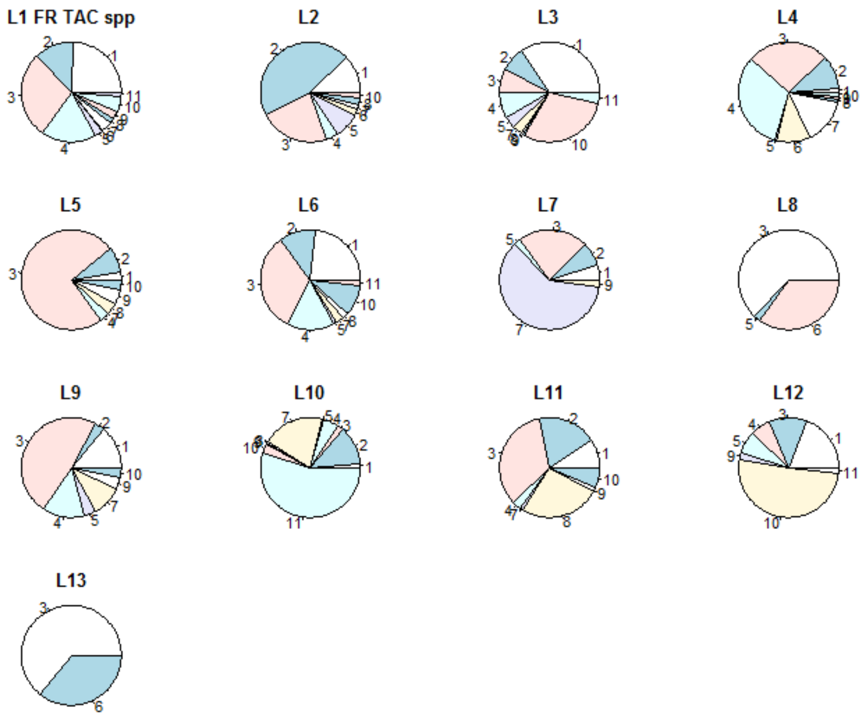
Spatial links between landings and discards species profile

When analysing the two data sets separately no perfect match are observed.

When focusing on the Irish observer at sea database, the best case is when 50 to 75% cell in a landing cluster are grouped together in a discard cluster (figure 7). This strong spatial link between landings and discards are observed for whiting (landing cluster 13 and discard cluster 7, figure 7), pollack and saithe (landing cluster 12 and discard cluster 10), rajiformes (landing cluster 8 and discard cluster 5, figure 7) and whiting and haddock and cod (landing cluster 5 and discard cluster 2). On the contrary several landings including the ones characterized by important proportion of hake, megrim and ling are clustered in discard cluster 3 characterized by the non Tac species group indicating week spatial overlap between landings and discards.

When focusing on the French observer at sea data base strong spatial correlation appears between landings and discards of nephrops, cod and megrim (landing cluster 10 and discard cluster 11, figure 7), hake (landing cluster 7 and discard cluster 7) and gadoids. When targeting whiting and haddock (landing cluster 12) there is a high probability of discarding whiting and haddock but also plaice (discard cluster 10) and when targeting haddock and cod (landing cluster 3) there is a high probability of discarding whiting and haddock (discard cluster 1). Discard cluster 3 represented by non TAC species is widely distributed and strongly correlated with landing cluster 13, 5 and 8.



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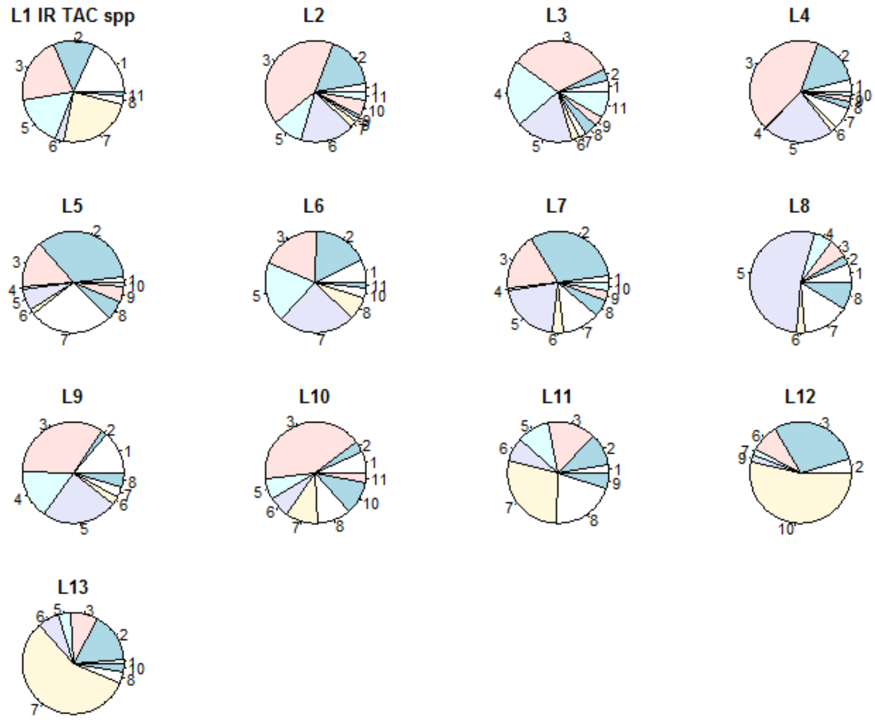

Figure 7 Pie charts illustrating how the cells locate in the same cluster of landings are classified in terms of discards. French data on the length and Irish data on the right. TAC species and international data set.

Discussion

When analysing maps of the landings available on the online atlas produced by Discardless project based on STECF data, one can spot the strong spatial segregation in effort by countries. As such it is necessary to integrate data of the different countries operating in the Celtic sea to draw a global and realistic picture. This study is the first fine scale spatial analysis combining landings and discards data coming from the two main country fishing in the area: France and Ireland. In that sense it highlights both the difficulty of long lasting data sharing process and the strong scientific interest of such meta-analysis. Unfortunately, this analysis suffers from the lack of the other contributors in that area: UK, Belgium, which might bias some stock level view for flatfish species especially, and Spain for the deeper area along the slope.

Matéo et al 2017 and Gerritsen & Lordan 2012 have already highlighted the strong spatial structure in landings profiles in the area and the highly mixed nature of these demersal fisheries. Our analysis show there is also a strong spatial structure in discards species assemblage with several distinct patches especially in the Celtic sea. Many of them correspond to well-known fishing grounds. Some clusters drawn condensed patches informing on homogenous discards assemblages in specifics areas. On the other hand, species assemblages of discards might be similar in cell quite far away from each other illustrating on the contrary more widely distributed species assemblages. The diversity of habitat that can be found in the Celtic sea could explain some of the spatial structure in landings and discards.

Analysis of the joined data set bring interesting view at the stock levels, on a complementary approach it is also very interesting to look at the maps derived for both country separately as the fishing grounds are different as well as metiers strategies and TAC limitations. The French fishery for example, is very limited by boarfish *Capros aper* as France does not have any quota for that species. As a consequence all catches are discarded. Under the full implementation of the LO, this catch will need to be landed which can many cases can represented important tonnage as this species is caught in big schools that can go up to several tons. Cluster 6, characterized by a high proportion of this species, and is spread out a bit everywhere on the maps. In this case, one recommendation would be to find a selectivity design that allowed strong escapement rate of that species while limiting potential commercials losses of target species.

Our results indicate that on a multi-species point of view there is little spatial correlation between landings and discards profiles at small spatial scale. One conclusion drawn from this work is that it would be challenging to infer on multispecies discards composition based on spatial landings data. Many hypothesis can be suggested to explained such results. The data analysed aggregate data from various gears including different mesh sizes that don't bring at the surface the same proportion and size class of species, metiers implying that the target species and as a consequence the discard portion may differ between two hauls performed at the same place, discards type (undersized discard versus high grading or unwanted catches) and season which unreflect potential succession of species and size classes through the year. On the contrary, when we look at the species level and especially at national scale higher spatial correlations were found. Hotspots of discard of commercially important species such as whiting, nephrops, flatfish and hake are highly correlated to hotspots of landings. In this case, improvement of selectivity gear might be a better option to comply with the LO than a modification of spatio temporal allocation of effort.

References

Gerritsen, H. and C. Lordan (2011). Integrating vessel monitoring systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. ICES Journal of Marine Science 68(1): 245-252.

Mateo, M., L. Pawlowski, & Robert, M. (2017). Highly mixed fisheries: fine-scale spatial patterns in retained catches of French fisheries in the Celtic Sea. ICES Journal of Marine Science 74(1): 91-101.

Chapter 2. Spatial management of discards: multispecies clustering analysis in Irish demersal fisheries in the Celtic Sea.

By: Marianne Robert & Lionel Pawlowski - IFREMER, and Julia Calderwood & David Reid - Marine Institute

Celtic Sea case study

Introduction & Objectives

The objective of this study was to characterize discarding in a multi-species context and at fine spatial scale. We aimed to make use of information from more than one nation in the analysis and so focused on the central part of the Celtic Sea where fishing activity from France and Ireland overlap. This is reported in Chapter 1. The purpose of this characterization was to take a closer study of the Irish information alone, recognising that discarding will often have different patterns of drivers for different MS fleets. We aim to make use of the information to help avoid unwanted catches in such a mixed fishery. Two of the main causes of discards are shortage of quota, leading to discarding of landable fish, and fish being below the minimum conservation reference size. Our analysis looked at both categories separately to account for differences in the cause of discards and to identify potential avoidance solutions. Comparison of the spatial maps produced will allow assessment of whether these two discards categories occurred in the same location.

Methods and Materials

Data sources

The onboard observer programme is part of the European founded Data Collection Framework (DCF, EC 2008) used as a basis for the assessment and management of EU fisheries. DCF data provides data on catch composition, as well as the characteristics and condition of the fishing operation. It is also the only source of information on discarding practices at sea. Based on national sampling schemes, observers embark on commercial fishing vessels and report the geographical positions, gear, mesh size, fishing time and target species of all fishing operations (FOs). Among them some FOs are sampled in the sense that all species of fish and commercial invertebrates from the landed and discarded part are identified, counted, weighed and measured (with subsampling performed when necessary).

We extracted data for 2010-2014 from the Irish observer at sea database for the central Celtic Sea ecoregion (49-52°N ; 5-11°W). The data were pooled across all years due to the limited scale of the observer programmes. We focused our analysis on the main TAC managed species targeted in the area and for which Minimum Conservation Reference Sizes (MCRS) are defined in European legislation for the Celtic Sea. The study species and their MCRS are listed in table 1. We did not include *Molva dypterygia*, *Nephrops norveigicus, Pollachius virens* and *Theragra chalcogramma* in the analysis, as while these are TAC species with MCRS, there were only small numbers recorded as discards in the Irish dataset.

Table 1. Minimum conservation reference sizes for TAC species caught in the Celtic Sea

Species	MCRS (cm)
Gadus morhua	35
Lepidorhombus whiffiagonis	20
Melanogrammus aeglefinus	30
Merlangius merlangus	27
Merluccius merluccius	27
Molva molva	63
Pleuronectes platessa	27
Solea solea	24

Analysis Methods

Discards maps

The analysis was carried out using a combined set of multivariate methods as described in Mateo et al 2016. Each fishing operation was attributed to a grid cell of 3'*3' (which corresponds approximately to a grid of 0.05° longitude*0.05°latitude) and the sum of discard quantities per species in each grid cell (over the period 2010–2014) were converted into proportions. As suggested by Deporte et al., 2012, a centred and normalised PCA was applied to this matrix prior to hierarchical cluster analysis (HCA using Ward's minimum variance method). This helps in reducing the dimensionality of the data and identifies the main recurring species combinations that explain the greatest variation (Legendre and Legendre, 2012). Only the first 6 axes of the PCA (accounting for more than 70% of the explained inertia) were kept for subsequent application of HCA to reduce random fluctuations. This was done to improve the partitioning and homogeneity between and among classes (Legendre and Legendre, 2012). The most appropriate number of clusters (k) was chosen using the "elbow criterion", which looks at the percentage of variance explained as a function of the number of clusters. The spatial clusters were described according to the relative abundance for each species in clusters. Discards maps were derived from two data sets for undersize and oversize.

Link between under and over size discards clusters

The spatial link between over and under MCRS discards of species is investigated by comparing how the classification of cells within each cluster of undersized data compares to the corresponding cell in the over MCRS data set. This highlights whether similar clusters of species are identified for both under and over MCRS discards or if species are spread between different clusters in the two data sets.

Analyses were performed using the ade4, labdv and mapplots packages available for R.3.3.3 (http://www.R-project.org/).

Results

Discard maps

The most important species discarded in terms of tonnage for Ireland in the area studied was haddock, followed by whiting, hake, cod, megrim and plaice. The percentage of undersize discards in the total shows a different picture. Ling has a very high percentage of undersize discards (64%), followed by haddock (51%), plaice (42%), cod (31%), whiting (20%) and hake (17%). For the remaining species less than 5% of those discarded were under MCRS.

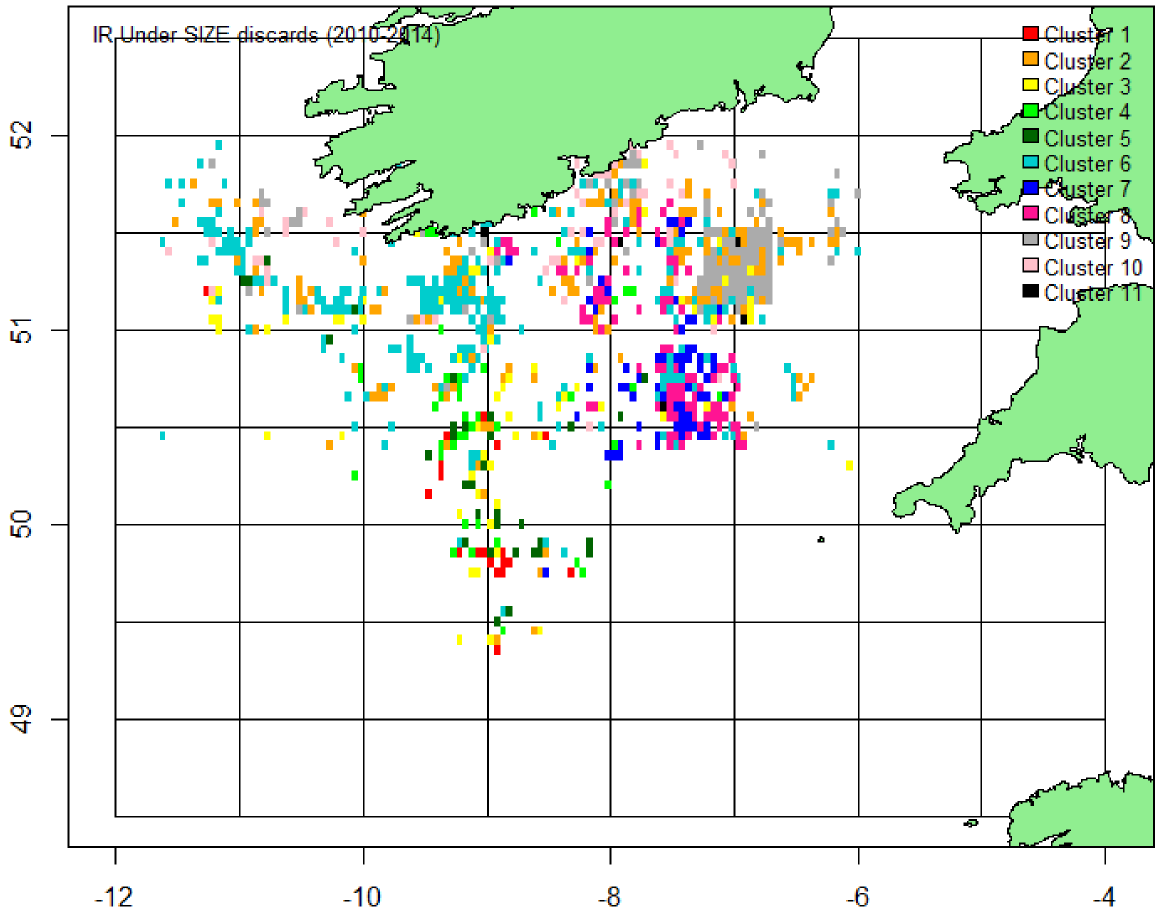

Figure 1. Discard cluster map of <MCRS fish based on Irish observer at sea data between 2010 and 2014.

Table 1. Under Size discard clusters based on Irish data by cluster

	1	2	3	4	5	6	7	8	9	10	11
Gadus.morhua	0,015	0,071	0,563	0,005	0,149	0,028	0,023	0,075	0,042	0,010	0,018
Lepidorhombus.whiffiagonis	0,726	0,007	0,039	0,007	0,199	0,002	0,006	0,001	0,004	0,005	0,003
Melanogrammus.aeglefinus	0,005	0,182	0,050	0,006	0,071	0,261	0,044	0,145	0,103	0,026	0,106
Merlangius.merlangus	0,009	0,097	0,045	0,024	0,014	0,016	0,010	0,018	0,559	0,043	0,165
Merluccius.merluccius	0,084	0,041	0,020	0,519	0,173	0,006	0,043	0,015	0,041	0,034	0,025
Molva.molva	0,000	0,012	0,009	0,004	0,000	0,004	0,613	0,253	0,005	0,003	0,097
Pleuronectes.platessa	0,003	0,073	0,029	0,015	0,027	0,012	0,015	0,049	0,021	0,577	0,179
Solea.solea	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,012	0,006	0,981

The first point to note from the cluster analysis, is that seven of the eight species (excluding haddock) were found predominantly (>50%) in one cluster each, suggesting that the <MCRS discards of these species tend to be caught separately. However, the map in figure 1 shows that the cells occupied by these clusters are often widely distributed in space. This is particularly the case for cod for which 56% of the <MCRS discards were in cluster 3 and were spread out across the entire study area (yellow cells in figure 1). On the other hand, 56% of <MCRS whiting discards

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were in cluster 9 (in grey), and there is a clear patch of these cells in the middle of the study area. The only species where the bulk of the <MCRS discards were not found in one cluster was haddock, which was found spread over five clusters, with the highest quantities found in cluster 6 in light blue (26%) and cluster 2 in orange (18%), and in smaller quantities in clusters 8, 9 and 11.

Some clusters were characterized by a more multispecies assemblage. Cluster 9 in grey for example shows highlights the co-occurrence of undersize discards of whiting, haddock. Cluster 5 (in dark green) has contributions from cod, megrim and hake, and mainly in the south-west of the area, while cluster 8 (in purple) shows haddock and ling from the south coast of Ireland to the central Celtic sea.

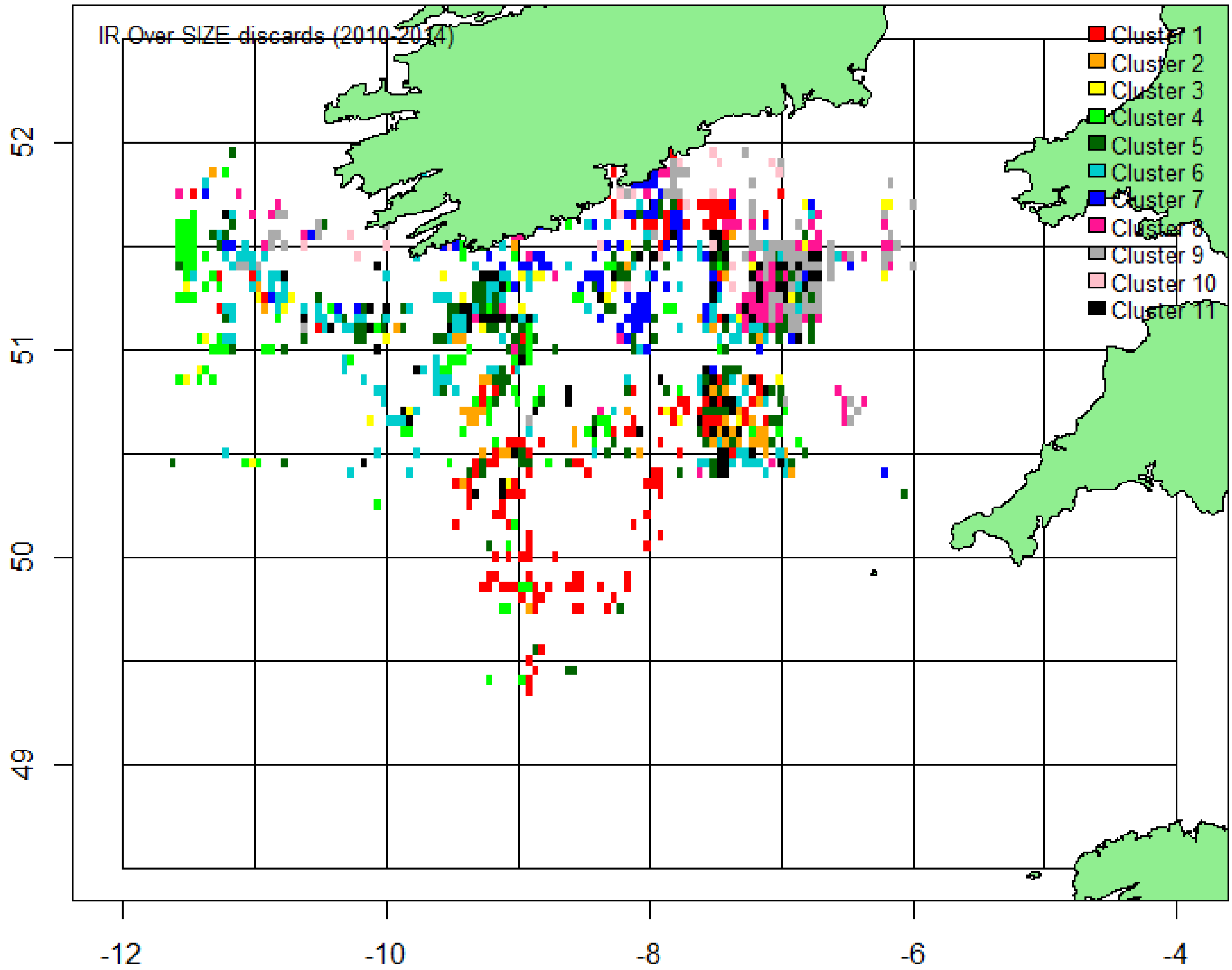

Figure 2. Discard cluster map of >MCRS fish based on Irish observer at sea data between 2010 and 2014.

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Table 2. >MCRS discard clusters based on Irish data

	1	2	3	4	5	6	7	8	9	10	11
Gadus.morhua	0,020	0,021	0,500	0,079	0,040	0,036	0,038	0,015	0,024	0,006	0,221
Lepidorhombus.whiffiagonis	0,441	0,197	0,034	0,031	0,094	0,040	0,041	0,017	0,008	0,036	0,060
Melanogrammus.aeglefinus	0,021	0,162	0,034	0,012	0,093	0,251	0,111	0,148	0,040	0,020	0,109
Merlangius.merlangus	0,007	0,019	0,031	0,012	0,083	0,033	0,098	0,227	0,381	0,030	0,080
Merluccius.merluccius	0,041	0,042	0,082	0,425	0,171	0,026	0,056	0,013	0,022	0,055	0,067
Molva.molva	0,055	0,008	0,754	0,002	0,005	0,019	0,008	0,000	0,000	0,000	0,149
Pleuronectes.platessa	0,031	0,022	0,010	0,008	0,023	0,019	0,219	0,017	0,009	0,614	0,028
Solea.solea	0,004	0,005	0,023	0,000	0,001	0,000	0,011	0,007	0,083	0,082	0,784

Unlike the case for the <MCRS discards, the pattern is less clear for the >MCRS fish. Two clusters were characterized by a single dominant (>50%) species (cluster 10 – plaice, and 11-sole). Both showed little obvious spatial pattern. Cluster 3 also had more than 50% of cod, and of ling in the same cluster, again with little evidence of spatial pattern. Some of the other clusters were dominated by a single species. For instance cluster 1, dominated by megrim, and spatially clustered in the south west and north east parts of the area. Cluster 4, dominated by hake was prominent along the shelf break, but also scattered across the area. Cluster 9, dominated by whiting, was concentrated in the Nephrops grounds, and up to the coast in an area bound by 51-52oN and 6-8oW. Cluster 8, characterized by both haddock and whiting was found mainly in the same area. As with the <MCRS case, the >MCRS haddock were identified across a number of clusters.

<u>Link between < and > MCRS discards</u>

Observer at sea data allow us to investigate the fine scale spatial link between discards that are over and under MCRS as information were collected at the haul level.

It is possible to identify some similarities between the maps for over and under MCRS fish, although generally there was little obvious match. Obvious features in the <MCRS discard map (Figure 1), such as cluster 9 in the central Celtic sea, can also be found on the >MCRS map (Figure 2). This would tend to suggest that both categories of whiting were fished and subsequently discarded in the same area. The relationship between the clusters for the two size categories can be explored further in the pie charts in Figure 3. For example, and to illustrate, the pie chart for cluster 1 shows that more than 90% of the cells in <MCRS cluster 1, were also in the same cluster for >MCRS discards. This indicates that both categories of megrim were fished and discarded in the same area. Other matches include; for hake in <MCRS C4 and >MCRS C4; for megrim in <MCRS C5 and >MCRS C1; for haddock in <MCRS C6 and >MCRS C6; and for plaice in <MCRS C10 and >MCRS C10. This indicates some support for the idea that both under and over MCRS fish were, to some extent, caught in same places e.g. for whiting, hake, megrim, haddock and plaice. However, for most of these species, the spatial overlap was relatively small (<50%). Haddock <MCRS discards were found in many of the clusters and this also true for the >MCRS discards. Sole in particular were discarded as <MCRS (C11) in quite different areas to the >MCRS fish.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633680

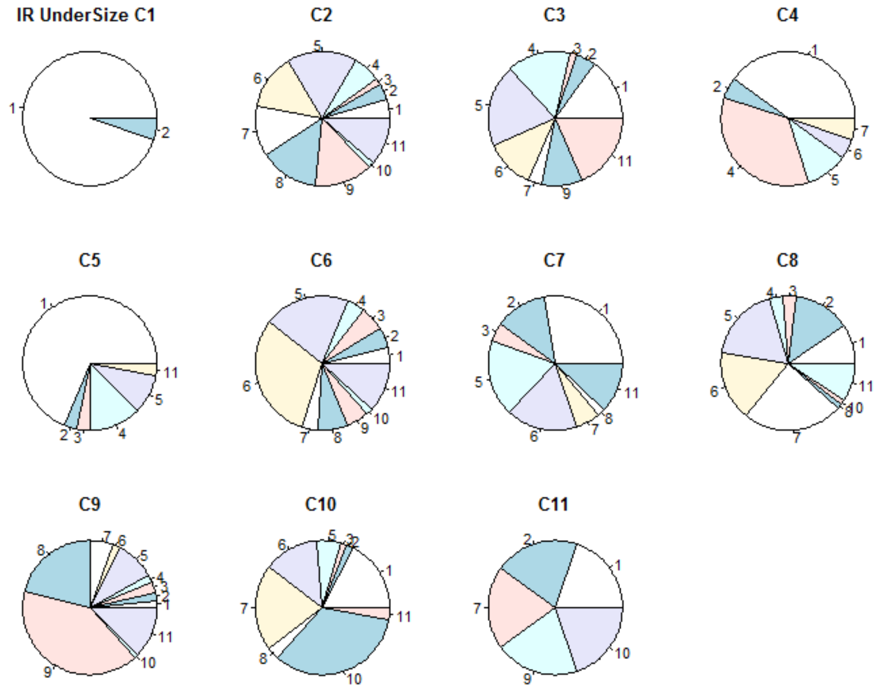

Figure 3 Pie charts illustrating how the cells locate in the same cluster of undersize discards are classified in terms of oversize discards, based on Irish data

Discussion

The core aim of the study was to use observer data to identify where commercial fish were discarded and with what other species. It also sought to identify the synchrony or lack of it for discards above and below MCRS. It provides a global overview of discard locations at species levels for both under and over MCRS discards in the central region of the Celtic Sea.

The causes of discarding are very diverse, from catches of small juveniles to high grading due to quota constraints and may be seen as the consequence of several factors including stock (e.g. seasonality, spatial aggregation), country (e.g quota share of the TAC), fleet or vessel levels (e.g. quota allocation at the vessel level, gear selectivity, fishing strategy) and market drivers (demand and price for fish) (Catchpole et al 2014, Morandeau et al 2014). What is clear, is that discarding of fish above and below the MCRS will have very different reasons and drivers. Therefore it is important to consider these two categories separately.

Discarding of undersized fish has, in the past, largely been driven by the restrictions on landing commercial fish below Minimum Landing Size, or now, MCRS. So it was illegal to land these fish, and they had to be discarded. It has been estimated that 11% (44,000 t) of the total catches of EU countries from which data were available are of fish under MCRS (Catchpole et al 2017). Under the LO, it is now required to land these fish, although not to sell them into the direct human consumption market. In either case, there is an incentive not to catch these fish. Classically, this has generally led to the use of more size selective gears (Catchpole et al 2017, Vogel et al 2017). However, it is impossible to design gears with so called "knife edge" selectivity, where all fish of one species are retained over MCRS, and the rest escape. So there will always be a trade-off, the more undersize fish we allow to escape, the more over MCRS fish also escape, with economic consequences. This is made even more complicated when we have different species with different MCRS and different catchability and behavior in the net. So while selectivity is part of the solution it can never solve it completely. A second possibility is to avoid catching these fish in the first place, and knowing where they are most likely to be caught is a key tool to achieving this. The present study has shown that there are clusters of discard events dominated by a single species <MCRS, and that, at least in some cases these can be delineated geographically.

Avoiding catches of <MCRS by avoiding "hot spots" of these fish may appear simple for a single species, but is more complex in a mixed fishery. We have shown, for instance that <MCRS whiting have a discrete pattern in space and in a single discarding cluster. But other species, most notably haddock show quite the opposite, occurring in many of the clusters and across the area. Figure 1 suggests that there was discarding of <MCRS fish of one more species throughout the study area. Choosing where to fish to avoid catching these fish may then be very difficult. But the mapping may help reduce the likelihood of catching these fish, while not eliminating it.

The exercise may seem simple for a single stock approach with well defined and similar hot spots for undersize and oversize discards such as whiting but may not be that straightforward when including other species with distinct undersize and oversize discard patterns. Trade-offs again have to be found to take account of spatial mismatches.

The position is different again for >MCRS discards. Prior to the implementation of the LO, any over quota fish had to be discarded. With LO implementation, this is not possible, and leads to the "choke" problem (Schrope 2010), where once the quota is reached on one species in a mixed fishery, fishing has to stop to avoid any over-quota catches. Again, gear based selectivity measures may represent part of the solution (Fauconnet & Rochet 2016), but only part. The design of gears to achieve species selectivity, is possible to some extent (Broadhurst 2008), but it is difficult to provide the specific proportions that would be needed to avoid choke. In addition, there will likely be trade-offs as with size selectivity, where improving the selectivity of one species will reduce legitimate catches of another.

As with <MCRS fish, identification of where the choke species was abundant, and then avoiding it has the potential to mitigate the choke problem to some extent. The mapping of where discards occur, and where they are dominated by a particular species could then be a valuable additional tool. The findings from this study suggest that there may be some potential in this approach. For instance we identifies clear clusters dominated by megrim, hake and whiting. The megrim cluster showed two areas of concentration, "hot spots", and whiting also showed two, different, hot spots.

The hake cluster while prominent at the shelf break was also found scattered across the shelf. Other species, such as plaice and sole, while being found in a single cluster each, were spatially scattered. Haddock was found in several clusters, and also well scattered. To some extent, it may also be possible to use the cluster maps to identify where a given species might be caught, without high levels of a choke species.

The final complexity is that, under the LO, fishermen will need to try and avoid catching any <MCRS fish, while also avoiding catching the choke species. In our analysis, we found that for a number of species the above and below MCRS clusters dominated by a single species, also had considerable spatial overlap. This was, to some extent, the case for clusters dominated by whiting, megrim, hake and plaice. So if one of these species were a choke species, we would definitely wish to avoid locations where these clusters occurred. If, however, they were a target species and not a choke, we could risk high <MCRS catches.

The actual use in the fishing grounds of the type of information we have generated is best left to the fishermen. The cluster analysis, the maps, and their analysis can help indicate the discarding risks of any particular area, but we should not be making decision on this for the fishermen. Our proposal with this, and other similar work with observer data, is then to work with fishermen to refine the analytical approach to best serve their needs. This could be as a risk map by species of what the likely issues with fishing in any given area might be, but again, that is for the fishermen to decide.

This study is based on observer at sea data, which represent the only source of information on discarding practice at sea. However, they represent a very small proportion of fishing trips, around 3% at the national level. As such, robustness of conclusions drawn in this study depend on the representativeness of the national sampling and provide only a partial view of discards, as many cells in the maps are not observed. Our analysis on the link between under and oversize discards indicates that no clear spatial link can be drawn between small grade of fish and fish smaller the MCRS preventing the use of species composition of landing data to infer species composition of discards for non-observed cells.

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Chapter 3. A tool to describe landings and discards in a mixed fishery's context – France, English Channel.

By: Youen Vermard, & Sigrid Lehuta – IFREMER

English Channel case study

Introduction & Objectives

From a Landing Obligation perspective, if a species is potentially seen as choke species, then fishermen may try to avoid it by redistributing their effort along the year and across their fishing areas. Lots of maps have consequently been produced to spatialize landings based on the coupling of logBooks and VMS. These maps are either based on monospecific landings or based on clustering of species composition of the landings. When mapping landings of a species in volume or average proportion in landings, it is not possible to determine if areas with high landings (or high proportions) result of numerous fishing operations with the species as by-catch or of few targeted operations. These two situations have very different implications in terms of avoidance ability.

We instead propose a tool that maps the risk of catching a given species in a given area at the fleet and gear (métier) scale.

Methods

Logbooks were merged with VMS data to allow the aggregating of landing at any spatial scale (.25'*.25' in the following document). All landings by species were then expressed as a fraction of the total landings reported for a fishing operation (as estimated by the VMS reallocation). The user then defines a maximum proportion (resp. minimum) of the species in the landings (proportion threshold), that he is willing to accept depending on the objective i.e. avoiding or targeting the species. Indeed the acceptable proportion may depend on the species and situation: e.g. TAC already reached (then the proportion must be null), de minimis (a threshold is imposed by the regulation), or optimization of quota over the year (avoiding is not compulsory but may allow spreading activity over the year). The probability of avoiding (resp. targeting) the species is then mapped as the proportion of the fishing operations that meets the objective at the cell scale. The time scale is user-defined (either year/quarter or month).

By playing with the proportion threshold and the risk level, fishermen can visualize areas to avoid and target. For instance they may choose to avoid a species by fishing in areas with high frequency of low proportions. Alternatively they may take the risk to go fishing in areas where that species was seen in the landings in high proportion but only occasionally. They can choose this strategy in a case where some technical avoidance can be put in place or they can endorse that risk in term of quota: proportion threshold high but frequency low. It also provides guidance for a reorganization of the activity within the year by allowing comparison of risk maps between seasons and months.

However, when restricting an area, fishermen will be interested in the proportion of the landings and revenues lost for the species of interest and the other species caught jointly. That is the purpose of the second tab of this tool. The user can then choose the acceptable level of risk he is willing to accept and directly see what are the areas overshooting this risk or those lower than the predefined risk. The tool will then map separately areas to be avoided and areas to be preferred. Associated to this cartographical representation of the landings, a graphic representing the percentage of the landed value of each species historically realized in each of the two areas (to be avoided or preferred) is provided.

The tool takes the form of a web interface with three tabs for mapping risk, quantifying losses and gains and mapping discards. It was built on declarative data over the period 2008-2014 and implemented within the R framework (library shiny).A minimum of nine operations per cell was set, below which the data is considered not representative and the cell colored in grey (with opposition with white that means no data).

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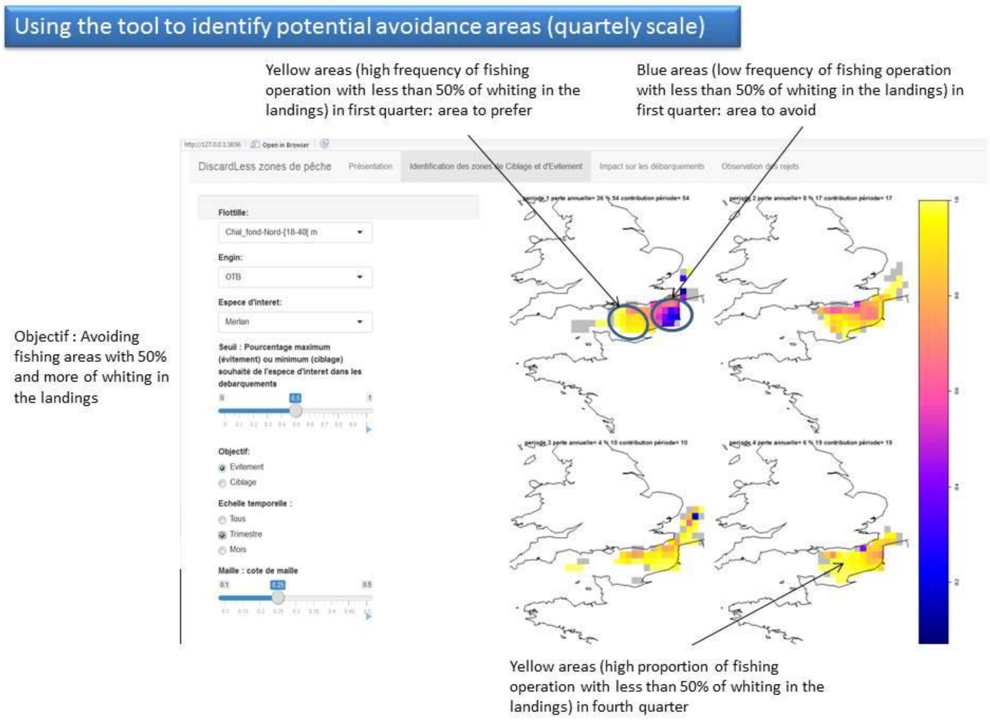
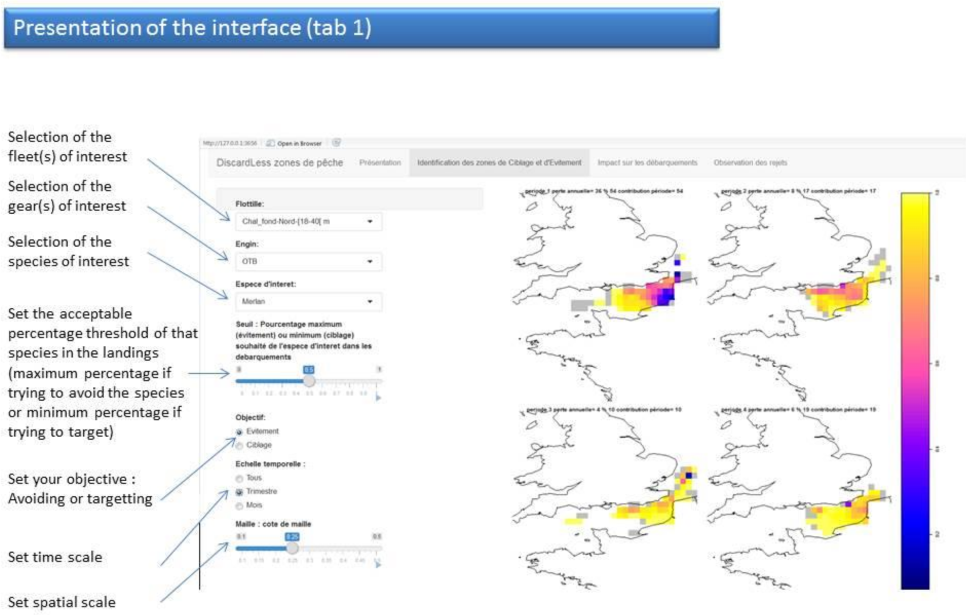
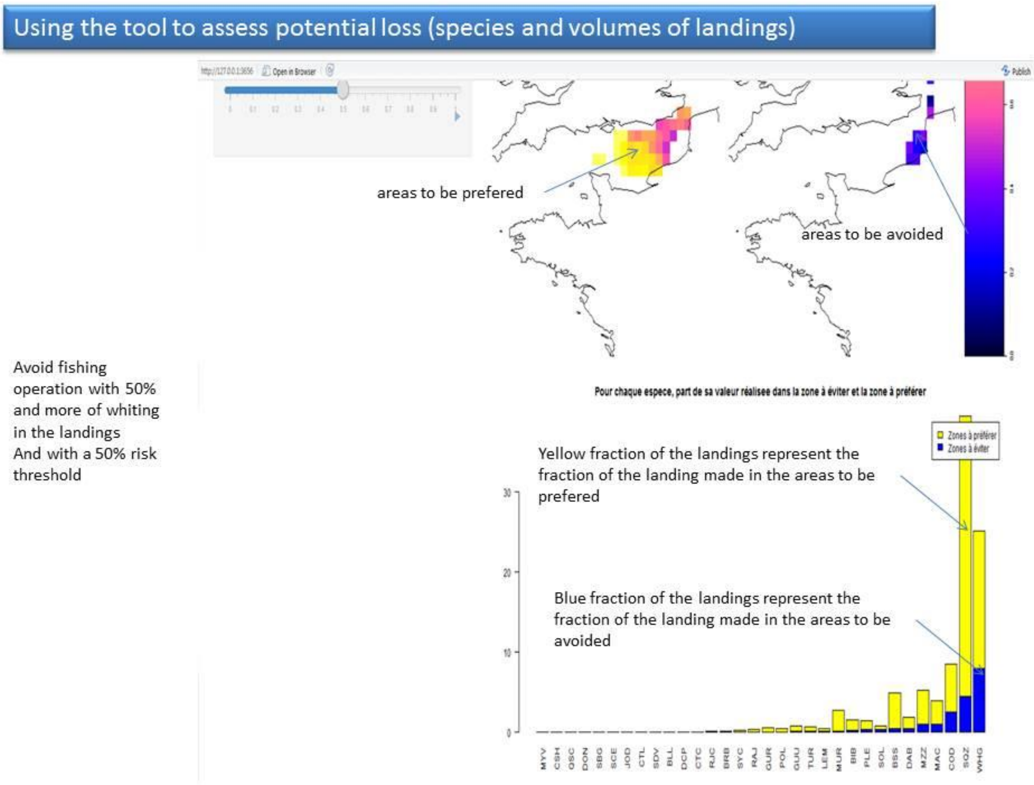
Results

The following graphics show how the tool can be used, and some of the data outputs provided.







Discussion

A limit of the tool pertains to the nature of data used that is to say landings instead of catches. Indeed, a low proportion of a species in landings does not guaranty a low proportion in the catch if discarding occurred. Data available in the onboard observer program were too scarce too allow a level of details appropriate for operational use (métier and spatial scale). However information regarding discards is made available in a third tab to allow relativizing the information in landings. The principle of representation is similar as for landings with cell color representing the frequency of observation of operations with a certain rate of discard of the species.

The tool has the advantage of preventing implementing new constraints to fishing activity thus leaving fisher with their freedom of choice while providing them with a decision support tool.

The tool was presented to fishermen representatives during a DiscardLess meeting held in Boulogne sur Mer in January 2018. Despite the complexity of the tool, the representatives rapidly understood the concept and recognized its practical interest. Two uses of it were envisioned: first, as originally planned, as a tool to help avoiding discards and second as a support in negotiations regarding the maximum allowed proportion of species in landings. Indeed, the tool evidenced that no cell present a high probability of having less than 1% of sea bass in the landings (the proportion currently under discussion) while respecting a 5% limit implies avoiding a third of the Eastern Channel, a measure much more realistic and acceptable for the fleets.

Several improvements were proposed and are in course of implementation: First an estimation of the expected revenues when avoiding a zone and reporting effort in the left opened area, second a graph of the proportion of the Channel that needs to be avoided as a function of proportion threshold and acceptable risk. Finally they would like to be able to select the years that enter the computation because some years were known to display unusual conditions. Representative requested that the tool be presented at the next national fishing commission.

Chapter 4. Identifying choke species challenges for an individual Danish demersal trawler in the North Sea.

By: Lars Mortensen, & Clara Ulrich – DTU-Aqua, and Jan Hansen & Rasmus Hald - KARBAK Aps, Denmark

North Sea case study

Published as: Mortensen, L. O., C. Ulrich, et al. (2018). Identifying choke species challenges for an individual demersal trawler in the North Sea, lessons from conversations and data analysis. Marine Policy 87: 1-11.

Introduction & Objectives

When the landing obligation of the 2013 Common Fisheries Policy is fully implemented in 2019, and provided that it is accurately enforced and controlled, fishers will no longer have the option to discard, i.e. return fish to the sea, in order to avoid landing unwanted catches (EU 2013). The landing obligation requires that all catches (i.e. everything retained in the fishing gear when hauling) of stocks under catch limits and/or with a legal minimum conservation reference size (MCRS) are to be recorded and, where applicable, counted against quotas. Some exemptions might apply, such as for protected species, for species with a high survivability and for small amounts of discards, that cannot be easily reduced further through selectivity and avoidance measures (de minimis exemptions). However, many species occur frequently as bycatch to the targeted species, especially in mixed fisheries, where it can be difficult to reduce catches of a single species when several species are caught together (Ulrich et al 2011,

Deporte et al 2012, Batsleer et al 2013). Thus, one of the main concerns raised against the landing obligation is the risk for early closures of fisheries, when the quota of one species is exhausted before the others. This is referred to as the “choke species” effect. The choke species can be either target or bycatch species, and they can be limiting either because of low productivity of the stock and reduced fishing opportunities, or because of discrepancy between historical right allocation compared to current abundance (e.g. Northern hake) (Baudron & Fernandes 2015).

Within the EU, the national quotas are fixed shares of the overall TAC by stock, using the relative stability key established in the early times of the CFP (Holden 1984). They are themselves shared across the various quota users, using often complex allocation systems that differ from country to country. These various layers of quota sharing have traditionally been based on some historical records of landings, not of catches, and have largely not been updated over time in spite of changes in fisheries’ and fish stocks’ distribution. For some stocks, discarding has thus emerged from the mismatch between the catching capacity of an individual vessel and the vessels landing opportunities. Historically, this mismatch has been partially mitigated through bilateral quotas exchanges (“quotas swaps”) between countries, but uncertainty remains on how these informal agreements will develop under the new CFP (Hoefnagel et al 2015). Addressing this mismatch by renewing the allocation keys with the implementation of the landing obligation would thus in theory relax one of the main drivers of discarding, but in practice the political complexity of this update means that at the time of writing, it still appears unlikely to take place in European fisheries.

In Denmark, the demersal fisheries management switched in 2007 from a system based on weekly rations to a Vessel Quota Share (VQS) system, a form of individual transferable quota where the share is linked to the vessel, implying that quota transfer requires buying the corresponding vessel out. The shares were based on the 2004-2006 recorded landings, but not on total catches (Andersen et al 2010). Thus, fishers were granted a fixed share of the national quota. However, as at the national level, the issue of quota mismatch between actual catch and quota allocation was created at individual level as well. To overcome this, fishers quickly formed quota pools, enabling the fishers to lease quota, either directly between vessels or through common pools (e.g. www.puljefisk.dk), correspondingly to the national quota swaps. However, the situation might change with the landing obligation. Hatcher (2014) predicted that fishers would likely have more difficulties to predict their own needs for quota, as the catches previously discarded would need to be landed and deducted from their quota. This would mean that fishers would become reluctant to lend quota to others to safeguard their own needs, and rental prices may increase, due to less supply and a larger demand. Thus, if the landing opportunities of the vessel cannot be adjusted to its catching capacity, the choke species issue will have to be addressed the other way around, by adjusting the catching capacity to its landing opportunities. Incentivizing fishers to reduce unwanted bycatch is indeed the underlying objective of the landing obligation. This takes place by modifying the catch composition of the fishing operation, either by switching to more selective gears (Alverson et al 1994) or through changes in when, where and how to fish (Branch & Hilborn 2008, Kuriyama et al 2016) Changes in gear selectivity have often proven effective in reducing bycatch, however the voluntary uptake of selective gears has so far remained very low by lack of appropriate incentives to fish more selectively. Additionally, the current technical measures regulations, along with complex approval guidelines, limits the possibility to develop new gears (STECF 2015), although some work is ongoing to address this (EU 2017, STECF 2017). The other option is thus changing where, when and how to fish, also referred to here as avoidance behaviour, where the fisher selects areas known to contain few choke species or displace the fishery if a large catch of choke species is encountered. The effectiveness of avoidance behaviour depends on the skills and choices of the skipper; nevertheless, its outcomes can also remain uncertain if the species to be avoided is largely distributed over the same areas as the target species or has a patchy distribution in large numbers (Hatcher 2014).

To investigate the scale and tactics linked to using avoidance behaviour to reduce the choke species problem, the fishing behaviour of a single demersal trawler in the North Sea was analysed. The aim is to understand how a fisher perceives and decides upon changes in behaviour, and to analyse whether these changes can be detected with high-resolution fisheries data derived from the vessel.

Material and Methods

The analysis was based on a quantitative analysis of fisheries data from a Danish demersal trawler, supported by information collected from a suite of meetings and interviews with the owner and the skipper of the vessel. The vessel is a 28 meters trawler, with at-sea packing facilities, conducting a mixed fishery primarily in the North Sea. The vessel was participating in a Fully Documented cod catch quota management (CQM) trial, where discarding was still allowed but all catches of cod were to be deducted from the vessel quota, against a 30% quota uplift on cod only (Ulrich et al 2015). As participant in the CQM trial, the vessel was conducting fully documented fishery (FDF), including remote electronic monitoring (REM) with CCTV cameras and reporting catches on a haul-by-haul basis. Additionally, the vessel was obliged to land all TAC species above MCRS (Bergsson & Plet-Hansen 2015, 2016. Interviews with the owner and the skipper of the vessel revealed that the main challenge during the CQM trials was to avoid cod (*Gadus morhua*) and saithe (*Pollachius virens*), as the vessels initial quota was not sufficient to land all catches of these species, when targeting valuable species such as monkfish (*Lophius piscatorius*) and hake (*Merluccius merluccius*). It was thus decided to focus the analyses on these two species, while all other species caught was grouped into a single group.

<u>Data</u>

Data from the vessel was collected both from the fisher and from the Electronic logbook and fishery auction. Data included position at haul-in, species composition in the landings, weight and value of landings, size sorting from the fishery auction, initial VQS of the vessel and quota lease through the period. The data also included information on cod discard collected from the participation in the CQM trial (Ulrich et al 2015), where cod discard was estimated by electronic monitoring. Data from 2013 – 2015 were used, to investigate whether and how choke species were a problem for the fisher. During this period, the stock of cod in the North Sea and Skagerrak experienced a slight increase in biomass and Total Allowable Catch (TAC), while the TAC for saithe in the North Sea, Skagerrak and West of Scotland decreased by 28% whereas its biomass remained stable (ICES 2015). The data covered fishing operations in the years 2013, 2014 and 2015 and included a total of 140 trips with 47 trips annually in 2013 and 2015, and 46 trips in 2014. A trip lasted on average 7.4 days [2-11 days] and contained on average 15 hauls [2 – 27]. The total landings in the years were between 1,023 tons and 1,357 tons, with approx. 20% cod, 35% saithe and 45% other species. There were no records of discards of saithe, however as the vessel was a part of a cod quota management scheme, discards data on cod were available. A total of 6 tons of cod was discarded over the three years (2013:1.6 ton, 2014:2.5 ton, 2015:1.9 ton) with an average discard ratio per trip of 0.2%. The low discard was a part of the CQM directives, as the vessel was only allowed to discard damaged fish and fish below MCRS. The estimated discard ratio for the entire stock of North Sea cod is around 25 % (ICES 2016). Thus, the discard was a negligible part of the catch and was not included in the subsequent analysis.

<u>Interviews</u>

Knowledge on fine-scale tactics was obtained through informal discussions and interviews with the vessel owner and the vessel skipper (hereby referred together as "the fisher") in three meetings, conducted prior and during the analysis work. The interviews aimed to obtain information on perceived current and expected challenges with the landing obligation, along with fishing strategies during the period 2013 to 2015. The unstructured interviews were chosen to maintain an open dialogue, where the interviewees would not feel restricted by a line of questioning and where unforeseen topics could arise.

Time of choke and quota usage

Estimation of if and when a choke species problem occurs in the fishery were conducted, using an analysis of the temporal development in quota accumulation and quota usage. Catches data was extracted from the electronic logbook of the vessel and the accumulated catches across the year for each of the three years were calculated. The time of year where the catch accumulation intercepted with the start of year quota was used as an indicator of when the fishery would be choked if no other quota acquisition options were available. This analysis was supplemented by a quota acquisition analysis, where the quota accumulation across the year, which included quota leasing, adjustments and CQM trial quota additions, was calculated. This was conducted to evaluate the tactical decisions made by the fisher to acquire quota in relation to the catch.

Economic effect of choke

To evaluate the effect of potential choke species, the potential loss in revenue following a choke was calculated. Trip by trip revenue was derived from the sale slips and were separated into cod, saithe and others. Assuming that no extra quota would be available, the fishery would stop when the initial quota of a species would be exhausted and all revenue after this point would not have been met. Thus, all revenue following the choke date was summarized to express the potential forgone revenue due to the choke effect. This measure must however be considered as indicative of the maximum expected choke effect, because it could be expected that the fisher may have taken other decisions if he had been certain that no extra quota would be available to lease.

Selected trips

The fisher was also asked to select two specific trips performed in 2015, one where he perceived that he had specifically tried to avoid saithe and one where no specific attention was paid to saithe catches. This was done to evaluate whether standard fishing practices were most comparable to either the avoidance or non-avoidance trip. Initially, the spatial distribution of the two trips was visually inspected and compared to other trips within that year. Furthermore, to investigate whether the catch of each type of trip differed significantly with respect to all the other trips, the haul by haul landings (L) was compared using an ANOVA, with trip type (T: normal, avoidance, non-avoidance) and species (S: saithe, cod, others) as explanatory variables, along with an interaction term between the two:

$$L = T * S \qquad \text{Equation 1}$$

Haul composition

The catch structure of each trip was analysed to estimate the potential for the fisher to predict catches, under the assumption that the occurrence in catches of evenly dispersed species is easier to predict than for patchy distributed species. To account for the distribution type of each species in the catch, the mean and the median catch per haul of saithe and cod for each trip were calculated and the median was subtracted from the mean. A large deviation from zero would indicate either few hauls with large catches in a trip with generally small catches (mean > median) and vice versa, demonstrating either fragmented catches or evenly distributed.

Haul composition was also analysed in terms of weight and economic value proportion of saithe and cod in each trip, to evaluate whether the two species made up the same proportion around the year or if periods of high and low catch proportions could be identified.

Spatial distribution of catches

To analyse the spatial dimension of the fishery, the fishing trips were mapped and the density estimation of catch per haul, was calculated for each year and species. The density estimation was a 2D kernel density estimation, estimated using the function "kde2d" in the R-library MASS. All species other than cod and saithe were pooled together. This shows areas of high catches per haul of the potential choke species and others species. Any overlap of the catches would indicate that the species could potentially act as a choke species, as they would co-occur with other species, unless there is a temporal displacement in the occurrence of the species.

Spatial avoidance behaviour

Additionally, distance moved after haul-in was calculated to investigate whether any significant displacement would be detectable after catching large quantity of saithe and cod. This was done by calculating the Euclidian distance between haul-in sites, using the function distCosine, in the R-package geosphere (geosphere version 1.5-1). Lastly, changes in depths after haul-in were also analysed in the same manner as distance moved, by calculating the depth change between haul-in and the subsequent haul-in, to investigate whether the size of catch of cod, saithe or others could induce a change in fishing depth. Fishing depth was derived from a bathometry map (DYNOCS, Dynamics of Connecting Seas, EEC-MAST Research project), where depth was inferred from the position at haul-in.

Results

Interview with skipper and owner on HM635

The discussions with both the skipper and the owner of the vessel resulted in a comprehensive description of the challenges experienced by the fisher and revealed the amount of real-time decisions made at every haul to fully utilize quotas. A primary concern raised by the fisher in relation with the landing obligation, was the potential for cod and saithe to choke the fishery. The fisher felt that the quota allocation for the two species did not match the catch opportunities and that the introduction of the landing obligation would result in few options for adjusting catches to the quota composition. The strategy agreed between the skipper and the owner was thus to avoid saithe as much as possible.

The skipper expressed a detailed knowledge of the spatial distribution of species, identifying specific areas of a few square nautical miles with unique species compositions; and as such told

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that it is possible to avoid saithe and cod in the catches, by targeting areas known to contain few of these species. However, according to the skipper, these areas may also have a varying abundance of other valuable species, primary monkfish and hake, but also lemon sole (*Microstomus kitt*), turbot (*Scophthalmus maximus*) and Atlantic halibut (*Hippoglossus hippoglossus*). Thus, in some trips where catch rates are low in these areas, decision must be made whether fishing should continue there or move towards other areas with known high densities of valuable species, though with the risk of encountering high concentrations of cod and saithe. The skipper reported that in recent years, cod was perceived as having a more homogeneous distribution, while high-density patches would exist mainly for saithe. In particular the area north of 59.30 N° on the ridge of the Norwegian trench [Figure 4] was no longer fished by the skipper in 2015 due to especially high risk of large saithe catches. Similarly, "the bird cage" east of Shetland [Figure 4] was considered a good fishing-ground, but where saithe catches after 2013 were so high that the area was visited only as a last resort, if catch rates elsewhere were insufficient.

According to the skipper, the tactic employed if large catches of saithe were encountered, was to continue along a transect, deploying the gear where it was hauled in and subsequently continuing along the current heading, expecting lower catch rates just behind the patch. To underpin the challenges with choke species, the owner of the vessel told that he decided in 2015 to switch fishery and started targeting plaice instead. A period of 4 months was spent in that fishery (from May 1th 2015 to September 1th 2015), where a quota of 70 tons of plaice was leased, a new gear was purchased and new areas were fished. Both the skipper and owner acknowledged that the change in target species reduced the choke problem as fewer saithe were caught.

From the interviews it was also advocated that the challenge of choke species was more difficult to cope with for small vessels than for larger ones like HM635, as the storage size on smaller vessels limits the action range and the number of hauls that can be carried out in a single trip. Thus, smaller vessels experience more difficulties navigating between areas and are subsequently more restricted in the number of choices they can make. Additionally, operation costs are proportionally higher for small vessels than large ones.

To explore what is perceived as avoidance and non-avoidance behaviour, the owner specified two trips (starting on April 15th (1) and May 12th (2) 2015, respectively), where saithe avoidance was applied during the first trip and non-avoidance was applied during the second. Saithe avoidance was described as fishing in areas with suspected low abundance of saithe and if hauls contained an unacceptable amount of saithe, gears would be deployed at haul-in site, but heading would be maintained, assumed that the encountered saithe patch would be behind the vessel. Non-avoidance would be that the vessel targeted its primary species (monkfish and hake) with no consideration for the amount of saithe in the bycatch.

<u>Quota leasing and quota uptake</u>

Initial individual quotas were 23, 22 and 35 tons for cod in 2013, 2014 and 2015, while the initial quota for saithe was 187, 204 and 176 tons, respectively. An additional 206, 149 and 229 tons of cod quota and 268, 189 and 241 tons of saithe quota were leased in the three years respectively, to supplement the initial quota [Figure 1], while the cod quota was supplemented with 44, 49 and 42 tons in the three years respectively, from the Cod Catch Quota management trials and other adjustments. The visual inspection of the accumulated catches per trip each year demonstrated a steady increase throughout the year for each species, except for cod in 2014 (where catch rates increased during the fall) and saithe in 2015 (where catches were low during summer when the vessel switched to plaice fishery) [Figure 1]. It was also variable when the initial quota was passed. In 2013, the initial saithe quota was exhausted on May 1st; while in 2014 and 2015, the quota was not exhausted until September. For cod, the initial quota was exhausted in 2013 by February 21th, in 2014 by February 22th and in 2015 by April 8th. Thus, the cod quota was the first to be exhausted all years.

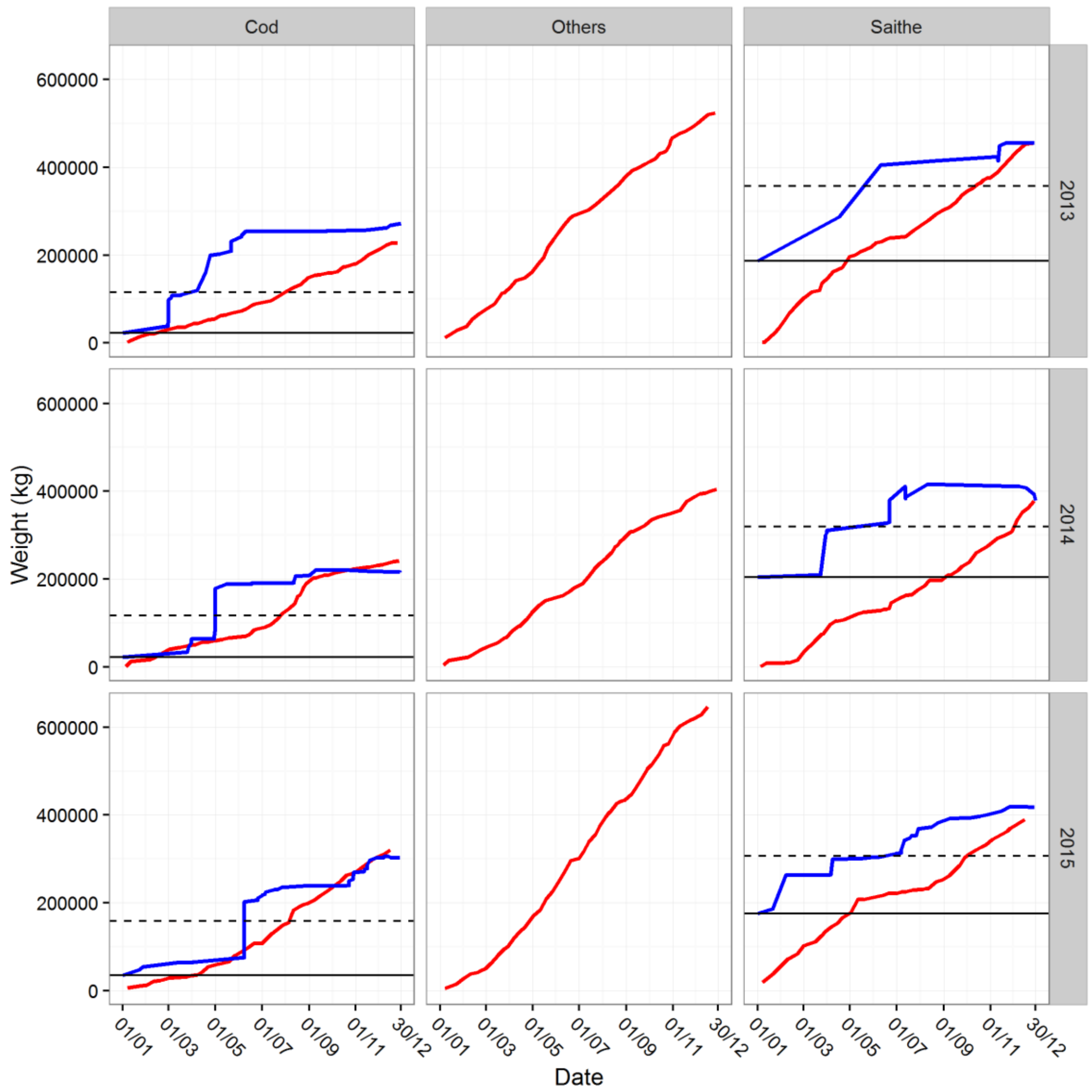

Figure 1 Plot showing the landing (red) and quota (blue) development of saithe, cod and other species (OTH) in the years 2013, 2014 and 2015. Horizontal lines indicates the initial quota (solid) and initial quota including transferred quota from partner vessel (dashed).

Economic effect of choke

The maximum short-term economic importance of the choke species effect can be estimated from the revenue yielded before and after exhaustion of the first quota. Landing sales after exhaustion of the cod initial quota with no quota lease or added quota from the CQM trials summed up to 17 mill. DKK on average (2013:16 mill, 2014:16 mill, 2015:19 mill) or 87% of the average total annual revenue (2013: 90%, 2014: 95%, 2015: 79%) (Table 1). Looking at saithe as choke-species alone, the landings sales after exhaustion of saithe initial quota with no quota lease summed up to 9 mill. kr.DKK on average (2013:13 mill, 2014:6 mill, 2015:6 mill) or 43% of the average total annual revenue (2013: 72%, 2014: 34%, 2015: 27%) (Table 1).

Table 1 Overview of annual revenue (total, '000 DDK) on cod, saithe and other species and the theoretical revenue loss (Loss) after initial cod or saithe quota is exhausted.

	2013			2014			2015		
	Total	*Loss saithe*	*Loss cod*	*Total*	*Loss saithe*	*Loss cod*	*Total*	*Loss saithe*	*Loss cod*
cod	4,496	3,491	4,094	4,914	1,228	4,625	7,026	2,110	6,319
saithe	4,135	2,616	3,483	2,869	1,861	3,777	4,518	1,144	2,875
Others	9,512	6,965	8,641	8,708	2,828	8,161	11,980	3,173	9,448

Haul composition.

The catch composition across trips [Figure 2] showed that cod represented around the same proportion in landing weight and value, while saithe represented a larger part of the landing weight than of the landing value. The size of catch in each haul was also variable across each year for each species [Figure 3], where the catch size per haul was more constant for cod than for saithe (F-test, $p<0.01$ for all years). The larger discrepancies between the mean and the median catch per trip for saithe indicated a very patchy occurrence of saithe in the catches, with most hauls containing little saithe, but a few hauls in a trip containing large amount of saithe. In the same trips, cod occurred in equal amounts in each haul, with some seasonal variation. Additionally, it can be noted from Figure 2 and Figure 3 that there was a period between May and September in 2015, where saithe only occur in small amounts in the catch. This coincides with the period where the fisher switched to plaice fishery.

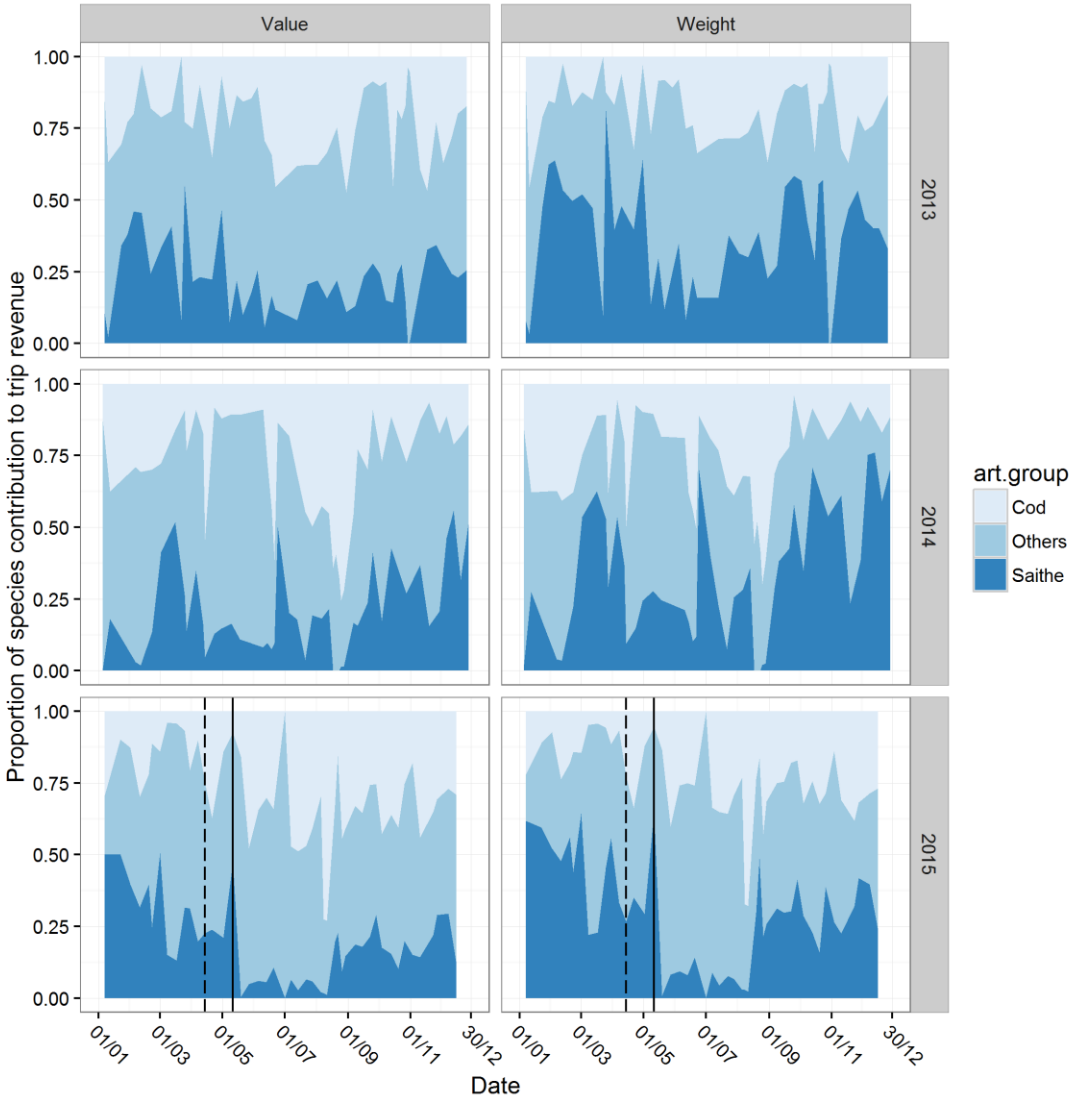

Figure 2 Stacked plot of the composition of landings per haul for Karbak HM635 across the year, divided into Value (left) and Weight (right). Solid line in 2015 indicates non-avoidance trip and dashed line in 2015 indicated avoidance trip.

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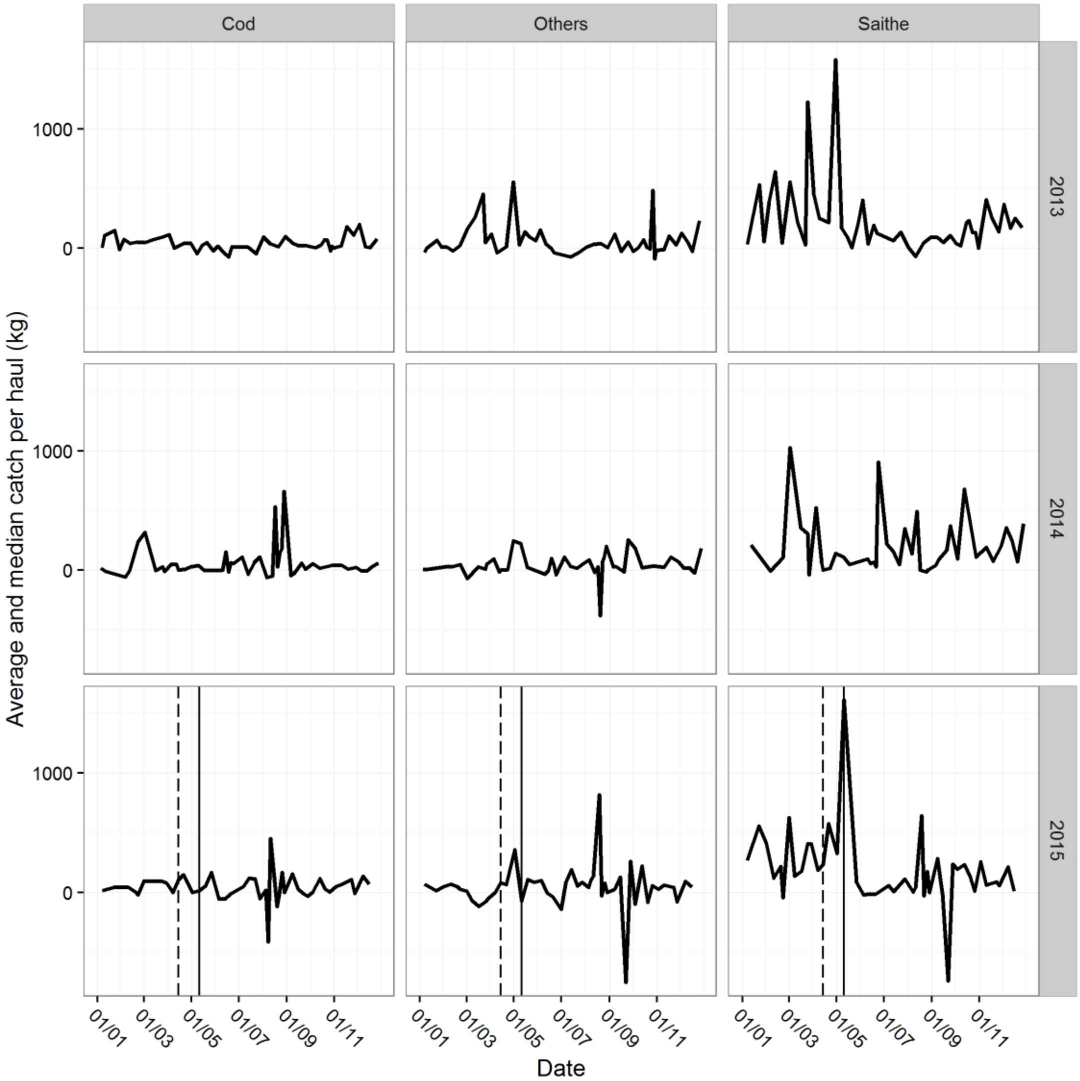

Figure 3. Mean catch per haul minus median catch per haul. Deviation from zero demonstrates uneven catches across a trip, indicating a patchy occurrence of the species. Solid line in 2015 indicates non-avoidance trip and dashed line in 2015 indicated avoidance trip.

Selected trips

The two trips specifically selected by the fisher were compared. There was little spatial overlap between the two trips [Figure 4], with the avoidance trip being located near the Shetlands and the non-avoidance trip near the southern part of the Norwegian trench. The avoidance trip landed less saithe than the non-avoidance trip (avoidance trip: 7 tons in total, non-avoidance: 30 tons in total). However the variability between hauls was too high to detect a significant difference between saithe landings in the two trips (Welch t-test: p=0.2, df = 17), as the average saithe catch per in the non-avoidance trip was 1.7 kg (± 3953 kg, SD), relies on one extraordinary large haul (16 tons of saithe) and three lesser hauls (3-4 tons of saithe in each).

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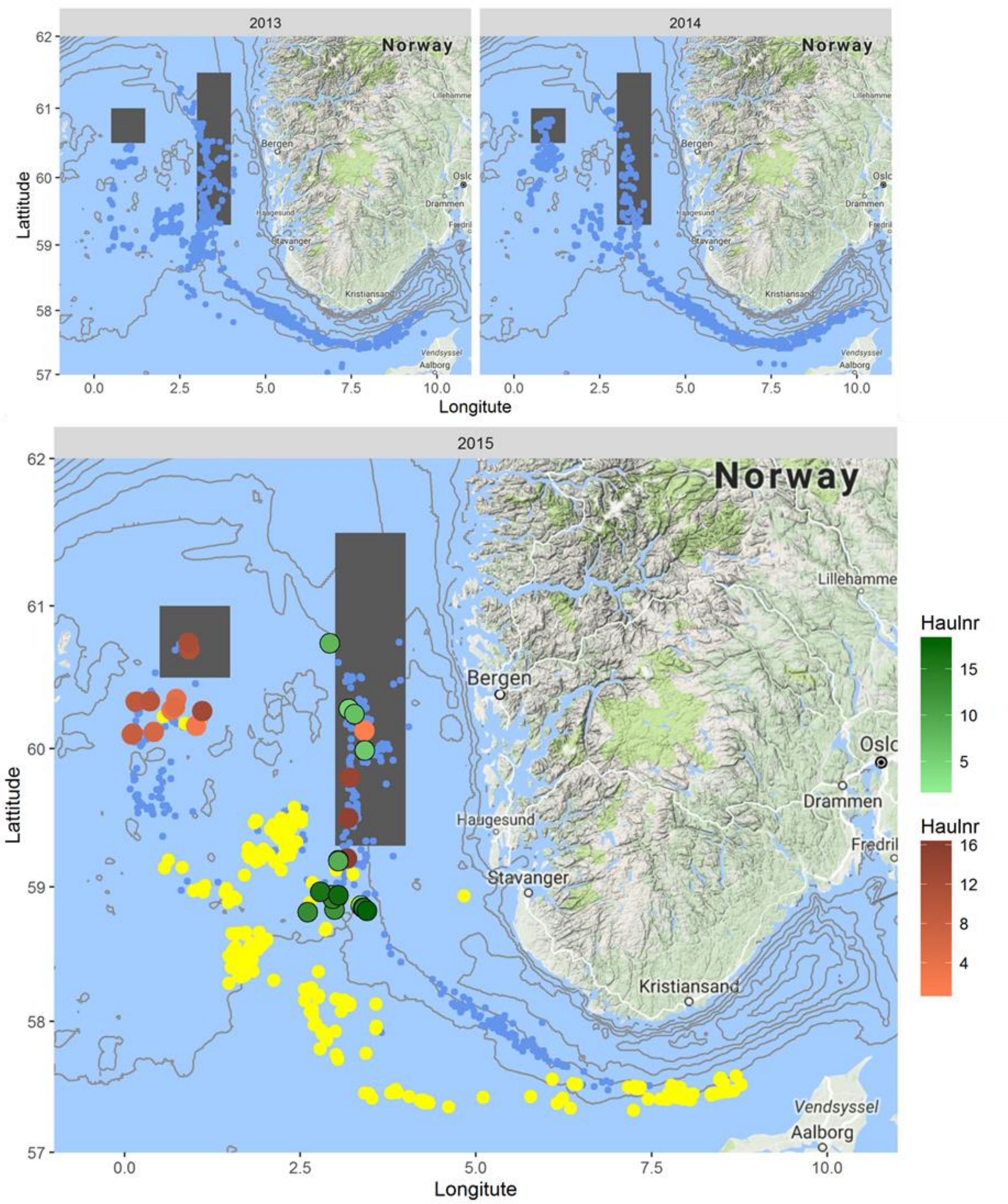

Figure 4. Map showing hauls location in 2013, 2014 and 2015 (blue dots). The 2015 map shows also the hauls where the vessel targeted plaice, between 1/5–2015 and 1/9–2015 (yellow), hauls between 10/04–2015 and 15/04–2015 with saithe avoidance behaviour (orange) and hauls between 4/5–2015 and 12/5–2015 with saithe non-avoidance behaviour (green). Color gradients show the haul sequence, with light colors indicating initial hauls and dark colors indicating last hauls. Grey boxes indicates the area called "the bird cage" and the area north of 59.30°N highlighted by the skipper.

Spatial distribution of catches

Plotting the spatial distribution of catches rates in the three years showed a substantial change in fishing areas between 2013-2014 and 2015 [Figure 4]. In 2013 the primary fishing occurred around the west coast of Norway, with little fishing effort allocated nearer the Shetlands. In 2014 more fishing effort was allocated around the Shetlands, but still with a high occurrence of fishing activities in the Norwegian trench. The 2015 switch to plaice fishery changed the distribution of fishing activities, which included a reduced fishing activity in the northern part of the Norwegian trench and near the Shetlands.

The results from the density estimates [Figure 5] showed that saithe and other species were often caught in the same areas, however there is a patch around 59 N° where there is cod and other species, but no saithe. Additionally, cod is not caught in the Norwegian trench north of 60 N°. In 2014, on the category "Other species" were caught in the Norwegian trench, while cod and saithe catches fully overlapped west of the trench. In 2015 the catch pattern was patchier and saithe was caught where it was not in 2013. Overall, the results from Figure 5 do not show any stable pattern in the spatial distribution of the catch.

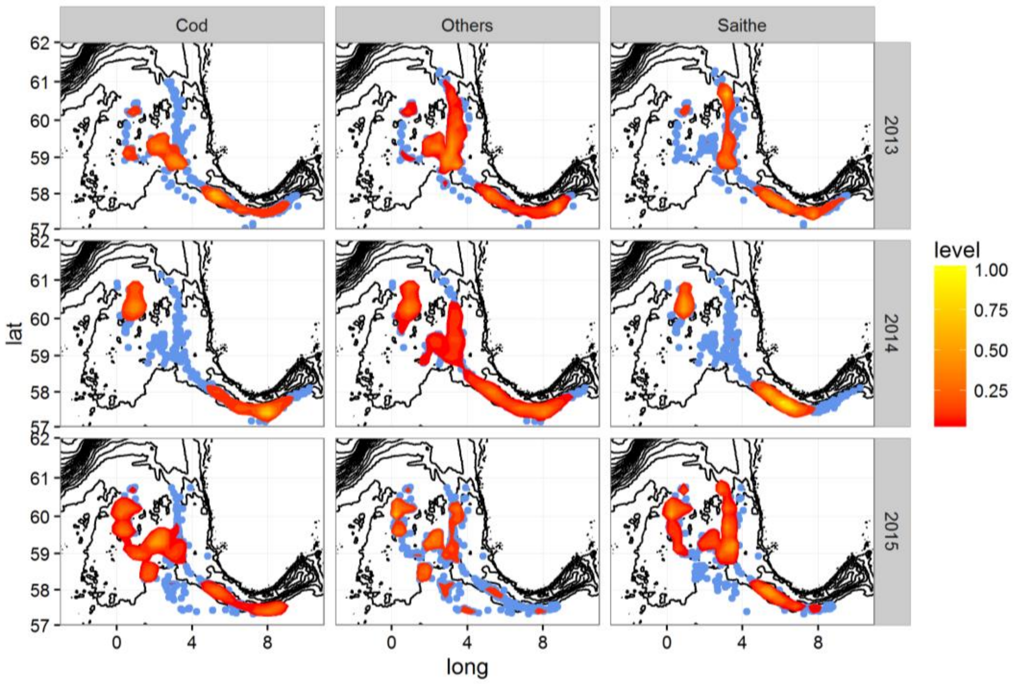

Figure 5 Spatial distribution of catches per haul, along with a density analysis. Blue dots represent a haul with a catch of cod, saithe or other species, while black lines represent depth curves. Red/yellow represents weighted density estimates of catches per haul, with level as a probability estimate.

The spatial distribution was also analysed in relation to catch size, by calculating the Euclidian distance moved between two sequential haul-in sites and comparing the distance with the catch size of the individual species before the move [Figure 6]. Assuming that the average haul time lasted 5 hours with a haul speed of 4 knots (Eigaard 2015) means an average haul length of 37 km. Here, the average distance moved between two haul-ins' was estimated at 38.6 km, close to the estimated standard length of a haul, indicating that the vessel did not change location after haul-in before deploying gear again. However there is no correlation between the catch weight of cod, saithe or others and the distance moved following haul-in in either 2013, 2014 and 2015 (Pearson: -0.11 – 0.08, Spearman: -0.27 – 0.03), indicating that changing fishing area was not directly relying on the catch weight and species composition of the haul.

Change in depth as an effect of catch size of the individual species was also analysed as with the spatial change after haul-in [Figure 7]. The average haul depth was 151 meters (±47m SD). Analysing the depth change between haul-ins did not show any correlation between the change in depth and catch weight of either cod, saithe or others (Pearson: -0.14- 0.04, Spearman: -0.16- 0.05).

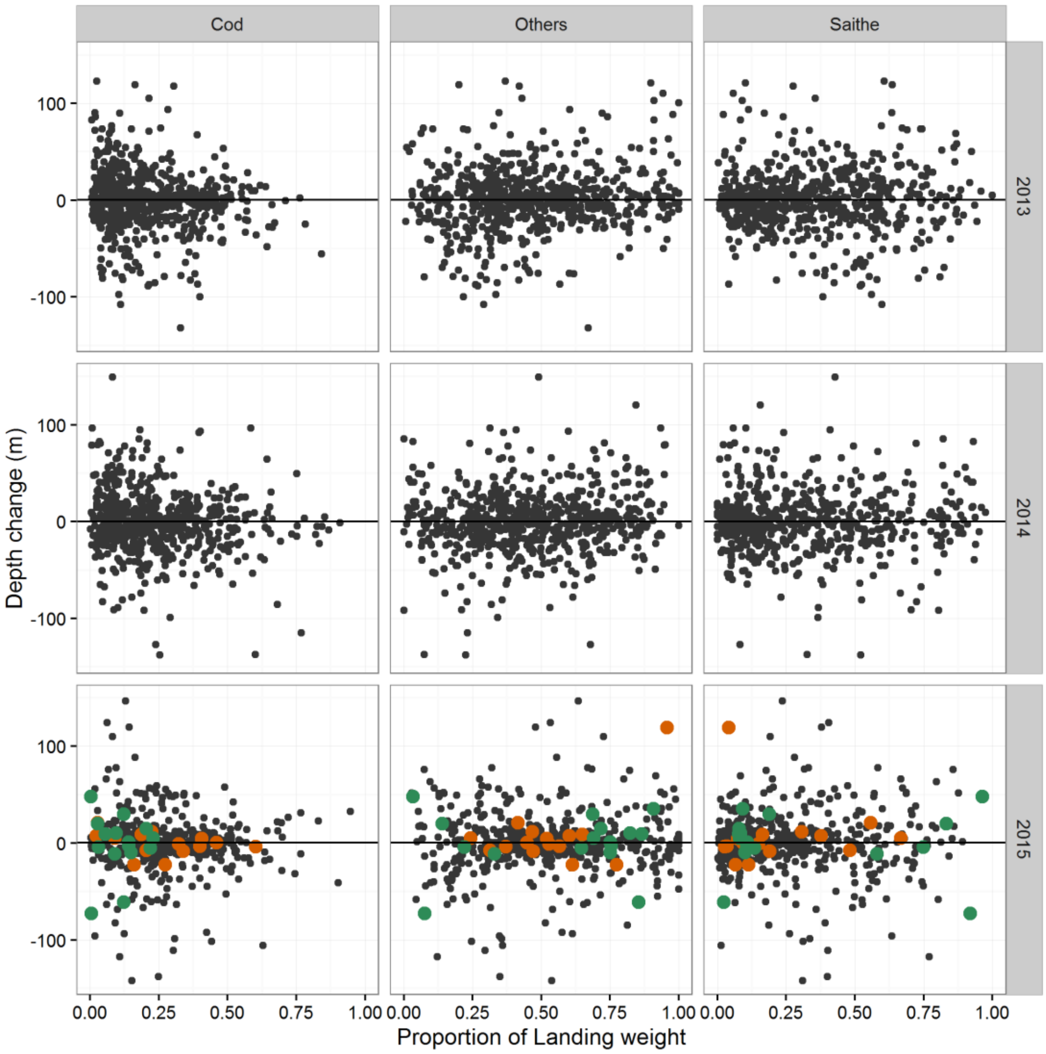

Figure 6 Scatter plot showing the correlation between the proportion of the landing weight in a haul for cod, saithe and other species and the distance moved after haul-in. Black line indicates average moving distance after haul-in across all hauls. Coloured points indicates hauls between 10/04-2015 and 15/04-2015 with avoidance behavior towards saithe (green) and hauls between 4/5-2015 and 12/5-2015 with non-avoidance behavior towards saithe (orange).

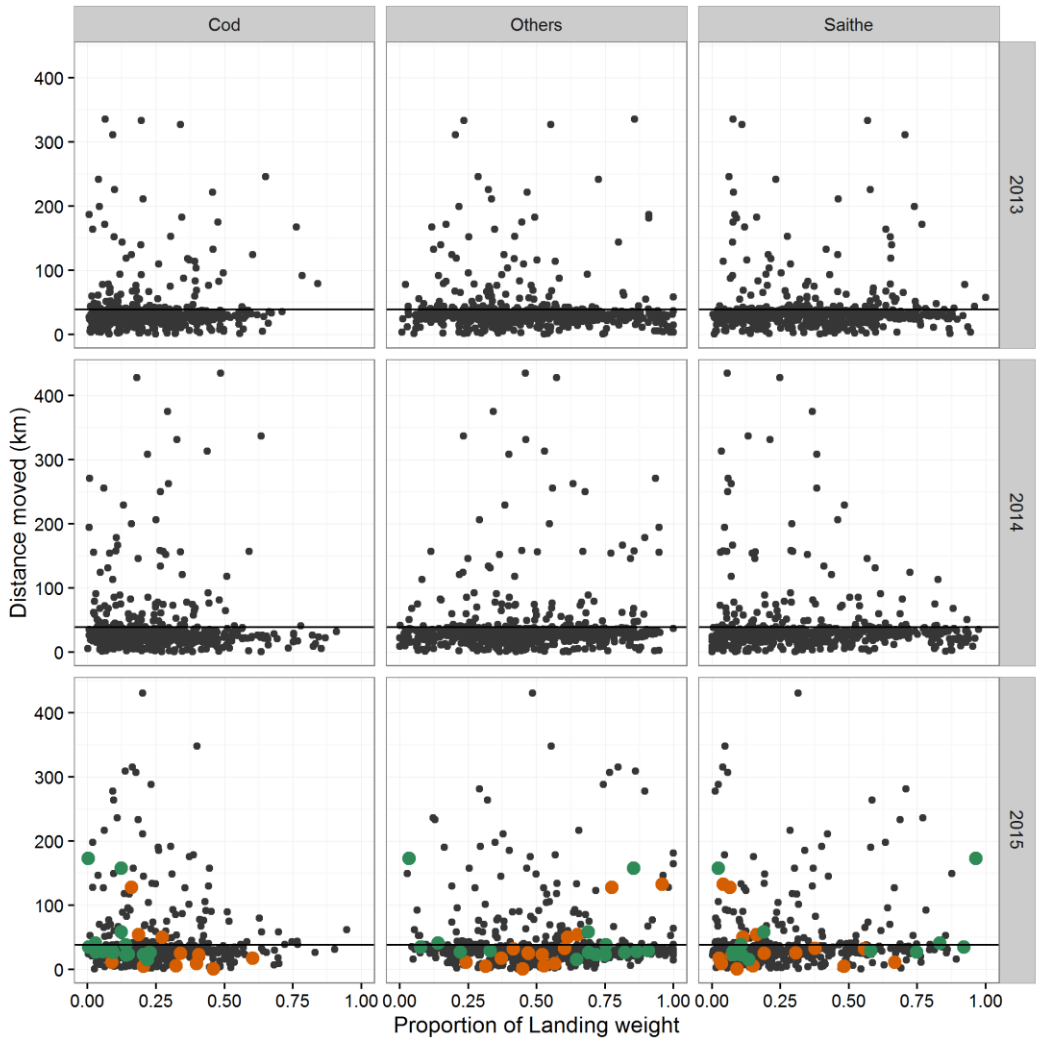

Figure 7 Scatter plot showing the correlation between the proportion of the landing weight in a haul for cod, saithe and other species and the depth change after haul-in. Black line indicates average fishing depth across all hauls. Coloured points indicates hauls between 10/04-2015 and 15/04-2015 with avoidance behavior towards saithe (green) and hauls between 4/5-2015 and 12/5-2015 with non-avoidance behavior towards saithe (orange).

Discussion

The vessel owner perceived that cod and saithe are likely to be choke species when they are included into the landing obligation, unless significant increase in TAC would be granted. He feared that leasing quota would become more difficult, for the same reasons as advocated by

Hatcher (2014). Indeed, high prices on saithe quota leasing were also experienced in 2016 where the TAC was further reduced by 10% compared to 2015, at approx. 13 DKK/kg (price date: 17/06/2016, Dansk Puljefiskeri, www.puljefisk.dk, pers.com) vs. 5 DKK/kg in 2013-2014 and 7-8 DKK/kg in 2015 (data from HM635). This supports the perception that supply and demand for saithe quota was mismatched in 2016. According to Dansk Puljefiskeri (pers.com), the mismatch was due to higher quota utilization on the individual vessels, and a limited quota available. On contrary, the price of cod quota lease remained relatively unaltered around 9 DKK/kg in 2016 (price date: 17/06/2016, Dansk Puljefiskeri, pers.com) compared to 2013-2015. A first explanation can be that the TAC for cod was slightly higher in 2016. But another interesting factor is the indirect effect of the limited saithe TAC: Cod and saithe co-occur in the Norwegian waters of the North Sea and Skagerrak. However, the Danish fishers are not allowed to fish in Norwegian waters if they do not own enough quotas to cover their catches (Dansk Puljefiskeri, pers.com). When they are limited by their saithe quota, fishers reduce their activity in Norwegian waters, which in return limit their ability to target cod and thus reduce the demand on cod quota. Additionally, the severity of the choke species problem largely depends on the discard of the individual vessel. When the landing obligation is fully implemented, all vessels receive a top-up indexed to the expected average discard, which was estimated for saithe in the North Sea in 2016 to be 6% (ICES 2016). However, in 2015 the estimates discard in Skagerrak increased to 15%, reflecting that the TAC had become more limiting. For vessels with a previous discard lower that the top-up, the extra quota will signify a revenue increase, however the opposite is true for vessels with a previous discard higher than the top-up. Notably though, significant revisions in the perception of the saithe stock have led to a major increase of the scientific advice for the TAC in 2017, implying that most of the concerns expressed here may likely not apply anymore in 2017 (ICES 2016).

The data and results collected in this research support the fisher's view on saithe and cod having acted as chokes in the fishery on HM635 in 2013-2015, with saithe as the primary choke species, followed by cod. For saithe, the initial quota was exhausted around May in these years. In a landing obligation scenario and if no other leasing opportunities had been available and the TAC would not have been increased significantly, the quota exhaustion would have hampered the fishery, forcing the fisher to find alternative options.

The haul composition on HM635 showed that saithe and cod together make up more that 50% of most hauls in weight, except when the vessel trialled a different fishery in 2015, switching to plaice fishery. In this period the catches of saithe dropped. The fisher reported that, during the switch to plaice fishery, he changed area since saithe and plaice do not co-exist, which was verified by visual inspection of the fishing positions [Figure 4]. Thus, it is not possible to distinguish if the drop in saithe landings was due to a switch in gears or fishing area. Regarding the usual fishing grounds for cod and saithe no overall change over time in haul composition was observed, indicating that there are no obvious periods in a year where saithe or cod are at higher risk of limiting the fishery. At the same time, it suggests that fishing practice has been largely the same throughout the year. The two trips supplied by the fisher were not statistically different from the other trips, except for a single haul in the non-avoidance trip, with extraordinary large saithe landings, although the trips were spatially different.

The density estimation maps demonstrated an overlap in catches between saithe, cod and other species, which supports the fishers claim that saithe, cod and other species often co-exist, which would hinder the possibility for more selective fishing. It could also indicate that areas with high co-existence of saithe, cod and other species were mainly fished on and alternatives rarely sought. However, the analysis on the discrepancy between the median and the mean shows that hauls generally contained low saithe catches, except for one or two hauls per trip, while cod catches were more constant. This indicates that the spatial distribution of saithe was patched, while cod distribution was more even. From the catch patterns, this indicates that the vessel mainly targeted areas with low saithe occurrence, however in each trip, hauls over areas with higher concentrations of saithe were risked. This supports the tactical choices explained by the skipper, that depending on the catches of other valuable species in areas known to have little saithe, real time decisions to try areas with higher concentrations of both saithe and other valuable species are made. Thus, it is likely that the primary avoidance behaviour of the fisher is to avoid areas with known high concentrations of potential choke species, however to utilize all quotas, risks are sometimes taken to fish in these areas anyway.

As saithe is likely occurring in patches, a secondary avoidance behaviour is possible when encountering high catches of saithe, by changing fishing area or depth. However, there was no significant evidence that the distance moved or change in depth was related to the value or weight proportion of either saithe or cod. The absence of evidence in the data was explained by the skipper, that secondary avoidance behaviour mainly consisted on maintaining heading after haul-in to avoid doubling back over the same saithe patch as just encountered.

In conclusion, this study has brought interesting perspectives on the concept of choke species and its impact in the daily tactical decisions made by fishers. In the frame of the analysis of the impact of the landing obligation, choke species have mainly been considered at the fishery scale, comparing the catching capacity and the landing opportunities of a fleet or a nation (Ulrich et al 2011, Prellezo et al 2016, Russell et al 2015, STECF 2013). In reality, choke species may affect differently individual fishers within the same fishery, since the most crucial factor is the individual quota share held by the fisher and his ability to lease additional quota, more than the national quota itself. Decisions are made every day regarding either discarding, avoiding or leasing quota for a given choke species, but such fine-scale decisions are difficult to capture by scientific models and data [4] and to integrate into management strategies that make sense for every individual fisher while achieving the overall policy objectives. This study has tried to link various sources of knowledge, bringing together fishers' tactic knowledge at local scale with scientists' explicit knowledge at wider scale. This helped assess some potentials and trade-offs of avoiding choke species, and contributed to building common grounds of understanding between stakeholders and scientists.

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Chapter 5. Unravelling the scientific potential of high resolution fishery traceability data - Denmark.

By: Kristian Plet-Hansen, Erling Larsen, Lars Mortensen, J. Rasmus Nielsen, and Clara Ulrich– DTU-Aqua.

North Sea case study

Introduction & Objectives

Fisheries science and management rely on scientific survey data and commercial fishery data to estimate the status of marine populations and assess the impact of fishery on the environment. A key challenge is that the two data sources differ much in quality and detail. Scientific survey data usually have a broader and more homogeneous geographical coverage than commercial fishery data, as fishers target certain species and areas. However, scientific survey data have less intensity and coverage (Pennino et al., 2016; Bourdaud et al., 2017). While both commercial and scientific data are important sources of information, it is a challenge to link the two types of data and provide a coherent picture (Poos et al., 2013; Bourdaud et al., 2017). Currently, integrated commercial datasets rely on coupling data from logbooks, sales slips and the Vessel Monitoring System (VMS) to allocate landings to vessels' hauls and fishing grounds (Hintzen et al., 2012). However, size composition at haul level is not known, and it is usually assumed that it is the same as the aggregated size composition from the entire trip (Bastardie et al., 2010). Fishing trips can cover several days and large areas, with a likely high variation in size composition; hence these estimates probably introduce a bias. Thus, expanding the commercial data to incorporate accurate recordings of size or age at haul level could add significant quality to the information available (Verdoit et al., 2003; Bourdaud et al., 2017). A Danish initiative of packing-at-sea came to our attention that might be able to provide such information. The project started in 1995 with the purpose of investigating whether sea-packing could provide additional profit to fishers, by reducing their costs of size-sorting and packing at the auctions, and by ensuring higher quality fish. The project found a reduction in costs of 6-7% when packing fish at-sea but remained inconclusive on whether sea-packing resulted in a profit increase (Frederiksen and Olsen, 1997; Frederiksen et al., 2002). Because sea-packed fish is labelled with information on size class, species, weight, vessel and time, a by-product of this project was the development of a database where the positional and temporal data as well as the size composition of landings is recorded at the haul level.

In 2002, the Council of the European Union laid down rules for increased traceability of food goods, including fish (EU, 2002). The traceability regulations apply for batches of fish, with a batch being a quantity of fish caught at one time. But the regulations do allow for the registration of a batch as the compiled landings from a full fishing trip. Additionally, spatial traceability regulations are complied with if a batch can be traced to the fishing area (e.g. an ICES subdivision) which covers large areas. In Denmark three traceability systems were developed to meet the requirements; the Vessels Data Exchange Center (VDEC) software, the yellow catch information notes and the "Sporbarhed i Fiskerisektoren" (SIF) database, which is a build-on on the sea-packing project. The VDEC is in theory capable of delivering more detailed data than the electronic logbook (eLog), including crate landing composition and size classes (a crate is a standard size box used to store fish for landing (Pack and Sea A/S, 2018)). But in practice, most of the data reported in the VDEC are reduced to haul position, time, and non-sized landings information (O. Skov, pers. comm.). The yellow catch information notes were developed by the industry to ensure compliance with the regulations among vessels unfit for sea-packing or VDEC equipment (Dandanell and Vejrup, 2013). A note is filled in for the crate with information of the fishing trip including date of first and last fishing, geographical area where fishing took place (as ICES subdivision), gear type and other administrative information, as well as the species and commercial size class. The minimum labelling and information requirements are thus complied with (EU, 2001, 2009, 2011; Dandanell and Vejrup, 2013).

The present study focuses on the third system, the SIF database. We analyse and explore the accessibility, coverage, consistency and reliability of the data, in order to assess whether it can be used for scientific studies and in management advice. The quality of the data is assessed by comparing it with the eLog, sales slips and data from a trial on Fully Documented Fisheries (FDF). We expect that because the SIF database includes the size composition at the haul level, it can in the future be used for comparison of the survey based statistical correlation models as well as VMS and logbook coupled data with in situ fishery data (Bastardie et al., 2010; Hintzen et al., 2012; Kristensen et al., 2014; Nielsen et al., 2014). Futhermore it can contribute with enhanced knowledge on spatial distribution, e.g. by mapping areas with a larger share of juveniles. The present paper describes these new data and assesses their quality.

Materials and Methods

The SIF database

The SIF database began in 2012 as collaboration between the Danish Fishermen's Association (DFPO), the Danish AgriFish Agency and the retail industry. It collects data from sea-packing vessels, as well as data from the VDEC, fisheries auctions, collectors (companies that collect landings from several vessels), and data from the yellow catch information notes (Lyngsoe Systems, 2009). The sea-packing data in SIF (hereafter called "SIF") provide information at haul level on the landed species and size composition by weight, together with detailed information on date, time and position of the haul. The size classes applied are those defined by the EU regulation and size classes used by the fish auctions (EU, 1996; Danske Fiskeauktioner, 2017). The weight of each size class of each species is recorded automatically into the dataset by the sea-packing equipment, using a dynamic scale during the handling operations where the fish are gutted and bled. The weight recorded by the sea-packing equipment is the gutted weight and not the live weight as recorded in the eLog (Frederiksen et al., 1997; Frederiksen et al., 2002; Danish AgriFish Agency, 2017). As in the eLog, the SIF database allows for entries of discards in addition to the landings. Figure 1 presents a schematic of the difference between landings information at haul level in the eLog and SIF. SIF provides the size composition of the landings directly at a haul level, assuming that the sea-packed fish of a given species are representative of the total landings of that species in the individual haul. SIF is linked with the eLog from where the temporal and spatial data for the hauls are derived. Because the SIF database also contains the landings data from the sales slips, a unique identifier is given to all hauls and all sales slips data in SIF in order to separate the two types of entries.

In 2016, funding for SIF operational costs was reduced. The hosting and collection of data is still in operation through the company Lyngsoe A/S with financial support from DFPO to maintain a minimum support for the administration and service provided by or for SIF (C. S. Pedersen, pers. comm.). The future of SIF is thus uncertain, although it recently proved valuable. In 2017, the German authorities required traceability data for a batch of fish a German buyer had purchased from a wholesaler in Denmark. The information on the Danish suppliers (fishing vessels) was found in SIF and met the expectations of the German authorities', thus demonstrating the operationality of the system (C. S. Pedersen, pers. comm.).

Data collection

As each vessel owns its own data in SIF, individual acceptance to use the data for the present study was needed. 26 vessel owners were contacted and asked whether they sea-packed their landings and were willing to grant access to their SIF data. The skippers were found using online searches for vessels with sea-packing equipment as well as skippers who had previously collaborated with scientists and were known to operate vessels with facilities for sea-packing. At the time of writing, confirmation was still pending from three skippers, 12 skippers had granted access to their SIF data and 11 skippers had refused (Table 1). Access to SIF was through a website, with no export function. A web scraper was developed to extract the data.

Table 1. Vessel ID, remarks and whether access to SIF data has been granted for contacted vessels. 4.a = Northern North Sea, 4.b = Central North Sea, 3.a = Skagerrak and Kattegat, 22-24 = Western Baltic Sea, 25-28 = Eastern Baltic Sea.

Vessel	Access granted	Usable SIF haul data	Main fishing areas	First entry at haul level	Remarks
A	Yes	Yes	4.a, 4.b, 3.a	10-04-2015	
B	Yes	Yes	4.a, 4.b, 3.a	27-03-2014	
C	Yes	Yes	4.a, 4.b, 3.a, 22-24, 25-28	09-12-2013	
D	Yes	Yes	4.a, 4.b, 3.a	20-03-2015	
E	Yes	Yes	4.a, 4.b, 3.a	19-12-2013	
F	Yes	Yes	4.a, 4.b, 3.a	19-10-2016	
N1	No				Did not believe the data could be used to help improve the fisheries
N2	No				Believe it to be too expensive in time and money to look into their SIF data
N3, N4	No				No reason given

N5	No				Only sea-pack hake. Did not see the use of sharing the data for one species
N6, N7, N8, N9, N10	No				Use the sea-packing machinery to clean the fish and report to the eLog.
N11	No				Was uncertain as to whether the data could be misused
U1, U2, U3	Undecided				Waiting for email confirmation
Q	Yes	No	4.b, 3.a, 22-24, 25-28	None	Only sales slips records in SIF.
V	Yes	No	4.b	None	Gillnetter. No hauls. Sea-packing is recorded at day level.
W	Yes	No	4.b, 3.a	05-12-2013	Use the sea-packing machinery to clean the fish and report to the eLog.
X	Yes	No	4.a, 4.b, 3.a, 22-24, 25-28	20-12-2013	Manually enter haul positions and time rather than coupling the eLog and the sea-packing equipment. Haul positions and timestamps are repeated and unreliable
Y	Yes	No	4.a, 4.b, 3.a, 22-24, 25-28	17-12-2013	Use the sea-packing machinery to clean the fish and report to the eLog.
Z	Yes	No	4.a, 4.b, 3.a	02-12-2013	Use the sea-packing machinery to clean the fish and report to the eLog.

Study period

The study period is January 1 2015 to December 31 2016. This period was chosen as there is high resolution haul data for five vessels as well as GPS sensor data from a FDF trial for vessels A and B.

Assessing validity of SIF against DFAD and eLog

For the validity assessment, the focus is on the five vessels with highest data quality available in the SIF database in 2015 and 2016; vessels A, B, C, D and E. Vessel F is not covered in this study because its SIF entries do not begin until October 2016. First, the SIF data was compared to the

DTU AQUA DFAD (Danish Fisheries Analyses Database) dataset. DFAD is based on sales slips merged with the eLog and fleet register data. All Danish commercial fishing vessels above 12 meters in length are required to report their catches in the eLog. Catches are recorded as total live weight of each species and since 2015 it has been mandatory to record catches in the eLog on a haul-by-haul level. Prior to 2015, it was only mandatory to record on a daily basis and when changing statistical rectangle (EU, 2011; Danish AgriFish Agency, 2017). The coupling of eLog haul data and sales slips data do allow for inference of landings' size composition at haul level assuming constant size distribution across all hauls (Bastardie et al., 2010, Hintzen et al., 2012). Sales slips record landings as gutted weight per trip, so the DFAD size distribution at haul level are created by 1) adding a conversion factor from gutted to live weight, 2) comparing and merging the reported landings of each species in sales slips and eLog and 3) distributing evenly the species size distribution from sales slips across all hauls where the species was caught. However, in reality size classes are unlikely to be evenly distributed, and this procedure induces a risk for inaccurate size distribution at the haul level.

Not all species landed by a vessel are sea-packed. To analyse the completeness of the SIF data the species recorded in SIF were compared to the same data from DFAD. The 10 most important species (in landings by weight) for the five vessels were identified based on DFAD landings records. The completeness of landings recorded in SIF compared to DFAD was calculated as:

$$(1)\ Completeness_{landed\ species} = 100 - \frac{(DFAD - SIF\ [kg])}{DFAD\ [kg]} * 100$$

No conversion factor is needed for the comparison, as both SIF and DFAD have records of the gutted weight.

Similarly, the completeness of hauls available in SIF was estimated based on the number of hauls according to the eLog, using:

$$(2)\ Completeness_{hauls} = 100 - \frac{(eLog - SIF\ [n])}{eLog[n]} * 100$$

A comparison of the recorded species and commercial size classes for trips conducted by vessel A, B, C, D and E during 2015 and 2016 for the 10 most landed species was then made. SIF and DFAD data were merged based on the trips' landing date. The weight of each commercial size class of the 10 most landed species for each trip was summed based on the unique logbook number identifying each fishing trip. Trips with no records in either SIF or DFAD were excluded. The largest size class for cod (*Gadus morhua*) and hake (*Merluccius merluccius*) in SIF is 0, whereas the largest size class is 1 in DFAD. The division between the second largest size class, size class 2, and size class 1 is the same for SIF and DFAD. Therefore, size class 0 where aggregated with size class 1 in SIF in order to make comparison of the SIF and DFAD data possible. In addition to a visual comparison of SIF and DFAD data at trip level, the fit between SIF and DFAD records was analysed using a linear model using the lm function in R. A log-transformation was applied to landings recorded in SIF and DFAD whereby normal distribution was induced. The model can thus be written as:

$$(3)\ y_i = e^b * x_i^{\alpha}$$

where y is the landings recorded in SIF, x is the landings recorded in DFAD and i is an index for the fishing trip.

Not all fishing trips recorded in DFAD had records in SIF for the species too. Therefore, the size class composition of the landings was calculated as a percentage of the total landings based on DFAD records. This was done for trips with both SIF and DFAD data and was compared to trips where only DFAD data was available, in order to detect potential bias in size distribution which could occur if fishers e.g. only sea-pack at hauls with ample volumes of large fish.

Spatial distribution of SIF data compared to FDF data

Because the SIF system depend on the eLog for the temporal and spatial haul information, a geographic comparison with DFAD is not relevant. Therefore, coverage quality was assessed using a different data set, comparing SIF with the GPS sensor data from a FDF trial run by the Danish AgriFish Agency in 2015 and 2016 (Bergsson and Plet-Hansen, 2016; Bergsson et al., 2017). This was done for vessels A and B as they took part in this trial during 2015 and 2016. Besides continuous video recording, the FDF system also recorded time and position of setting and towing of the gear by use of drum rotation sensors as well as the GPS position every 10 seconds while vessels were at-sea (Bergsson and Plet-Hansen, 2016; Bergsson et al., 2017). The FDF trial did not cover the Baltic Sea and vessels C, D and E did not participate in it. To ease the computation, FDF GPS data were plotted as points at a 1 minute interval. Start and end position according to SIF was used to plot lines for each haul on the same chart. Because this assumes linear track courses some deviance is expected. Additionally, some hauls with unrealistic haul lengths and towing speeds were spotted in SIF. SIF hauls were excluded if towing speed exceeded 7 knots. This exclusion criteria was set to allow for a certain margin of error, in order to reduce the risk of excluding hauls with correct positional data but with errors in the timestamp, and bearing in mind that if a vessel conducted a haul in the same direction as the dominant current, towing speeds could be higher when calculated from GPS positional data than the actual towing speed through the water. Finally the criteria for exclusion was based on information from the vessel owners on their maximum and usual towing lengths as well as an investigation of the maximum towing speeds recorded in the FDF trial.

For vessel A, 91 hauls were excluded, corresponding to 6.33% of recorded hauls. For vessel B, 71 hauls, corresponding to 7.67% of recorded hauls were excluded.

Results

Although it is possible to enter discards in SIF, none of the investigated vessels had any discards recorded. Half of the 12 skippers who granted access to their SIF data had recordings at the haul level with high resolution, whereas the data from the other half showed that on these vessels, the sea-packing equipment was not used in a manner where the size classes were recorded at the haul level. The main reason given for this were that the vessels used the sea-packing equipment to clean the fish during their catch processing's but did not store their landings in size graded crates (Table 1). This was also the main reason given by the 11 skippers who did not grant access.

Assessing validity of the SIF data against DFAD and eLog data

Most species were reported in DFAD and SIF. For vessel A, five species were not reported in SIF: Atlantic mackerel (*Scomber scombrus*), edible crab (*Cancer pagurus*), marine crabs (*Brachyura* sp.), greater weever (*Trachimus draco*) and lumpfish (*Cyclopterus lumpus*). Vessel B had six species in DFAD but not in SIF: Norway lobster (*Nephrops norvegieus*), golden redfish (*Sebastes marinus*), greater forkbeard (*Phycis blennoides*), long-rough dab (*Hippoglossoides platessoides*), cuttlefish (*Sepiidae* sp.) and tope shark (*Galeorhinus galeus*). Vessel C and D had three species in DFAD but not found in SIF: Atlantic mackerel, edible crab and lumpfish. Vessel E had Norway lobster, golden redfish, lumpfish, greater forkbeard and blue ling (*Molva dypterygia*) in DFAD but not in SIF. The weight of the species not recorded in SIF constituted 0.06% of the landings for vessel A, 0.10% of the landings for vessel B, 0.02% of the landings for vessel C, 0.03% of the landings for vessel D and 0.02% of the landings for vessel E.

Comparison of trips, hauls and 10 most landed species

Table 2 presents the completeness of the data in SIF compared to DFAD for the 10 most landed species. The majority of hauls and trips are represented in both SIF and DFAD, although a third of the 14,570 combinations species*haul were missing in SIF. For the reported landings the highest completeness is achieved for vessel B at roughly 90% on average, followed by vessel A at around 80% on average, whereas vessel C has the poorest completeness, with a high of 69% and vessels D and E fall in between. Figure 2 present the landings composition for the different size classes of each species for all trips with only DFAD data and all trips with both SIF and DFAD data. Overall the size class composition is fairly equal. For cod, hake, haddock (*Melanogrammus aeglefinus*), lemon sole (*Microstomus kitt*), turbot (*Scophthalmus maximus*) and witch flounder (*Glyptocephalus cynoglossus*), the size classes constitute roughly the same percentage of the landings regardless of whether the trips only had DFAD data or SIF too. The largest discrepancy is for saithe (*Pollachius virens*) where size class 3 constitutes a lower percentage of the landed weight while size class 4 constitutes a larger share when trips are not in SIF.

Table 2. Completeness of SIF when compared to the eLog (hauls and trips) and vessel landings data from DFAD for the 10 most landed species in 2015 and 2016.

Completeness [%]					
	Vessel A	**Vessel B**	**Vessel C**	**Vessel D**	**Vessel E**

	2015	*2016*	*2015*	*2016*	*2015*	*2016*	*2015*	*2016*	*2015*	*2016*
Fishing trips	**100.0**	**100.0**	**89.7**	**78.7**	**98.8**	**100.0**	**100.0**	**98.1**	**95.5**	**100.0**
Hauls	**89.8**	**82.6**	**92.3**	**74.8**	**82.6**	**71.5**	**61.6**	**79.0**	**65.3**	**80.0**
Wolffish	81.1	94.9	87.7	83.6	49.6	60.5	66.4	75.0	62.5	85.5
Lemon sole	88.0	77.9	77.2	100.0	58.7	67.9	41.4	54.6	63.0	86.3
Witch flounder	91.8	89.7	96.0	91.8	46.6	51.8	59.0	52.9	61.2	81.6
Hake	95.2	87.1	90.0	93.0	57.5	64.4	51.1	69.9	69.0	77.1
Turbot	79.0	82.4	93.3	76.3	58.6	68.8	16.1	76.8	64.7	83.2
Haddock	81.4	88.9	96.8	85.3	52.0	69.2	51.8	69.4	62.6	70.6
Monkfish	94.2	91.1	95.3	90.2	60.5	59.6	56.8	73.2	58.9	76.3
Cod	85.0	89.3	93.9	89.4	20.2	29.4	62.6	77.4	63.4	77.3
Saithe	68.0	94.7	91.8	90.7	21.5	55.7	60.7	70.3	55.3	74.6
Plaice	19.1	15.5	90.0	96.4	56.3	64.2	45.6	63.8	61.6	84.3
Overall species results	**78.3**	**81.2**	**91.2**	**89.0**	**48.2**	**59.2**	**51.2**	**68.3**	**62.2**	**79.7**
Fishing trips, Number in SIF	**39**	**67**	**35**	**37**	**83**	**88**	**59**	**53**	**42**	**48**

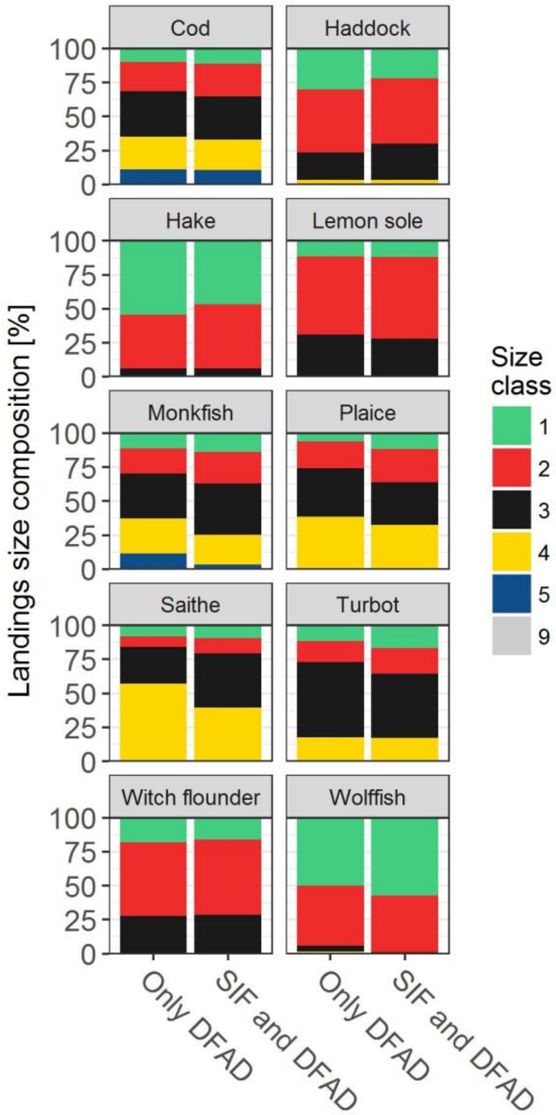

Figure 2. Landings (kg) size composition in percent stratified on trips with only DFAD data and trips with both DFAD and SIF data. Size class 1 are the largest specimens. Size class 9 is unsorted.

A scatterplot and a linear model fit are provided for the 10 investigated species of each vessel at trip level (Figure 3 and Table 3). Saithe, turbot, witch flounder, wolffish (*Anarchichas* sp.) and monkfish (*Lophius piscatorius*) had R^2-values and a scatterplot close to a 1:1 ratio between SIF and DFAD at each trip for most vessels. However, the scatterplot shows that monkfish was not sorted into size classes on vessel A when sea-packed. Correlations were also generally high for hake and lemon sole but lemon sole is rarely landed for vessel B. Haddock had high R^2-values too but not for all years and all vessels, with especially vessel B and D in 2016 having a poor fit. Cod had R^2-values and a scatterplot with a good fit between SIF and DFAD for vessel B, but not for the rest of the vessels. For plaice (*Pleuronectes platessa*) the scatterplot and R^2-values are poor for most vessels. Interestingly, some occurrences of more SIF than DFAD records appeared, mainly for witch flounder, which should in theory not be possible, since the summing of all SIF data should also be found in the total recorded landings for any given trip. Presenting this to the fishers revealed two reasons; 1) small mismatches are inevitable, as the fishery auctions, from where the landings data in DFAD are derived, only record landings in total kilograms whereas the sea-packing equipment consists of scales with dynamic motion compensation and relay data with two decimals. 2) Larger mismatches could be an artefact in the SIF system. If a crate is labelled wrongfully, e.g. by recording the wrong size class or species, a new label must be made. This in turn will be recorded as a new entry in SIF and the fishers cannot delete the old entry, meaning that the same crate will count twice in SIF.

Table 3. R^2 and degrees of freedom for linear model fit of landings in SIF and DFAD for the 10 most landed species in 2015 and 2016. SIF data has been aggregated to trip level in order to make the comparison possible with DFAD and comparison is done solely for trips where both SIF and DFAD have records.

	Vessel A				**Vessel B**				**Vessel C**				**Vessel D**				**Vessel E**			
	2015		*2016*		*2015*		*2016*		*2015*		*2016*		*2015*		*2016*		*2015*		*2016*	
Species	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**	**df**	**R^2**
Wolffish	38	0.997	82	0.993	35	0.999	59	0.885	40	0.793	65	0.952	46	0.946	60	0.953	62	0.914	81	0.975
Lemon sole	88	0.936	156	0.978	5	0.574	8	0.859	146	0.836	155	0.985	56	0.981	100	0.890	65	0.944	88	0.985
Witch flounder	55	0.966	84	0.975	33	0.986	12	0.805	28	0.952	69	0.999	21	0.995	83	0.876	82	0.841	105	0.912
Hake	38	0.979	39	0.985	37	0.987	65	0.997	77	0.747	77	0.981	53	0.701	71	0.777	94	0.775	131	0.963
Turbot	117	0.946	228	0.921	27	0.899	31	0.732	120	0.940	165	0.949	30	0.988	79	0.940	40	0.919	63	0.983
Haddock	40	0.972	89	0.855	50	0.991	26	0.704	95	0.880	111	0.978	72	0.813	95	0.552	98	0.831	139	0.857
Monk-fish	NA	NA	NA	NA	69	0.997	121	0.996	139	0.933	191	0.886	75	0.922	161	0.899	152	0.749	181	0.880

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Cod	122	0.776	212	0.981	56	0.994	109	0.998	227	0.703	260	0.713	125	0.702	169	0.743	160	0.607	182	0.803
Saithe	22	0.908	27	0.994	56	0.999	98	0.998	13	0.737	63	0.963	61	0.904	40	0.853	123	0.731	146	0.918
Plaice	70	0.524	124	0.472	9	0.825	5	0.779	201	0.673	207	0.763	49	0.889	104	0.889	81	0.897	94	0.980

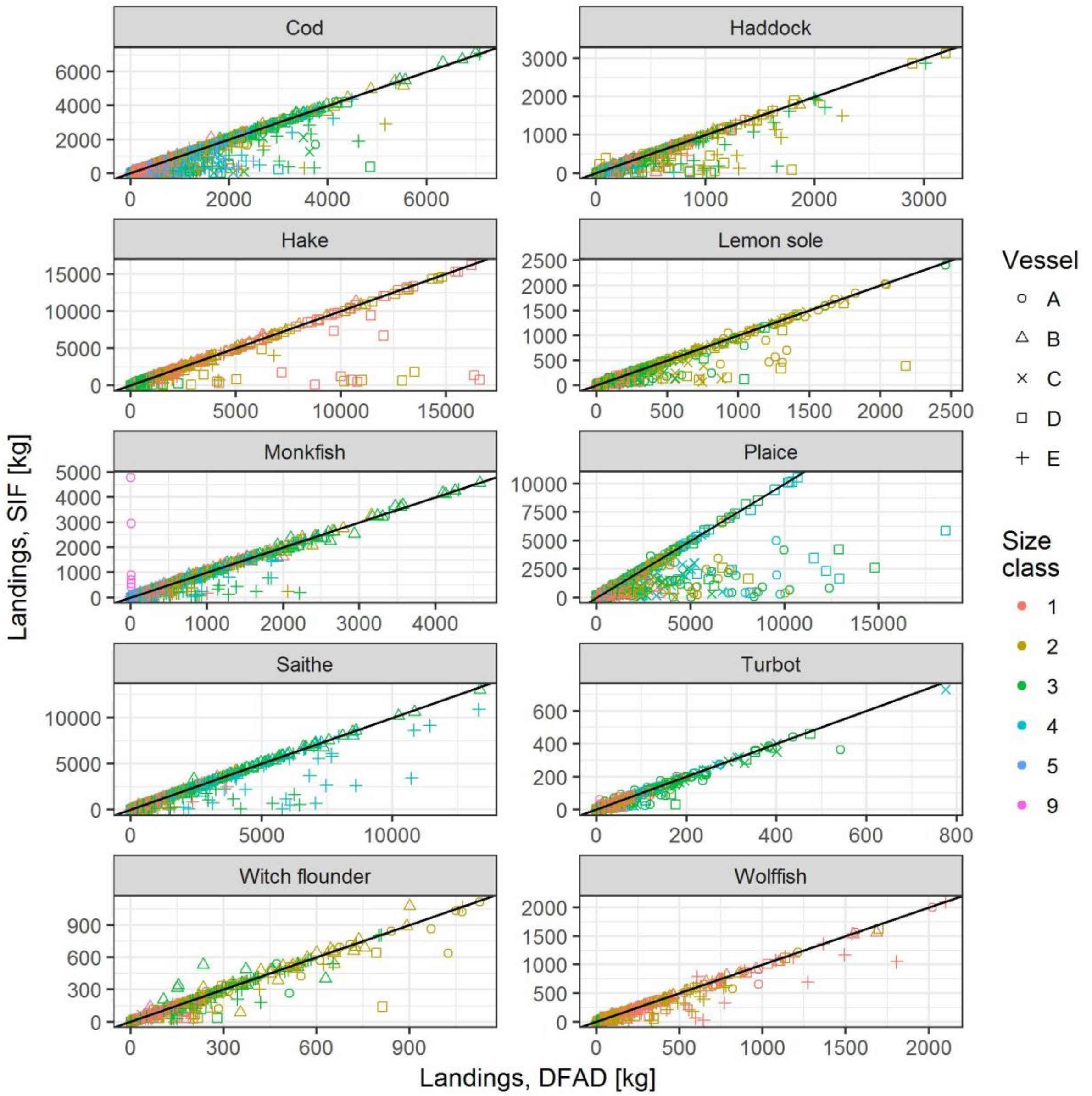

Figure 3. Landings per trip according to DFAD and SIF for the 10 most landed species in 2015 and 2016 by species and commercial size class. Points: The aggregated weight of the species and size

class for a fishing trip. The x-axis represent the weight according to DFAD, the y-axis represent the weight according to SIF. Black line: The 1:1 ratio between DFAD and SIF. Size class 9 is unsorted.

Spatial distribution of hauls compared to FDF data

Overlay maps for positions according to FDF GPS data and according to SIF for vessels A and B in 2015 and 2016 are presented in Figure 4. The maps have black points where fishing activities took place according to FDF but no hauls have taken place according to SIF and grey lines where hauls recorded in SIF but not in FDF occurred. Most areas have overlap between SIF and FDF. Vessel A have a more compact area of operation than vessel B and vessel B have an area at roughly 59° N and 0.5° W where no hauls have been recorded in SIF but fishing took place according to FDF in both 2015 and 2016.

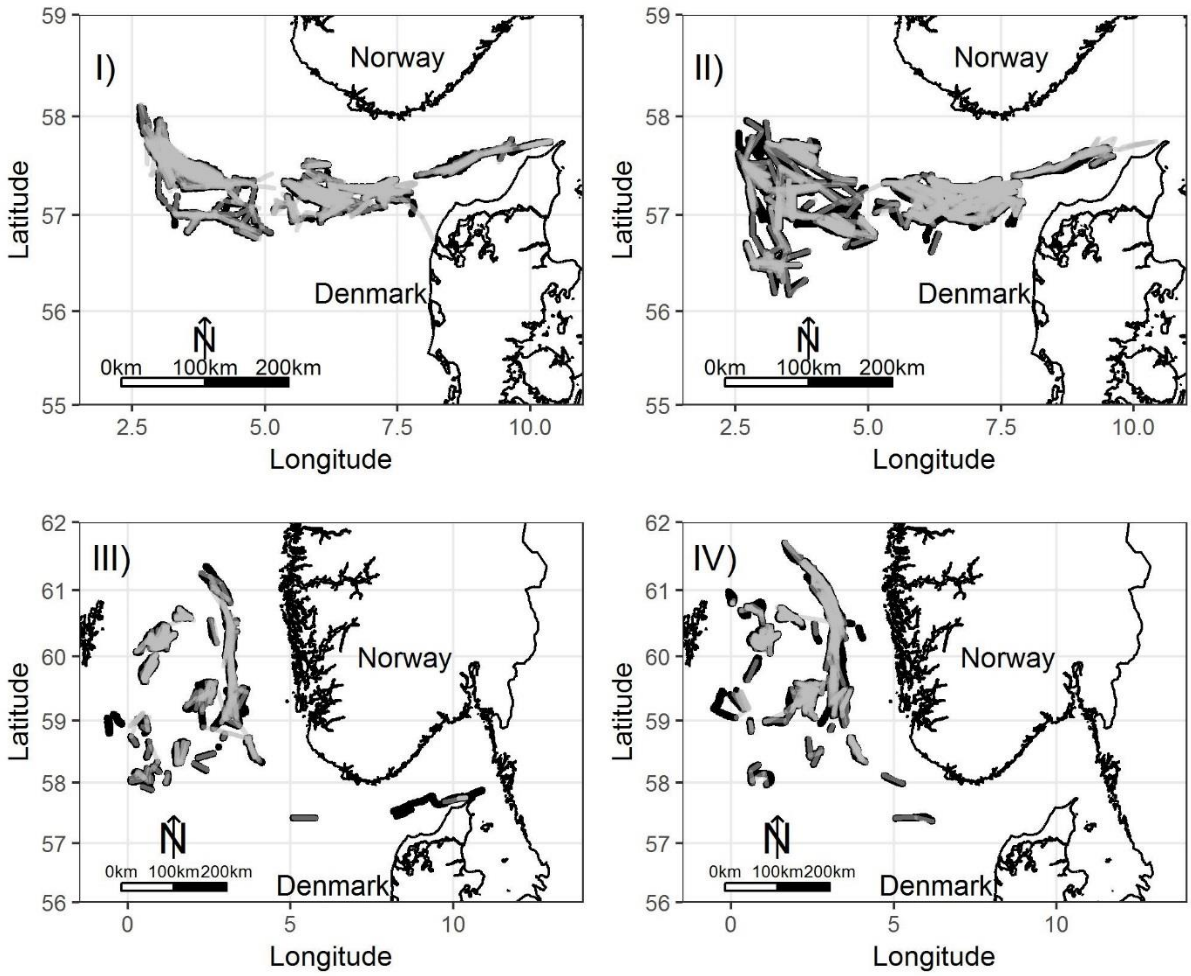

Figure 4. Fishing activity overlap between FDF and SIF. I) Vessel A, 2015. I I) Vessel A, 2016. III) Vessel B, 2015. IV) Vessel B, 2016. Black points: Fishing activity recorded by FDF GPS sensors (1 minute interval). Grey lines: Hauls according to SIF. The FDF trial did not cover the Baltic Sea and the maps do therefore not include hauls in this area.

Discussion

SIF has data not available in the currently used commercial fisheries data, as SIF contains direct observations of size distributions at the haul level instead of the trip level. The completeness of SIF compared to DFAD shows a good match, albeit not perfect, between the two datasets. Although all five vessels had species that were present in DFAD but not in SIF, these constituted a minor fraction of the total landings. Vessels engaged in sea-packing may choose not to sea-pack a species if it is not considered worth the effort of sea-packing during catch processing according to the fishers. Norway lobster is an example of a target species which is not sea-packed, as the added value is not considered to be large enough. This is also the case for several flatfish species.

Fishing trips and hauls recorded in the eLog were overall well represented in SIF. No discards were recorded in SIF, likely because the legal purpose of the dataset is for traceability requirements of the landings.

The SIF landings did not match DFAD landings fully. Several trips had records of landings for one or more of the 10 investigated species in DFAD but no records of the species in SIF. A reason for this may be the loss of data when merging DFAD and SIF because there are no unique haul and trip ID's shared between SIF and DFAD. Therefore, the common identifier used to merge SIF and DFAD was the landings date which can be inferred from SIF and is recorded in the DFAD data. However, it is possible that some fishing trips were not merged due to this. The mismatches are also possible if vessels do not have storage capacity to pack all their landings in crates at-sea. Because it takes up more storage room to sea-pack landings there is a trade-off between continuing to fish after the storage capacity for sea-packing is reached. On one hand, sea-packing should give a higher quality and thereby higher price for the landings (Frederiksen and Olsen, 1997; Frederiksen et al., 2002). On the other hand, the cost of steaming between fishing grounds and port may make it more profitable to continue fishing, store landings in larger bulk and land a larger amount of unsorted fish which will give a higher total profit. The choice between one or the other is likely to be influenced by several factors such as remaining quota, estimated value of the landings already in storage and weather. There is therefore not necessarily consistency between fishing trips in whether a species is sea-packed or not. The fact that plaice is the species were SIF records are poorest supports this, since plaice is a relatively low value species in this context. Further analysis of the factors influencing the sea-packing of landings is beyond the scope of this study. Future studies on the frequency of storage limitations, possible correlation between expected fish prices and sea-packing or cost-benefit analysis of the added workload at-sea compared to the potential gain from sea-packing could shed further light on the underlying reasons behind trips with landings recorded in DFAD while lacking in SIF. However, the potential bias created by lack of SIF records for certain trips seems limited. Overall, there are only small differences in the percentwise size composition in the landings for the DFAD dataset when looking at trips where SIF data was available compared to trips where no SIF data was available. For the species where some skewedness is detected, the difference is between two adjoining size classes (e.g. saithe with the main difference being the share of size class 4 compared to size class 3). If the skewedness had been between two size classes in the opposite scale of each other, e.g. size class 1 compared to size class 4, the risk of a bias would have been greater.

As a whole, the investigations and tests comparing SIF and DFAD revealed that a bias in SIF records seems unlikely but that the lack of entries in SIF varies between vessels, years and species. In light of this, SIF should not be viewed as a full record but rather as a subsample of the landings with higher resolution.

Spatial data

Overall there is a good overlap between the SIF and FDF datasets. However, some gaps in spatial coverage occur. Several reasons can explain this discrepancy. First, hauls recorded in SIF with unrealistic lengths and towing speeds were excluded which inevitably creates gaps for SIF compared to FDF. Second, positional data in SIF is exported from the eLog. Although the eLog software allow for real-time entries of the vessel's position, the skipper may postpone entries of haul data, including time and position, as long as the data has been entered prior to the mandatory transmission of data (once every 24 hours). Therefore a certain mismatch could be caused by human errors if positional data is entered manually in the eLog. Third, there is an inherent error in plotting a haul as a simple straight line from haul start to end. Adjustments in vessels' course and drag will mean that towing paths are not completed in straight lines in the real world. Fourth, some gaps may come from fishers testing a fishing area. If the catch in this area is poor, then no sea-packing will occur, meaning no haul record in SIF, but because any fishing activity was recorded in FDF, the haul will appear in the FDF data as a fishing activity. This could explain the mismatch in an area around 59° N and 0.5° W for vessel B. Finally, breakdowns have happened in the GPS equipment during the FDF trial, meaning that it is possible for hauls to have taken place and be present in SIF without being recorded in FDF.

Possible applications

When taking the differences in data between DFAD and SIF into account it is clear that the quality of the SIF data has to be scrutinized at the vessel and species level before it can be utilized for scientific and management purposes. There are clear limitations of the usefulness of SIF owing to the facts that the future of SIF is uncertain due to funding issues, the majority of Danish fishing vessels do not use it, and vessels can refuse to share SIF data. Furthermore several vessels with sea-packing do not complete the entries into SIF in a manner that allow for better spatial resolution than DFAD. The relatively short time coverage of SIF further limits its use. Nevertheless, SIF have several added values: SIF does not serve as a direct control measure but is used for commercial purposes and to fulfil traceability requirements, whereby there should be little if any incentive to tamper with the system. SIF serves as a proof of concept that it is possible to obtain precise size distribution from fisheries data at haul level even though it is not a legal requirement. Indeed, the fisheries control in Greenland already requires vessels above 75 GRT to include the size distribution of the landings at the haul level (Greenland's Autonomy, 2010). Although the number of sea-packing vessels is low, the five vessels investigated in this study have SIF data from 258 trips in 2015 and 293 trips in 2016. In 2015 and 2016, the entire Danish observer programme covered a total of 224 and 262 trips respectively. The investigated vessels did not have on-board observers in 2015 and 2016. Therefore, SIF could be used as an add-on to the on-board observer data or as a reference fleet when investigating spatial distributions and landings compositions for targeted fishing grounds. That the quality of the SIF data is lower than observer data, lacking specific information on age and length distributions as well as discards limit the possible integration of both SIF and observer or scientific survey data. However, the commercial size classes do allow for the calculation of proxies of the age and length distribution, and the spatial resolution of the investigated vessels' landings data from SIF is of the same quality as that gained from observer trips. As the SIF data seem representative for the vessels' landings composition, SIF could be used to verify the survey based statistical correlation models and the VMS and logbook coupled data and for enhanced knowledge on spatial distribution such as mapping areas with a larger share of juveniles for certain species, whereby fishers may improve their spatial selectivity.

Conclusion

SIF provides new, reliable data on the size composition of important commercial species at the same or higher resolution than what is available. However, the quantity, quality and reliability vary between vessels and species. Although SIF has high coverage and detailed landings and spatio-temporal information, the dataset has limited extent in the number of vessels. We believe that SIF data can provide knowledge on detailed spatial patterns of fishing effort and commercial species distributions as well as serve as a reference fleet. Because SIF provide direct observations at the haul level it could be used for analysis at a vessel or métier level, for instance on catchability, spatial selectivity, seasonal patterns or to compare and verify outcomes of spatial fishery models. A fleet-wide application or stock assessment usage would require an expansion of the vessel coverage and better accessibility to SIF data. It is our hope that this study may serve as a case study to highlight the possibilities that exist in enhancement of commercial fisheries data available to science.

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Chapter 6. Identification of locations, times and practices to fish to avoid unwanted catch - Balearic Islands

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Western Mediterranean case study

Introduction

According to Article 15 of the Common Fisheries Policy (Regulation EU Nº 1380/2013), the Landing Obligation in the Mediterranean applies to catches of species which are subject to minimum sizes as defined in Annex III of Regulation (EC) Nº 1967/2006 (Table 1).

The Mediterranean demersal fisheries are both multifleet and multispecific, with more than 100 species in their landings (Moranta et al. 2008). In addition, both small-scale and bottom trawl fisheries are characterized by spatial and temporal variability of their fishing strategies that mainly depend on the bathymetric range and determine both the target species and demersal communities exploited (Colloca et al. 2003, Massuti and Renones 2005).

In the Balearic Islands (western Mediterranean), commercial trawlers use up to four different fishing tactics (Palmer et al. 2009), which are associated with the shallow and deep continental shelf, and the upper and middle continental slope (Guijarro and Massuti 2006, Ordines et al. 2006). Vessels mainly target striped red mullet (*Mullus surmuletus*) and European hake (*Merluccius merluccius*) on the shallow and deep shelf respectively. However, these two target species are caught along with a large variety of fish and cephalopod species. The Norway lobster (*Nephrops norvegicus*) and the red shrimp (*Aristeus antennatus*) are the main target species on the upper and middle slope respectively. The Norway lobster is caught at the same time as a large number of other fish and crustacean species, but the red shrimp fishery is the only Mediterranean bottom trawl fishery that could be considered monospecific.

Stakeholders from the Balearic Islands consider that the best measures to reduce discards in the Mediterranean fisheries are the improvement of gear selectivity and the use of spatiotemporal closures for effort control (Task 2.5). They also consider that in order to protect recruitment, both the fishermen skill and the available scientific knowledge can allow identifying the best seasons, depths and/or areas to be closed for some target species of the bottom trawl fishery. Such considerations are in line with the main aim of this task, which is to provide decision support tools to assist fishers to make choices of fishing location to avoid discards. This work develops the scientific information on fish distributions in time and space, nursery areas and discarding hotspots from the Balearic Islands (Western Mediterranean Case Study) bottom trawl fishery.

Table 1. Minimum sizes of marine organisms in the Mediterranean according to Annex III of Regulation (EC) Nº 1967/2006.

ANNEX III

Minimum Sizes of marine organisms

SCIENTIFIC NAME	COMMON NAME	Minimum size
1. Fishes		
Dicentrarchus labrax	Sea-bass	25 cm
Diplodus annularis	Annular sea-bream	12 cm
Diplodus puntazzo	Sharpsnout sea-bream	18 cm
Diplodus sargus	White sea-bream	23 cm
Diplodus vulgaris	Two-banded sea-bream	18 cm
Engraulis encrasicolus *	European anchovy	9 cm
Epinephelus spp.	Groupers	45 cm
Lithognathus mormyrus	Stripped sea-bream	20 cm
Merluccius merluccius ***	Hake	20 cm
Mullus spp.	Red mullets	11 cm
Pagellus acarne	Spanish sea-bream	17 cm
Pagellus bogaraveo	Red sea-bream	33 cm
Pagellus erythrinus	Common pandora	15 cm
Pagrus pagrus	Common sea-bream	18 cm
Polyprion americanus	Wreckfish	45 cm
Sardina pilchardus **	European sardine	11 cm
Scomber spp.	Mackerel	18 cm
Solea vulgaris	Common sole	20 cm
Sparus aurata	Gilt-head sea-bream	20 cm
Trachurus spp.	Horse mackerel, Scad	15 cm
2. Crustaceans		
Homarus gammarus	Lobster	300 mm TL 105 mm CL
Nephrops norvegicus	Norway lobster	20 mm CL 70 mm TL
Palinuridae	Crawfish	90 mm CL
Parapenaeus longirostris	Deep water rose shrimp	20 mm CL
3. Mollusc bivalves		
Pecten jacobeus	Scallop	10 cm
Venerupis spp.	Carpet-clams	25 mm
Venus spp.	Venus-shells	25 mm

TL total length; CL carapace length;

Material and methods

Species analysed

A total of 19 demersal species, including fish, crustaceans and cephalopods, were chosen for the analyses (Table 2). Together with the species regulated by MLS in the Mediterranean, the most important commercial species for the bottom trawl fishery from the Balearic Islands were studied. Analyses to delineate hotspots for these species were done considering two different criteria for the definition of recruits and adults: 1) MLS in the case of the species under regulation; and 2) size at first maturity (L50) for those species without MLS but also for those having MLS.

Table 2. List of demersal species of the bottom trawl fishery from the Balearic Islands analyzed in this work. The minimum landing size (MLS), size at first maturity (L50) and the bibliographic source of this maturity size are shown. SNDCF refers to data from sampling within the Spanish National Data Collection Framework.

Taxonomical group	N	Species	MLS (mm)	L50 (mm)	L50 source
Fish	1	*Merluccius merluccius*	200	327	(Oliver 1993)
	2	*Mullus surmuletus*	110	142	SNDCF
	3	*Mullus barbatus*	110	128	SNDCF
	4	*Pagellus acarne*	17	177	(Velasco et al. 2011)
	5	*Pagellus erythrinus*	15	164	SNDCF
	6	*Trachurus mediterraneus*	150	129	SNDCF
	7	*Trachurus trachurus*	150	175	SNDCF
	8	*Helicolenus dactylopterus*		162	(Peirano and Tunesi 1986)
	9	*Phycis blennoides*		320	(Glavic et al. 2014)
	10	*Lepidorhombus boscii*		170	(Mannini et al. 1990)
	11	*Scyliorhinus canicula*		399	(Ramirez-Amaro et al. 2016)
	12	*Galeus melastomus*		510	(Ramirez-Amaro et al. 2016)
	13	*Raja clavata*		686F-781M	(Ramirez-Amaro et al. 2016)
Crustaceans	14	*Aristeus antennatus*		25F-19M	(Guijarro et al. 2008)
	15	*Nephrops norvegicus*	20	37	(Guijarro et al. 2013)
	16	*Parapenaeus longirostris*	20	28	(Guijarro et al. 2009)
Cephalopods	17	*Octopus vulgaris*		120	SNDCF
	18	*Eledone cirrhosa*		86	SNDCF
	19	*Illex coindetii*		151	SNDCF

Data sources and analyses

Two different data sources were used: 1) Fishery independent data taken during scientific surveys (MEDITS); and 2) Fishery dependent data collected by observers on board bottom trawlers working under commercial conditions. These two data sources were analysed separately due to differences in the spatiotemporal sampling. Whereas surveys only provide information of the specific period when they are performed, the monitoring of the fishery along the year allows analysing seasonal changes. Whenever possible (see Results), all study species were analyzed from samples taken by these two different sampling sources.

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Fishery independent data: MEDITS surveys

A two step methodological approach following (Colloca et al. 2015) were used in order to analyze the spatial distribution of species density (number of individuals per Km^2). The methodology started with the identification of areas with higher densities (hotspots) on an annual basis, and then analyzed the persistence of these hotspots through the time series as indicative of the most important areas of density that are independent of interannual variability. Finally, the overlap of persistent hotspots for the different fish species was also analyzed.

Data was collected during the MEDITS scientific trawl surveys, which are annually conducted in spring-summer in European Mediterranean waters (Bertrand et al. 2002). The study area covered the continental shelf and upper slope fishing grounds between 50 and 800 m depth around the Balearic Islands (Western Mediterranean, Fig. 1). A total of 766 bottom trawls conducted between 2003 and 2016 were analyzed. Although the surveys are carried out from 2001, only data collected between 2003 and 2016 were used in order to analyse the same time period for the two data sources (information from onboard samplings is only available from 2003 on).

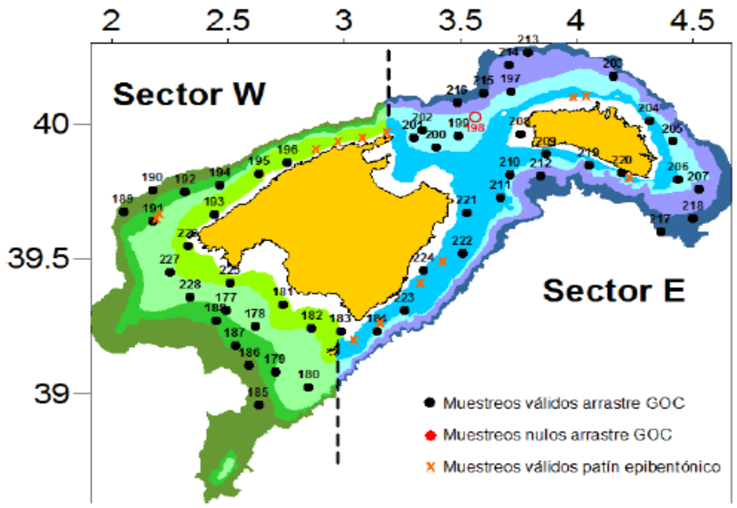

Fig. 1. Location of the sampling stations analysed annually during the MEDITS surveys carried out around the Balearic Islands.

On a first step, the spatial distribution of the study species was analyzed considering, as aforementioned, different population fractions (under and above the MLS and the L50). The spatial modelling was performed with generalized additive models (GAMs; (Wood 2006) using the "mgcv" R-package. The smoothing parameters were selected by restricted maximum likelihood (REML), which is supposed to be more effective than other available options (Marra and Wood 2011). Depth, position (longitude, latitude) and year were used as explanatory variables in the GAMs.

Owing to the high frequency of zeros in the data, a two-stage GAM approach was used (Barry and Welsh 2002, Borchers et al. 1997). This approach assumes independence between presence-absence and abundance values, so that the likelihoods are obtained by multiplying the predictions of the two components (presence-absence and abundance). In the first stage, a presence-absence variable is constructed by giving a value of 1 to observations where the response variable is greater than zero and a value of 0 otherwise. The derived variable is modelled as a binomial distribution with a logit link function. In the second stage, the log-transformed abundance is modelled by means of a Gaussian distribution with an identity link function. Finally, the predictions of the models in both stages are multiplied at each prediction grid cell in order to obtain an estimation of species abundances.

On a second step, the selected models were used to produce annual predictions of the spatial distribution of the species abundances in a squared mesh grid with cells of 0.01 x 0.01 geographical degrees. Hotspots were defined on an annual basis as those grid cells in which the predicted value of abundance (N/km^2) was above a threshold defined as the upper level of the 95% confidence interval of the mean predicted values in the whole time series in the "optimal" depth range for each species and population fraction. This "optimal" was defined as the depth range at which the output of the GAM model for the depth smoother was above 0 (i.e. above the mean abundance when considering the depth effect). The temporal persistence of the hotspots at a grid cell level (probability of being a hotspot) was defined as the amount of years for which a particular cell in the spatial grid was identified as a hotspot divided by all the years in the time series.

Finally, spatial overlap among persistent hotspots of the different species was also investigated. An overlap index, obtained as the sum of species (≥2 species) that had persistent hotspots in a particular grid cell, was calculated. In this case, the overlap was assessed considering four different levels of persistence when defining persistent hotspots: 0.5, 0.6, 0.7 and 0.8.

Fishery dependent data: on board bottom trawlers sampling

This data source was used to provide information on the spatiotemporal distribution and potential main discarding hotspots of the study species. The on-board observers program is carried out within the EU Data Collection Framework (DCF) that takes place in the Balearic Islands from 2003. The monitoring of the bottom trawl fishery consists of five monthly samplings on board randomly selected vessels, which ensures temporal and spatial coverage of the fishing activities.

The information collected by the observers includes the main characteristics of the haul (e.g. date, position, duration, depth) and the weight by species of the commercial catch and discards. Representative size-frequency distributions of the most important species of both the commercial catch and discards are also taken. In the case of crustaceans, these size distributions are collected for males and females separately.

The random sampling scheme used during the onboard sampling does not allow producing maps as in the case of the regular sampling scheme performed during the MEDITS scientific surveys. For this reason, data were analysed for the main commercial fishing grounds of the bottom trawl fleet. VMS data around the Balearic Islands were used to define such fishing grounds (Farriols et al. 2017). The VMS signals were assigned to a net of points defined from a 0.01 degrees resolution grid using Matlab R2013a, and the different fishing grounds were inferred from VMS density contours assigned at each grid point. A total of 32 fishing grounds were identified around the Balearic Islands (Fig. 2). Finally, using expert knowledge of the bottom trawl fishery in the area, each fishing ground was checked in order to differentiate adjacent fishing grounds and delimiting fishing grounds with low densities of VMS.

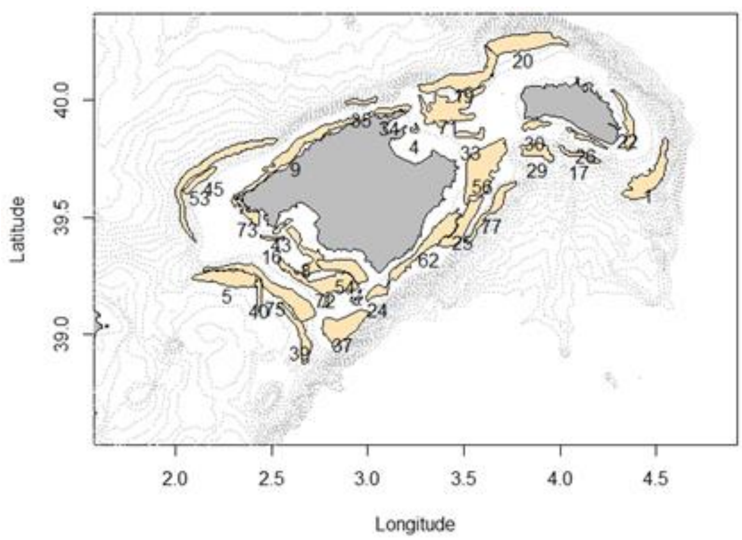

Fig. 2. Main fishing grounds used by bottom trawl fishers from the Balearic Islands.

A total of 1445 fishing hauls performed between 2003 and 2016 were analysed (Fig. 3). The mean species density (number of individuals per hour of effective trawling) and the species size-frequency distribution were computed for each fishing ground. As above, these two parameters were obtained for individuals under and over the MLS and the L50. Both seasonal and interannual variations in species density were analysed.

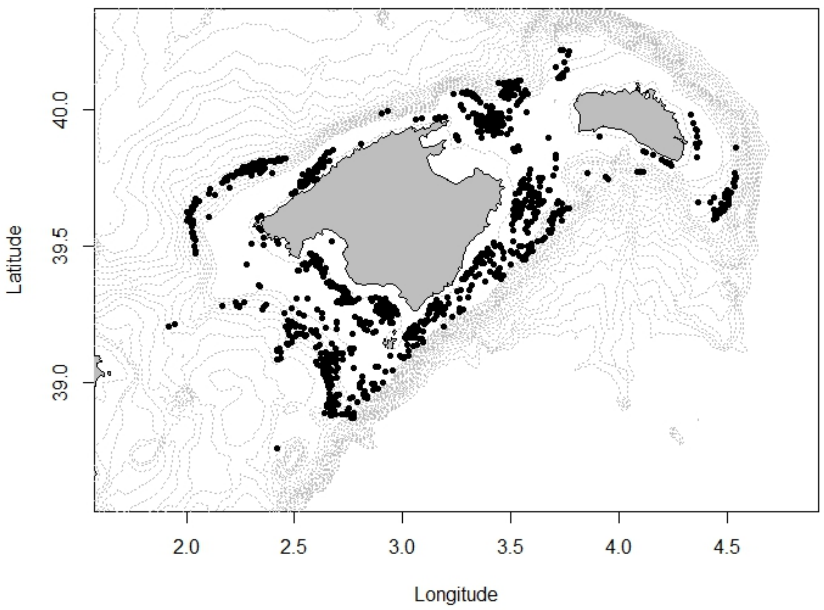

Fig. 3. Stations of the on board commercial trawlers sampling from the Balearic Islands used in this work.

Feedback with fishers

The main objective of Task 4.3 was "using the knowledge from fisheries scientists in collaboration with fishers to identify the best locations, times and practices to fish to avoid unwanted catch". Once available, the main results of this Task for the Balearic Islands study area were presented to fishermen in order to check if these results were in accordance with their daily experience at sea. With this goal, bottom trawl fishers with good knowledge of the fishing grounds around the Balearic Islands were consulted.

Decision support tools

Task 4.3 was aimed at providing maps of commercial catch operations to allow fishers to make choices of fishing location that avoid discards and provide decision support tools to assist fishers in those choices. In accordance with these aims, the maps and rest of information analysed in this work was presented in a web application developed with Shiny (https://shiny.rstudio.com/), which is an R package to build interactive web apps straight from the software R (https://www.r-project.org/).

The Shiny web developed to synthesize these results is structured in different tabs, according to the two data sources used in the analyses: the survey data and the onboard observers' data.

The Survey data tab displays the maps elaborated from data gathered during the MEDITS surveys. It is organized in three sub-tabs, including a general map showing all sampling stations (Map tab) and the maps obtained considering both the L50 (Discards tab) and the MLS (Maturity tab).

The Observer's data tab, which displays the outputs obtained analyzing data collected onboard commercial vessels, is organized in four sub-tabs. It contains the same three groups as the Survey data tab (Map, Discards and Maturity tabs) together with a new one with the length frequency distribution of the catches by fishing ground and species (Length frequency tab). In this case, however, the Discards and Maturity tabs do not display the information in maps but using graphs of density (number of individuals/effective hour of trawling) of individuals under and above the MLS and the L50. These two tabs are structured in four different sub-tabs showing general results (Discard ratio tab) along with seasonal (Seasonal variability tab) and interannual variations (Inter-annual variability tab) and a table with the data (Summary tab).

The Species' Info tab provides a table with the MLS and the L50 for the species included in the analysis. It also provides links to other websites with general information on the biology and ecology of the species.

Finally, the About tab contains general information about the DiscardLess project and the development of this Shiny app.

Results

The total list of 19 species previously selected (Table 1), based on the criteria of being under size regulation or having important commercial interest, was analyzed in the case of fishery dependent data. However, the following four species could not be analyzed with fishery independent data owing to limitations in the sampling scheme: the fish Mullus barbatus and the crustaceans Aristeus antennatus, Nephrops norvegicus and Parapenaeus longirostris. In the case of M. barbatus and P. longirostris, two species with size regulation, the low number of individuals taken in the study area prevents analyzing spatiotemporal variations in their populations. The situation is different for A. antennatus and N. norvegicus, two crustacean species abundant in the study area but which undersized population fraction (MLS or L50) are taken in such a small number that it also prevents the analyses.

<u>Fishery independent data: MEDITS surveys</u>

For each species, maps of population density (number of individuals per Km2) and hotspot persistence (in percentage of years) were elaborated for individuals under and over the MLS (if applicable) and the L50. That is, eight maps (4x MLS plus 4x L50) for the species regulated by legal size and four maps (4x L50) for those species without size regulation. A single example of one species of each case is shown in this section: a fish having MLS (hake, Merluccius merluccius) and a skate without MLS (thornback ray, Raja clavata). The maps of all species analyzed with fishery independent data are in Annex 1.

Figure 4 shows the density (above) and persistence (below) maps of hake. Density maps of immature individuals (<32.7 cm) of hake revealed two elongated, narrow areas of high density along the 200 m isobaths in the southwest and northeast (in this case, with some spots at shallower grounds) of Mallorca. Hotspots for mature individuals revealed the same two main areas, but the southwest area get larger, extending along the southwest coast of Mallorca between the 100 and 200 m depth isobaths; the northeast area also extended to waters shallower to the south and deeper to the north than the 200 m isobaths. Although the density maps of hake under and above the MLS (20 cm) revealed a similar pattern, some differences arose in the contours of the hotspots, notably for the legal individuals. The two hotspots are shorter and larger than the areas of the mature individuals, which also extend between 100 and 200 m, and the southwest area is restricted to the south coast of Mallorca. Compiling all the information shown in these maps, the following conclusions could be drawn: i) hotspots of hakes under the MLS are restricted to two main areas in the northeast and southwest of Mallorca at 200 m depth; ii) areas inhabited exclusively by mature individuals (>32.7 cm length) are located along the west coast of Mallorca and the northwest coast of Menorca both between 200 and 500 m depth.

The picture changed substantially when the persistence maps were considered. For small-sized individuals (<L50 and <MLS), the same two main hotspot areas found in the density maps were detected but in this case the northeast area extends along the north coast of Mallorca and Menorca; there also appeared a third area along the south of Menorca. For hakes above the MLS, the same northeast and southwest hotspots were found, extending between the 100 and 200 m depth, and a third area also appeared in the northwest of Mallorca. Hotspots of mature individuals (>32.7 cm length) were found in a continuous strip along all the coast of Mallorca (except an area in the central north), the northeast coast between Mallorca and Menorca and a small area in the southeast of Menorca.

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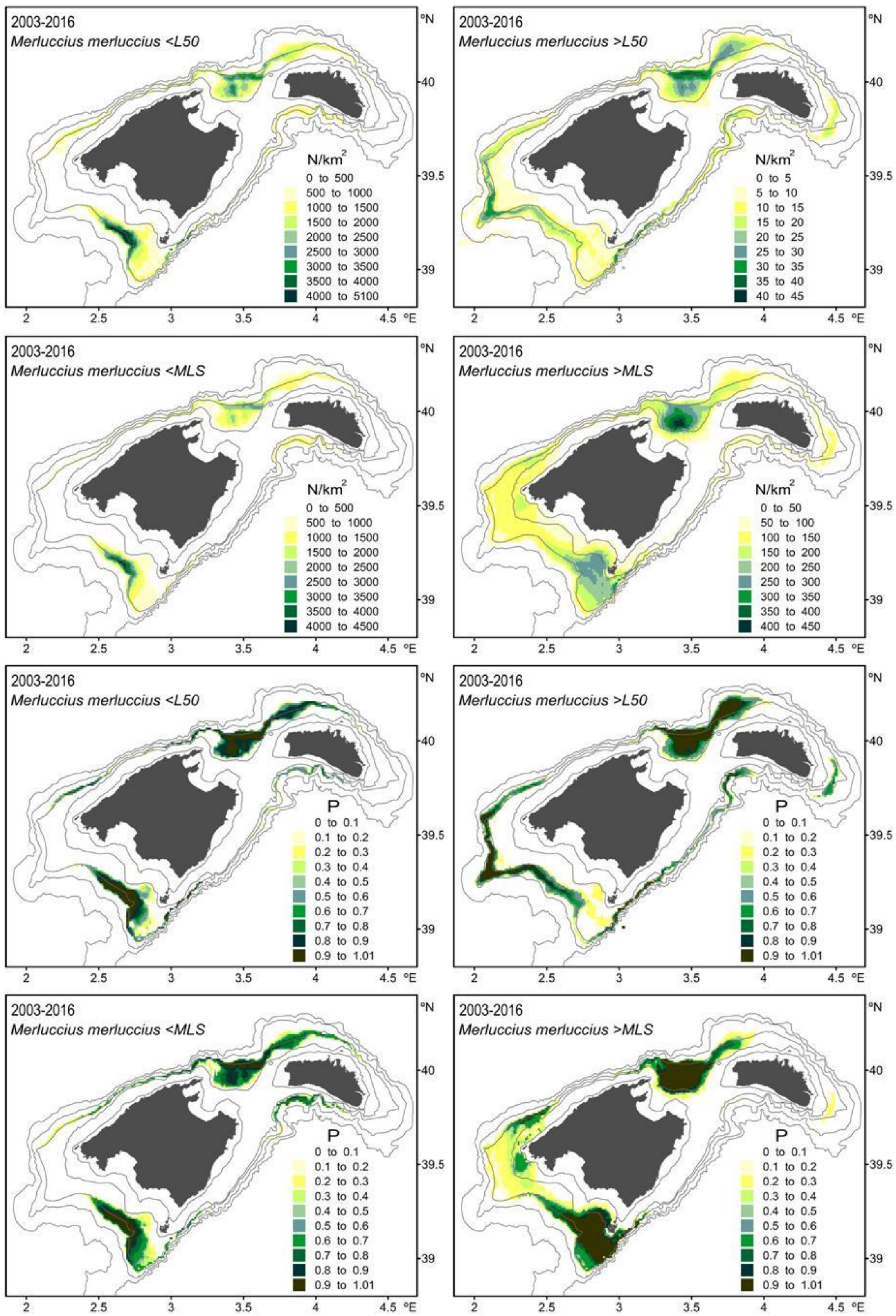

Fig. 4. Maps of density (N individuals/km^2; above) and persistence (P, fraction of years; below) of hake individuals under and over both the minimum landing size (20 cm) and the size at first maturity (32.7 cm).

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Figure 5 shows the density (above) and persistence (below) maps of the thornback ray. The density maps showed that the species is caught all around the Balearic Islands but at low densities, with the only exception of some areas that changed between juveniles and adults. In the case of juveniles, hotspots were located along the north coast of the Menorca Island and a well defined spot in the west coast of Mallorca. Hotspots of adults extended around Menorca (except the west coast) whereas in Mallorca there is only a spot of slightly higher density than the adjacent areas in the south coast.

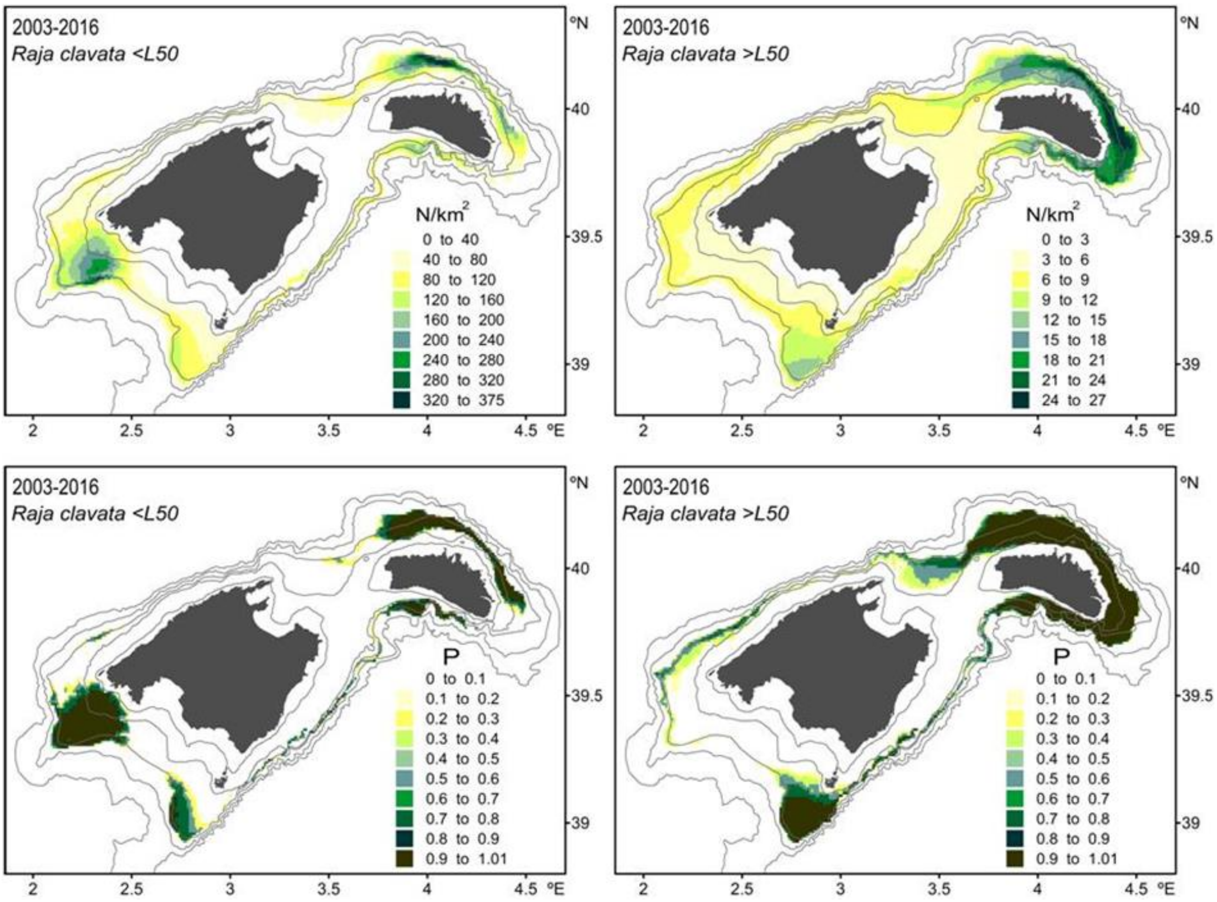

Fig. 5. Maps of density (N individuals/km^2; above) and persistence (P, fraction of years; below) of hake individuals under and over both the minimum landing size (20 cm) and the size at first maturity (32.7 cm).

The persistency maps of the skate showed hotspots for juveniles in two areas of Mallorca (west coast between 50 and 200 m, and south coast around the 200 m isobath) and along the north and south coast of Menorca. Areas of high persistency for adults were found along Menorca (except the west coast) and along the 200 m isobaths of Mallorca (except the southwest coast) and notably in a large area between the 200 and 500 m depth in the south.

The species overlap among the species analyzed in this study considering their corresponding L50 and four levels of persistence (0.5, 0.6, 0.7 and 0.8) are shown in Figure 6. Overlap between two species is found all around the Balearic Islands for the different persistence levels but, as expected, the overlap area decrease with increasing persistence values to the point that it disappears along the east coast of Mallorca at the persistence value of 0.8. Overlapping areas of more than two species are also widespread along the islands for the persistence value of 0.5 but they also shrink with increasing persistence values.

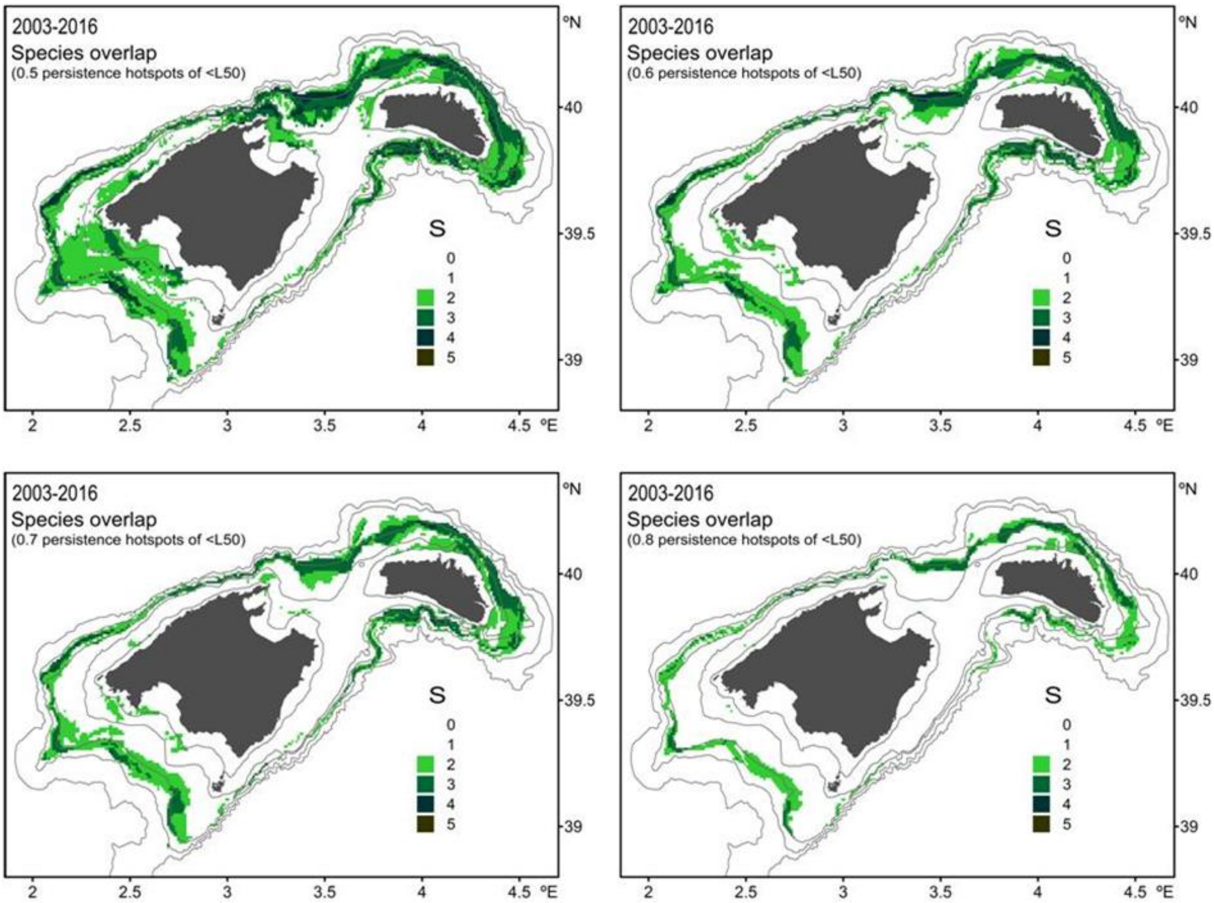

Fig. 6. Maps of overlap among the species analyzed in this study considering their corresponding L50 and four levels of persistence (0.5, 0.6, 0.7 and 0.8).

When considering the MLS, species overlap was not found for persistence levels of 0.6, 0.7 and 0.8. In the case of persistence level of 0.5, only overlap between two species were observed in two areas located in the southwest and northeast of Mallorca (Fig. 7).

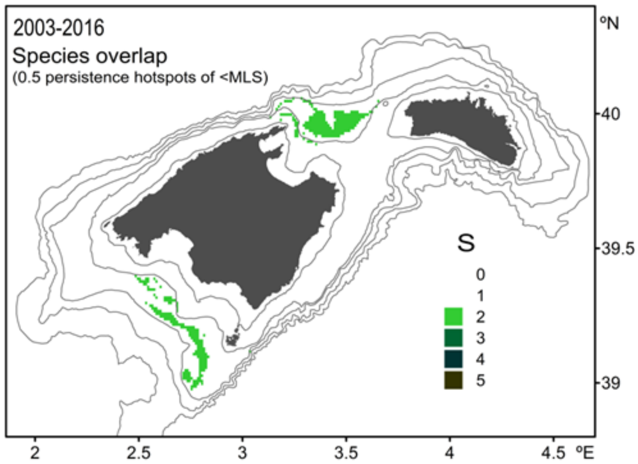

Fig. 7. Map of overlap among the species analyzed in this study considering their corresponding MLS and the persistence level of 0.5.

Fishery dependent data: on board bottom trawlers sampling

For each fishing ground, graphs of population density (number of individuals per effective hour of trawling) were elaborated for individuals under and over the MLS and L50. The population structure of all study species were also produced to show the relationships between the size frequency distributions and both the MLS and L50.

As in the previous section, we also use here two species for description purposes, one of them with (again the European hake) and the other without (the high-value red shrimp Aristeus antennatus) MLS. Figure 8 shows the population structure of hake in one of the most important fishing grounds of these species located in the northeast of Mallorca. The graph shows that the modal size of this population is 20 cm, the minimum legal size of hake in the Mediterranean, and that the majority of individuals caught by the bottom trawl fleet are larger than this size. The situation, however, changes dramatically when the size of first maturity is used instead of the MLS. In such a case, the vast majority of individuals have sizes below the maturity size.

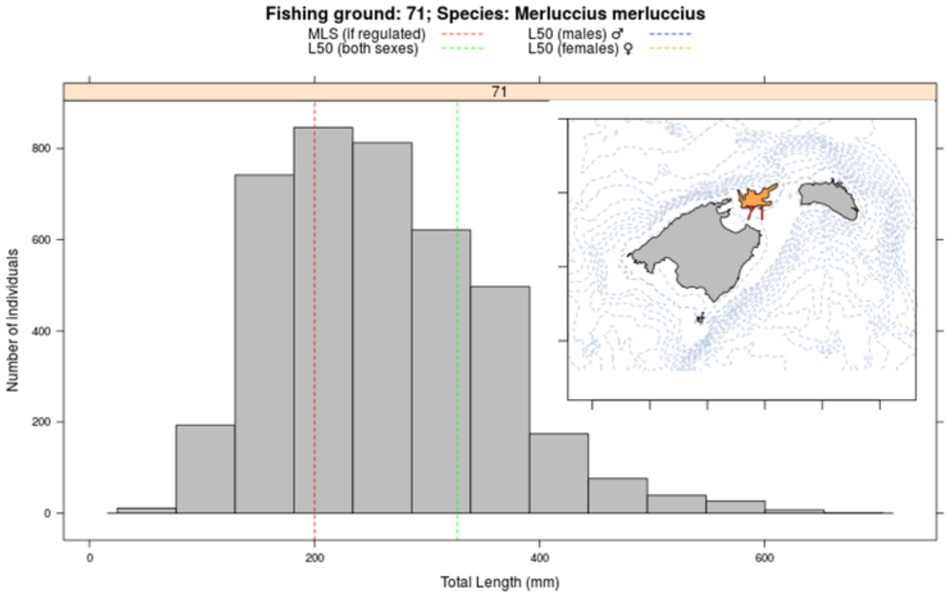

Fig. 8. Population structure of hake taken by the bottom trawl fleet from the Balearic Islands in one of the most important fishing grounds of this species in the area (map inlet). The minimum landing size (MLS) and length at first maturity (L50) are also shown.

Figure 9 shows that both the discards and commercial catch of hake in this fishing ground follow the same trend, increasing from spring to summer but decreasing afterwards in fall and winter. In this area, the commercial fraction is higher than the discard fraction throughout the year, notably in winter when the lowest discard values are found. The interannual variation of discards and landings of hake do not show any clear trend during the study period (2003-2016) but it is observed that the discard fraction displays higher interannual variations than the commercial catch fraction.

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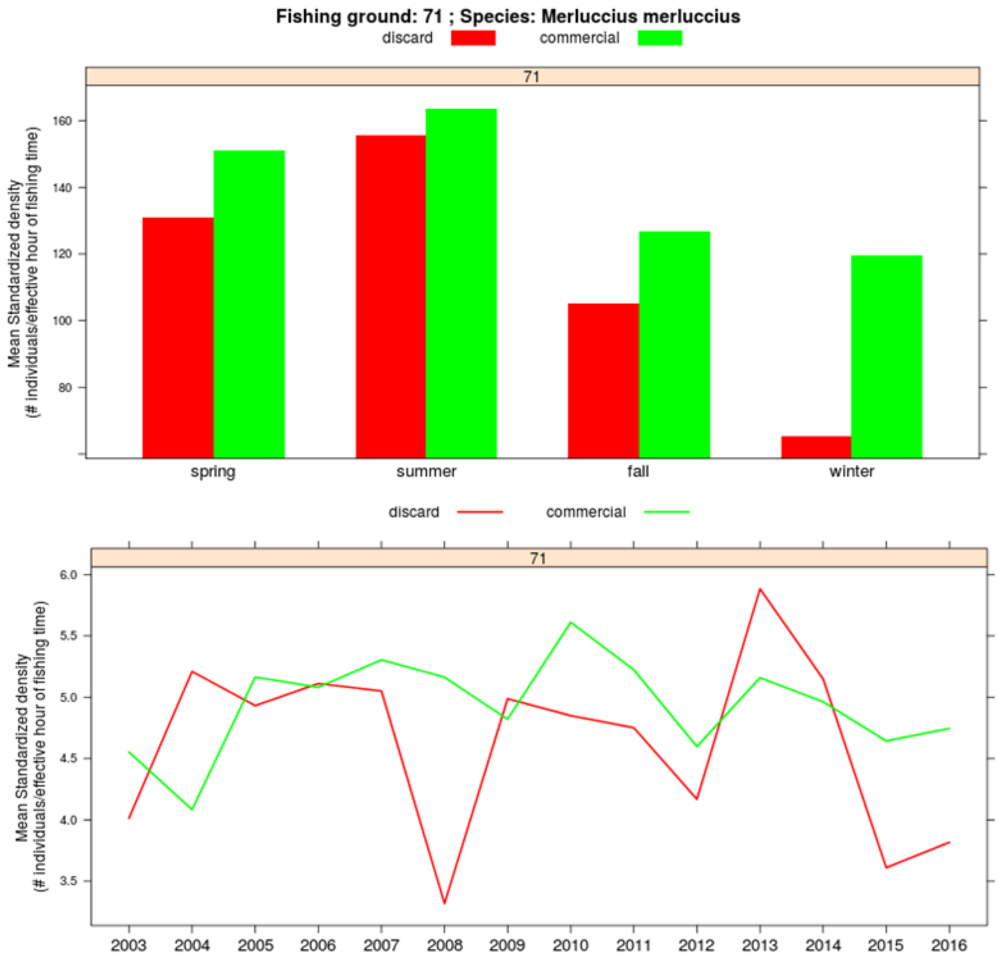

Fig. 9. Seasonal and interannual variations in discards and commercial catches (number of individuals per hour of effective trawl) of hake taken by the bottom trawl fleet from the Balearic Islands in one of the most important fishing grounds of this species in the area.

The picture of this fishing ground changes substantially when the data is analyzed by the L50 instead of the MLS (Fig. 10). In such a case, the vast majority of the population consists of immature individuals throughout the year. The figure displays the same seasonal trend as shown for MLS analyses. This indicates that most commercial individuals shown in Figure 8 have sizes higher than the MLS but lower than the L50. Whereas immature individuals show important variations in density, but without a clear trend, the density of mature individuals remains constant between 2003 and 2016.

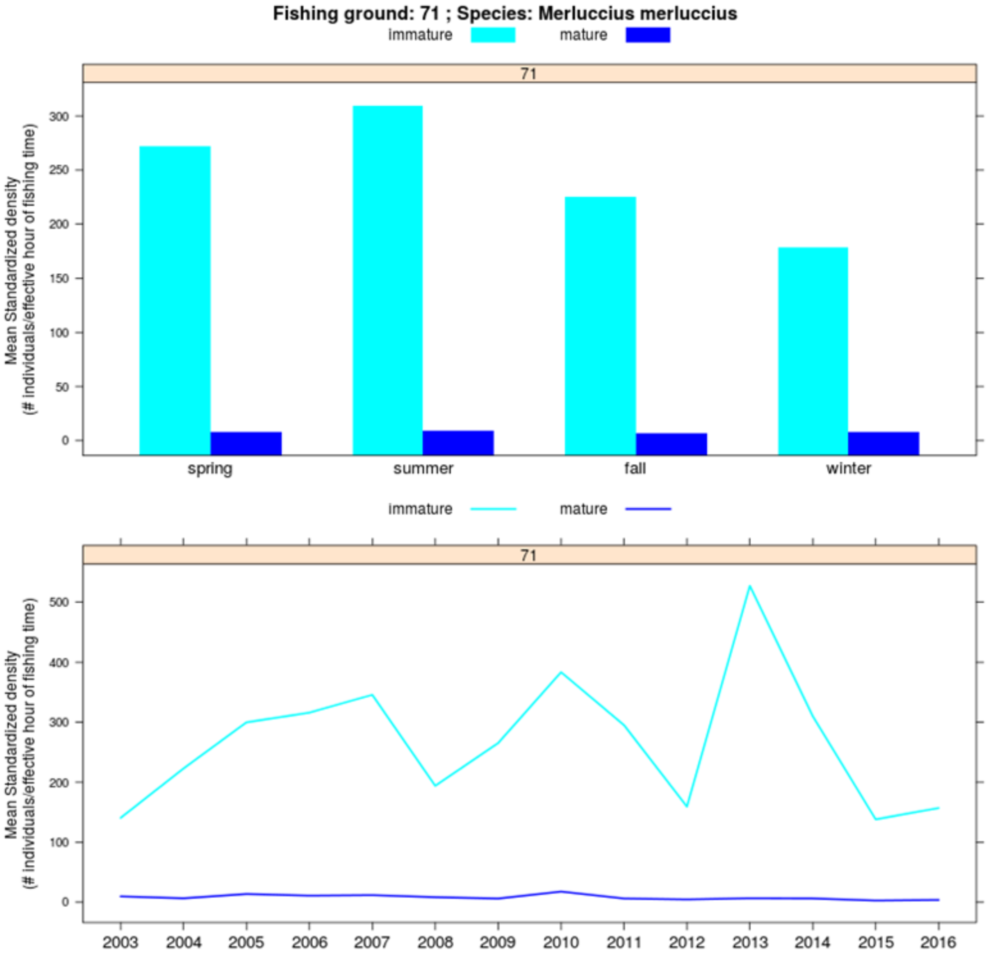

Fig. 10. Seasonal and interannual variations in the catches (number of individuals per hour of effective trawl) of immature and mature individuals of hake taken by the bottom trawl fleet from the Balearic Islands in one of the most important fishing grounds of this species in the area.

Figure 11 shows the population structure of the red shrimp in one of the most important fishing grounds of these species located in the northwest of Mallorca. As this species is not regulated by minimum landing size, results are only shown considering the size at first maturity. The graph shows that this population is constituted by two cohorts with modal sizes of 28 and 48 mm carapace length. The predominance of mature individuals is maintained along the year, although the number of immature ones increases during fall-winter compared to spring-summer (Fig. 12). The interannual variation of density for mature and immature shrimps does not show any clear trend during the study period (2003-2016).

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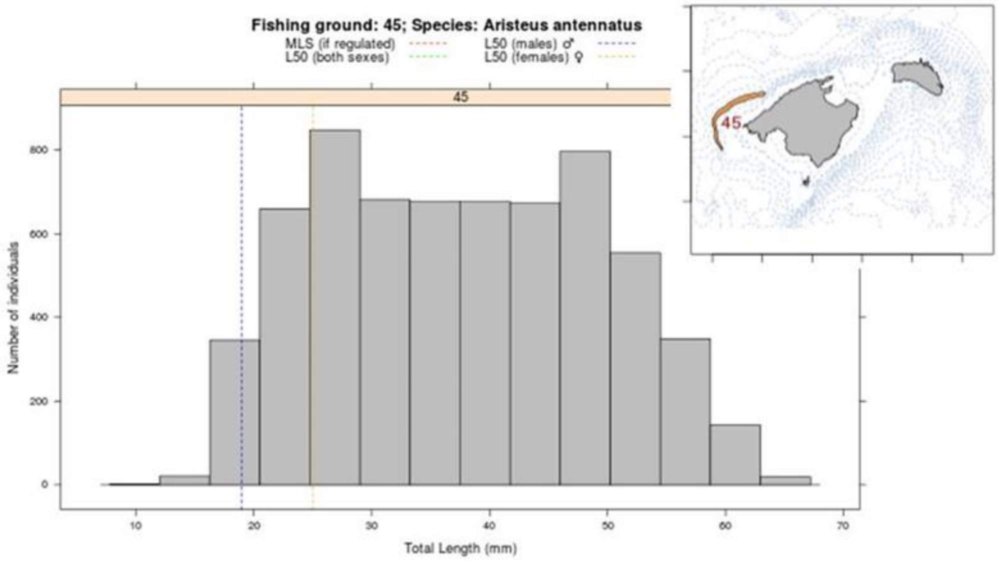

Fig. 11. Population structure of red shrimp taken by the bottom trawl fleet from the Balearic Islands in one of the most important fishing grounds of this species in the area (map inlet). The length at first maturity (L50) for females and males are also shown.

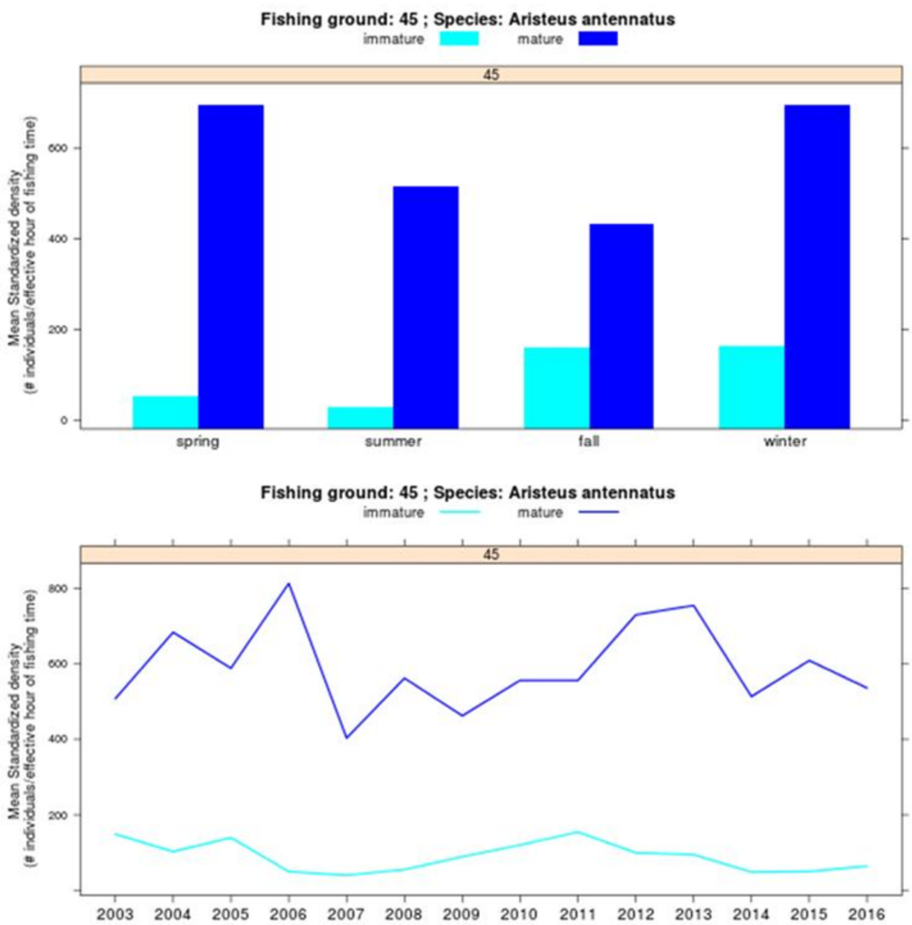

Fig. 12. Seasonal and interannual variations in the catches (number of individuals per hour of effective trawl) of immature and mature individuals of red shrimp taken by the bottom trawl fleet from the Balearic Islands in one of the most important fishing grounds of this species in the area.

Decision support tools

In accordance with the main aim of providing decision support tools to assist fishers to make choices of fishing location to avoid discards, the following Shiny app, which contains all the results obtained in this work, were developed: https://lucia2r.shinyapps.io/prueba_nolog/.

Figure 13 is a snapshot of the home page displaying the different tabs described above: Observer's data, Survey Data, Species' Info and About. In this example, the snapshot shows the specific case of the Observer's data tab, which contains the following sub-tabs (also available for the Survey Data tab): Map, Length Frequency, Discards and Maturity. On the left hand side there appear the dropdowns to choose the species and the fishing grounds to be shown. As it is shown below the dropdowns, only those fishing grounds containing a number of sampling stations higher than 25 were used in the analyses.

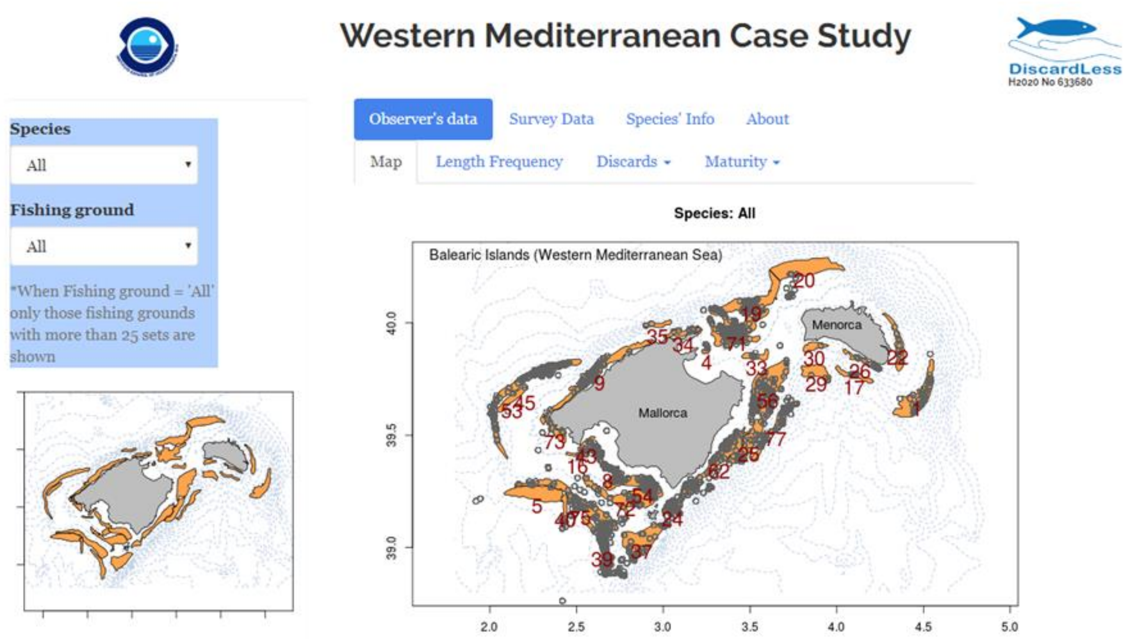

Fig. 13. Snapshot of the home page of the Shiny App produced as a decision support tool to assist fishers to make choices of fishing location to avoid discards.

Figure 14 shows an example of a species that does not have MLS, in this case the common octopus (Octopus vulgaris) taken by commercial trawlers (Observer's data tab). The snapshot shows the population structure of this species for all fishing grounds where the species was caught (sample size >25) under the Length Frequency tab. As this species does not have MLS, the Discards tab does not contain graphs but only a message informing about this (Fig. 15). In this case, only graphs considering the MLS can be produced showing the information for immature and mature individuals: total (Fig. 16), seasonal (Fig. 17) and interannual (Fig. 18) variability in species density (number of individuals per hour of trawling).

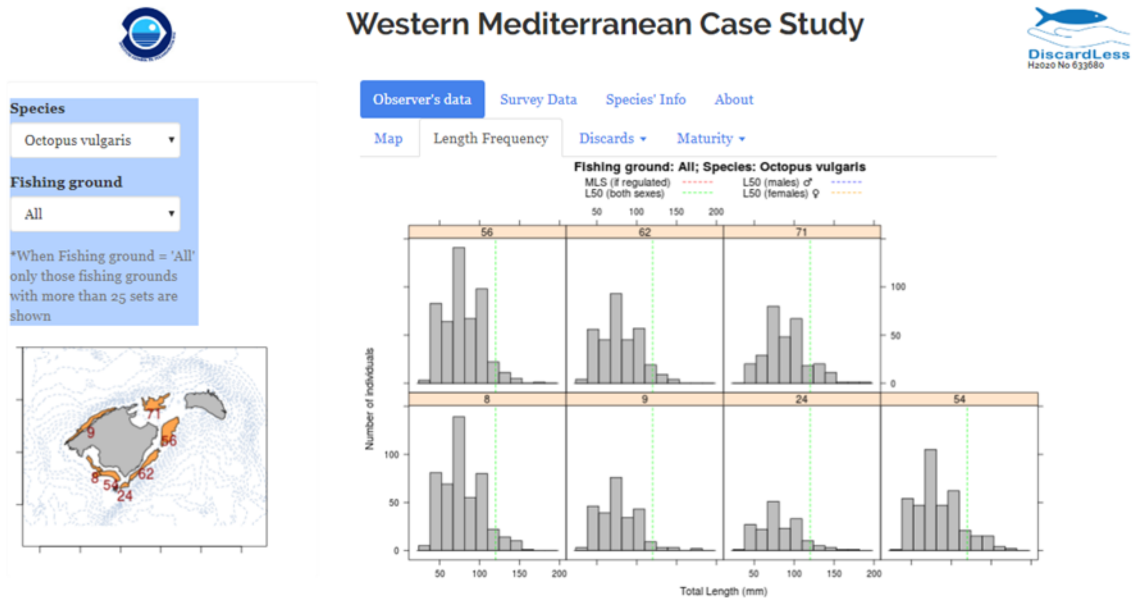

Fig. 15. A message informs that discards cannot be computed when a species does not have MLS.

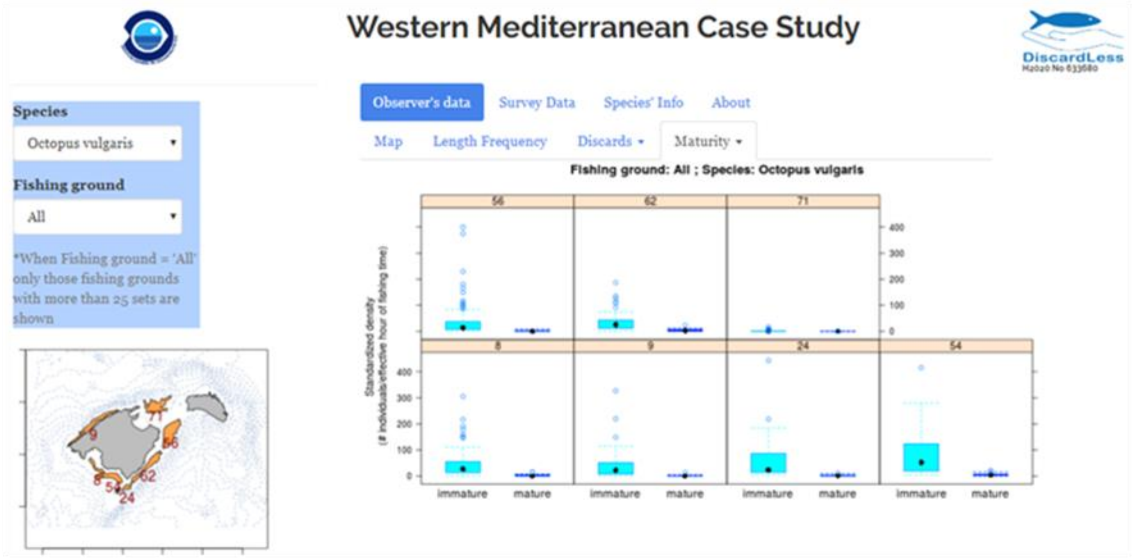

Fig. 16. Density of mature and immature individuals of the common octopus obtained with observers data in all fishing grounds.

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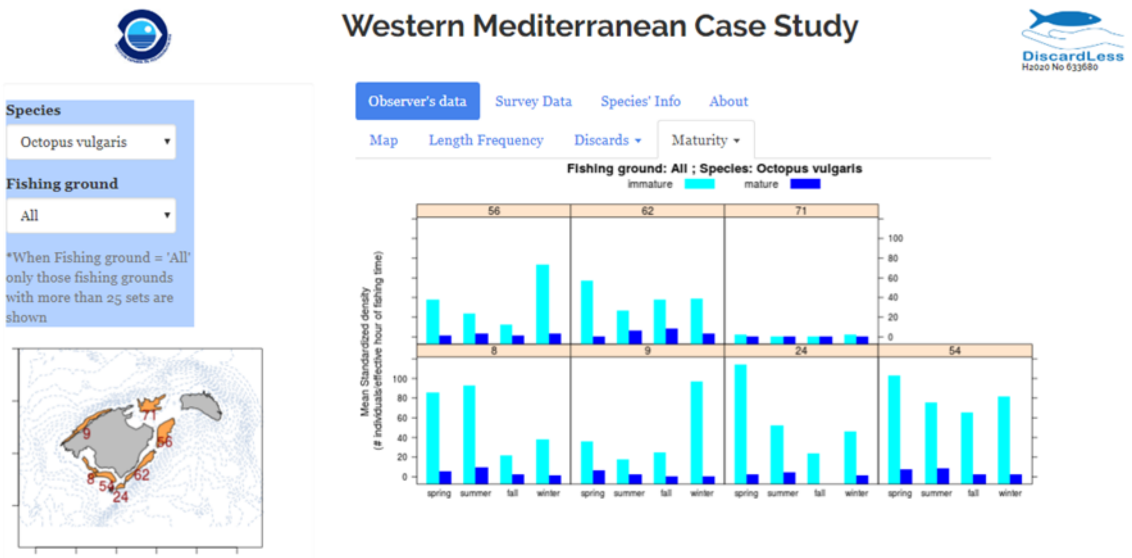

Fig. 17. Seasonal variations of density of mature and immature individuals of the common octopus obtained with observers data in all fishing grounds.

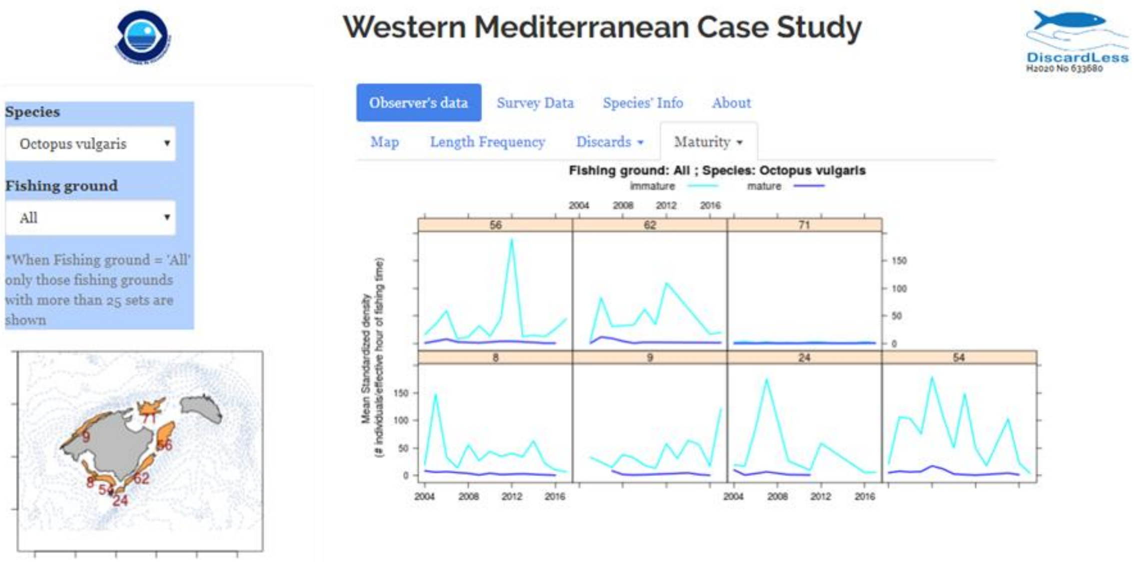

Fig. 18. Interannual variations of density of mature and immature individuals of the common octopus obtained with observers data in all fishing grounds.

The Species' Info tab (Fig. 19) provides a table with the MLS and the L50 for the species included in this work. It also provides links to other websites with general information on the biology and ecology of the species. Finally, the About tab contains general information about the DiscardLess project and the development of this Shiny app (Fig. 20).

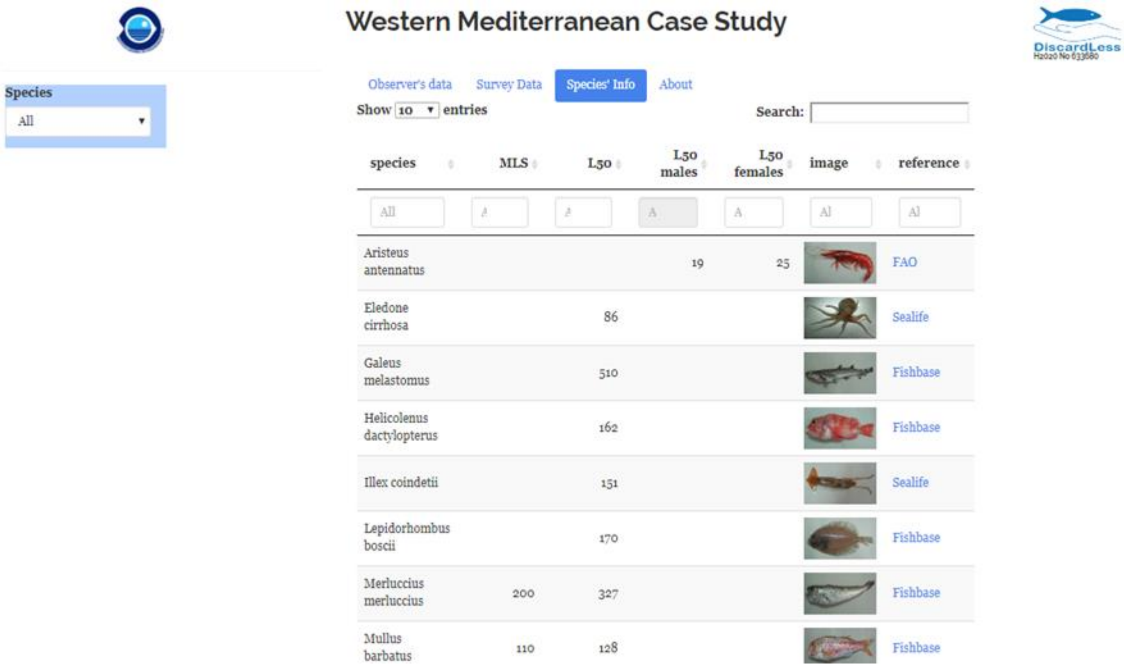

Fig. 19. The Species' Info tab provides a table with the MLS and the L50 for all the species analyzed.

Fig. 20. The About tab contains general information on the DiscardLess project and this Shiny App.

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Chapter 7. Does Ireland's monthly quota system influence discarding patterns amongst the commercial fishing fleet?

Julia Calderwood & Dave Reid - MI

Celtic Sea case study

Introduction

Discards, the component of the catch returned to the sea and not retained onboard during fishing operations, are acknowledged as a widespread part of commercial fishing practices (Borges et al., 2005; Catchpole et al., 2014). Discarding has allowed fishermen to adjust their landings to meet both legal and market constraints and can represent a significant component of fishing related mortality for many important fish stocks in Europe (Veiga et al., 2016; Milisenda et al., 2017). Initial catch composition, which can be related to factors including season, area, habitat, vessel and gear type may also drive discarding behaviour (Feekings et al., 2012; Catchpole et al., 2014; Pennino et al., 2017). Management constraints such as quotas and minimum landing size restrictions in addition to market and economic factors are also recognised as being important influences on discarding behaviour (Hatcher, 2014; Rochet et al., 2014; Prellezo et al., 2016). As such, discarding behaviour can be complex, resulting from various choices made throughout the fishing process in addition to regulatory restrictions (Rochet and Trenkel, 2005; Pennino et al., 2017).

EU fisheries are managed as part of the Common Fisheries policy (CFP) whereby Total Allowable Catches (TACs) are set for a number of commercially important species (Carpenter et al., 2015). In the EU TACs are divided among member states according to relative stability, a concept established as part of the CFP in 1983, which operates on an equal access principle (Morin, 2000; Sobrino and Sobrino, 2017). Annual TACs for each stock are divided between member states based on a fixed key, which was founded on fish caught during a reference period from 1973 to 1978 in addition to considering how each region's economy depends on fishing (Morin, 2000; Shepherd, 2003; Hoefnagel et al., 2015). How each member state then allocates its quota share to its fishing fleet is determined at a national rather than EU level.

In Ireland quota is a public resource and is managed in a way that ensures property rights are not granted to any one individual operator (DAFM, 2016). The Irish fishing fleet is subject to monthly quotas which are designed to ensure the optimum spread both between fishing vessel operators and in terms of uptake of quota throughout the year (DAFM, 2016). There is no opportunity for quota swapping or sharing within the fleet and once a vessel has reached its monthly quota it will not be allocated any more until the following month. In Ireland, as each month progresses and the catch of commercial species begin to near or exceed a quota there is likely to be an influence on subsequent fishing behaviour.

Until the introduction of the Landing Obligation (LO), which resulted as part of the 2013 reform of the CFP, catches above quota as well as fish below minimum landing size (MLS) for TAC species were discarded at sea. Prior to the introduction of the LO it may, therefore, have been expected that as an Irish vessel becomes more quota limited as a month progresses, the rate of discarding would increase. Understanding how such a quota management system may influence discarding behaviour is important when developing management tools to assist in avoiding unwanted catch. This is especially important with the introduction of the LO where the discarding of quota species will be prohibited in EU fisheries by 2019 as per article 15 of EU regulation 1380/2013 (European Commission, 2013). This new legislation represents a major change for the management of EU fisheries from the control of landings to the control of total catch, and will introduce a number of challenges to the Irish fleet (Calderwood et al., 2016; Catchpole et al., 2017). Consequently there is a need to fully understand what drives and influences discarding practices so that tools can be developed to mitigate against these.

This study was designed to investigate whether Ireland's monthly quota allocation had any impact on discarding practices. In particular, we aimed to find out if discarding increased as quota was used up across the month. In other national fisheries, with annual quota management, there have been suggestions of increased discarding towards the end of a year. The Irish case Increases in discarding tow This study aimed to use the data collected by on-board observers, working as part of the discard sampling programme, to determine how discarding patterns may be influenced by Ireland's monthly quota system. We hypothesised that (i) discards were likely to increase towards the end of the month, as quotas became more restrictive; (ii) monthly discarding patterns would be more evident for species subject to TACs; and (iii) those species most quota restricted for the Irish fleet (i.e. cod and haddock) would show the greatest increases in discarding over the course of a month. As such we examined whether the proportion of the total catch discarded varied over the course of the month for vessels operating towed gears, whilst also considering the effect of season and depth fished, two factors known to influence discarding (Rochet and Trenkel, 2005; Feekings et al., 2012). To further examine discarding patterns we assessed discards for the portion of the catch consisting solely of TAC species, as well as examining monthly variation in discarding patterns for cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*), three key TAC species targeted by the Irish demersal fishing fleet.

Materials and Methods

Data

Since 1993 the Irish discard sampling programme has placed observers on commercial fishing vessels to collect biological information on the fish that are discarded at sea (Borges et al., 2004; Viana et al., 2011). Data are collected at haul level and include length information on all species caught, both those later landed or discarded. Additional information on the vessel length, gear type and mesh size, haul position, depth and time of haul deployment and recovery are recorded. Data collected by observers from 2005 to 2014 on Irish vessels were included in the analysis. Data after 2014 were not included as the LO began to be phased in to EU fisheries from 2015 and we wanted to capture discarding practices prior to the introduction of this legislation. Further only information collected on vessels using towed gears (beam trawls, otter trawls and dredges) were included in the analysis. This allowed us to examine how monthly quota restraints affect those operating in mixed demersal fisheries, where the co-occurrence of multiple species subject to varying quotas can result in discarding. The final dataset analysed included 362 trips, with an average of 18.7 hauls occurring per trip.

To allow for the comparison between data collected on different vessels operating at different times of year and targeting different species, catch data were converted into proportions by weight of discards per haul in relation to the total catch. Further subsets of this dataset were analysed to examine more closely how discarding patterns may vary for different species. The catch data were subsetted in line with the hypotheses above. First we looked at all TAC species, then just TAC species fish above Minimum Landing Size (>MLS), and finally, individually, for the three key commercial species; cod, haddock and whiting, again for all discards and then just those over MLS. It was assumed here that non TAC species, and fish under MLS would be discarded routinely, and hence any driver resulting from quota depletion would be absent. The MLS values for the three key species were; cod = 35cm, haddock = 30cm, and whiting = 27cm.

Analysis

Data were tested for normality and homogeneity of variance prior to analysis using Shapiro Wilk's, Bartlett and Levene's tests as appropriate, as well as through the visual inspection of residuals. Total catch data, TAC species data, haddock, cod and whiting discard data were transformed using a Box-Cox transformation to meet necessary assumptions (Osborne, 2010). These data were then analysed using a linear mixed-effects model to test the effect of day of the month on the proportion of discards in the catch. Month of the year (12 levels) and depth fished (10 levels, with an equal number of observations in each depth category; Table 1) were fitted as additional fixed ordered factors. The interactions between these variables were also examined. Vessel was included in the model as a random factor to remove possible bias as vessels may have been sampled more than once by observers during the analysis period.

Table 1: Depth categories created with an equal number of observations within each category

Depth category	Depth range (m)
1	20<52
2	52<73
3	73<91
4	91<98
5	98<106
6	106<115
7	115<136
8	136<169
9	169<280
10	280<1600

Following transformation >MLS TAC species data, > MLS haddock, > MLS cod and > MLS whiting data did not meet the assumptions of the analysis and thus were analysed using generalised linear mixed models (GLMMs) based on a Poisson distribution with a log link distribution to account for the positive skew of the data (Zuur et al., 2009). As with the previous analysis the month of the year and depth fished were fitted as fixed, ordered factors with the vessel being fitted as a random factor by Maximum Likelihood Estimate (MLE).

All models were optimised by the selecting the best explanatory factors using Akaike Information Criterion (AIC) values, where the lowest value represented the optimal model (Zuur et al., 2007). Post-hoc Tukey tests were used to make comparisons among levels of significant terms. All analyses were undertaken in R 3.2.5 (R Core Team, 2012).

Results

Total catch

Day in the month had no significant effect on discard proportion across the total catch. Month of the year, was shown to significantly affect the proportion of discards in the catch (χ^2 = 230.14, $p<0.001$). Post-hoc tests did not reveal a clear annual pattern in discarding behaviour although a lower proportion of the catch was generally discarded between July and October (Figure 1). The lowest proportion of the catch was discarded in September with a mean of 0.27 compared to the highest proportion of discards in February with a mean of 0.36.

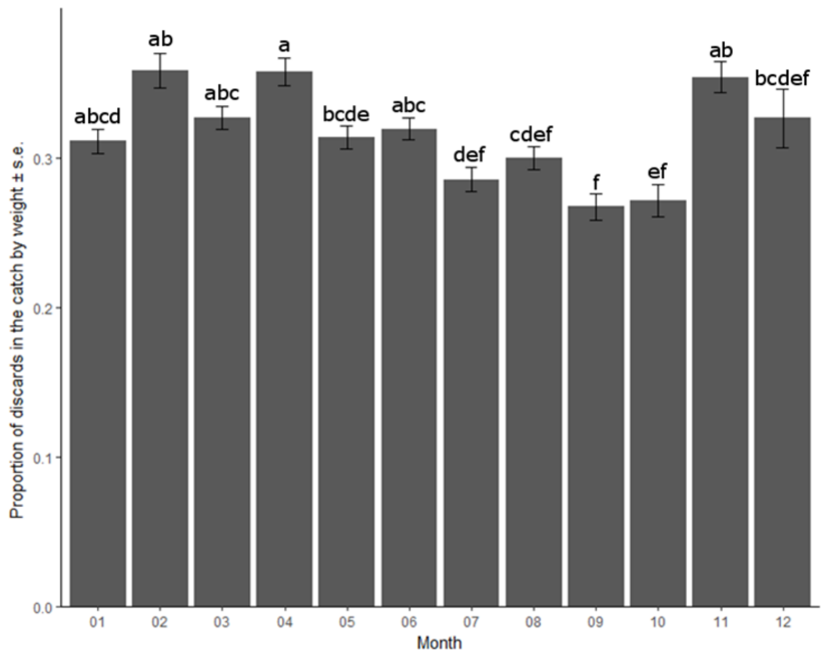

Figure 1: Mean (±SE) proportion of discards in the catch per haul during each month of the year. Letters indicate groups that are statistically indistinguishable from each other ($p > 0.05$).

Total and >MLS TAC species

Again, there was no significant effect of day of the month. The depth fished was the main explanatory variable influencing the proportion of discards in the catch when looking only at TAC species (χ^2 = 217.33, $p<0.001$). Post-hoc tests revealed a trend of decreasing discarding with depth (Figure 2). The smallest proportion of the catch was discarded at depths between 136m and 280m with a mean of 0.21 across depth categories 8 and 9. This is compared with a proportion of 0.47

being discarded in the shallowest depth category, showing that discarding of TAC species can be more than halved by fishing in deeper waters.

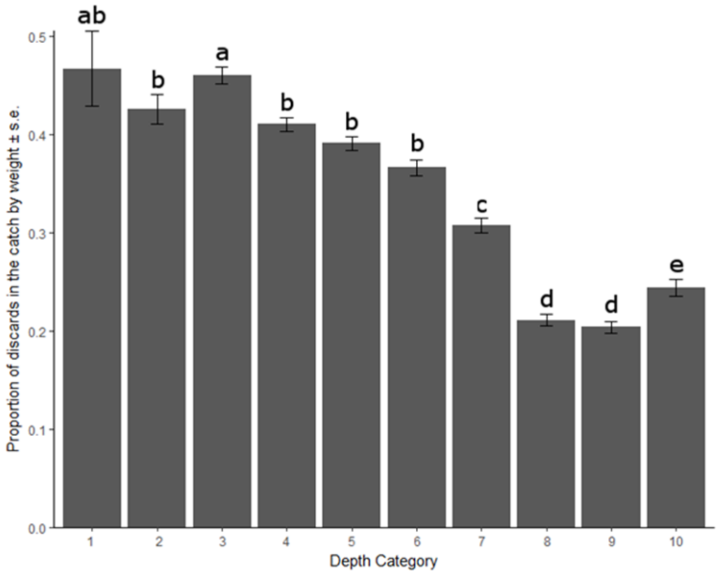

Figure 2: Mean (±SE) proportion of discards of TAC in the catch per haul at consecutive depth intervals. Letters indicate groups that are statistically indistinguishable from each other (p > 0.05).

Examination of AIC values indicated that none of the variables examined explained variation in the proportion of >MLS TAC species discarded. Additional factors not included in this analysis could, therefore be affecting the proportion of >MLS discards throughout the month. Alternatively discarding could be occurring randomly with different factors affecting decisions to discard this component of the catch at different times.

Total and >MLS haddock

There was no significant effect of day of the month for haddock either for all sizes or those below MLS. Depth fished was the main explanatory and sole significant variable influencing the proportion of all haddock caught that were subsequently discarded (χ^2 = 243.18, p<0.001). Month had no significant influence on haddock discards. Post-hoc tests showed a general trend of decreasing discards with increasing depth (Figure 3). The mean proportion of haddock discarded between the depths of 20m and 136m was statistically similar with a mean of 0.52, with greater than half of the haddock caught being discarded in these shallower waters. This level of discarding was dramatically reduced when fishing took place in depths greater than 136m with mean discards of haddock constituting 18% of the haddock catch. For >MLS haddock none of the factors included in the model sufficiently explained the variation in the proportion of discards in the catch.

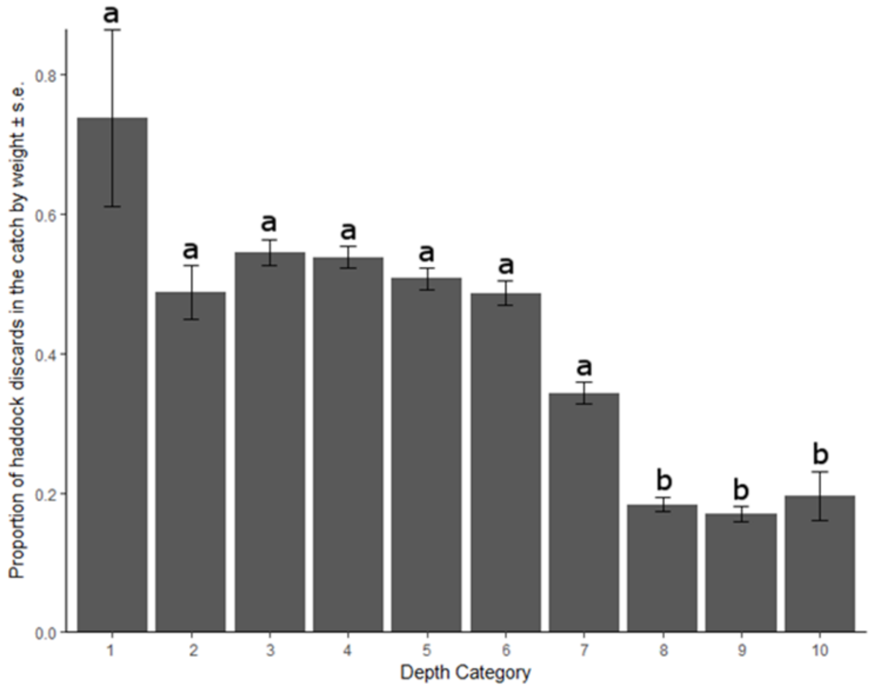

Figure 3: Mean (±SE) proportion of discards of haddock in relation to total haddock caught per haul at consecutive depth intervals. Letters indicate groups that are statistically indistinguishable from each other ($p > 0.05$).

Total and >MLS cod

None of the variables, including day of the month, examined explained variation in the proportion of the total catch of cod discarded on sampled trips. This was also the case when the proportion of >MLS cod discarded was analysed, with none of the factors included in the model sufficiently explaining variation in the proportion of discards.

Total and >MLS whiting

Both day of the month ($\chi^2 = 17.06$, $p<0.001$) and month of the year ($\chi^2 = 120.09$, $p<0.001$) have a significant effect on the proportion of whiting discarded in relation to the amount of whiting in the catch. There was a positive relationship between the proportion of whiting discarded and the day of the month with discards ranging from 0.24 on day one to 0.45 on day thirty, almost doubling over the course of a month (Figure 4A). Although month was a significant factor affecting discards, post-hoc tests showed a variable relationship over the course of the year with no clear seasonal pattern in the discarding behaviour of vessels (Figure 4B).

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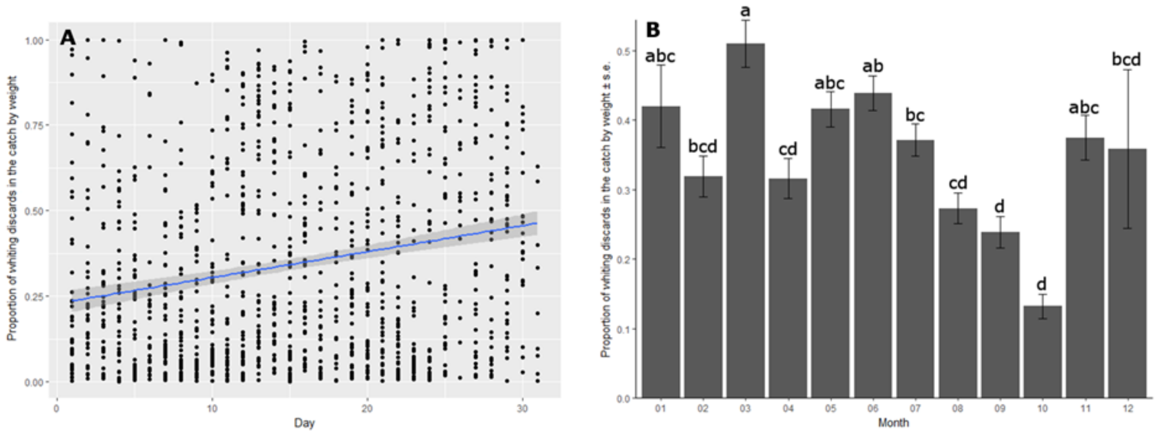

Figure 4: A. Relationship between the proportion of discards of whiting in relation to total whiting caught per haul on varying days of the month. The shaded area represents the confidence interval based on standard error. B. Mean (±SE) proportion of discards of whiting in relation to total whiting caught per haul during each month of the year. Letters indicate groups that are statistically indistinguishable from each other ($p > 0.05$).

For >MLS whiting, day of the month had a significant effect on the proportion of the >MLS catch discarded (χ^2 =6.87, p=0.009). There was also a positive relationship between the proportion of the >MLS whiting caught that was discarded with day of the month. Discards of >MLS whiting ranged from 0.18 to 0.33, almost doubling over the course of the month and displaying a significant increase.

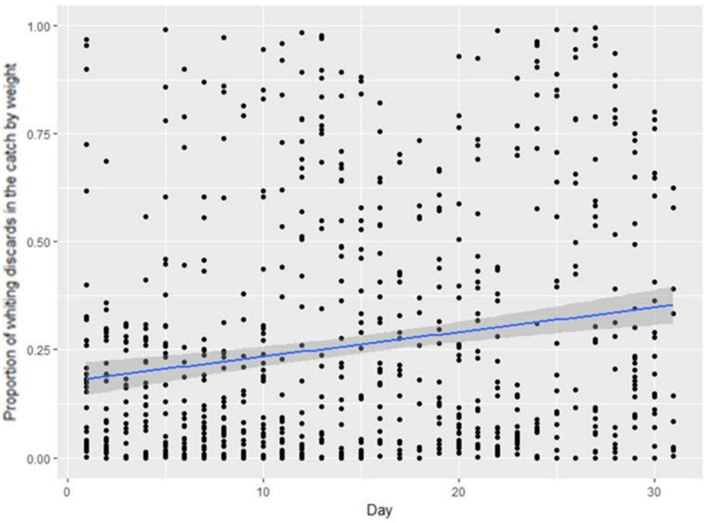

Figure 5: Relationship between the proportion of discards of >MLS whiting in relation to total whiting caught per haul on varying days of the month. The shaded area represents the confidence interval based on standard error.

Discussion

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633680

Ireland has a unique fisheries quota system in Europe, whereby quotas are assigned to individual vessels on a monthly basis without the possibility of buying or trading quota. Despite this no research to date has examined how such a monthly quota system may influence fishing or discarding behaviour amongst the Irish fleet. Understanding the drivers of discarding behaviour is especially important in light of the introduction of the landing obligation if management strategies are to successfully reduce unwanted catches (Rochet et al., 2014). We, therefore, examined how discarding patterns varied over the course of a month, testing the hypothesis that discards would increase with day of the month as quotas became more restrictive. Other than for whiting, however, our results showed no relationship between discarding behaviour and day of the month, and instead highlighted how it is difficult to discern single drivers of discarding.

When examining discards as a proportion of the total catch there was evidence of seasonal variability. Temporal effects on discarding have been recognised in a number of studies (Borges et al., 2006; Feekings et al., 2012; Pennino et al., 2017) and may in part be due to seasonal changes related to fish condition (Feekings et al., 2012). Previous work by Viana et al., (2011), concentrating on discarding behaviour in the Irish Sea, found an annual cycle with a peak in the second quarter of the year. Similarly our data shows higher rates of discarding in the first two quarters compared with the third quarter. Biological seasonal variation could in part be responsible for these trends although temporal variation in markets as well as weather and subsequent fishing behaviour could also influence discarding behaviour throughout the year. When examining the whole catch, however, there is no clear monthly pattern in discarding and seasonal variation overrides other factors that may influence discarding.

For TAC species seasonal variation in discarding was not evident. Instead depth was a significant factor affecting the proportion of discards in the catch, as has been recognised by previous research (Rochet and Trenkel, 2005; Borges et al., 2006). Interestingly depth was not significant when just examining the >MLS proportion of the catch suggesting the variation of discards with depth is primarily due to <MLS catches being discarded. It has certainly been recognised the there is a positive relationship between depth and fish size for a number of demersal species (Macpherson and Duarte, 1991; Petrakis, 2001; Labropoulou et al., 2008). This is reflected in the results showing a decrease in discards as depth increases, thus suggesting <MLS discards could be avoided by fishing in deeper water. Although all TAC species are subject to monthly quotas, however, there was no influence of day of the month on the proportion of discards in the catch. The relative importance of different variables effecting discarding has been noted to vary with species (Feekings et al., 2012) and some TAC species are more quota restricted than others within the Irish fleet so a distinct monthly discarding pattern across all TAC species caught was not evident.

Cod and haddock have been identified as key choke species for Irish vessels operating in mixed demersal fisheries due to the low quotas available for these species (Calderwood et al., 2016). This in part is due to the limited quota available for these species in many EU fishing areas around Ireland. In January in 2017 for example 0.5 tonnes of cod was available to fishing boats over 55 feet in length operating in areas VIIb, VIIc, VIIe-k, VII, IX and X and 2 tonnes of haddock was available for vessels operating in VIIb-k, VIII, IX and X (DAFM, 2017). This is in contrast to whiting for which 35 tonnes were available in Januray 2017 in areas VIIb-k (DAFM, 2017). These species often share the same fishing grounds and because selectivity of gear cannot ensure the selection of a single species in mixed fisheries a skipper will allocate effort to harvest a range of species (Hutton et al., 2004; Simons et al., 2015). Regulations apply to single TAC species, however, and when there is a significant mismatch in quota between co-occuring species discarding is likely to occur (Cosgrove et al., 2015). It may, therefore, have been expected that cod and haddock would choke prior to whiting and discards of these two species would increase over the course of the month, whilst the larger quota for whiting might mean monthly variation in discarding may not be so obvious. The opposite was in fact seen in our results with whiting showing increased discarding over the course of the month, whilst both haddock and cod discarding behaviour showed no relationship with day of the month.

None of the factors included in our analysis explained variation in cod discarding rates for either the whole catch or >MLS portion of the catch. Uhlmann et al., (2014) noted that cod discards were homogenous across European fisheries and we found they were homogenous both temporally and with depth in our analysis. It may be expected that vessels will only discard marketable fish once the quota for that species is reached (Poos et al., 2010). It is possible, however, that due to the very low and restrictive quota available for cod it is necessary to discard this species in equal amounts throughout the month as vessels can become quota limited within just a couple of days of fishing (Calderwood et al., 2016). Thus no monthly variation in discarding was seen for cod.

Depth influenced the discarding rate of total haddock caught, although this was not evident for >MLS haddock alone, again indicating that fishing in greater depths can help in avoiding <MLS haddock. Under minimum landing size haddock constitute a significant volume of discards across EU countries (Catchpole et al., 2017) and avoiding shallower waters could certainly assist in the Irish fleet avoiding this unwanted component of the catch. As with cod day of the month had no influence on discarding of >MLS haddock, again indicating that the species is so quota restricted marketable fish are discarded in equal quantities throughout the month. It is also possible that fishermen are adopting other tactics to avoid exceeding quotas of TAC species and reducing the need for discarding. For many species ICES area VIa is subject to different quota limitations than VIIb-k and fishermen often split their time between different areas during a month to take advantage of all quotas that are available to them, despite the large distances that must be covered to achieve this (pers. comm). Although smaller vessels in the fleet may not adopt such behaviour it is possible for fishermen to mitigate against some of the restrictive quotas they have, and reduce the need for discarding, by fishing in different areas.

It was only for whiting that we observed an increase in discarding over the course of the month. Day of the month was the sole factor that explained discarding for >MLS catches, so for this species the monthly quota system does seem to affect discarding behaviour. As a larger quota is available for whiting it may be the case that fishermen are able to fish within the limits of the quota at the beginning of the month and it is only towards the end of the month where they near the quota that they are more selective with the whiting they land and discarding increases. Both whiting and haddock have been recognised as constituting significant amounts of the discards from Irish fisheries (Borges et al., 2005) but the drivers of discarding for these two species appear to vary.

Market forces have been recognised as the main reason for discarding whiting in English north east coast Nephrops norvegicus fishery (Catchpole et al., 2005). Prior to quota restriction at the end of the month discarding of whiting in the Irish fishery is likely to be influenced by other factors including market forces, but these may become less influential on discarding as the month progresses.

Discarding behaviour is driven by multiple factors from economics, as fishermen are unlikely to land any catch if it is not profitable to do so (Hatcher and Drakeford, 2015), through to the restrictions placed upon them by regulations (Prellezo et al., 2016). Spatial and temporal variation in catch composition within mixed demersal species is also likely to influence subsequent discarding (Pennino et al., 2017). We found that depth certainly had an influence on the discarding of <MLS species, with fewer discards of smaller fish taking place following hauls in deeper water. For species with very restrictive quotas such as cod and haddock it appears discarding remains constant throughout the month suggesting continual discarding is the only way to ensure monthly quotas will not be exceeded. Only where quotas are more generous is there evidence that the monthly quota system in Ireland results in increased discarding towards the end of the month. This certainly highlights that there will be issues for the Irish fleet when the landing obligation is fully implemented. It appears that quota restrictions are the main driver of >MLS discards of cod and haddock throughout the month and thus there is limited ability for vessels to reduce catches of these species whilst targeting other non-quota restricted species. Without addressing quota mismatches, therefore, it is likely that choke species are going to prove to be a significant problem for Irish vessels operating under the landing obligation.

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Chapter 8. Hotspot mapping in the Celtic Sea to best inform fishing practices under the Landing Obligation

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Celtic Sea case study

Introduction

Advanced spatial analysis techniques and methods used to identify and manage the spatio-temporal nature of bycatch are acknowledged as being important in optimising catch composition and extending fishing opportunitis under the Landing Obligation (LO) (Dunn *et al.*, 2011; Paradinas *et al.*, 2016, Vignaux, 1996; Tidd *et al.*, 2012; Van Putten *et al.*, 2012; Vilela and Bellido, 2015). Survey data collected from research vessels, observer data collected from commercial fishing vessels and catch information from logbooks, coupled with VMS data can be used to produce maps that identify species hotspots. The inclusion of discards in such data sources provides more precise estimates of catch than just using landings data alone (Viana *et al.*, 2013). Maps produced from observer data could, therefore, provide a real insight into the spatial distribution of all species caught by commercial vessels. There are, however, problems associated with discard sampling from observers including low sampling frequency and irregular sampling (Villasante *et al.*, 2016).

The Celtic Sea contains stocks of several important ground fish species, thus supporting a number of international fleets including those from Ireland, France, and the UK. The collaborative nature of the DiscardLess project has meant for the first time observer data from vessels operating out of these three countries can be combined for the Celtic Sea. Such an opportunity helps to overcome some of the problems associated with the sparse nature of data supplied by observers. This work, therefore, aims to use a tri-national dataset to identify areas where catches of species subject to TAC (total allowable catch) are likely to occur within the Celtic Sea. The resultant maps can be used to identify hotspots of catches that fishermen may want to better target or avoid to optimise catches under the landing obligation. The resultant information will be presented in the form of an interactive app so that fishermen can extract tailored information, ultimately helping to inform where to fish to reduce bycatch.

Methods

Data

Data collected by onboard observers working on Irish, British and French vessels operating in the Celtic Sea between 2010 and 2015 were used in the analyses. Data were collected by each member state as part of the EU data collection framework (Council regulation (EC) No 199/2008). Observer data were specifically used as it is the only source of information on the component of catches that are discarded at sea providing biological data on the whole catch and not just fish and shellfish later landed. In addition meta-data such as the position and duration of hauls, gear and mesh size used, vessel type and vessel size are all collected by observers. Initial analysis concentrated on data collected on-board TR1 vessels i.e. those operating bottom trawls, Danish seine nets and similar towed gear with mesh sizes between 70mm and 100mm, but excluding beam trawls (Davie and Lordan, 2011).

Mapping Methodology

The geographical midpoint of all hauls were calculated and catch data assigned to this point. Catch data were then assigned to 0.2 by 0.2 degree grid cells to ensure individual vessel and national data could not be identified. The proportion of the haul by weight for both the below and above MCRS (minimum conservation reference size) component of the catch for each species subject to a TAC was calculated. Mean annual values were calculated for each grid cell and grid cells were subsequently binned into 20% intervals with an additional category being used to identify where grid cells contained zero catch within a year. A final, amalgamated map for 2010 through to 2015 was created for each species and size component grouping by identifying grid cells that were consistently and uniquely within the same binned category over multiple years (Fig. 1).

The above process was also conducted using catch per unit effort (CPUE) rather than proportion by weight. CPUE was calculated by dividing the total weight of both below and above MCRS TAC species caught in each haul by the total haul duration. Again mean annual values were calculated for each grid cell and subsequent values were divided into five equal quantiles, following the removal of zero catches. Again an amalgamated map was created for the whole time period studied by identifying grid cells that were consistently and uniquely within the same quantiles over multiple years.

In addition to determining annual catch patterns, seasonal patterns were investigated by sub setting the observer data into four data sets based on the quarter of the year in which fishing operations took place. Mean quarterly values per grid cell for each individual year were calculated before again being binned or assigned to quantiles with amalgamated quarterly maps being produced for both proportion and CPUE data as before.

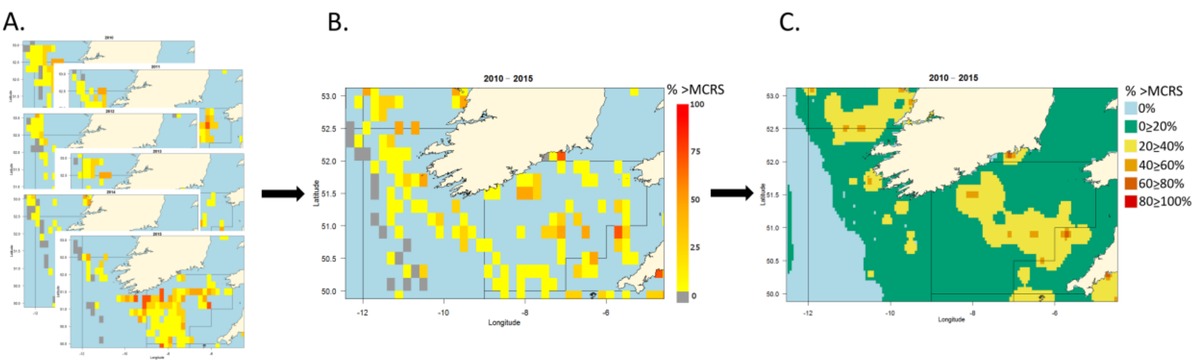

Figure 1. Diagram showing the steps in the map production process. (A. Individual binned maps created for each year; B. Amalgamated map for all years identifying grid cells within consistent binned categories over multiple years; C. Final interpolated map)

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Interpolation

The resultant gridded maps show where over time consistent proportions or volumes of certain species within the catch are likely to be found. This provides valuable information to inform where to target fishing activities and optimise catches in relation to available quotas. To provide a more user friendly end product the grided maps were interpolated using inverse distance weighting using gstat in R (Pebesma, 2004; R Core Team, 2012). Due to the grid structure of the data a number of suitable interpolation techniques were compared prior to the final interpolation technique being applied. Proximity polygons, nearest neighbour analysis and inverse distance weighting techniques were validated against a test data set and the root mean square error (RMSE) was calculated for each method (Luo *et al.*, 2008). The inverse distance weighting interpolation consistently produced the lowest RMSE values for each interpolated map and thus this method was used throughout our analyses.

App Development

To produce a user friendly and interactive tool for use by stakeholders an app was developed using Shiny and Leaflet in R (Chang *et al.*, 2017; Cheng *et al.*, 2017). Layers were extracted from the interpolated maps based on the original bin and quantile categories. These were converted to spatially referenced shape files and saved separately. Users of the app are able to select the time period they are interested in (Annual Data, Quarter 1, Quarter 2, Quarter 3 or Quarter 4), the numerous species they wish to target and those they wish to avoid. For each species selected the user can specify whether they are interested in the below or above MCRS component of the catch. They are then able to toggle the levels of catch they either wish to target or avoid, selecting either the minimum proportion of the selected species or minimum level of CPUE of interest (Fig. 2). Multiple target and non-target species can be selected at once and semi-transparent map layers are displayed on an interactive map, identifying where selected levels of catch are likely to occur.

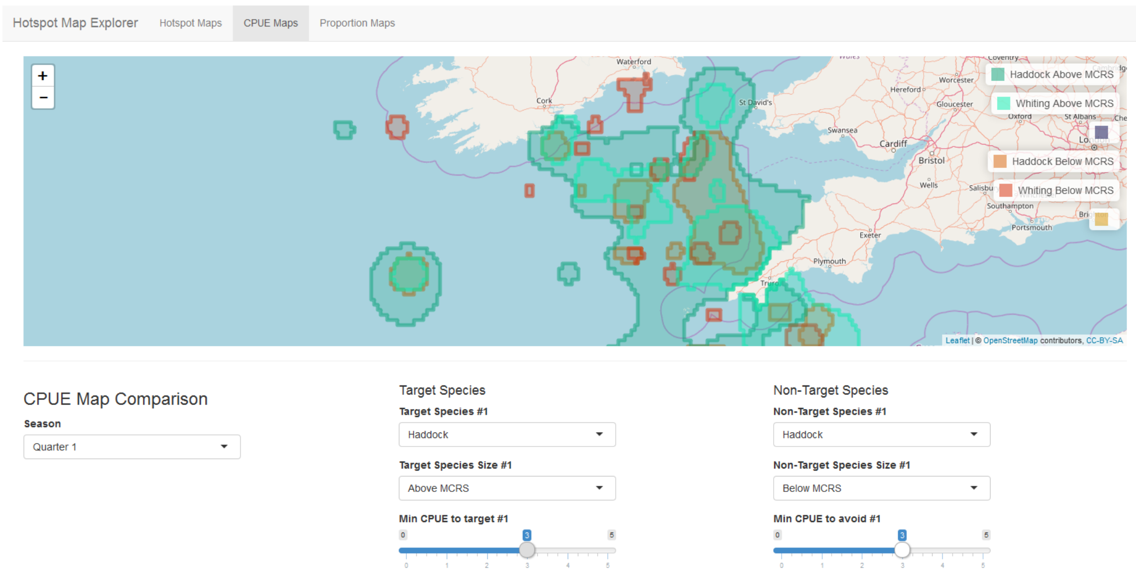

Figure 2. A screenshot of the shiny app developed to allow stakeholders to select the size, species and quantity of fish they would like to target and/or avoid during different seasons. The resultant map displays layers representing where to target or avoid fishing operations to optimise catch composition.

Results

The maps as described previously have been created for the above and below MCRS component of the catch for all demersal species subject to a TAC. To better focus comparison and analysis of the results this paper will focus on three key species; haddock, whiting and cod. Both haddock and whiting have been recognised as high risk species in the Celtic Sea with catches exceeding TAC across multiple member states (Rihan *et al.*, 2017). Cod has also been noted as being at moderate risk for member states as a whole but presents particular problems for the Irish fleet due to low quota share amongst its' vessels (Calderwood *et al.*, 2016). Examples of how the information in these maps compares and contrasts for selected species are described below.

CPUE vs Proportion

Both CPUE (kg hr^{-1}) and proportion by weight in the catch were used as metrics to identify hotspots of key TAC species. Figure 3 shows an example of how these two metrics compare for above MCRS haddock in the Celtic Sea. Areas with consistently high levels of haddock CPUE within the catch are centred around the coordinates 51.1 -6.85 between the south coast of Ireland and the north coast of Cornwall and to the west of Ireland centred around the coordinates 52.5 -11.0 (Fig 3.A). Catches where above MCRS haddock consistently constitutes at least 20% of the catch are identified in similar locations (Fig3.B), although for both areas higher proportions of haddock are identified closer in towards the coast than with the CPUE data. There are also a few discrepancies with small hotspots of high CPUE areas at 51.4 -9.4, 51.4 -11.2 and 50.3 -10.5 not being reflected in the proportion data. Similarly areas with high proportions of haddock identified at 51.79 -10.49 and 51.13 -7.14 are not reflected in the CPUE data. Less relief is also evident on the map representing the proportion of haddock in the map as few catches were identified with greater than 60% of haddock in the catch.

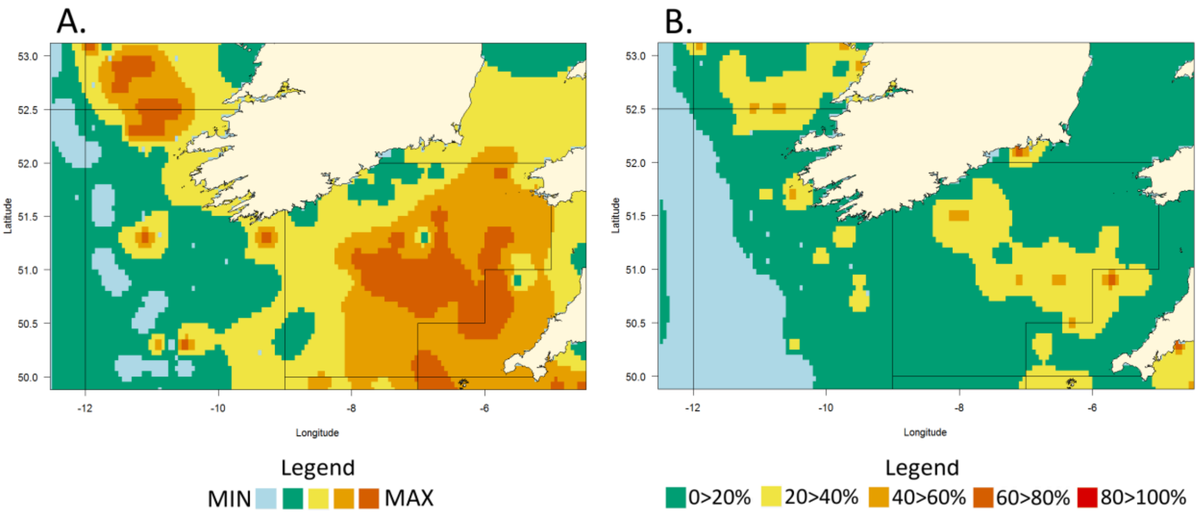

Figure 3. Interpolated maps identifying A. Areas with consistent levels of >MCRS haddock CPUE over multiple years (2010-2015) and B. Areas with consistent proportion of >MCRS haddock in the catch by weight over multiple years (2010-2015).

Below MCRS vs Above MCRS catches

All species maps were created for two size categories based on fish either below or above MCRS, allowing for a comparison of the distribution of these two size categories amongst and between species. When comparing whiting catches the largest volumes are again caught in an area centred around the coordinates 51.1 -6.85 (Fig. 4). The majority of points with the greatest CPUE of below MCRS whiting are also encompassed by the areas with greatest CPUE for above MCRS whiting. Areas with high CPUE of below MCRS whiting do, however, cover a much smaller area compared to the above MCRS component of the catch. Small distinct hotspots, representing the highest CPUE category, cover a total area of less than 430km^2 for below MCRS catches compared to 9500km^2 for the above MCRS catches in the same CPUE category. There are also a few distinct patches identified as having a high likelihood of high above MCRS catches where there are no below MCRS catches identified. Namely along the 52.5 degree latitude line and just off of the south west coast of Ireland at approximately 51.3 -9.28.

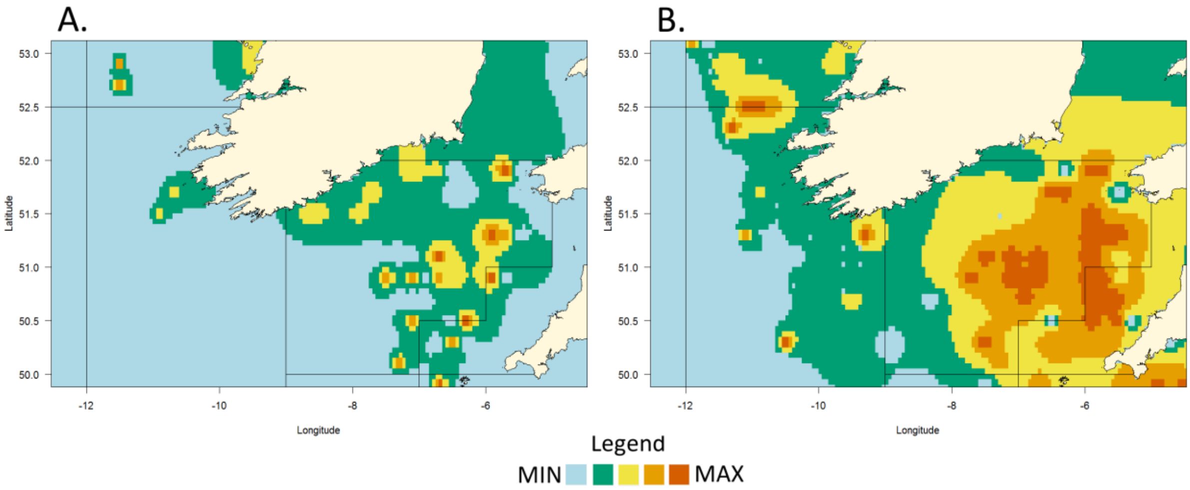

Figure 4. Interpolated maps identifying areas with consistent levels of whiting CPUE over multiple years (2010-2015) for A. Below MCRS fish and B. Above MCRS fish

Species Comparison

The same metric can be used to compare the likelihood of different species co-occuring. The area with consistent proportions of haddock in the catch over multiple years in the Celtic Sea for example is much greater than that of whiting (Fig.5). No areas are identified as having consistent proportions of whiting in the catch south of the 52.5 degree latitude line or west of the -9 degree longitude line (Fig.5B). There is a distinct chance of catching haddock in this area, with some hotspots of up to 60% of haddock being identified (Fig.5A). There is also overlap of the haddock and whiting map extents, especially within area VIIg. Overall there are relatively small areas being noted as consistently having at least 20% of whiting in the catch, whilst areas identified as likely to have at least 20% of above MCRS haddock in the catch cover a much greater extent (approximately 5200km^2 compared to 38700km^2).

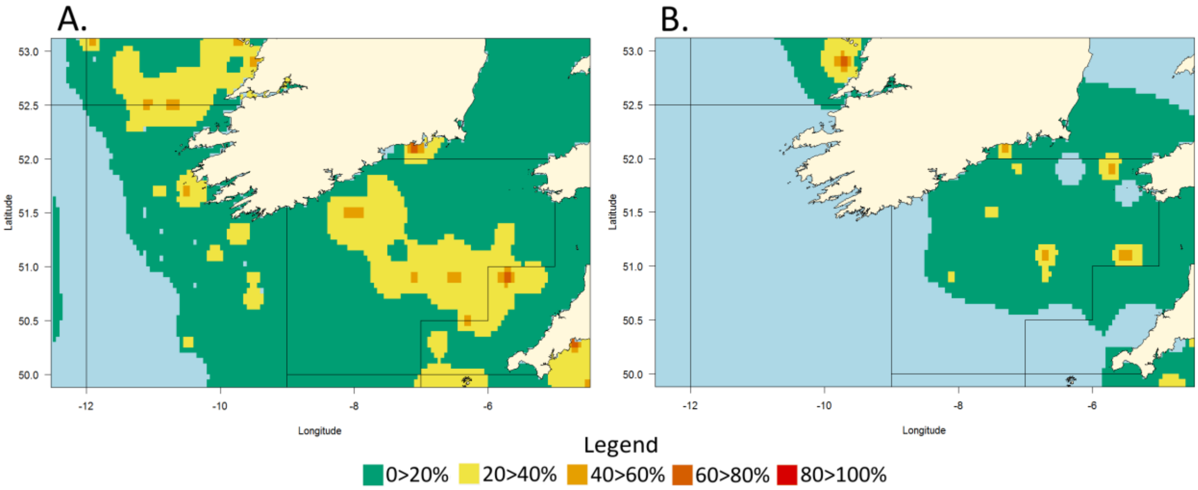

Figure 5. Interpolated maps identifying areas with consistent levels of the proportion of above MCRS A. Haddock and B. Whiting in the catch over multiple years (2010-2015)

Seasonal variation

Seasonal variation in catches can be identified by examining amalgamated quarterly rather than annual data. When comparing areas where there are likely to be consistent levels of CPUE of above MCRS cod over each quarter distinct seasonal patterns can be seen (Fig.6). In the first quarter of the year areas with consistent levels of cod in the catch are found in a small number of isolated spots within area VIIg. Moving on to quarter two there is a sudden large expansion in the range of the area where cod is likely to be caught. In this period the area covered by the map layers extends to most of area VIIg. During the third quarter of the year the extent of the map retracts a little, splitting into two smaller regions within VIIg and also extending further east into VIIf, with some hotspots being concentrated along the boundary between these two ICES areas. In the final quarter of the year the extent of the cod CPUE map retracts further shifting north towards the south coast of Ireland in addition to a small hotspot emerging just above the north coast of Cornwall in areas VIIf.

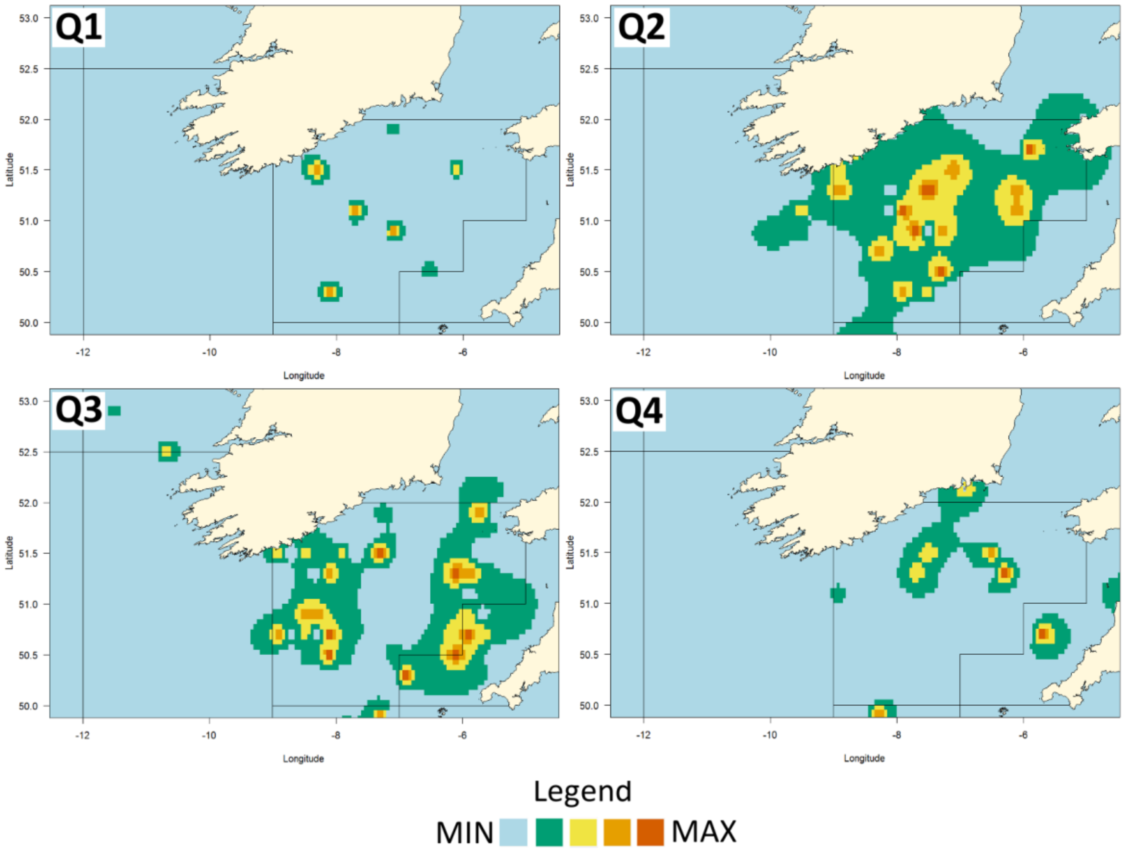

Figure 6. Interpolated maps identifying areas with consistent levels of CPUE for above MCRS cod over multiple years (2010-2015) for each quarter of the year.

Shiny App

All of the maps produced provide useful information that can be compared in numerous ways depending on the user's interests and objectives. Providing the maps in an interactive app thus provides the opportunity to pick those layers of interest to easily compare and contrast. Figure 2, for example, shows the overlap of four different layers. The first two are species that wish to be targeted. Both above MCRS haddock and whiting have been selected as the target species, with the level of CPUE being set to include the highest two levels identified during the mapping analysis. Below MCRS haddock and whiting are selected as the non-target species, again with the layers highlighting the two highest levels of CPUE identified. The resultant overlap of all of these layers is displayed within an interactive map layer. Although there are overlaps between all four of the layers there are distinct areas that highlight where just the target species are likely to be found.

Discussion

Hotspot mapping provides essential information to allow the optimisation of fishing efforts to catch target species and avoid unwanted and quota restricted species. Observer data, collected from commercial fishing vessels, provides an ideal basis for such maps as these data include the discarded component of catches, in addition to landings. The sparse coverage of observer data and limited sampling of commercial vessels can present problems when trying to identify patterns in such data. By combining data from three EU member states with commercial vessels operating within the Celtic Sea for the first time, we were able to produce maps highlighting where catches of TAC species show consistent patterns over multiple years. Further by using the output of these maps in an interactive app we have produced a tool that can easily be used by stakeholders to help inform decisions on where to fish to reduce unwanted catches.

Two catch metrics were used to identify where similar catches are expected to occur over time. CPUE gives an indication of how the volume of a species in a catch varies. When trying to avoid non-target species it would make sense to avoid areas where there is increased probability of high CPUE catches. When targeting species, although stakeholders are likely to be drawn to areas with high CPUE, it is also important to consider the proportion of that species within the catch and how clean the catch is if bycatch is to be avoided. Thus it is important to use these two metrics together, depending on what is driving fishing behaviour and how restrictive other quotas may be in relation to the target. Our example comparing CPUE and proportion maps for above MCRS haddock shows how these two metrics compare and contrast. There is some agreement between the two maps as to where hotspots of this species occur, and identifying these areas would be beneficial to best target fishing. There is certainly less relief in the maps based on proportion by weight and this is especially true of the below MCRS component of the catch where often there is never greater than 20% of the catch by weight. For these cases the CPUE map provides more detailed information as data categories are based on quantiles rather than pre-defined equal intervals.

Under the LO all catch of TAC species regardless of size will count against quotas (European Commission, 2013). Thus it is important to avoid all below MCRS fish as this component of the catch cannot be sold for human consumption and receive full market value. Whilst the extent over which below MCRS catches are likely to occur may overlap with that of the above MCRS component of the same species we have shown that for whiting areas can be identified where it would be possible to target large, marketable fish whilst reducing the chances of catching smaller fish. In the Celtic Sea, where there is a mixed demersal fishery and numerous species co-occur it is also to be able to highlight those areas where fish are less likely to occur together to allow fishermen to target certain species whilst avoiding chokes. Haddock and whiting are two species that co-occur but for which there are often uneven quotas (Calderwood *et al.*, 2016) and so it may be necessary to target one species whilst attempting to avoid the other. Again the comparison of maps for these two species showed that there is potential to concentrate fishing efforts in areas to minimise the likelihood of catching one whilst maximising the likelihood of catching the other.

The mapping method adopted identifies areas with consistent proportions or volumes in the catch over time. Obviously fish populations are mobile and aren't always going to be found in the same location. These maps do, however, give an indication of where the likelihood of catching certain species is greatest. Examining how cod distributions vary with season shows how important it is for stakeholders to consider the data provided in these maps at greater temporal resolution than just annually. Due to the resolution of input data used in this work, quarterly data is currently the finest temporal resolution that the maps can be divided into. This still provides greater detail than solely presenting annual data and allows fishermen to consider how the dynamics of fish stocks over the course of a year requires seasonal adaptation to fishing practices.

It is clear that these maps hotspot provide information that is essential if stakeholders are to make the most informed decisions when choosing where to fish whilst operating under the LO. A suite of measures from gear adaptations through to the provision of spatial-temporal information will be required for the fishing industry to successfully reduce unwanted catches and meet the legislative requirements of the LO. The data provided in these maps provides one element of this suite but to ensure this data is easily accessible and digestible it needs to be presented to industry in the appropriate format. As a result an interactive app was developed to allow stakeholders to pick and choose the information that is relevant to them at any one point in time. They are able to select those species they want to target as well as those they wish to avoid and display all of the relevant information on one map. Areas with a high chance of catching solely the target species can easily be identified and help stakeholders to make the most informed decisions when deciding when, where and how to fish to avoid unwanted catches. Making the information stored within these hotspot maps easily accessible could aid in making fishing operations in the Celtic Sea more efficient, ultimately reducing operating costs. By arming industry with such knowledge and information it is hoped fishing operations can be optimised with fisheries continuing to be profitable whilst operating under the LO.

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Chapter 9. Mapping the distribution of landing and discard per unit of effort for two dissimilar case studies using a nested grid method

Fabien Pointin and Marie-Joëlle Rochet – IFREMER.

Celtic Sea case study

Introduction

Discards are defined as unwanted fish retained by a fishing gear which have been brought on board fishing vessel and are thrown back into the sea (European Commission, 2002). Discarded fish are often dead or dying (Nordic Council of Minister, 2003), except for some species with a high survival rate (Berghahn et al., 1992; Revill et al., 2005). Kelleher (2005) estimated that European fisheries discarded on average 1.3 million of tonnes per year between 1992 and 2001 (around 13 % of the total catch). Discards are often caused by regulation (e.g. catches in excess of quota or below the minimum landing size), technical limitations (e.g. limited storage capacity, non-selective fishing gear) and/or economic considerations (e.g. high grading - the practice of discarding legal fish of low market value or damaged or poor quality) (Alverson et al., 1994; Pascoe, 1997, Morandeau et al., 2014; Catchpole et al., 2014).

In 2013, a Landing Obligation (LO) was introduced within the new Common Fisheries Policy (CFP) to cope with the discard issue. The LO contained in article 15 of Regulation (EU) N°1380/2013 requires gradually to retain onboard, register and then land all catches of species which are subject to catch limits. The primary objective is to gradually eliminate discards (European Parliament and Council. Reg.n°1380/2013). The implementation of the LO within the European fisheries drives new constraints for fishers. Spatio-temporal reallocation is part of adaptation strategies to reduce the LO impact on fishers.

In the context of the LO, the reallocation of effort to other fishing grounds or seasons is a matter of interest considering it as a way to reduce discards (Salas and Gaertner, 2004; Poos et al., 2010; Batsleer et al., 2013). Fishers are encouraged to avoid areas or periods with a high abundance of unwanted fish (FAO, 2010; Bellido et al., 2011). Spatio-temporal reallocation strategies require to adapt spatially and/or temporally fishing effort with the objective of reducing discards while at the same time maintaining a sufficient amount of commercial catch (i.e. target marine species which are caught, landed and then sold). Maps of landings and discards are useful for fishers to select better fishing grounds and/or periods (Sims et al., 2008).

The purpose of this study is to describe the spatial and temporal patterns of landings and discards in French waters. Herein landings and discards per unit of effort (LPUE/DPUE) are used as mapping units. They are easy-to-interpret units for fishers as it helps them visualizing the amount of landings and discards per fishing zone according to their fishing effort. Furthermore, they are also standardized units, which allow the integration and comparison of estimates among different fishing zones and/or fishing periods.

The French on-board observer programme (ObsMer) is a sampling programme designed to observe fisheries catches. Since the introduction of the EU data collection regulation (2002-2008) and the subsequent data collection framework (Commission decision-2008/949/EC), the observer programme has collected data on the biomass, length and species composition of landings and discards of all commercial fisheries. The main purpose of this programme is to quantify discards, determine their composition and identify what it is discarded, when and by whom (e.g. Cornou et al., 2016). As fishers target particular fish species in locations where they know fish are, fishing activity is non-randomly distributed in space as shown by the ObsMer data (Sims et al., 2008; Augustin et al., 2013; Poos et al., 2013; Pennino et al., 2014). Data collected on-board fishing vessels have already been examined in past studies (e.g. Sims et al., 2008; Lewison et al., 2009; Viana et al., 2013; Pennino et al., 2014; Paradinas et al., 2016) using statistical modelling methods: to model spatial and/or temporal patterns of landings and discards, to test assumptions on the factors influencing the distribution of a particular species, or to predict future outcomes (e.g. consequences of implementing the LO). However, one common problem arises when taking the distribution of the data into consideration. It makes mapping the data challenging. To overcome the non-random spatial distribution of the data, Gerritsen et al. (2013) developed a mapping method based on nested grids where the size of each cell depends on the number of observations: in areas with few observations a large cell size is used, and in areas with many observations, a smaller cell size is used. This method deals with the distribution of the data by ensuring that a sufficient number of observations is obtained per cell to estimate landings and discards with a good precision. This nonparametric method is therefore chosen over statistical modelling to describe the spatial and temporal patterns of landings and discards in French waters.

A métier being defined as "a group of fishing operations targeting a given (group of) species, using a given gear, during a defined period of the year and/or within a defined area and which are characterized by a similar exploitation pattern" (2008/949/EC). Two fishing métiers are selected to illustrate the advantages and issues when using a nested grid method: the French trawling métier targeting demersal species in the eastern Celtic Sea and the western English Channel, and the French netting métier targeting demersal species, cephalopod and crustaceans in the western English Channel and West of Brittany, hereafter referred to as the trawling and netting métiers.

At the end of the mapping process, the objectives are threefold: (1) the method is expected to be appropriate to the distribution of the data; (2) the resulting maps are expected to be representative of the métier-associated fishing activity; and (3) the LPUE and DPUE are expected to be estimated with a minimum degree of precision. The performance of this method with respect to these criteria is assessed using quality indicators.

The aim of the study is to explore spatio-temporal reallocation strategies using the French observer programme data: where and when can the fishing effort be reallocated to reduce discards with a minimum impact on production? To achieve this, a nested grid method was developed and applied to the ObsMer data and its ability to provide a comprehensive overview of the spatial and temporal patterns of landings and discards on a métier-based approach was evaluated: how to create a nested grid structure to map LPUE and DPUE for any fishing métier observed by the ObsMer programme? What are the advantages and issues of the nested grids related to specific métiers? The method creates specific nested grids and estimates LPUE and DPUE in each grid cell to investigate spatio-temporal reallocation strategies. The method is applied to two contrasting case studies and then is discussed on how it can be applied to any fishing métier being observed by the French observer programme.

Material and Methods

Case Studies

The trawling métier, targeting demersal fish species with the use of single or twin-rig otter trawls in the eastern Celtic Sea and the western English Channel, is carried out by vessels larger than 18 meters. Fishing activities remain relatively unchanged over the year and fishing trips last on average 7 days. In 2015, a total of 46,294 tonnes of fish were landed and around 13,938 tonnes were discarded accounting for an average discarded proportion of 23.1 % (Cornou et al., 2016). The most important target and non-target species subject to quotas were haddock, whiting, European hake, cod, megrim, boarfish, anglerfish, cuckoo ray, pollack, and common cuttlefish.

The netting métier, targeting demersal fish species, cephalopod and crustaceans with the use of gill or trammel nets in the western English Channel and West of Brittany, is carried out by vessels less than 15 meters with seasonal fishing activities. Fishing trips last on average 1 or 2 days and vessels may switch fishing gear at any time (e.g. longlines, traps). Cornou et al. (2016) estimated that a total of 4,096 tonnes of fish were landed in 2015 and around 845 tonnes were discarded accounting for an average discarded proportion of 17.2 %. The most important target and non-target species subject to quotas were angler fish, pollack, European hake, whiting, and common sole.

Data

The ObsMer data are collected by at-sea observers who embark on fishing vessels for the duration of a fishing trip. For a fraction of the fishing operations (FOs), they observe separately the retained and non-retained portions of the catch by identifying, weighing and measuring all species; when the catch is too large, a sample is measured and extrapolated to total catch. For the other FOs, only landings are weighed and counted (Cornou et al., 2016). Data also include information on the characteristics of fishing trips (duration, landing port, etc.) and FOs (gear type, fishing effort, etc.). These data are available over the period 2010-2015 for both métiers (Table 1; Fig. 1).

In addition, lists containing vessel characteristics such as length, identification code, name, and harbor are available for all vessels of each métier and not only those that were observed by the ObsMer programme.

Vessel Monitoring System (VMS) data were available over the same time period. These data include information on the geographical positions, dates, times, speeds and courses of every vessel larger than 12 meters in length (and some vessels less than 12 meters). An algorithm is used to compute fishing times based on vessel speed (e.g. Murawski et al., 2005; Eastwood et al., 2007; Walter et al., 2007; Mullowney and Dawe, 2009): a vessel was considered "fishing" if its average speed between two successive positions did not exceed 4.5 knots. VMS data can be spatially averaged on any grid size.

Fishery statistics are based on logbooks and sales. Masters of fishing vessels in the EU are under the obligation to report their landings and fishing effort in logbooks (Council Regulation (EC) N°1224/2009). These data are submitted by date, gear (mesh/size) and sector (statistical rectangle). Fish auction sales are also recorded, with vessel ID, date of sale, volume and value of landings per species. As there are potential errors within these two data sources (i.e. declarative data), a tool aiming at cross-checking data from different sources (VMS, logbook, sales) has been designed; the most likely estimates for each fishing trip of the total landings and the associated fishing effort per species, gear and statistical rectangle are then provided (Demanèche et al., 2013). These fishery statistics are available over the period 2010-2015.

Table 1: ObsMer data for the sampled number of vessels, fishing trips and days-at-sea for both métiers from 2010 to 2015 (extracted from the ObsMer database). The number in () represents the sampled proportion.

		2010	**2011**	**2012**	**2013**	**2014**	**2015**
TRAWLING	**No. vessels**	35 (21.1 %)	17 (12.3 %)	23 (15.9 %)	21 (13.9 %)	26 (19 %)	25 (17.6 %)
	No. fishing trips	51 (1.7 %)	21 (0.6 %)	29 (0.8 %)	26 (0.6%)	36 (0.9 %)	44 (1 %)
	No. fishing days	642 (2.3%)	263 (0.9 %)	351 (1.1 %)	332 (0.9 %)	422 (1.2 %)	432 (1.1 %)
NETTING	**No. vessels**	10 (18.5 %)	36 (18.1 %)	51 (27.4 %)	33 (12 %)	25 (11 %)	34 (15.5 %)
	No. fishing trips	13 (1 %)	60 (0.7%)	90 (1 %)	54 (0.5 %)	46 (0.5 %)	81 (0.9 %)
	No. fishing days	13 (0.8 %)	61 (0.7 %)	91 (0.9 %)	63 (0.5 %)	50 (0.5%)	84 (0.9 %)

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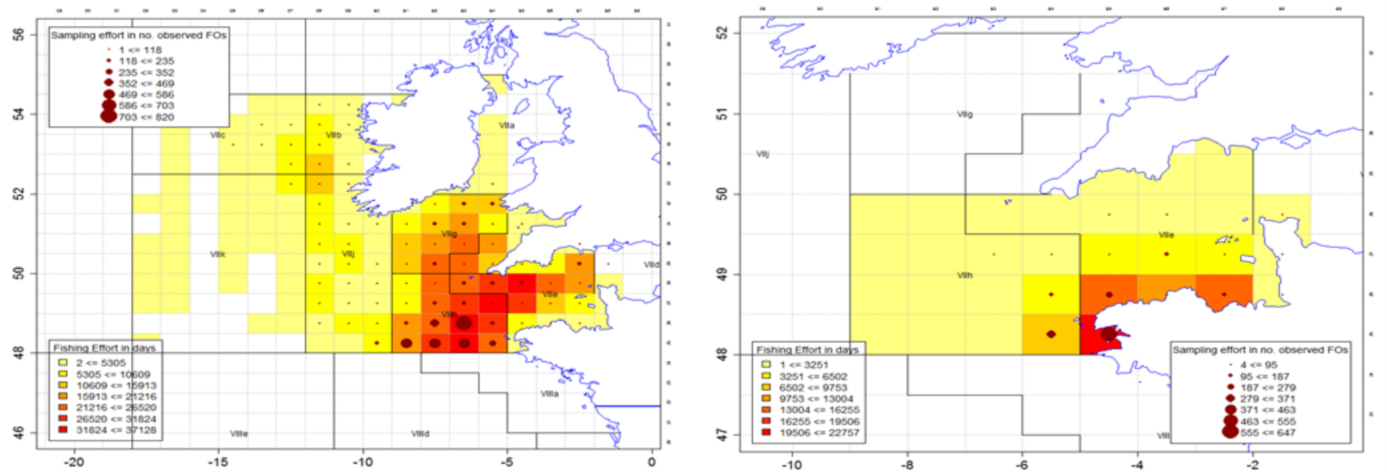

Figure 1: Geographical distribution of the observed FOs (circles) and the métier-related fishing effort (colours) in days-at-sea for the (a) trawling and (b) netting métier from 2010 to 2015 (extracted from the ObsMer database).

First, the ObsMer data were used to build the nested grids. Second, the ObsMer, VMS data and fishery statistics were combined to estimate LPUE and DPUE in each grid cell, and finally to calculate some quality indicators. The next sections explain how the nested grid parameters were determined, how LPUE and DPUE were estimated in each grid cell, and how the resulting maps were assessed.

Nested Grid Method

The nested grid method relies on an iterative process of cell division starting with a regular grid with large cells and ending with a nested grid where each cell of the initial grid has been divided one or several times (Gerritsen et al., 2013). These divisions are related to the number of observations per cell: if a cell has many observations, it is divided many times. A cell is removed if there are too few observations. The end point of the division process is defined by a specified minimum cell size.

The first step to create a nested grid was to select all observed FOs associated with the métier being studied. From the geographical coordinates of these FOs, a division-based procedure was used to build the nested grid. This procedure includes two types of parameters: size and division parameters. The former are the maximum and minimum sizes of the nested grid, which correspond to the regular grid and specified minimum cell sizes. The division parameters, a minimum and maximum thresholds, determine how many times a grid cell is divided according to the number of observations therein. The choice of these parameters aims at maximising the precision of the estimates made in each grid cell in relation to the minimum grid size.

Selection of the FOs

For all the métier-related FOs sampled by the ObsMer programme, the average geographical coordinates were estimated by averaging the initial and final longitudes and latitudes; LPUE and DPUE were derived from the amount of landings and discards and the associated fishing effort (expressed in hours for the trawlers and length of net in kilometers for the netters).

Division-based procedure

A nested grid was constructed as follows: first, an initial grid is built with cells of maximum size including all the métier-related FOs. The initial grid cells containing more FOs than the maximum threshold are divided into two sub-cells and each sub-cell with less FOs than the minimum threshold is deleted. A resulting new grid is obtained with large and intermediate cells. The same process is repeated with this new grid: small cells are obtained after intermediate cell divisions. This process is repeated until the cells derived from cell division reach the minimum cell size. In addition, a cell not divided into two sub-cells (i.e. less FOs than the maximum threshold) and not deleted (i.e. more FOs than the minimum threshold) can be divided into a smaller sub-cell if and only if all points are included in the sub-cell. From the average geographical coordinates of all observed FOs, a nested grid was created for each fishing métier.

Choice of the nested grid parameters

Nested grid sizes

The minimum size parameter of the nested grids was determined to maximize the precision of local (i.e. per cell) LPUE and DPUE estimates. For different minimum cell sizes (1' latitude x 1' longitude, 2.5'x2.5', 5'x5', 7.5'x7.5', 10'x10', and 15'x15'), a minimum number of FOs per cell was calculated to estimate local LPUE and DPUE with a given target precision. To this purpose, regular grids with the different minimum cell sizes were created. For each regular grid, a bootstrap was carried out by replicating 200 times a number of samples ranging from 2 to 50 (by steps of 2) of all observed FOs within each grid cell; provided that there were at least 10 FOs per cell. LPUE and DPUE were calculated in each cell, as well as the associated coefficients of variation (CVs). A model was then fitted to the CVs as a non-linear, decreasing function of sample size: CV ~ f(x) with x = 1/ √ (sample_size – 1). This function was then reversed to estimate a number of FOs to be used to obtain a target CV: Sample size = (slope / (CV - intercept)) ^{2} + 1.

For each regular grid, the minimum numbers of FOs needed to estimate LPUE and DPUE with target precisions of 0.1, 0.2 and 0.3 were determined for all cells. As the results might be over-influenced by outliers, the 3rd quartile of the minimum numbers of FOs was then calculated and used to select the best minimum cell size for each métier. The maximum cell size was defined as 5 times the minimum one.

Division parameters

Building a nested grid involves a minimum and maximum thresholds for the number of FOs per cell. A cell is divided into two sub-cells if and only if the number of FOs exceeds the maximum threshold; and, a cell with a number of FOs less than the minimum threshold is automatically removed from the process. The choice of the maximum threshold reflects a trade-off between precision and spatial resolution (Gerritsen et al., 2013), and is thereby defined as twice the minimum threshold.

To compare the maps of LPUE with DPUE, the division parameters were defined with equivalent minimum/maximum thresholds for both variables. The higher minimum number of FOs needed to estimate either LPUE or DPUE per cell of the specified minimum size, as previously determined, was therefore chosen to be the minimum threshold; the maximum one was twice its value. The following is a method for estimating local LPUE and DPUE within the nested grid.

Method for mapping LPUE and DPUE

To map LPUE and DPUE, the total amount of landings and discards, fishing time and length of nets were estimated over the whole study area for each métier and for each one of the most important target and non-target species subject to quota. Next, they were distributed proportionally in each cell of the nested grid based on local estimated values obtained from the observed FOs.

Estimating the total amount of landings and discards, fishing time and length of nets

Total fishing time (in hours) for the trawling métier was calculated from the fisheries statistics and total length of nets (in kilometers) for the netting métier was extrapolated from the observed FOs using "days-at-sea" as raising variable (Cornou et al., 2016). Total landings (in tonnes) per métier x species were calculated from the fisheries statistics, while total discards (in tonnes) were estimated using discarded proportions (Cornou et al., 2016):

$$Total\ Discards_{spp} = \frac{Discarded\ Proportion_{spp}\ \times\ Total\ Landings_{spp}}{1\ -\ Discarded\ Proportion_{spp}}$$

This method cannot be used when the whole catch of a given species is discarded because it results in a discarded proportion of 1. So, in those cases, total catch of all species (in tonnes) was extrapolated from the ObsMer data using "days-at-sea" as raising variable (Cornou et al., 2016). The proportion of the discarded species in the catch was determined from the species composition. Both variables were then combined to estimate the total catch of the discarded species over the whole study area:

$$Total\ Catch_{spp} = Total\ Catch_{Allspp}\ \times Catch\ Proportion_{spp}$$

As the discarded proportion was calculated from the ObsMer data, a discarded proportion of 1 did not mean there was no landings for the given species in the whole study area. Consequently, the total amount of discards for the species was estimated by subtracting the total amount of landings (calculated from the fishery statistics) from the total catch of the discarded species.

Distribution of the total estimates into the nested grid cells

From the ObsMer data, the observed landings and discards, fishing times and lengths of nets in each cell of the nested grid were estimated. By dividing the local observed values in each cell by the sum of all local observed values of the grid, the local proportion of each variables were estimated. The previously estimated total landings and discards, fishing times and lengths of nets were then distributed into the nested grid according to the local proportion in each cell. Finally, LPUE and DPUE were calculated as the ratio of the local landings and discards, and local fishing effort (fishing time or length of nets).

From the nested grid sizes to the specified minimum cell sizes

To better visualize the distribution of LPUE and DPUE within the nested grid, the local estimates were re-calculated on a regular grid with only cells of the specified minimum size. For example, an intermediate grid cell containing 8 specified minimum cells had its local estimates divided by 8. However, some minimum cells were intersected by the sea-shore borders causing the estimates made in the cells partly unreadable.

To illustrate the nested grid method can be applied for mono- or multispecific fisheries, haddock was examined individually for the trawling métier while angler fish, pollack, European hake, whiting, and common sole were studied as a group of species for the netting métier.

Quality indicators for the maps and estimates

The resulting maps were assessed using five quality indicators: two indices of the representativeness of the ObsMer sample, one index of the randomness of the distribution of FOs within each cell, and two indices of the similarity of the estimates.

Are the ObsMer samples representative of the actual fishing activity?

The ObsMer samples used to create the nested grids and to estimate LPUE and DPUE for each fishing métier should be representative of the actual fishing activity: is the distribution of the sampled FOs representative of the main métier fishing areas? As the nested grid reflected the distribution of the FOs, two grid-related indices were used: one for the fishing effort and one for the landings. The former index is the percentage of total fishing effort (estimated in hours from VMS data) included in the nested grid:

$$Coverage\ index\ (Effort) = \frac{Total\ Fishing\ Effort_{Nested\ grid}}{Total\ Fishing\ Effort_{VMS}}$$

The landings index is the percentage of total landings, estimated from cross-checking logbooks (i.e. declarative landings) and VMS data, included in the nested grid. For the trawling métier, only haddock landings were investigated:

$$Coverage\ index\ (Landings) = \frac{Total\ Landings_{Nested\ grid}}{Total\ Landings_{VMS}}$$

The landings index cannot be estimated for the netting métier. As fishing effort is more difficult to quantify using VMS data than it is for the trawling métier (Lee et al., 2010), it makes it impossible to cross-check logbooks and VMS data. The index was thus calculated as the percentage of total declarative landings (on a statistical rectangle scale) included in the nested grid.

Are the FOs homogeneously distributed in the nested grid cells?

As the nested grid method averages all FOs together in a cell, it requires that the FOs are homogeneously distributed with limited spatial patterns within each cell of the nested grid. Gerritsen et al. (2013) tested this hypothesis by comparing the mean distance $(\overline{r_A})$ of each point in the cell to its nearest neighbor with the expected mean nearest neighbor distance $(\overline{r_E})$ for randomly distributed points where:

$$\overline{r_E} = \frac{1}{2\sqrt{\rho}}$$

where ρ is the density of points (*Clark and Evan, 1954*). The ratio of the observed ($\overline{r_A}$) and expected ($\overline{r_E}$) mean distance was therefore expected to be 1 for randomly distributed points. A ratio of 0 indicated that the points were all in the same place. A ratio larger than 1 indicated that the points were more regularly distributed than expected.

How are the estimates of LPUE and DPUE compared to other estimates?

To evaluate the precision of the estimates of LPUE and DPUE, they were compared with other estimates produced by geostatistics. This method has proven useful for estimating discards per unit of effort (e.g. Viana et al.,2010). But each map requires specific geostatistical model and validation. The question was: does the easily automatable, and not computationally intensive (Gerritsen et al., 2013), nested grid method give results similar to geostatistics?

The purpose of geostatistics is to model the spatial variability of a given variable and then utilise the model to estimate the value of the variable at given locations (Matheron, 1971; Petitgas, 2001). First, an exploratory data analysis orientates the model choice. The model is finally selected using semi-variograms and cross-validations. The former are used to study the relationship between points as a function of the distance (i.e. spatial variability). This provides the mean squared value of the difference between two points separated by a distance h (Chilès and Delfiner, 1999):

$$\hat{\gamma}(h) = \frac{1}{2N_h} \sum_{x_\beta - x_\alpha \approx h} \left[z(x_\beta) - z(x_\alpha)\right]^2$$

Where N_h is the count of pairs of points separated (approximately) by the lag *h*. $z(x_\beta)$ and $z(x_\alpha)$ are known values of the variable z(x), separated by the lag *h*. A theoretical model is then fitted to the semi-variogram. Supported by cross-validations, this model is validated and it best describes the structure of the underlying stochastic process which generated the data. Finally, interpolation algorithms estimate the value at a given location as a weighted sum of data values at the surrounding locations (*Cressie, 1993*):

$$Z(s) = \mu(s) + \delta(s)$$

Where Z(s) is the random process of the variable of interest; $\delta(s)$ is the random stationary function partly defined by the previous model; $\mu(s)$ is the deterministic mean structure, also called large-scale variation, and supposed unknown (i.e. ordinary kriging). For further details on the method, see Matheron (1965, 1971) and Chilès and Delfiner (1999). Predictions of Z(s) and kriging variances were estimated in each cell of the nested grids.

To assess the similarity between the two sets of estimates, the geostatistical estimates were compared to the 95 % confidence interval of the nested grid ones in each grid cell. The 95 % confidence interval were obtained using a bootstrap method. A difference larger than 1 indicated that the geostatistical estimate was outside the 95 % confidence interval, and the methods provided significantly different results.

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In addition, an overall comparison of the two sets of estimates was also carried out in the nested grid using the Spearman rank correlation coefficient (*Conover, 1971*). The null-hypothesis (H_0) was "both methods provided independent results", while the alternative hypothesis (H_1) was "there is a tendency for the larger values of the nested grid and geostatistical estimates to be paired together (i.e. positive correlation)". First, the ρ-value and degrees of freedom were calculated as follows:

$$\rho = 1 - \frac{6[R(X_i) - R(Y_i)]^2}{n(n^2 - 1)}$$

where $R(X_i)$ is the rank of X_i, $R(Y_i)$ is the rank of Y_i, n is the sample size; with n-1 degrees of freedom. This coefficient varies from -1 (i.e. negative correlation) to +1 (i.e. positive correlation). A value of 0 indicated no correlation between the two set of estimates. To test the statistical significance of the ρ-value, a w-value was determined from the quantiles of the spearman test statistic. If w-value was below a significance level of 5%, H_0 was rejected in favor of H_1.

Results

<u>Nested Grid Method</u>

The 7,619 FOs related to the trawling métier are mainly distributed in the eastern Celtic Sea and West of Ireland (Fig. 1a); the 2,008 netting métier-related FOs are mainly distributed near the French coast in the western English Channel and West of Brittany (Fig. 1b).

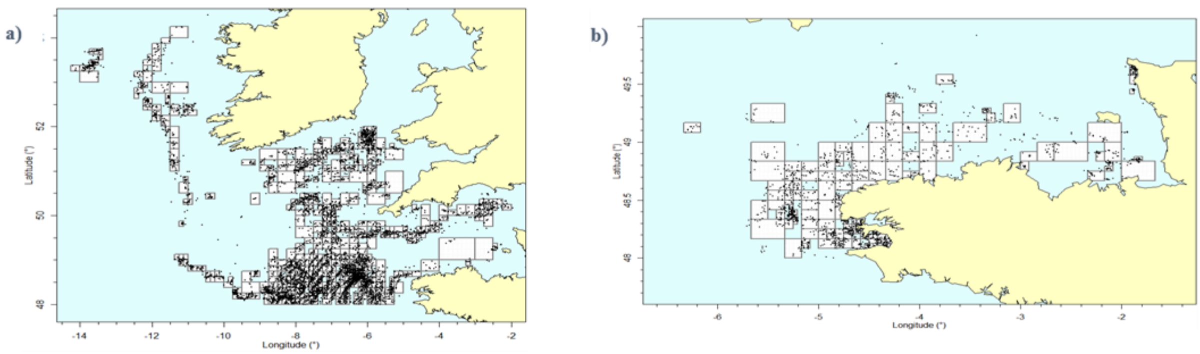

Figure 1: ObsMer data points (dots) and the associated nested grid (rectangles) for the (a) trawling and (b) netting métiers. No. FOs outside the nested grids: 471 FOs for the trawling métier and 288 FOs for the netting métier.

The average CV of the mean LPUE and DPUE decreased as a non-linear, decreasing function of sample size per cell (Fig. 2): they were relatively high for small samples, and low for large ones. The average CV of the mean LPUE was also usually lower than for DPUE at equivalent sample sizes. This occurred because of a potentially higher variability in the discard data.

The minimum sample size, or minimum number of FOs, needed to estimate LPUE and DPUE with a target precision was estimated for the different cell sizes using the reversed function (Table 2). Target precisions of 0.1 and 0.2 required too many FOs per cell regardless of the size of the cells or the fishing métiers. The reference precision was therefore set to 0.3. When considering the average number of observed FOs per grid cell and the number of cells for each grid size, the 7.5' x

7.5' minimum cell size was selected for the nested grid used for the trawling métier (Table 2). The maximum grid size was therefore 60' longitude by 30' latitude; and, the minimum and maximum thresholds were 5 and 10 FOs respectively. For the netting métier, the 2.5' x 2.5' minimum cell size was chosen (Table 2). The maximum grid size was therefore 20' longitude by 10' latitude for the netting métier. The minimum threshold was 8 FOs, with thereby a maximum threshold of 16 FOs.

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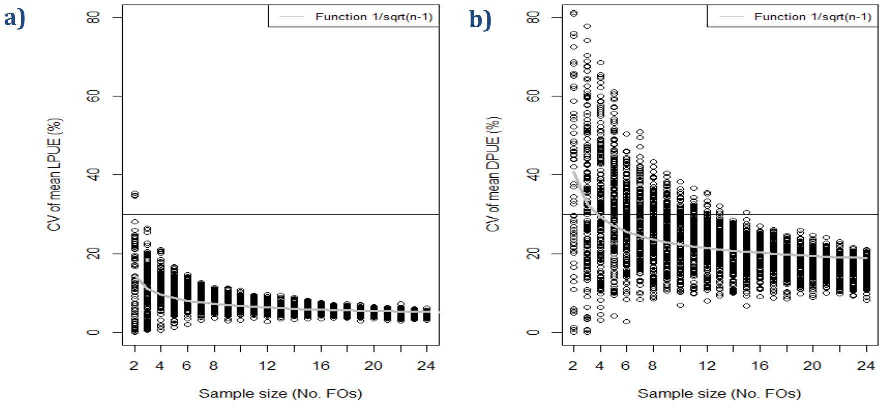

Figure 2: Coefficients of variation (CV) of the mean (a) LPUE and (b) DPUE for sample size (n) varying from 2 to over 24 FOs (circles). The grey curve displays the fitting function in f(n) = 1 / √ (n -1). The horizontal line displays the CV of 30 %. These results are obtained from one random cell for the trawling metier.

Table 2: Minimum number of FOs needed to estimate LPUE and (DPUE) per cell with a CV of 0.1, 0.2 and 0.3 for different cell sizes for the two fishing métiers. No. FOs: average number of observed FOs per grid cell. No. cells: number of cells with a sufficient number of observed FOs (> 10) to carry out the bootstrap.

	ll sizes	CV0.1	CV0.2	CV0.3	No. FOs	No. cells
TRAWLING	1'x 1'	-	-	-	-	0
	.5'x 2.5'	-	-	-	-	0
	5'x 5'	21.5 (2287.5)	.75 (37.25)	2 (5.75)	11.6	10
	.5'x 7.5'	37 (325)	5 (19)	3 (5)	13.6	33
	10'x 10'	23 (403)	4 (14)	2.75 (5)	15.4	50
	15'x 15'	30 (497)	4 (16)	3 (5)	18.8	74
NETTING	1'x 1'	149.5 (225.5)	2.5 (33.75)	5 (7)	13	4
	.5'x 2.5'	139.75 (1117)	21.75 (43)	5.75 (8)	15	27
	5'x 5'	399.5 (1111)	18.5 (31.5)	5.5 (8.5)	24	29
	.5'x 7.5'	515.25 (608)	15.75 (34)	.75 (9.75)	26	34
	10'x 10'	189.2 (1035)	19.25 (31)	8 (9)	27.2	40
	15'x 15'	256 (2715)	19 (43.75)	6 (9)	37.3	33

The resulting nested grid created for the trawling métier comprised 555 cells in total (Fig. 1a), where around 75 % grid cells were 7.5' x 7.5' in size (Table 3). The intermediate cells contained 6 to 7.7 FOs on average, while there were 14.6 FOs per 7.5' x 7.5' cell. For the netting métier, 136 cells composed the nested grid (Fig. 1b), and around 32 % grid cells were 2.5' x 2.5' in size (Table 2). The intermediate cells contained 10.8 to 12 FOs on average, while there was 15.3 FOs per 2.5' x 2.5' cell.

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Table 3: Summary statistics for the cell in the final nested grid designed for each fishing métier.

	Cell sizes	No. cells	Average No. FOs per cell
TRAWLING	60' x 30'	1	6
	30' x 30'	2	7.5
	30' x 15'	13	7.7
	15' x 15'	32	7.3
	15' x 7.5'	82	7.1
	7.5' x 7.5'	425	14.6
NETTING	20' x 10'	9	11.3
	10' x 10'	22	11.7
	10' x 5'	27	10.8
	5' x 5'	20	11.4
	5' x 2.5'	15	12
	2.5' x 2.5'	43	15.3

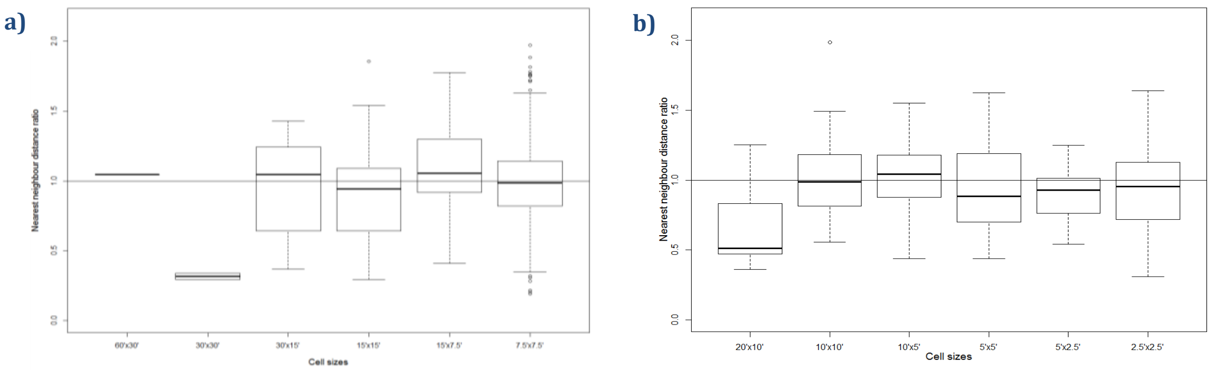

Figure 3: Nearest neighbour distance ratio for a) the trawling métier with cells from 60' x 30' to 7.5' x 7.5' in size and for b) the netting métier with cells from 20' x 10' to 2.5' x 2.5' in size. The horizontal line indicates a random uniform distribution.

Mapping the LPUE and DPUE estimates

Haddock landings and discards produced by the trawling métier from 2010 to 2015 were respectively 23 kg.h^{-1} and 6.2 kg.h^{-1} on average (Fig. 4). The main fishing areas in terms of LPUE were located in the region extending from the mid- to the northern part of the Celtic Sea (from 25 to 257 kg.h^{-1}) and off the west coast of Ireland (25-231 kg.h^{-1}; Fig. 4a). The former area was also associated with high discards: 23 to 194 kg.h^{-1} in the northern part of the Celtic Sea and 23 to 67 kg.h^{-1} in the mid-Celtic Sea (Fig. 4c). On the contrary, the region off the west coast of Ireland was associated with low discards (less than 23 kg.h^{-1}). Both the geostatistical and nested grid methods provided similar results for LPUE (Fig.5b) and DPUE (Fig.5d) in each grid cell. In addition, highly positive correlations were found between the two sets of estimates for both LPUE and DPUE: 0.97 and 0.82, respectively (w-values $<10^{-16}$).

From 2010 to 2015, all fishing vessels which practiced the netting métier landed on average 18.5 kg.km^{-1} and discarded 1.7 kg.km^{-1}(Fig. 5). For the LPUE (Fig. 5a), four main fishing areas were identified: two isolated areas in the eastern region of the western English Channel (24-71 kg.km-

DiscardLess

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^{1}), further offshore in the northern part of Brittany (24-227 kg.km^{-1}), and in a wider area off the west coast of Brittany (8-71 kg.km^{-1}). The two fishing areas near the northeast and off the west coast of Brittany were also associated with DPUE (Fig. 5c): 4-9 kg.km^{-1} and 4-7 kg.km^{-1}, respectively. Although few isolated areas showed high differences between the nested grid and geostatistical LPUE estimates (209 to 227 kg.km^{-1}), both methods provided very similar results in most of the nested grid cells (Fig. 4b), as for DPUE (Fig. 4d). H_1 was also accepted for both LPUE and DPUE (w-values <10^{-16}) with ρ-values of 0.73 and 0.77, respectively.

Considering the spatio-temporal reallocation strategies, the estimated discards of haddock were mainly located in areas with high landings (Fig. 4a-c), except in some cases. In the mid-Celtic sea, for example, one area (longitude 6.75-6.375 E and latitude 49.5-49.875 N) was characterised by low LPUE (<25 kg.h^{-1}) and high DPUE (23-67 kg.h^{-1}) while another area located nearby (from -6.375° to -6 ° longitude and from 49.5° to 49.875° latitude) had high LPUE (25-231 kg.h^{-1}) and low DPUE (< 23 kg.h^{-1}). These maps suggested that reallocating fishing effort from the former area to the latter would likely reduce the amount of discards and even increase the amount of commercial catches. On the contrary, the map of DPUE of the 5 most important target and non-target species subject to quota (Fig. 5c) revealed that the main discard areas were associated with high landings (Fig. 5c), and so limited the scope of reallocation strategies in space.

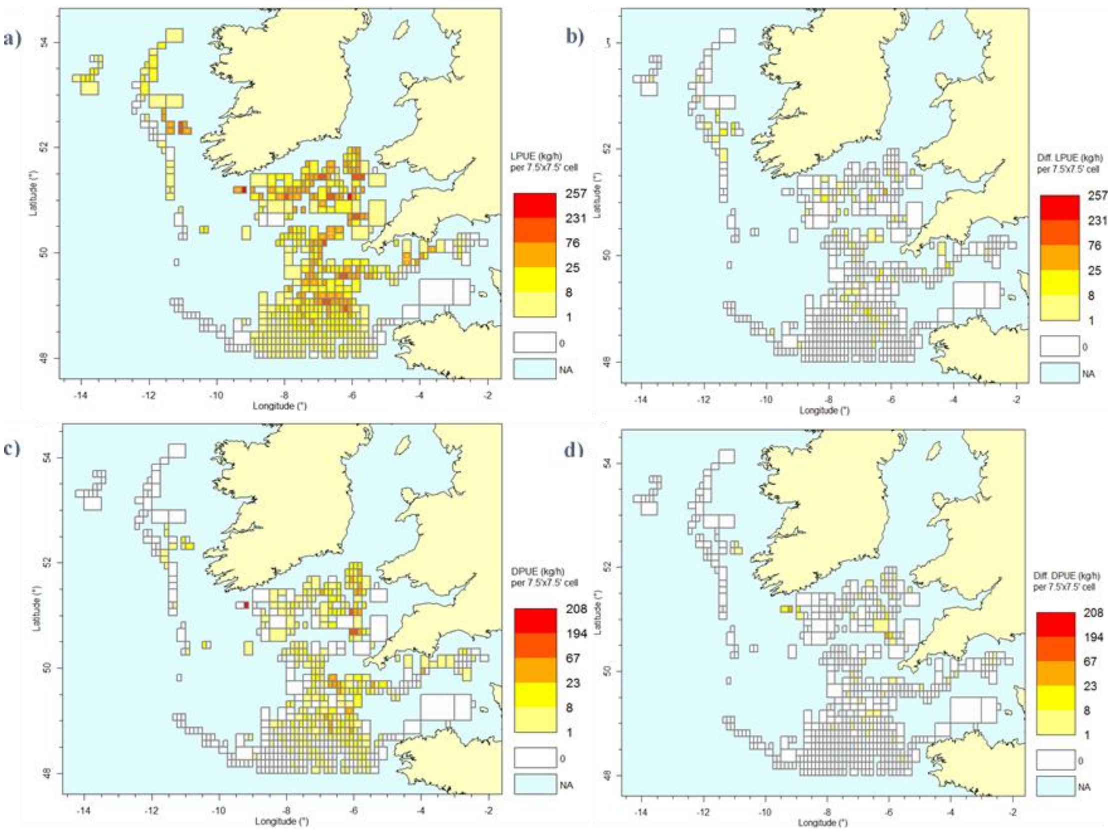

Figure 4: Map of the (a) LPUE and (c) DPUE of haddock (kg.h^{-1}) between 2010 and 2015 for the trawling métier. Mean LPUE = 23 kg.h^{-1}; Mean DPUE = 6.2 kg.h^{-1}. No. FOs = 7,619. No. fishing trips (FT) = 212. Size of the observed vessels = 18 - 42 m. Panels (b) and (d) show the differences

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between the geostatistical results and the 95 % confidence interval limits of the nested grid estimates. A 0 value indicates that the geostatistical result lies within the confidence interval.

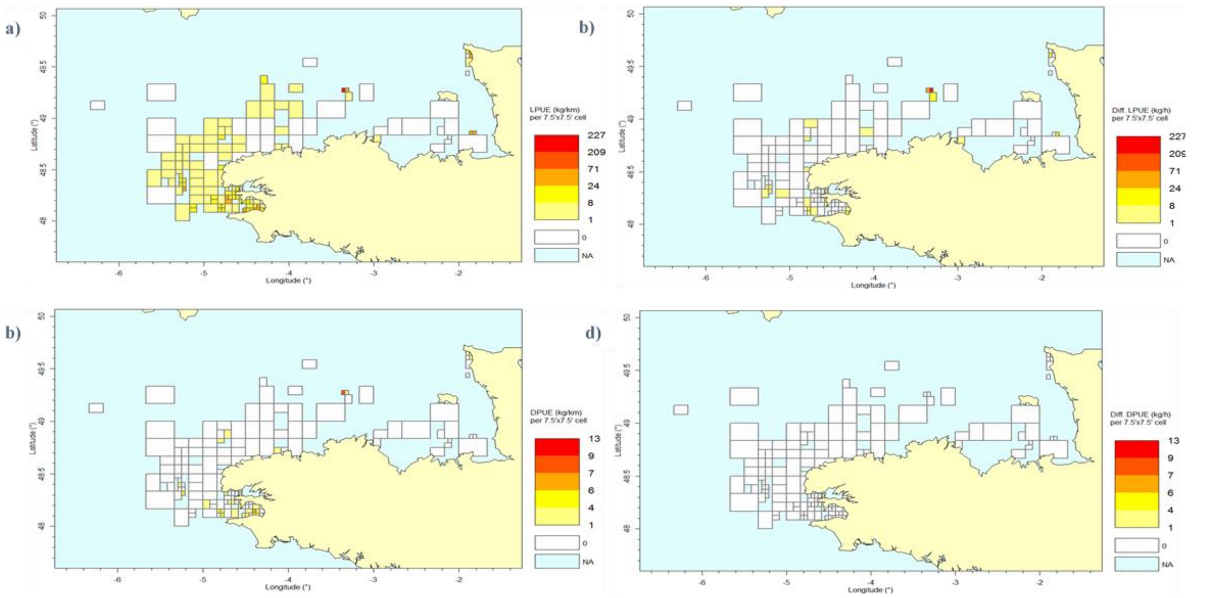

Figure 5: Map of the (a) LPUE and (c) DPUE of the 5 most important target and non-target species subject to quotas (kg.km^{-1}) between 2010 and 2015 for the netting métier. Mean LPUE = 18.5 kg.km^{-1}; Mean DPUE = 1.7 kg.km^{-1}. No. FOs = 2,008. No. fishing trips = 587. Size of the observed vessels = 5 - 15 m. Panels (b) and (d) show the differences between the geostatistical results and the 95 % confidence interval limits of the nested grid estimates. A 0 value indicates that the geostatistical result lies within the confidence interval.

DISCUSSION

The nested grid created for the trawling métier comprised 555 cells with different sizes; 75 % cells were 7.5' x 7.5' in size (Table 3). The average number of FOs per cell varied from 7 to 15 depending on the size of the cells. This nested grid was assessed: the ObsMer sample was representative of the métier-related fishing activity and the distribution of the points in grid cells was homogeneous. Furthermore, the nested grid estimates were similar to the geostatistical ones. Based on the resulting maps (Fig. 4), one spatial reallocation strategy was identified to reduce and avoid excessive discarding of haddock in the mid-Celtic sea.

For the netting métier, the nested grid was characterized by a smaller number of cells (136) with smaller sizes (32 % cells were 2.5' x 2.5' in size) and greater average numbers of FOs per cell (10-16). The indices of the representativeness of the ObsMer sample were unreliable, but the distribution of the points in each grid cell was mainly homogeneous. The nested grid estimates were similar to the geostatistical ones. Based on the resulting maps (Fig. 5), no spatial reallocation strategies were found. The ObsMer sample may not be representative of the actual fishing activity, as for the nested grid, and so the spatial reallocation strategies were misidentified. Or there may not be practical spatial reallocation strategies. This is explained in the following sections.

Nested grid parameters

Gerristen et al. (2013) established that the size of the cells has no influence on the precision of the estimate in each cell. It is rather the number of observations per cell. The minimum cell size for a given métier is thus selected based on the minimum number of observations per cell (i.e. minimum thresholds) estimated for different minimum cell sizes. The maximum cell size and threshold are then estimated based on the respective minimum ones. So the grid size parameters depend on the grid division parameters, which in turn depend on the density of observations per cell and variability. If the density of observations per cell is low, the number of cells with enough observations to carry out the bootstrap is low or null, and makes it impossible to estimate a minimum number of observations per cell. For example, there is no information on the 1' x 1' and 2.5' x 2.5' regular grids for the trawling métier (Table 2). This métier has a lower density of observations compared to the netting one: 7,619 FOs located in the Celtic Sea against 2,008 FOs located in the Western English Channel. Second, the higher the variability in the observations per cell, the higher the minimum number of observations to estimate LPUE and DPUE with a precision of 0.3. For example, the trawling métier requires a smaller number of observations per cell compared to the netting one. As the netting métier encompasses five sub-métiers (gill or trammel nets targeting either demersal fish species, cephalopod or crustaceans) compared to the two trawling sub-métiers (single or twin-rig otter trawls targeting demersal fish species), there is probably more variability within the data associated to the former. In addition, as discards are commonly associated with many factors of variability (*Rochet and Trenkel, 2003*), it may also explains that DPUE must be estimated with a larger number of observations per cell compared to LPUE. Lastly, the nested grid method also implies a loss of data. Each cell with a number of FOs less than the minimum threshold is deleted and the associated FOs are lost: 471 and 288 FOs are respectively not taken into account by the nested grids for the trawling and netting métier (Fig. 1); but these FOs only account for a small proportion of all available FOs (6% and 14 %, respectively). In fact, the proportion of lost data depends on the minimum number of observations to estimate LPUE and DPUE with a precision of 0.3: the higher the minimum number of observations, the higher the loss of data.

The amount of fishing data available also plays a key role in the nested grid precision. The trawling métier for which there are many data is described by a nested grid composed of 75 % cells of the minimum size against 32 % for the netting métier.

Nested grids

The two métier-related nested grids are in close agreement with *Gerritsen et al.* (2013): fishing areas with the highest number of observed FOs are represented by the highest spatial resolution of the grid, and vice versa.

In the case of determining the nested grid coverages of total fishing effort and landings, the findings suggest that the ObsMer sample for the trawling métier is representative of the actual fishing activity. The nested grid coverage indices do not display perfect scores (66 % and 72 %) because of the low proportion of fishing trips sampled from 2010 to 2015 (Table 1) and a low sampling effort in ICES Division 27.7.e (Fig. 1a) where no fishing trip was observed from 2011 to 2013 (*Cornou et al., 2013*). As a result, part of the data on trawling activities are not accounted for by the nested grid, especially for haddock which is one the main target species in ICES Division 27.7.e (*Cornou et al., 2016*).

For the netting métier, the nested grid evaluation is inconclusive for two main reasons: (1) it is characterised by small vessels (11 meters on average), for which VMS data are partially absent. These data are available used on-board vessels less than 12 meter, explaining the poor coverage index of total fishing effort (40 %). (2) VMS data associated to static fishing gears (e.g. nets) are problematic as fishing effort depends on the size, type, and soak time of nets (*Lee et al., 2009*). Total fishing effort calculated for the netting métier is therefore biased, as for the associated total landings which have to be estimated on a statistical rectangle scale (see "Materials and methods"). Accordingly, the nested grid coverage indices are limited for fishing métiers carried out by small vessels (< 12 meters) using static fishing gear.

LPUE and DPUE estimates

The nested grid estimates of haddock LPUE and DPUE are found similar to the estimates made by geostatistics on a local and global scales. The spatial patterns of landings and discards are also consistent with *Anon* (2011): high landings in the Celtic Sea and west of Ireland, and high discards in the Celtic Sea. In the west of Ireland (Fig. 4), a lower discarding level is found compared to *Anon* (2011) which may be an artefact of the low fishing effort exerted by the trawling métier in the area. The estimates for angler fish, pollack, European hake, whiting, and common sole are also similar to the geostatistical estimates on a local and global scales. These similarities provide reliance on the nested grid method to map landings and discards for specific fishing métier.

Spatio-temporal reallocation strategies

Fishers practicing the trawling métier could benefit from the spatial reallocation strategy identified in the mid-Celtic sea. Under the Landing Obligation (LO), they are likely to reduce the amount of discarded haddock which otherwise requires time (e.g. sorting time) and room (e.g. in the storage room) to be landed. Haddock is individually examined as an example for mono-specific fisheries whereas the trawling métier is part of a multi-specific fishery. Spatial reallocation strategies are thus more complex when more than one fish species is involved. In this case, it includes whiting, European hake, cod, megrim, boarfish, anglerfish, cuckoo ray, pollack and common cuttlefish.

For the netting métier, no spatial reallocation strategies is found: adapting fishing effort in space do not significantly reduce the discards of anglerfish, pollack, European hake, whiting and common sole. Nonetheless, this métier is seasonal with high variability of discarded quantities and fractions according to the fishing zone and season (e.g. *Cornou et al., 2016*). Further analysis should therefore investigate temporal and/or spatio-temporal reallocation strategies: by exploring LPUE and DPUE on a fishing seasonal scale.

Advantages and issues of the nested grid method

The nested grid method requires to specify size and division parameters for each fishing métier, improving the quality and precision of the maps. The nested grids are created based on the characteristics of the métier-related data, especially the density and variability. A fishing métier associated to many observed data with high density and low variability is likely to produce a precise nested grid with small cells, low numbers of points per cell and low loss of data.

Furthermore, the advantages of using an active gear against a passive one are two-folds: (1) fishing effort, in hour, is easily calculated from the fisheries statistics. It is otherwise estimated using an auxiliary variable (e.g. days-at-sea). (2) VMS data allow for the precise calculation of coverage indices unlike the passive gears, for which they are unreliable.

Maps of landings and discards with 7.5' x 7.5' (≈150 km^2) or 2.5' x 2.5' (≈50 km^2) grid sizes will not identify spatial reallocation strategies on small scales, also because all points in a cell are average. But they will obviously provide a useful and simple tool for fishers to adapt their fishing effort on medium-large scales. Moreover, the method is easy to implement and is not particularly computationally intensive. Management measures (e.g. gear selectivity, area and seasonal closures, etc.), information on stock abundance or on factor influencing discards could therefore be easily incorporated in the analysis.

A potential application of this study would be to create an atlas of landings and discards for each métier observed by the ObsMer program. This atlas would help fishers to explore spatio-temporal reallocation strategies for their fishing métiers. A more systematic use of the nested grid method is therefore imperative with, for example, specific quality thresholds for accepting or rejecting resulting maps: a map is accepted if it meets all the criteria.

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Chapter 10. Inferring the annual, seasonal, and spatial distributions of marine species from complementary research and commercial vessels' catch rates

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English Channel case study

Bourdaud, P., M. Travers-Trolet, et al. (2017). Inferring the annual, seasonal, and spatial distributions of marine species from complementary research and commercial vessels' catch rates. ICES Journal of Marine Science 74(9): 2415–2426.

Introduction

Ecosystem-Based Fisheries Management (EBFM) requires enhancing knowledge of ecosystem functioning, therefore allowing forecasting the impact of fisheries on salient ecosystem components (Long et al., 2015) and to design future management plans and tools including Marine Protected Areas (Meyer et al., 2007) or fishing closures (Hunter et al., 2006). This necessitates a stepwise approach, the first tier of which, and one of the most important, is to gain fine scale knowledge on the seasonal and geographic distribution of marine organisms, in general, and fish stocks in particular (Booth, 2000).

Scientific surveys have been implemented for decades to derive spatially- and yearly-resolved abundance indices of commercial fish and shellfish species (e.g. van Keeken et al., 2007). Surveys provide abundance indices, derived from standardized and controlled protocols, which allow for a wide spatial coverage associated with a weak selectivity (Verdoit et al., 2003). Survey data, however, are costly to obtain and therefore rarely provide for adequate seasonal coverage of the resource distribution. In contrast, information derived from commercial fisheries are generally available all year through. Consequently, the catch per unit of effort (CPUE), the most common and easily collected fishery-dependent index of abundance (Maunder and Punt, 2004), has the potential to reflect fish distributions. However, commercial CPUEs can generally not be used directly as abundance indicators. This is because fishers target rather than sample fish densities, and continuously adapt their activities to prevailing conditions, through technological development and tactical adaptations (Marchal 50 et al., 2006), including discarding practices on which information is often limited (Rijnsdorp et al., 2007).

A major challenge for fisheries scientists is then to reconcile fisheries-independent and -dependent information into abundance indices that consistently mirror the annual, seasonal and spatial dynamics of commercial marine species. Kristensen et al. (2014) have reconstructed spatial and seasonal cohorts of cod (Gadus morhua) in Skagerrak by kriging, in both time and space, data provided by survey and also by fisheries subject to a survey-like sampling protocol. To our best knowledge, however, no method has yet been developed to estimate spatio-temporal distributions of fish at high resolution, by combining survey and true commercial fisheries data.

The main objective of this paper is to provide detailed annual, seasonal and spatial distributions of major Eastern English Channel (EEC) commercial fisheries resources, using a novel approach combining fisheries-independent and -dependent information. The gain in knowledge on fine scale temporal and spatial fish distribution in the EEC will expand the scope of earlier results (e.g. Vaz et al., 2007), and strengthen the science support to an EBFM in this area. To that purpose, we (i) inferred the seasonal and spatial abundance distribution based on survey and commercial abundance data for several species in the EEC, (ii) investigated the degree of similarity of fine scale spatial distributions derived from these two data sources and (iii) investigated abundance indices derived from these data sources.

Material and methods

Study area

The Eastern English Channel (ICES subdivision VIId) is delimited by latitudes 49.3°N and 51°N and longitudes 2°W and 2°E (Figure 1). This shallow area constitutes a corridor between the northeast Atlantic Ocean and the North Sea, and a strategic region in the northeast Atlantic, as it hosts a very intense maritime traffic and human activities such as mixed fisheries, aggregate extraction and wind farms (Dauvin, 2012). This area is also important for several commercially important migratory species, e.g. red mullet (*Mullus surmuletus*) (Mahé et al., 2005), cuttlefish (*Sepia officinalis*) (Royer et al., 2006), mackerel (*Scomber scombrus*) (Eltink et al., 1986), herring (*Clupea harengus*) (ICES, 2015), or European seabass (*Dicentrarchus labrax*) (Pawson et al., 2007).

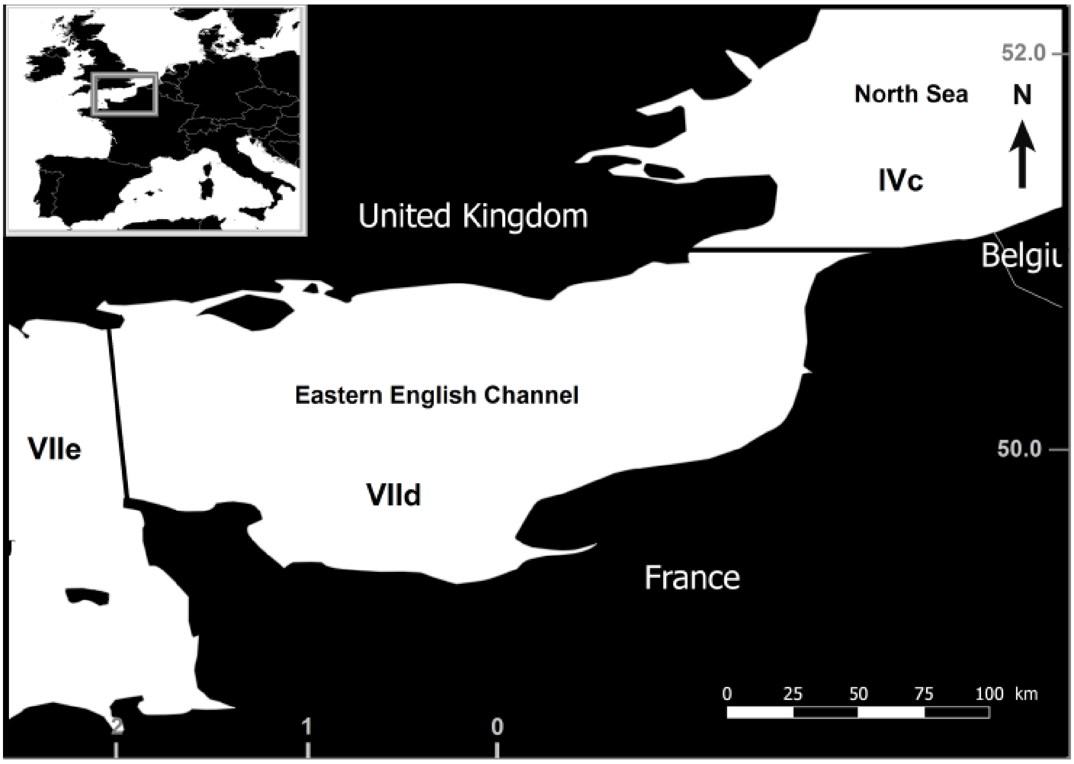

Figure 1. Study area of the Eastern English Channel, corresponding to the ICES division VIId.

Fishing is a key socio-economic activity in the region (Carpentier et al., 2009), which has also generated a strong pressure on its marine ecosystem (Molfese, 2014).

Data

This study is supported by two main data sources: a scientific survey (the Channel Ground Fish Survey – CGFS; Coppin and Travers-Trolet, 1989) and observations on-board commercial vessels (hereby referred to as the OBSMER French programme; Cornou et al., 87 2015).

The CGFS has sampled the entire EEC demersal community annually since 1988. The survey occurs every year in October, with a systematic fixed sampling design of 88 trawling stations located between 49.3°N and 51.3°N. The sampling gear is a GOV trawl with 3 m vertical opening, 10 m horizontal opening and a 20 mm codend. For each haul, all fish caught are sorted, identified and measured to the nearest inferior centimetre. In case of large catch, random subsampling is performed while ensuring representativeness of species and length distributions. For the current study only survey data from 1998 to 2014 were retained as this period corresponds to a relatively stable state of the community structure with no detected regime shift in species spatial distributions (Auber et al., 2015).

The CGFS provides information for a large panel of economically valuable demersal fishes and cephalopods, i.e. European seabass, red mullet, cod, whiting (*Merlangius merlangus*), plaice (*Pleuronectes platessa*), cuttlefish, squids (*Loligo* spp.) and thornback ray (*Raja clavata*). Other commercially important species such as common sole (*Solea solea*), herring or sardine (*Sardina pilchardus*), are poorly sampled by the GOV trawl (Carpentier et al., 2009), and thus have not been considered in this study.

On-board observer programmes allow estimating catch and effort for a sample of fishing operations. Unlike other fisheries data collection programmes, e.g. building on port sampling and/or mandatory logbooks, observer's data are precisely geo-referenced and allow inferring the total catch, including the discarded fraction, and more accurate measurements of effective fishing effort. Although on-board fisheries data can generally not be collected for all the vessels belonging to a given fleet, and although the presence of observers may be perceived as overly intrusive to fishers, they offer an opportunity to derive CPUE-based abundance indicators, at a fine spatial and temporal scale.

The OBSMER programme covers the period 2003-2015. It was developed to better estimate the discard quantity and assess catch composition. Precise information on ship characteristics (e.g. homeport, length, and engine power), fishing activity (time, latitude, longitude, gear, fishing effort, and targeted species assemblage) and catch composition (landings and discards of fish and commercial invertebrates) are collected for each fishing operation by scientific observers. For each fishing operation, a subsample of the catch (including both the part to be landed and the part to be discarded) is sorted, identified and measured. This data compilation has already been operated to characterize pressures exerted on communities, discarded fractions of catches, or discarding drivers (Fauconnet et al., 2015).

Spatio-temporal species distributions estimated using OBSMER data are primarily expected to corroborate previous knowledge on these species life cycles. In addition, they could reflect species distributions as observed using scientific surveys (considered as a reference) in converging time lapse. However, because species spatial distributions are dynamic and vary from one time step to another, and because fishers continuously adapt to prevailing conditions (Eigaard et al., 2014), time and spatial variations in CPUE reflect two entangled signals prompted by fisher's plasticity and stock fluctuations. Using CPUEs to reflect time changes in stock abundance therefore requires to preliminarily filter out the skipper effect signal it originally contains (Maunder and Punt, 2004).

Standardizing survey and commercial catch rates

Surveys and commercial fisheries operate at different temporal and spatial scales, with different gears and strategies, thereby targeting dissimilar species assemblages and/or size ranges. The first step of this study was to identify common temporal and spatial scales, then to select a common pool of representative species and size ranges, and finally to standardize survey and commercial catchabilities using a delta- Generalized Linear Model (GLM) approach.

The temporal scale retained is the month, while the spatial scale considered is cells of 0.3° x 0.3° (~ 700 km^2). These seasonal and spatial scales result from a trade-off between having a sufficient amount of data and maintaining a sufficient level of precision, as described further.

Based on these small-scale spatio-temporal units, a mean CPUE index in number of individuals caught per hour is calculated separately from OBSMER data for each month and from CGFS data (only for October) for a set of demersal species (Table 1). These species have been selected based on their economic importance, relative abundance and/or catchability by the survey gear being considered. Survey data were only kept from 2005 to 2014 for the cephalopods (i.e. *Sepia officinalis* and *Loligo* spp.), as no length information is available for these species before 2005. To harmonize the survey and commercial gear selectivities of the species being considered, we used a common length threshold (Ls) above which a species is considered to be correctly selected by the different gears (Table 1). Ls was graphically determined from length distribution for each species following the method used by Ravard et al. (2014): in commercial data most of the length-frequency were unimodal and Ls was approximately set for each species at the length of the highest mode of the different gears combined. In our study, Ls mainly corresponded to the official minimum landing sizes for the few species concerned. The potential case of a different selectivity of large individuals to particular gears (e.g. Bertignac et al., 2012) is not considered in this study.

Table 1. List of species considered in this study, with their minimum total length Ls (cm), above which individuals are considered to be equally selected by survey and commercial gears, and Minimum Landing Size (MLS) during the 2003-2014 period in Eastern English Channel when relevant.

species	L_s (cm)	MLS (cm)	Common name
Chelidonichthys cuculus	22	-	Red gurnard
Chelidonichthys lucerna	26	-	Tub gurnard
Dicentrarchus labrax	36	36	European seabass
Gadus morhua	35	35	Atlantic cod
Limanda limanda	21	-	Common dab
Loligo spp.	14 [a]	-	Squids
Merlangius merlangus	24	27	Whiting
Microstomus kitt	25	-	Lemon sole
Mullus surmuletus	20	-	Red mullet
Mustelus asterias	60	-	Starry smooth-hound
Platichthys flesus	29	-	European flounder
Pleuronectes platessa	25	27	European plaice
Raja clavata	49	-	Thornback ray
Scyliorhinus canicula	54	-	Lesser-spotted dogfish
Sepia officinalis	13 [a]	-	Common cuttlefish
Spondyliosoma cantharus	17	-	Black seabream
Trisopterus luscus	25	-	Pouting
Trisopterus minutus	13	-	Poor cod
Zeus faber	21	-	John Dory

[a] mantle length

OBSMER data were filtered to avoid abundance overestimation. Thus, for each species and each size, only hauls with all the subsamples representing at least 5% of the total catch weights each were kept for further calculations. Furthermore, to obtain a clear overview of abundance for each demersal species being studied, only fishing gears sufficiently represented (i.e. > 10 observations for a given species) were kept in the analysis.

Finally, we adjusted the remaining catchability differences by standardizing CPUE values derived from both OBSMER and survey data. This was operated by applying a delta-GLM to the CPUEs of each species under consideration. The delta-GLM first fits the probability of observing a zero catch as a function of the explanatory variables, and then fits another GLM to the non-zero catches (Maunder and Punt, 2004; Meissa et al., 2008; among others).

The probability of presence is based on the binomial distribution after a binary recoding (0=absence and 1=presence). For hauls with positive CPUE a logarithmic transformation was first applied on data in order to homogenize variances and to transform the multiplicative effects into additive effects (Meissa et al., 2008).

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The delta-GLM for OBSMER data contains a maximum of six explanatory variables:

logit( ) = $\beta_a\delta_m + \lambda_y + \rho_g\tau + \upsilon_s$ (1)

$\log(IA_{i,a,m,y}) = \beta_a\delta_m + \lambda_y + \rho_g\tau + \upsilon_s + \varepsilon_{i,a,m,y}$ (2)

where is the mean presence probability and IAi,a,m,y the CPUE of a species caught by vessel *i* of length *τ* rigged with gear *g* (e.g. bottom otter trawl, trammel net), fishing in (0.3° x 0.3°) area *a*, year *y* and month *m*. *βa* is the area effect of the fishing operation (treated as factor), *δm* is the month effect of the fishing operation, *ρg* is the gear effect, *λy* is the annual effect, *υs* isthe sediment effect, which accounts for small scale habitat variability and is decomposed into five categories *s*: mud, fine sand, coarse sand, gravel and pebble, based on a sediment map of EEC from Larsonneur *et al*. (1982), and εi,a,m,y a term of residual error.

Sediments are kept because they proved to have the strongest influence on the distribution of species in the shallow Eastern English Channel, compared with, e.g. depth, temperature and salinity (see Carpentier *et al*., 2009). Engine power information was also available but only vessel length was kept as these two variables are usually highly correlated for bottom otter trawlers (r = 0.94 using OBSMER data), the main size-varied vessels of the available commercial data.

CGFS survey data are always collected in October (i.e. no month effect) with the same research vessel (i.e. no vessel or gear effects), hence the previous formula was reduced to the following, with a maximum of three explanatory variables:

logit( ) = $\beta_a + \lambda_y + \upsilon_s$ (3)

$\log(IA_{i,a,m,y}) = \beta_a + \lambda_y + \upsilon_s + \varepsilon_{a,y}$ (4)

Model retained explanatory variables were selected for each species based on Akaike information criterion (AIC). Model selection was largely influenced by the previous choice of the spatial resolution for area variable.

In none of the models (1-4) an interaction term between area (or area-by-month) and year effects was considered. This requires some clarifications, given such an interaction term could potentially reveal spatial shifts in fish distribution over time.

In the analysis of commercial CPUE indices, spatio-temporal interactions were partly covered by introducing an area-by-month term. It was, however, not possible to explore the effect of introducing the higher-ranked interaction area-by-month-by-year, partly owing to the limited amount of observations available but also to opportunistic fisher's behaviour, which in combination resulted in a variable inter-annual coverage of the OBSMER dataset. In the analysis of survey abundance indices, only area-by-year effects could potentially be considered, since the CGFS is operated in October only. Auber et al. (2015) concluded that although October EEC fish communities were subject to a substantial spatial shift in 1997, no significant change was observed during 1998-2014, i.e. the period being considered in this analysis. Still, we did investigate a model including a spatio-annual effect. According to the AIC none of the presence/absence models and only 3 out of the 19 abundance models showed improved goodness of fit performances when an area-by-year interaction term was added (poor cod, starry smooth-hound and thornback ray), without statistically significant differences in the distribution outputs. Furthermore, 14 out of the 19 presence/absence models did not converge with an area-by-year interaction term.

Final predictions are obtained by the product of presence probabilities and CPUE. Knowing the sediment characteristics of each area, the total abundance in each cell is computed by reallocating the environmental effects in proportions to sediment type coverage.

Finally a limit of 10 observations per cell in both OBSMER and CGFS was determined as the threshold above which the square was kept in the analysis, resulting from a trade-off between a sufficient coverage of the EEC and a consistent number of observations (Figure 2). By applying this limit and our spatial resolution to survey data, 88% of the EEC is covered (for OBSMER data this percentage is variable among month and species). In comparison, using cells of 0.4° x 0.4° instead of 0.3° x 0.3° leads to the representation of 90% of the Eastern English Channel, while using smaller cells of 0.2° x 0.2° only allows representing 68% of the Eastern English Channel. Thus our choice seems to be the best trade-off between precision and coverage.

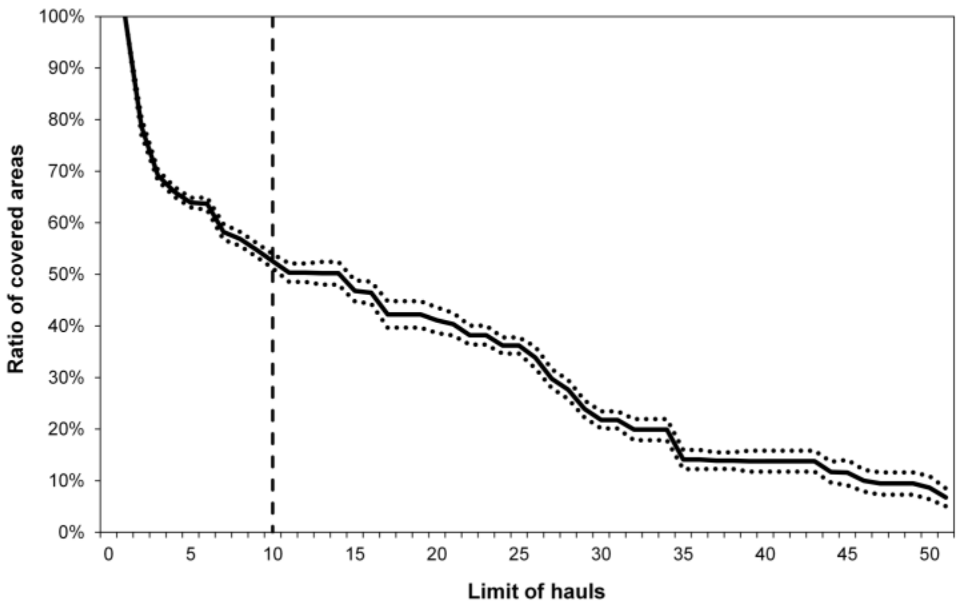

Figure 2. Mean percentage of cells kept in the analysis according to the minimal threshold of hauls set per cell. Dotted lines represent the standard deviation along the 19 species. Dashed vertical line represents the chosen limit of 10 observations.

Importantly, the explained variables presented above are likely to include inherent spatial dependence (spatial autocorrelation SAC; Legendre, 1993), owing to the nature of the data at hand. As a result, the values of the dependent variables are unlikely to be conditionally independent as assumed in these models. The SAC inherent to both CGFS and OBSMER data was here accounted for by applying the Moran's Eigenvectors (MEV) mapping method following the protocol described by Cormon et al. (2014) with R packages {spdep} (Bivand et al., 2013), {spacemakeR} (Dray, 2013) and {packfor} (Dray et al., 2013). The concept of this method is to allow the translation of the spatial arrangement of the data into a set of explanatory variables through the eigenvector decomposition of data coordinate connectivity matrix previously built (Dormann et al., 2007). For OBSMER data, MEV are computed and selected for each month separately, and then integrated in the whole model set of parameters. Temporal dependencies were not examined in the study.

Assessing the similarity between fisheries- and survey-based spatial abundance

The data treatment described above allows to produce monthly maps of species abundance distribution. While the global seasonal patterns obtained can be compared with disparate knowledge available for some species, the degree of reliability of the fine scale spatial distribution derived from commercial data can be addressed through comparison to survey-based maps.

To quantitatively determine how similar spatial distribution derived from commercial and survey data are at fine scale, we estimated, for October, the local overlap between distributions, using the geostatistical index Local Index of Collocation (LIC, Woillez *et al*., 243 2009):

LIC = Σ ( ) ( )√Σ ( ) Σ ( ) (5)

where *zobsmer(i)* and *zsurvey(i)* are the computed abundances in area *i,* as provided by OBSMER and CGFS data, respectively. LIC was computed using R package {RGeostats} (Renard *et al.*, 2014). This spatial indicator is considered appropriate to assess local overlapping between two densities of population, without taking the mean abundance into account (Woillez *et al*., 2009).

This index theoretically ranges between 0, showing absolutely no match between the two spatial distributions (*zobsmer(i)* = 0 if *zsurvey(i)* > 0, *zsurvey(i)* = 0 if *zobsmer(i)* > 0, ∀ *i*), and 1, demonstrating a perfect match between them (*zobsmer(i)* = *zsurvey(i)*, ∀ *i*).

The significance of index values was assessed using random permutations of OBSMER abundance values against constant CGFS ones. This procedure is repeated 5000 times, and the spatial distributions derived from commercial data were considered to overlap spatial distributions derived from the CGFS survey when the actual LIC value was above the 95th percentile of the LIC randomly permutated values.

The Horn's index (Horn, 1966) was also tested for the study, but it provides approximately the same results and is less efficient with extreme values of abundance, thus only results based on LIC are presented.

Finally, to assess the sensitivity of our results to the set of areas being considered, a jackknife resampling was operated for all species, by removing sequentially each area, and by evaluating its impact on LIC significance.

Comparing yearly abundance indices

Additionally to the spatial abundance, the model provides a year effect that can be used to derive an inter-annual abundance index in both survey and OBSMER data following the method of Lo *et al*. (1992). The time series ranges from 1998 to 2014 for survey data (2005-2014 for cephalopods series) and from 2003 to 2015 for OBSMER data. It is obtained by varying only the year parameter on the computation of CPUEs, and taking the mean of all areas in natural space to avoid variance disparities. Pearson's correlation index was computed to quantify the correlation between abundance indices from the two data sources.

Monthly spatial distribution patterns

In the delta-GLM applied to commercial CPUEs, every parameters were kept, with an exception for the sediment parameter in the presence/absence model of cuttlefish. However, area-by-month was replaced by month alone in the presence/absence models of starry smooth-hound, flounder and John Dory. In the delta-GLM applied to survey CPUEs, the parameters selection is more variable. For example, the year parameter is not kept in both presence/absence and abundance models for tub gurnard, and the sediment one is not kept for three species: cod, pouting and tub gurnard. The area parameter was always significant and kept. The monthly spatial distribution of cuttlefish derived from the delta-GLM models applied to commercial and survey CPUEs is presented in Figure 3. This species has been chosen for illustration because it is one of the main species in terms of yields in the EEC (Royer et al., 2006). These maps are partial and do not cover the same areas over all months, owing to varying fisheries distributions. The map presented for October results from survey-based information, hence explaining its wider spatial coverage. Some informative spatial patterns can be evidenced for cuttlefish: their quasi-absence in the EEC from January to March, a coastal aggregation along the French coast in May-June, and a more offshore distribution in October-November indicate the existence of a seasonal migration pattern for 291 this species.

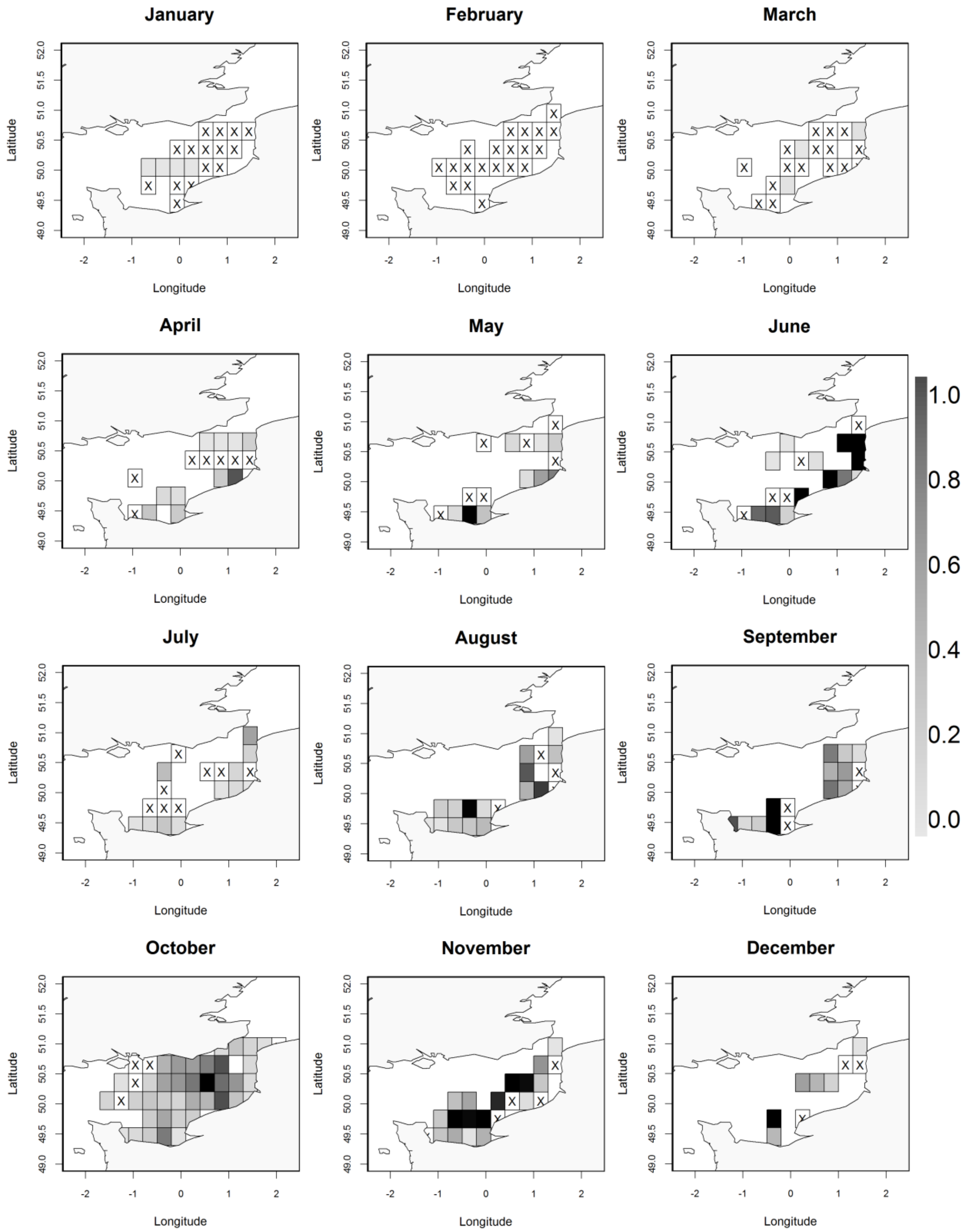

Figure 3. Monthly spatial abundance distribution estimated from OBSMER and CGFS for cuttlefish. ‗X' represents areas where no cuttlefish was ever fished during a month in the database.

Comparison of fine scale spatial distributions from survey data and commercial data

The fine scale match between the spatial abundances estimated from fisheries and survey has been quantified for each species by computing the LIC value, and testing its significance with 5000 random permutations of CPUE abundances. Of the 19 tested species, 9 had a LIC significance above 95%, 6 between 75% and 95%, and only 4 under 75% (Figure 4). Considering 95% significance threshold, survey- and fisheries-based spatial distributions were therefore found to overlap for half of the species under investigation. Although the distribution of LIC values resulting from the permutation tests is variable among species, the results highlight that almost all species with a LIC above 0.6 showed high significance (except John Dory for which the LIC value of 0.67 falls just below the third quartile of permutations), while species with a LIC value smaller than 0.6 showed no significant overlap (except cod with a LIC of 0.52). It can also be noted that John Dory, the only species showing no significant overlap despite a LIC above 0.6, shows a very low variability of LIC in the permutation test.

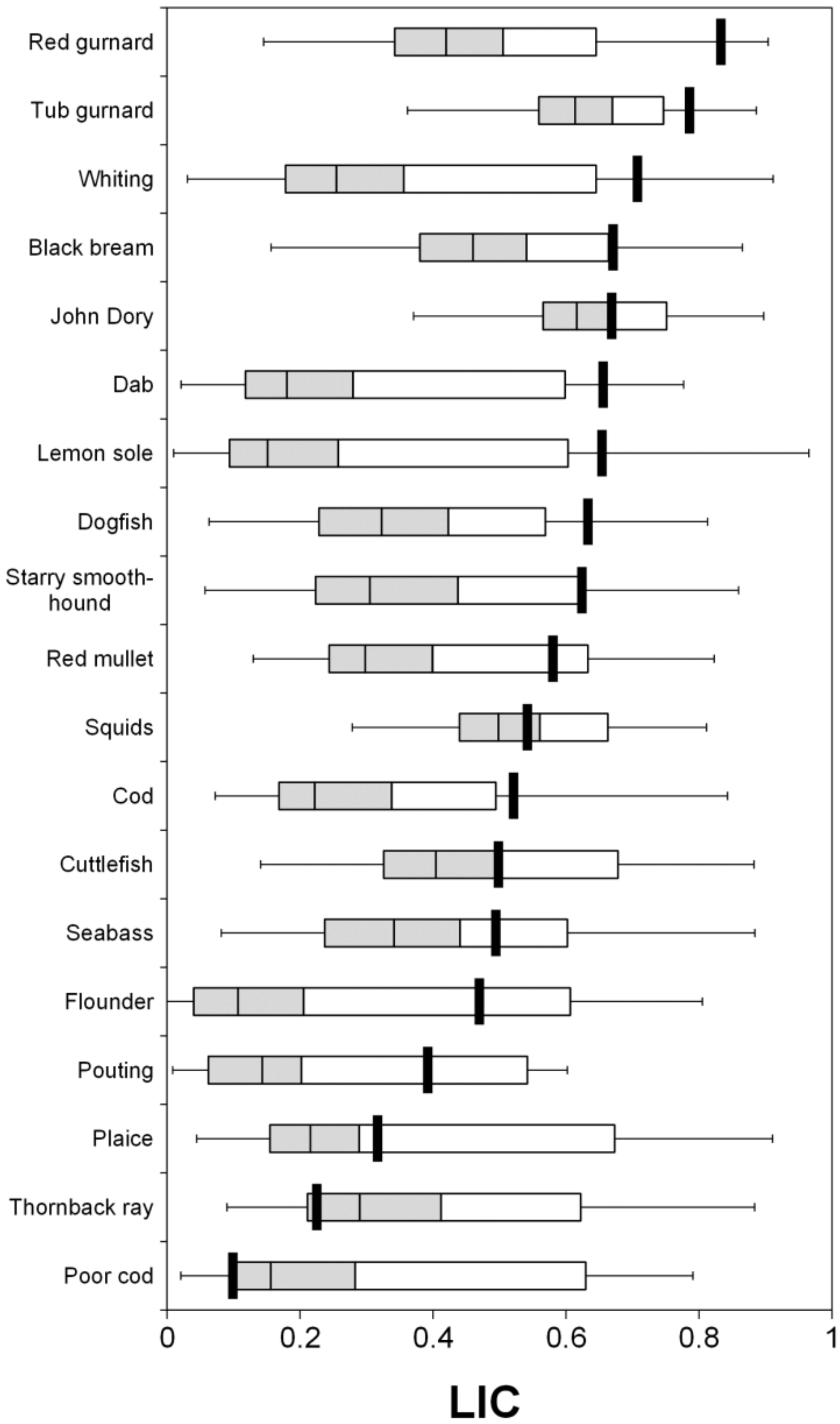

Figure 4. Actual Local Index of Collocation of the 19 species investigated in the Eastern English Channel (bold black line), compared to the distribution of 5000 randomly simulated LICs (permutation test). Minimum and maximum simulated LIC are represented by the short segments. Grey boxes represent Q1, median and Q3 ranges of simulated LICs. The white box represents the range of values between Q3 and the 95th percentile of simulated LICs.

Thornback ray, poor cod, plaice and pouting had the lowest LIC values, under 0.4. Cephalopods species, cuttlefish and squids, had intermediate LIC values of 0.50 and 0.54, respectively, and both were between the median and the 95th percentile. Finally, of the four flatfish species, i.e. common dab, lemon sole, European flounder and plaice, only common dab and lemon sole had a significant LIC.

Sensitivity to areas

In order to assess the sensitivity of the results obtained, a jackknife resampling was performed and results were analysed in regard to some characteristics of sensitive areas (Table 2). Of the 10 species for which no overlap could be evidenced, red mullet was the only one for which LIC became significant by removing one area. Red mullet original LIC significance value compared with permutations was close to 0.05, and dropped below that threshold with the removal of either the first or second top abundance areas as derived from CGFS information (ranked 8th and 4th building on OBSMER data).

Table 2. Jackknife results and main data attributes for species that did not initially demonstrate significant overlap between OBSMER and Channel Ground Fish Survey (CGFS) istributions. LIC: original value of Local Index of Collocation. p-value: situation of the LIC value related to the distribution of permutation tests (values below 0.05 indicate significant overlap). JK: number of areas which prevented from having significant overlap (with total number of areas). % abundance OBSMER & CGFS: percentage of abundance represented by these sensitive areas among all OBSMER and CGFS areas respectively (with ranking among all areas).

	LIC	p-value	JK	% abundance OBSM	% abundance CGFS
Seabass	0.49	0.156	0 (24)	/	/
Squids	0.54	0.440	0 (20)	/	/
Red mullet	0.58	0.063	2 (23)	5.8 (4/23) 3.7 (8/23)	12.4 (2/23) 19.2 (1/23)
Flounder	0.47	0.118	0 (21)	/	/
Plaice	0.32	0.194	0 (24)	/	/
Thornback ray	0.22	0.703	0 (22)	/	/
Cuttlefish	0.50	0.248	0 (21)	/	/
Pouting	0.39	0.108	0 (23)	/	/
Poor cod	0.10	0.768	0 (21)	/	/
John Dory	0.67	0.259	0 (24)	/	/

Among the nine species for which the LIC was significant for all areas being considered, the LIC of seven species became not significant when removing one area (Table 3). The LIC of tub gurnard, common dab, lemon sole, starry smooth-hound and lesser-spotted dogfish were thus sensitive to the absence of one particular area, ranked first or second in abundance. The LIC of cod and black seabream became not significant with the removal of one area among a list of 6 and 8, respectively. Their original p-values, close to the 0.05 threshold (i.e. 0.046 and 0.043), can partially explain the high number of sensitive areas.

Table 3. Jackknife results and main data attributes for species that did initially demonstrate significant overlap between OBSMER and Channel Ground Fish Survey (CGFS) distributions. LIC: original value of Local Index of Collocation. p-value: situation of the LIC value related to the distribution of permutation tests (values below 0.05 indicate significant overlap). JK: number of areas which allowed having significant overlap (with total number of areas). % abundance OBSMER & CGFS: percentage of abundance represented by these sensitive areas among all OBSMER and CGFS areas respectively (with rank among all areas).

	LIC	p-value	JK	% abundance OBSM	% abundance CGFS
Red gurnard	0.83	6e-04	0 (24)	/	/
Tub gurnard	0.79	0.016	1 (24)	11.1 (2/24)	11.3 (1/24)
Cod	0.52	0.046	6 (24)	1.9 (2/24) 0.0 (23/24) 45.3 (1/24) 0.2 (20/24) 3.8 (7/24) 0.0 (24/24)	0.7 (19/24) 1.2 (14/24) 10.6 (2/24) 0.5 (20/24) 2.3 (12/24) 3.4 (10/24)
Common dab	0.66	0.019	1 (23)	22.2 (1/23)	43.1 (1/23)
Whiting	0.71	0.030	0 (23)	/	/
Lemon sole	0.65	0.021	1 (22)	25.5 (1/22)	27.1 (1/22)
Starry smooth-hound	0.62	0.046	1 (22)	14.9 (3/22)	25.9 (1/22)
Lesser-spotted dogfish	0.63	0.020	1 (24)	27.9 (1/24)	12.2 (2/24)
Black seabream	0.67	0.043	8 (23)	0.2 (18/23) 0.0 (20/23) 0.0 (21/23) 0.2 (17/23) 0.0 (22/23) 7.8 (5/23) 0.0 (23/23) 14.8 (2/23)	1.0 (17/23) 0.1 (22/23) 0.1 (21/23) 0.3 (20/23) 0.0 (23/23) 12.6 (3/23) 1.6 (13/23) 12.7 (2/23)

Rebuilding of yearly abundance index

The year effect derived from each delta-GLM analysis can be considered as a yearly abundance index for each species. Figure 5 displays two examples of different levels of fit between survey and commercial data, ranging from good visual fit, for cod, to poor fit for black seabream. Cod abundance index shows consistent fluctuations in both survey and commercial data, with higher abundance from 2007 to 2009 followed by 4 years of lower abundance. Black seabream abundance index derived from survey displayed a general decrease from 2004 until 2014. In contrast, the index derived from commercial CPUEs shows an increase over this period. The Pearson's correlation index was computed to quantify the link between the two abundance indices produced for each species (Table 4). The results indicated that spatial overlap represented by LIC's significance is not necessarily related to concordant abundance indices time series, as most of the species with a significant LIC value have an intermediate correlation (Figure S1). Black seabream, with a significant LIC, has even the third lowest value for Pearson's correlation metrics.

Table 4. Correlation between Channel Ground Fish Survey (CGFS) and OBSMER annual abundance indices assessed by Pearson's correlation index (Pearson). LIC values are also reported for 18 species Eastern English Channel species. Tub gurnard is not represented because the year effect was not significant ($p > 0.05$) in the survey model. * emphasizes species for which spatial overlap was significant ($p < 0.05$).

Common name	Pearson	LIC
Poor cod	0.81	0.10
Cod	0.72	0.52*
John Dory	0.71	0.67
Red mullet	0.66	0.58
Plaice	0.65	0.32
Lemon sole	0.63	0.65*
Cuttlefish	0.51	0.50
Common dab	0.24	0.66*
Red gurnard	0.20	0.83*
Whiting	-0.01	0.71*
Starry smooth-hound	-0.05	0.62*
Thornback ray	-0.08	0.22
Squids	-0.12	0.54
Pouting	-0.13	0.39
Lesser-spotted dogfish	-0.22	0.63*
Black seabream	-0.23	0.67*
Flounder	-0.27	0.47
Seabass	-0.50	0.49

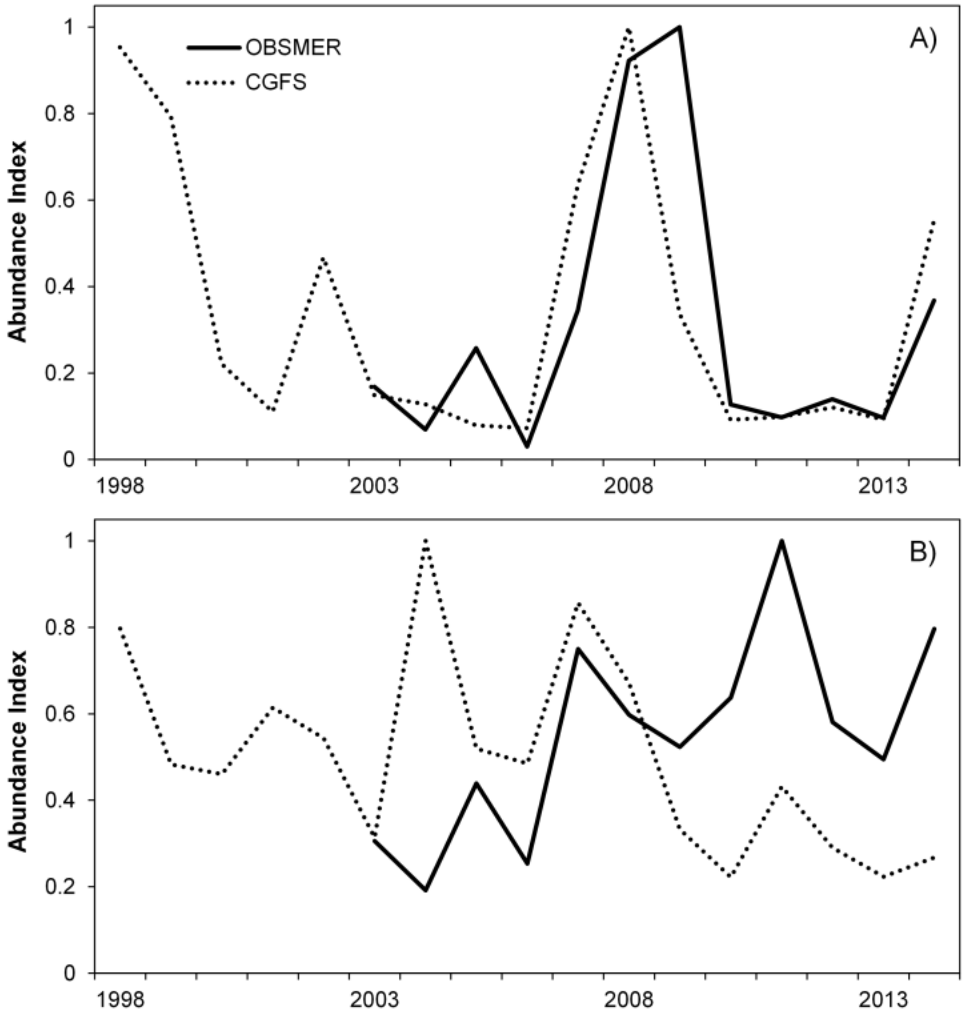

Figure 5. Annual abundance index estimated from Channel Ground Fish Survey (CGFS; dotted line) and OBSMER (solid line) for A) cod and B) black seabream.

Discussion

Seasonal distribution patterns of the main fishing resources in the EEC 344

Our results show the usefulness of fisheries data to infer, in combination with surveys, the spatial and seasonal distributions of several species. The spatial and seasonal distribution of cuttlefish, one of the main commercial species for French fleets (Royer *et al.*, 2006), is in agreement with literature. Indeed, from the examination of landings data, cuttlefish adults are known to start migrating in October to spend winter in the Central and Western English Channel, and to be inshore in the Eastern English Channel during summer for feeding and reproduction (Royer *et al.*, 2006). Other remarkable life distribution can be derived from the maps (see Figures S2-S19), like the high winter abundance of squids in the EEC, confirming previous knowledge (Royer *et al.*, 2002), or the quasi-absence of red mullet in the East of the EEC in the beginning of the year while it concentrates in the East central part of the EEC in the end of the year, which adheres to the conclusions of Mahé *et al.* (2005) based on fishers interviews. On the contrary the spatial distribution of other species remains more stable through the year, e.g. red gurnard in the centre of the EEC, or European flounder inshore except during the winter period, as described by Skerritt (2010). Finally punctual abundance or absence can be detected, like the high concentration of cod along the English coast in June and in the Dover Strait in November, or the high presence of black seabream in the centre of the EEC in February, contrasting with its absence in the eastern part, consistent with Pawson (1995).

Coherence between fisheries-dependent and -independent abundance indices

In addition to the accordance between the global seasonal pattern produced here and the available literature, our results also show that half of the species' spatial distributions exhibited good coherence at fine scale across the two data sources. This conclusion built on an analysis of the LIC overlap metric, the statistical significance of which was quantified using a permutation test. Prior to this study, LIC values were compared with and have been found very close to Horn index values. The Horn index is another overlap metric that is commonly used in trophic ecology, and for which a value > 0.6 is usually considered significant, without further testing (Scrimgeour and Winterbourn, 1987). Our results cross-checked this approach. Except for John Dory (i.e. LIC = 0.67) and cod (i.e. LIC = 0.52), every species distribution with a LIC above 0.6 were significant. The unexpected outcome obtained for John Dory reveals a shortcoming of the method we applied to assess overlap significance. Indeed, when abundance is homogeneously spread in the entire study area (here the EEC), LIC can be above 0.6 and still non-significant when compared with values resulting from the permutation test. Actually, the LIC (as well as the Horn index) random permutation test can only be efficient with areas of contrasted abundance, as demonstrated by lemon sole or common dab with one area of high abundance contrasting with relatively low values. Therefore, for the evenly distributed John Dory spatial distributions derived from survey and fisheries data can be considered to be close.

Concerning the remaining half of species with lower coherence, a number of reasons can be invoked to explain the discrepancies observed. The results of jackknife analysis demonstrated the impact of some influential areas on the result of the LIC, which cannot be observed depending on the fishers spatial distribution in October, and highlight the sensitivity of using fine scale comparison when high abundance areas are not available. Another issue is a possible non-proportionality between CPUE and abundance (Hilborn and Walters, 1992). Indeed, commercial fisheries are expected to concentrate their activities into attractive areas (Gillis, 2003). This issue was addressed by standardizing CPUEs using a delta-GLM, and by filtering out spatial auto-correlation. Owing to the limited amount of data, however, SAC correlations could not be computed separately for each year. This could be a concern, as species presence in a precise area/season may vary from one year to another. Thus, a more realistic approach could consist of computing SAC separately for each year, which could not be achieved in this study owing to the low number of observations in the dataset. For similar reasons, the CPUE delta-GLM could not be applied to each gear separately. Instead, observations from the different gears were analysed through the same model, where gear type was treated as an explanatory variable. This approach allowed to estimate the overall impact of gears on CPUE. However, more specific effects of gear types on CPUEs (e.g. selectivity, saturation) could not be fully addressed. In particular, the selectivity of large individuals could be a challenge, as the trawl selectivity ogive is sigmoid-shaped, while that of gillnets could be bell-shaped, or bi-normal, reducing the catch of larger individuals (Dickson *et al.*, 1995). Among other potential limits, the soaking time of gillnets is much longer compared with trawls, and it is more subject to saturation effect, which could result in an asymptotic relationship between catches and fishing time (Hickford and Schiel, 1996).

Still, the lack of overlap between the spatial distributions derived from fisheries-dependent and -independent abundance indices for some species could also be explained by their actual biological and ecological characteristics. These could have strong impact on abundance estimations, particularly if only few observations are available within an area. Based on a scientific protocol, the CGFS sampling strategy is fixed and the timing of the survey almost does not vary from one year to the other. However, the EEC ecosystem constitutes for several species a migration path between the North Sea and the Atlantic Ocean, and this can lead to biased estimates of abundance based on survey conducted at a fixed period. For example, red mullet migrates during fall from the southern part of the North Sea to the Western English Channel (Mahé *et al*., 2005), but its migration timing appears variable across years Carpentier *et al*., 2009), which could lead to high variance in some areas and thus causes difficulties to obtain a clear static mean distribution.

Pouting, poor cod, thornback ray and plaice have the lowest LIC in our results. Various species are known to change their behaviour between day and night (Pitcher, 1992), which may affect our results (Fréon *et al*., 1993). Indeed, pouting are known to have diel activity patterns, forming shoals near wrecks or rocks during the day and disperse during the night for feeding (Jensen *et al.*, 2000). Thornback rays predate also at night and burry in the sand during the day (Wilding and Snowden, 2008). There is evidence that poor cod is mainly caught at night (Gibson *et al*., 1996). Concerning plaice, differences in catches between day and night are less clear and vary across studies (De Groot, 1971; Arnold and Metcalfe, 1995). Surveys like CGFS occur only during daylight, while about half of the fishing operations are conducted during the night. Including explicitly the time of the day in our model would be a way forward, which would require a larger set of data (Benoît and Swain, 2003). Finally, variability in species distribution can occur by environmentally-driven spatial and annual shifts (Verdoit *et al*., 2003). As previously evoked, with sufficient data, dealing with these shifts would require interaction parameters, introduced by fixed effects (with associated restrictions, e.g. Thorson and Ward, 2013) or random effects (with corresponding bias-correction, e.g. Thorson and Kristensen, 2016). The high number of presence/absence models that did not converge with an area-by-year interaction can be explained by the small number of observations for each occurrence (i.e. on average 2 per area-by-year), often 0 or 1 for a substantial part of the new parameters. Increasing the number of iteration failed to improve model convergence.

In the coming years, the growing collection of data may allow for accommodating such processes, but also fine-scale targeting (e.g. Thorson *et al*., in press), and hence lead to more reliable abundance estimates per area for a broader coverage of the EEC. A next step could then be to derive spatially-explicit estimations of fish lengths, building on innovative approaches (e.g. Petitgas *et al*., 2011; Nielsen *et al.*, 2014). These could help to distinguish between mature and non-mature individuals, which are driving fish movement (Pittman and McAlpine, 2001).

Uses of data collected on-board commercial vessels

Another objective of this study was to provide annual series of abundance indices. The comparison between fisheries-dependent and -independent time series suggested contrasted results across species.

For species like cod (Figure 5a) and lemon sole, both the spatial and annual abundance distributions derived from fisheries and survey data were reasonably consistent. However, consistent annual trends across the two data sources were not necessarily linked with spatially overlapping distributions, e.g. cuttlefish or red mullet. Potential reasons for the lack of spatial overlap for such species were discussed above.

For other species, a good spatial overlap between fisheries-dependent and -independent abundance distributions was not necessarily associated with synchronous time series (e.g. lack seabream, Figure 5b). This could be owing to data limitations, but also to some hyperstable relationship between abundance and CPUE (Hilborn and Walters, 1992), that could not be completely filtered out by our standardization approach. In addition, the species which present a good spatial overlap can be subject to intra-annual fluctuations of abundance owing to high exploitation, migrations and recruitment (Gillis and Peterman, 1998) that could strongly impact the mean annual abundance value.

Finally, abundance indices derived from fisheries data could be an appropriate source of information to provide seasonal and spatial distributions, particularly during periods where surveys do not operate. A better overview of species migrations is first a progress in current knowledge on species ecology, which could further be linked with seasonally-explicit abiotic and biotic environmental conditions. Secondly such information could be linked with fishers movement throughout year, which could enhance our knowledge on fishers-resource interactions. Thirdly, seasonally- and spatially-resolved information such as that output from this study could also serve to calibrate complex end-to-end models such as Atlantis (Fulton *et al.*, 2007), OSMOSE (Shin and Cury, 2001), ISIS-Fish (Pelletier *et al.*, 2009) or Ecospace (Walters *et al.*, 1999), and enhance their capacity to evaluate ecosystem-based management strategies (e.g. closed areas and seasons). Finally, further studies could validate the assumptions that on-board commercial data give a better overview of spatial distributions than survey for a small portion of species (e.g. pouting). However, the distributions derived for species presenting strong variability in selectivity or behavioural pattern (e.g. diel variations or migrations) should be interpreted with caution.

In addition to spatial distributions, annual abundance indices derived from fisheries data could potentially complement the survey-based series used in stock assessments. This would require, as a follow-up to this study, to structure those fisheries-based annual indices by length and/or age, and perhaps to try to obtain such indices on a shorter duration than year. reviously, fisheries-based abundance indices should be closely examined, on a case-by-case basis, cognisant of the life cycle and exploitation features of the species under investigation.

Conclusion

This study shows the potential of combining fisheries-dependent and -independent data to increase our knowledge on the seasonal and spatial distribution of several marine species. Even if the comparisons realized during this study showed that fisheries-dependent data did not always mirror the time and spatial survey-based distribution of some species, they still remain a valid source of information. Fisheries-dependent data are relatively abundant, opportunistic and cheaper than survey data, and their use should be encouraged, especially to reflect abundance distributions in areas and seasons that are not covered by surveys. Moreover, some species are poorly sampled by surveys owing to their diel behaviour, and the use of at-night observations on-board commercial vessels could help better inferring their spatial distributions. The method we used here is relatively simple compared with, e.g. log-Gaussian Cox model method developed by Kristensen *et al.* (2014). Still, the quality of the resulting outputs we presented was assessed, and these provide valuable information on spatial and temporal species distributions, which concur with existing ecological knowledge. This approach would benefit from a better spatial representation along the English coastline, nd further cooperation, data sharing and on-board observation program strengthening could substantially enhance our understanding of the spatio-temporal distribution of marine species in the Eastern English Channel.

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HORIZON 2020

Chapter 11. Technical developments and lesson from 7 years of video documentation in Danish fisheries

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North Sea case study

Paper in preparation – summary

Summary

Remote Electronic Monitoring (REM) with CCTV is an often mentioned tool to ensure compliance with fishing regulations while vessels are at-sea. Since 2008 several trials have been conducted in the European Union on the use of REM with CCTV, not least due to the introduction of the landing obligation. One of the largest and longest running European trials was the 2010 to 2016 Cod Catch Quota Management trial (CCQM) in Denmark. This paper reviews the methods and experiences gained from this trial, with focus on the last two years where criteria for video audits were expanded and major technical developments took place. The cost-effectiveness and potential of REM for compliance, management and scientific purposes is discussed. The present study demonstrate that REM is capable of high precision detection of non-compliance with a discard ban and that developments in the transmission of REM data allowed for a smoother and more reliable Monitoring, Control and Surveillance (MRS) system. Although further developments are needed, especially within the field of automated image analysis, we conclude that REM is one of the few feasible tools where fisheries information and compliance can be ensured under a landing obligation.

Main developments of the REM trial during 2015 and 2016:

Expansion of species audit to cover discards of cod, whiting, haddock, saithe and hake. Previously the audit had solely reported discards of cod at species level. All other discards were pooled under the category "others". This changed the audit from assessing all discards but with low species resolution to assessing the discards of five species only but with higher quality of the discard estimate and recorded information.

Improvement of grid overlay system with measuring line. Final version of this software meant that video auditors would identify the species discarded and use the measuring line to record the length of the discarded fish. This would be recorded for every single discarded of cod, whiting, haddock, saithe or hake and based on the length estimate the weight would be calculated of each fish. Additionally, an image would be stored of the discarded fish with a reference to the vessel, haul, auditor and time.

Results

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633680

Time used per audited catch processing

Technical developments, like the introduction of a grid overlay, and the change in audit procedure to focus on a few species served the purpose of enhancing the quality of the recorded data and reducing the time needed for audit of a catch process. As the majority of participating vessels had conveyor belts and these tended to include the hauls with the largest volume of discards, the developments tended to focus on optimization for vessels with conveyor belts. Figure 1 present an overview of the time used per haul for video audit during all years for vessels without conveyor belts and with conveyor belts respectively.

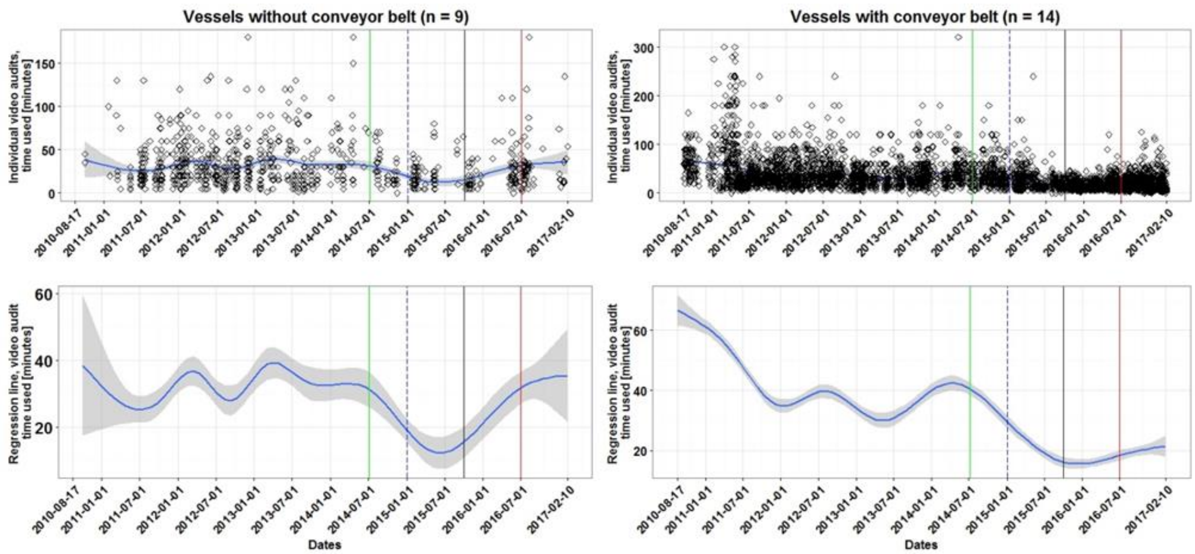

Figure 1. Time used for video audit of catch processing per haul divided by vessels with and without conveyor belt from 2010-2017. Note that the date is for video audit, not for recording of catch processing. Green vertical line represent the first replacement of REM hardware and first use the "Netfisk" grid overlay and the "SigmaFish" software for audit, blue vertical line represent the end of the audit of all discarded species and beginning of length interval audit for cod, saithe, haddock and whiting, black line represent the inclusion of hake for length interval video audit, bringing the audited species to five, red vertical line represent the onset of the final length measurement method using a line overlay for all recorded discards of the five audited species.

Discard maps

Besides the verification of entries of discards in the eLog, the coupling of REM GPS positioning, discard data and eLog data can be used to produce maps showing the total catch, total discards and average discard rate as well as number of hauls in areas. As an example figure 2 present the map for the total discards, catches, hauls and average discard rate for the five species audited in 2016 where ICES rectangles are used as the scale for areas. The five species were: cod (*Gadus morhua*), saithe (*Pollachius virens*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*) and hake (*Merluccius merluccius*).

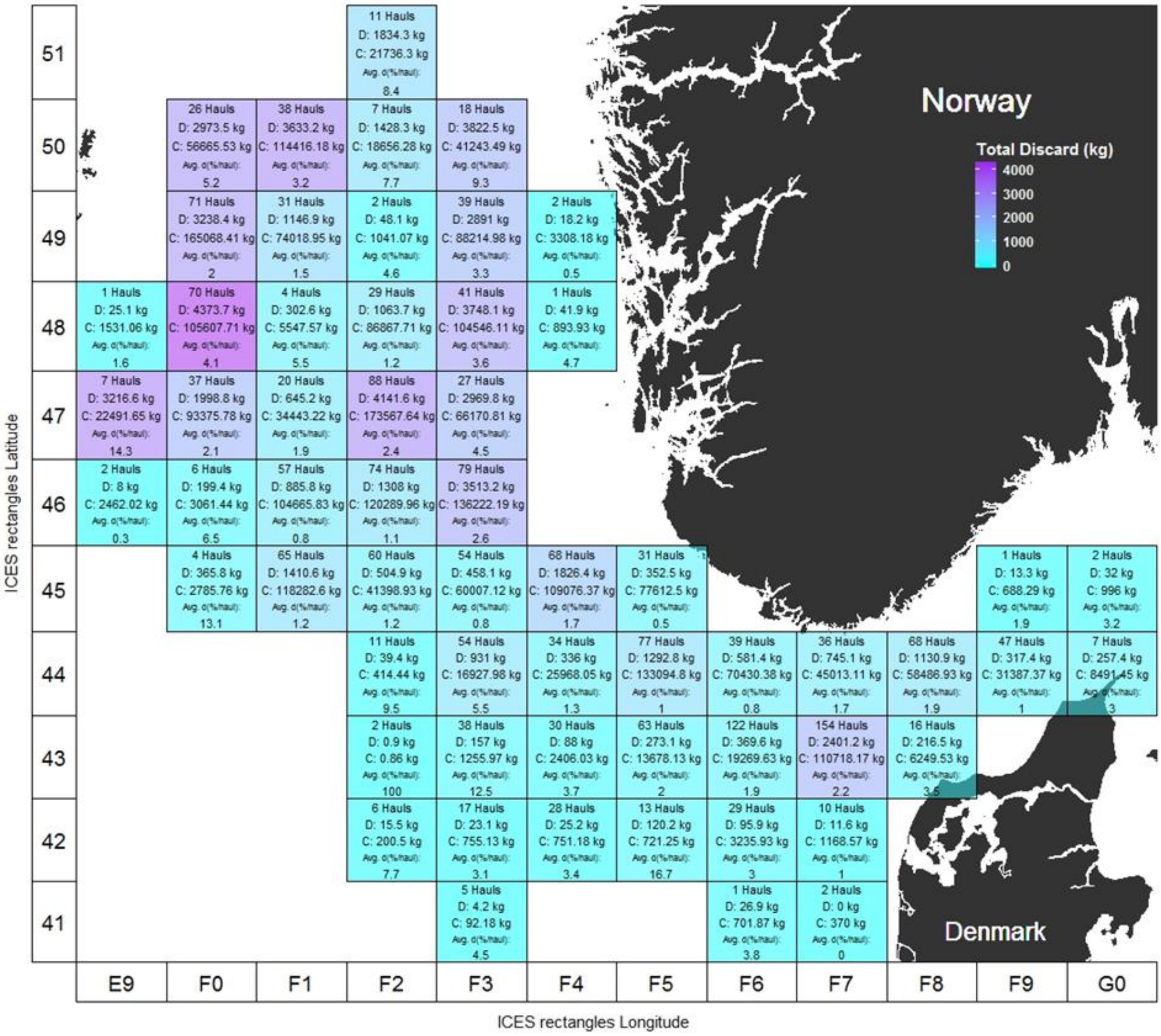

Figure 2. Cod, hake, saithe, whiting and haddock discard, catch and discard rate map, 2016. Cyan areas have low total discards in kg, purple areas have higher total discards. Each grid cell is an ICES rectangle. The x-axis show the ICES rectangles' longitudinal ID, the y-axis show the ICES rectangles' latitudinal ID. The number of hauls conducted in each ICES rectangle by the 12 CCQM vessels' is written together with the discard in kg (D), the catch in kg (C) and the average discard rate pr. haul (%).

Frequency distribution of discards

Because all discards of the five audited species were recorded individually in the latter half of 2016, it is possible to construct a frequency plot of the size of the discarded fish. Figure 3 present the length of discards by species as smoothed line based on the frequency of the discard of all individual fish. See Bergsson et al. 2017 for the discard length frequency by species.

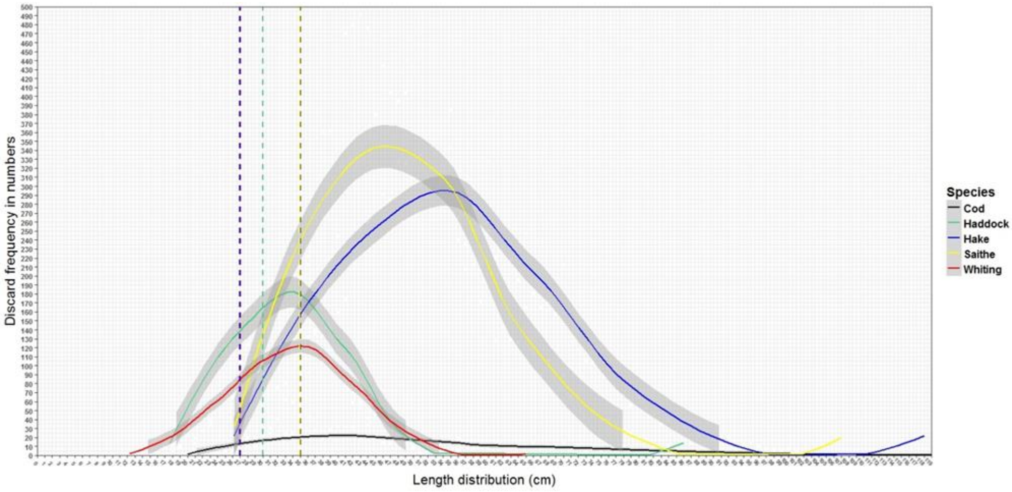

Figure 3. Frequency distribution of cod (black line), haddock (green line), hake (blue line), saithe (yellow line) and whiting (red line) discards in 1 cm interval from July 2016 to December 2016. Yellow and black dashed vertical line denote the MCRS for saithe and cod in the North Sea, blue and red dashed vertical line denote the MCRS for hake and whiting in the North Sea and green dashed vertical line denote the MCRS for haddock in the North Sea.

Of the five audited species the species with the highest number of individuals discarded is saithe (12,214 individuals), followed by hake (10,461 individuals), haddock (3,316 individuals), whiting (2,376 individuals) and cod (930 individuals). In terms of discards above the MCRS, hake is the species with the highest percentage (99.2% of discards > MCRS) followed by saithe (95.4% of discards > MCRS), whiting (84.8% of discards > MCRS), cod (79.9% of discards > MCRS) and haddock (25.5% of discards > MCRS). Although haddock was subject to the LO in 2016 for participating vessels, no enforcement of the LO was done using REM as the CCQM was a trial and should therefore mainly collect data for verification rather than act as a control measure. Fishers were therefore not confronted with this non-compliance.

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Chapter 12. Can deep-water sharks be avoided? Spatial mitigation measures in the deep-sea longline fisheries in the Azores.

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Azores case study

Introduction

The Azores is an oceanic archipelago in the mid North Atlantic Ocean, located between the continental Europe and North America. It has a vast exclusive economic zone of 1 million km^2 and largely contributes to the Portuguese claimed 2.1 million km^2 extended continental shelf. The seafloor is mostly deep but over 100 seamounts, a fraction of the Mid Atlantic Ridge, and the slopes of the islands compose the shallowest parts. With the absence of a continental shelf and surrounding great depths, fishing occurs around the island slopes and the many seamounts present in the area (Morato et al., 2008; Silva and Pinho, 2007).

The bottom longline and handline fishery is by far the most valuable in terms of landed value with an average annual landed value of 18-29 million Euros, representing about 76% of all landed value in the Azores. It is also the main fishery in the region in terms of number of boats and jobs, and relies essentially on fresh export (Carvalho et al., 2011). This fishery uses both longlines and handlines, is highly multi-specific and targets a wide diversity of deep-sea demersal fishes, such as wreckfish (*Polyprion americanus*), alfonsinos (*Beryx spp.*) and blackbelly rosefish (*Helicolenus dactylopterus*), along with the blackspot seabream (*Pagellus bogaraveo*) given its number one rank in value (Morato, 2012). Recent estimates of bycatch (Pham et al., 2013) including discards (Fauconnet et al., unpublished) in the bottom longline and handline comprises many deep-water elasmobranchs. The dominant elasmobranch catch in bottom longline and handline by weight (tons/year) was the thornback ray (*Raja clavata*) followed by the leafscale gulper shark (*Centrophorus squamosus*) and the tope shark (*Galeorhinus galeus*). Sixteen other species of deep-water elasmobranchs are occasionally caught by this fishery, in smaller proportions, accounting together for 2.4% of the fishery catch (Table 1).

Since the late 90s, a deep-water drifting longline fishery targeting the deep-water black scabbardfish (*Aphanopus carbo*) has also been experimented in the region (Machete et al., 2011) but has little developed due to absence of local market. This fishery is still in an experimental phase in the Azores, with a very limited, thought not accurately known, number of fishing vessels involved. According to a report prepared by seaExpert (Ramos et al., 2013) in 2010 there might have been about 10 fishing vessels with a mean length of 14m operating the drifting deep-water longline in the Region, but this number is believed to have diminished since then. Landings are small but have peaked at 450t in 2012 (Fauconnet et al., unpublished). Bycatch species of this fishery accounted for about 4.0–7.5% of the total number of fish caught (Machete et al., 2011), 17.5% in weight (Fauconnet et al., unpublished). In the Azores as in other regions, deep-sea sharks composed the main by-catch (Machete et al., 2011, Bordalo-Machado et al., 2009), mainly leafscale gulper shark and Portuguese dogfish (*Centroscymnus coelolepis*). Other species of elasmobranchs reported as by-catch of this fishery but with low numbers include *Etmopterus sp., Deania cf. calcea, Centroscymnus crepidater,* and *Deania profundorum* (Table 1).

Many deep-water sharks taken as bycatch by those two fisheries (Pham et al., 2013; Fauconnet et al. unpublished) are listed in the IUCN red list of endangered species. For example, the thornback ray, the dominant elasmobranch catch in the bottom longline and handline fishery, was assessed as 'near threatened' by the IUCN European Red List, similar to velvet belly lanternshark (*Etmopterus spinax*) and the blonde ray (*Raja brachyura*). The leafscale gulper shark (*Centrophorus squamosus*), predominant in both the drifting deepwater longline and in the bottom longline/handline fishery is assessed as 'endangered', along with the kitefin shark (*Dalatias licha*), birdbeak dogfish (*Deania calcea*), leafscale gulper shark and Portuguese dogfish. Multiple species assessed as 'vulnerable' also occur as bycatch in these fisheries, such as tope shark, shagreen ray (*Leucoraja fullonica*) and common eagle ray (*Myliobatis aquila*). The 'data deficient' arrowhead dogfish (*Deania profundorum*) and the smooth lanternshark (*Etmopterus pusillus*) and velvet dogfish (*Zameus squamulosus*) commonly feature in the catch of these fisheries. Two species assessed as 'critically endangered' are caught in high quantities, gulper shark *Centrophorus granulosus* (>35 t/y) and blue skate *Dipturus batis* (>15 t/y, Table 1).

The fishery resource management strategy in place by Azorean authorities is largely driven by the EU Common Fishery Policy, implemented primarily through total allowable catches (TACs) for various species including blackspot seabream, alfonsinos, black scabbardfish and deep-water sharks (EC Reg. 2340/2002; EC Reg. 2270/2004). As a result of the deep-sea shark vulnerability, a TAC 0 was implemented by the EU for over 15 species of deep-sea sharks since 2010, including *Deania spp., Centrophorus spp., Etmopterus spp., Centroscymnus spp.* and kitefin shark (EC. Reg. 1359/2008). The upcoming implementation of the LO in European fisheries, that will take place from 2019 onward in Azorean demersal fisheries, will compel fishers to land all catch of quota species. As this catch will be counted against fishing quotas, thus compelling fishers to stop fishing whenever the quota will be reached, it is a strong incentive to study mitigation measures.

The aim of this study is to evaluate the efficacy of spatial management measures to reduce unwanted by-catch of deep-water sharks on Azorean deep-sea fisheries. For doing so, we combined information on the spatial distribution of deep-sea sharks with spatial information of fishing effort to identify areas most important for considering avoidance measures. To analyse the spatial distribution of deep-sea sharks, we used: i) Habitat suitability models (also known as species distribution models) to identify areas of higher abundance by combining data on species abundance with environmental variables and model the likelihood of species occurrence across the whole potential habitat, ii) acoustic tracking experiments to identify areas of increased habitat of deep-water sharks. For mapping fishing effort, we used Vessel Monitoring System data to identify the main fishing areas and create maps of fishing distribution and hotspots. Finally, this information is combined to suggest potential mitigation measures to fishers to avoid unwanted shark catch.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633680

Table 1. Deep-water sharks and rays caught as bycatch in the deep-water bottom longline and drifting longline fisheries in the Azores, with annual catch weight estimates and 95% Confidence Intervals, percentage of the species catch within the total catch of the fishery, and IUCN Red List status for Europe 2015. * identify TAC 0 species. Adapted from Fauconnet et al. (unpublished data).

		Bottom longline and handline			Drifting deep-water longline			
Scientific name	Common name	Catch (t/y)	95% CI	% of total catch	Catch (t/y)	95% CI	% of total catch	IUCN
Raja clavata	Thornback ray	109.54	[91.98 - 127.53]	2.39	-	-	-	NT
**Centrophorus squamosus*	Leafscale gulper shark	83.26	[40.89 - 222.5]	1.82	14.89	[14.89 - 14.9]	11.86	EN
Galeorhinus galeus	Tope shark	64.86	[58.22 - 71.51]	1.42	-	-	-	VU
**Dalatias licha*	Kitefin shark	37.80	[26.14 - 47.83]	0.82	0.04	[0.03 - 0.04]	0.03	EN
**Centrophorus granulosus*	Gulper shark	36.47	[8.24 - 60.76]	0.80	0.02	[0 - 0]	0.02	CR
**Deania profundorum*	Arrowhead dogfish	19.89	[14.51 - 37.58]	0.43	0.07	[0.07 - 0.07]	0.06	DD
Dipturus batis	Blue skate	17.63	[7.69 - 26.19]	0.38	-	-	-	CR
Hexanchus griseus	Bluntnose sixgill shark	14.41	[2.5 - 24.66]	0.31	-	-	-	LC
**Etmopterus spinax*	Velvet belly lantern shark	13.35	[9.47 - 16.7]	0.29	-	-	-	NT
**Centrophorus lusitanicus (+)*	Lowfin gulper shark	7.86	[7.86 - 7.86]	0.17	-	-	-	EN
**Deania calcea*	Birdbeak dogfish	7.21	[2.04 - 11.65]	0.16	0.35	[0.35 - 0.35]	0.28	EN
Etmopterus pusillus	Smooth lanternshark	2.87	[1.13 - 4.37]	0.06	0.36	[0.35 - 0.36]	0.28	DD
Leucoraja fullonica	Shagreen ray	1.46	[0.94 - 1.91]	0.032	-	-	-	VU
Myliobatis aquila	Common eagle ray	1.42	[1.42 - 1.42]	0.031	-	-	-	VU
Pteroplatytrygon violacea	Pelagic stingray	1.05	[1.05 - 1.05]	0.023	-	-	-	LC
Raja brachyura	Blonde ray	0.157569	[0.16 - 0.16]	0.003439	-	-	-	NT
Heptranchias perlo	Sharpnose sevengill shark	0.15	[0.15 - 0.15]	0.003	-	-	-	DD
Torpedo nobiliana	Electric ray	0.12	[0.12 - 0.12]	0.003	-	-	-	LC
Centroscymnus cryptacanthus	Shortnose velvet dogfish	0.11	[0.11 - 0.11]	0.002	1.12	[1.12 - 1.12]	0.89	na
**Centroscymnus crepidater*	Longnose velvet dogfish	0.09	[0.07 - 0.12]	0.002	0.82	[0.82 - 0.83]	0.66	LC
**Etmopterus princeps*	Great lanternshark	-	-	-	0.74	[0.73 - 0.74]	0.59	LC
**Centroscymnus coelolepis*	Portuguese dogfish	-	-	-	0.65	[0.65 - 0.65]	0.52	EN
Zameus squamulosus	Velvet dogfish	-	-	-	0.005	[0 - 0]	0.004	DD

(+) Large quantities of Centrophorus lusitanicus have been reported in the landings before this species was included in the list of species subject to TAC 0. However recent evidence suggest that this species does not exist and will actually be a junior synonym of C. granulosus (White et al., 2017).

Material and Methods

1) Species distribution and potential overlap with fishing

a. Species Distribution Models

Study area and selected species

Habitat suitability models of deep-water elasmobranchs (sharks and rays) were developed for the Azores Exclusive Economic Zone (EEZ), between 33–43⁰N and 20–35⁰W. We limited the area of the models to water depths shallower than 2000m. Species to be modelled were selected based on their ecology (predominantly benthic), depth distribution (>150m depth), importance as by-catch of both hook-and-line fisheries, and on the availability and spatial coverage of existing records (occurred in more 20 survey fishing sets). Twelve shark and three ray species of deep-water elasmobranchs were selected for this study (Table 2).

Fisheries surveys

Models were built using catch data from fisheries monitoring surveys, performed from 1996 to 2017 (except 1998 and 2006) onboard the research vessel "Arquipélago". These surveys followed a standardized methodology to monitor demersal and deep-sea fish species abundance. In total, 597 bottom longline sets were used in the analyses. Most of these sets were completed in spring (n = 547) with a few opportunistic sets performed in summer (n = 36) and autumn (n = 13). The fishing gear was similar to the one used by the Azorean commercial fishery, known as stone/buoy bottom longline (LLA), with few deeper sets undertaken with a different longline design (LLB - with larger hooks and a different disposition of mainline, details and schematic representation in Menezes et al., 2009). The fishing sets were randomly located around an island or seamount and deployed till 2500 meters of depth (figure 1). Each longline section was composed of about 30 hooks (hook size no.9 for LLA, no.6 for LLB), approximately 36.5m long, and baited with chopped salted sardine.

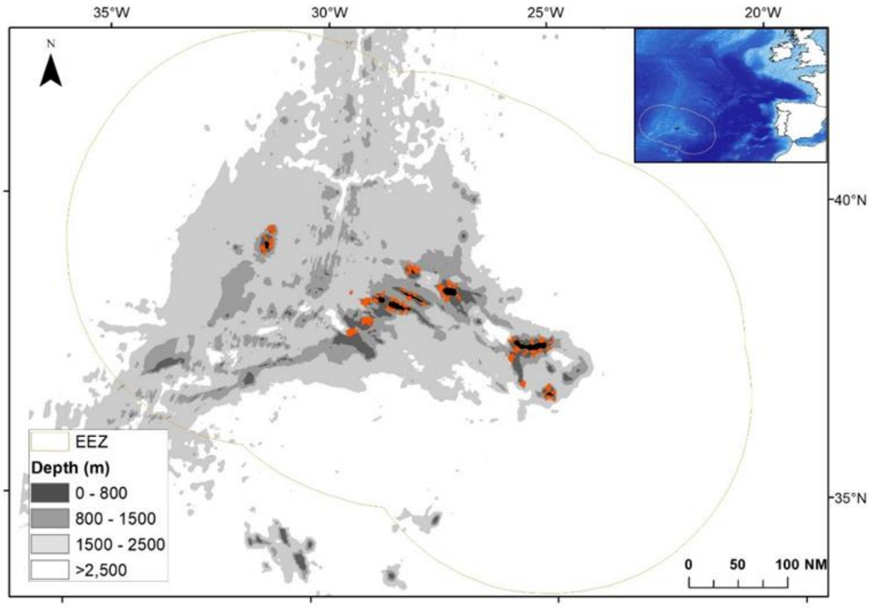


Figure 1. Bathymetry around the Azores archipelago, EEZ (yellow line) and position of the sampling sets (orange dots).

Each section of the longline was allocated to a 50m depth strata. Geographic coordinates were recorded for each "event" (for eg. stone or buoy) during gear deployment, as well as the corresponding depth strata. During hauling, the total number of each species of fish caught and the number of hooks deployed were recorded by depth strata. Hence, each depth strata of each fishing set was considered a sampling unit. All details of the surveys can be found in Menezes et al. (2006, 2009).

Coordinates for the start and end of each depth strata were extracted from the gear deployment data per fishing set. These points were then used to derive length of the strata (in meters), and mean coordinates using GIS software. The fish caught per strata was allocated to this mean position of the strata. Lack of catches of the studied species for any strata was considered an 'absence'. The relevance of the location error associated to this method of allocation of fish catches was considered minimal since the mean length of a strata (~320 m), similar to the resolution environmental data used in the analysis (cell size=280m x 280m) and therefore inside the recommended parameter for SDMs (Naimi et al., 2011; Osborne and Leitão, 2009). However, some spatial data had to be removed due to erroneous geographic positions (n=139), or the lack of associated effort data (n=200). A total of 10,239 sampling units were thus included in this study.

All elasmobranch species with more than 20 catches were included in the spatial modelling routine. The analysis included 15 species of sharks and rays, excluding the blue shark Prionace glauca, which is a pelagic species occasionally occurring as bycatch in the bottom longline fisheries (table 2). The selected species further display an interesting wide range of depth preferences (figure 2). Binomial presence/absence maps were generated for all species.

Table 2. Selected species list, number of capture events within the demersal survey data and associated environmental characteristics.

	No. of individuals	No. of captures	Range-Depth (mts)	Avg depth (std. dev.) (mts)	Avg. temp (std. dev.) (ºC)	Avg. slope (std. dev.) (degree)	Avg oxygen saturation (std. dev.) (%)	Avg. salinity (std. dev.) (‰)
Etmopterus spinax	3649	1100	136.48-1471.72	575.43±153.08	11.3±1.18	11.96±6.1	76.64±5.4	35.58±0.11
Deania profundorum	3124	1002	281.63-1483.63	751.44±147.55	10.17±1.31	13.53±6.05	72.08±4.27	35.5±0.1
Raja clavata	2380	613	11.79-616.3	178.62±121.61	14.75±1.53	6.9±5.13	92.47±6.43	35.95±0.14
Etmopterus pusillus	1348	910	136.48-1447.35	702.8±225.30	10.37±1.82	13.39±6.1	74.21±5.73	35.53±0.14
Deania calcea	1323	553	416.05-1486.33	992.7±154.36	8.15±1.5	11.35±5.12	71.27±3.07	35.39±0.12
Galeorhinus galeus	1288	361	12.13-619.5	178.38±130.74	14.87±1.49	6.91±5.66	93.2±6.45	35.96±0.14
Centroselachus crepidater	243	181	703.24-1486.33	1068.13±127.85	7.65±1.13	10.44±4.49	71.37±2.59	35.36±0.1
Centrophorus squamosus	195	99	549.55-2178.56	1249.14±449.28	6.64±2.47	8.63±6.21	75.79±5.47	35.24±0.21
Dipturus batis	162	139	34.15-807.63	448.24±161.65	12.28±1.37	8.23±5.72	81.03±6.58	35.69±0.16
Etmopterus princeps	147	54	820.98-2113.44	1525.98±364.49	5.08±1.65	9.59±7.00	78.17±4.66	35.11±0.16
Dalatias licha	122	119	179.51-1242.28	570.91±170.91	11.43±1.22	12.43±5.99	76.93±5.89	35.6±0.13
Centroscymnus coelolepis	117	56	797.64-2178.56	1411.34±338.25	5.5±1.72	9.83±6.92	76.95±5.06	35.15±0.17
Squaliolus laticaudus	77	70	79.31-1045.93	612.95±199.58	11.38±1.69	11.87±5.46	77.23±6.69	35.62±0.15
Centroscymnus owstonii	35	31	440.92-1473.23	1049.45±267.98	8.31±2.28	9.86±5.32	73.56±3.61	35.38±0.17
Leucoraja fullonica	33	22	251.77-670.15	433.12±110.19	12.35±0.9	6.62±4.33	82.23±4.86	35.69±0.11

Environmental data

Candidate environmental predictor variables to be included in the analysis were extracted from Perán et al. (2016) and Amorim et al. (2017). Candidate predictors included depth, slope, aspect, and bathymetric position index (for the distance of seashore or seamounts), bottom temperature, salinity, oxygen saturation, nitrates, and particulate organic carbon (POC) flux. Predictors were available for the entire Azores EEZ at a grid cell resolution of 0.0027° (approximately 300 x 250 m), comprising a total of about 24 million cells. In order to avoid including correlated predictors in the models, a preliminary data exploration was conducted using Variation Inflation Factor (VIF) analysis along with multi-panel scatterplots. Predictors with a VIF higher than 3 were removed stepwise and the analysis repeated until all values were below this cut-off level (Zuur et al., 2010). After the VIF analyses, bottom temperature, salinity, and oxygen saturation were removed from model development. Finally, a final selection process was carried out for each species following the methodology described by Genuer et al (2010) using the function VSURF (Genuer et al., 2016).

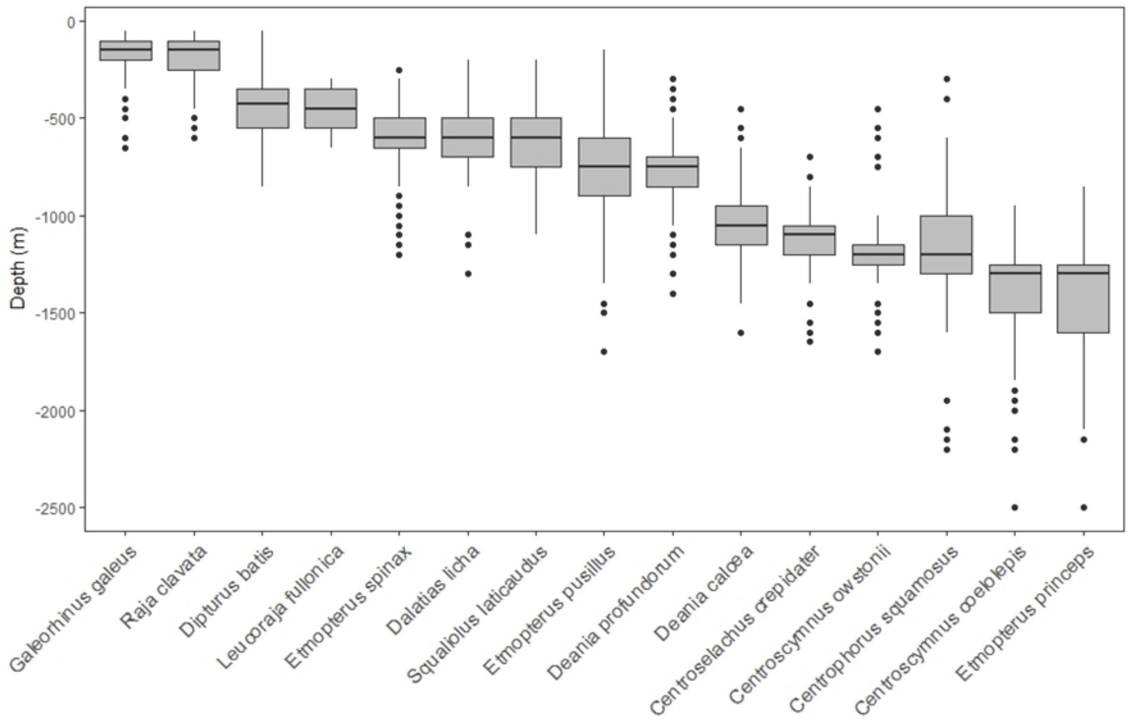


Figure 2. Boxplot of depth range at which deep-water sharks were captured during experimental longline surveys performed in the Azores between 1996 and 2017 (black line represents the median and points lie beyond 1.5*IQR).

Modeling approach

Random forest models were used to assess the relationships between the environmental variables and presence of selected species, using a spatial resolution grid of 280 m^2, down to 2000 m depth.

The quality of the final models was tested using the percentage of variance explained by the models. Cross validation was also performed. The data was divided among the training data (66% of the data that were used to built the model) and evaluation data (the other 33%, this data were used only to evaluate the model built with the training data). The performance of the models was estimated using two different statistics: the area under the curve (AUC) of the receiver operating characteristic (Fielding and Bell, 1997) and the kappa statistic (Cohen, 1960) were used to evaluate the performance of the presence/absence models. The AUC varies between 0 and 1. Values higher than 0.9 are considered excellent whereas values between 0.9 and 0.7 indicate good prediction. Values lower than 0.7 indicate poor prediction and values lower than 0.5 indicate that the model is not better than a random classification (Hosmer et al., 2013). The kappa statistic ranges from -1 to 1, with values higher than 0.75 indicating excellent prediction, values between 0.4 and 0.75 indicating good prediction, values lower than 0.4 indicating poor prediction, and values lower than 0 indicate that the model is not better than random (Landis and Koch, 1977). The process was repeated 10 times for each combination of species and model, calculating the AUC and Kappa values each time based on a different random selection of training and test subsample. The mean value (from the 10 values) and the SD for each species and metric was computed to assess the overall performance of the models for each species.

Partial plots and a summary of the relative importance of each variable for each model were produced using the methodology described in Ehrlinger (2015) to evaluate the influence of the different variables on the predicted distributions of the selected species.

To create binomial maps of presence/absence based on the projected probability of presence of each species, a threshold was applied. Three thresholds were tested: a) maximization kappa, b) prevalence, c) max SSS. While the threshold obtained with the maximization of the kappa was predicting absence in most of the EEZ, the one using prevalence was on the contrary predicting presence in most of the EEZ. The max SSS was giving intermediate results, and was thus selected to create the presence / absence maps. This threshold has been recommended for its use in only presence models (Liu et al., 2013). The fact that is performing well in this work could be related with lack of reliability of our absences because of the low catchability of some of the studied species and it shows how sensitive the maps are of the thresholds selected. As a decision support tool, this threshold could be adapted by users to fix the risk they are willing to take. Outputs of the models include maps of probability of presence, and maps of presence / absence per species based on the max SSS threshold. A composite map overlapping all selected species was also created to highlight areas of higher shark richness.

To better highlight the areas that should be avoided by local fishers, we further developed a map overlapping the predicted distributions of the main TAC 0 species caught by the bottom longliners (for which we have reliable SDMs), ie. *Centrophorus squamulosus*, *Deania profundorum*, *Etmopterus spinax*, *Deania calcea.* A similar map was developed for the main species caught by the drifting longliners, ie. *Centrophorus squamosus, Centroscymnus crepidater, Etmopterus prínceps, Centroscymnus coelolepis, D. calcea.*

a. Mapping Fishing Effort

Vessel Monitoring System data were provided by the Regional government of the Azores for the period 2006-2015 and contained data on latitude and longitude position, instantaneous speed and heading (or course). In this study, only data from those vessels that declared bottom longline and handline as their main fishing gear was used. The database was cleaned for duplicated records, and for erroneous positions, speed and courses. Records with VMS speeds greater than 20 knots and course greater than 360 were removed. The cleaned database contained about 40,000 VMS data points. Vessel states were defined as in harbor, steaming, fishing or resting based on rules related to speed, change in course, length of the leg, and distance to harbor.

The "Fishing" state was defined by the combination of a speed ≤ 3.0 knots, a distance from harbor ≥ 1.5 nm, and a time of the day between 3 am and 7 pm. Fishing effort was estimated as the time in hours spent fishing in each cell of 10 x 10 km).

1) Fine-scale patterns using telemetry experiments

Kitefin and bluntnose sixgill sharks were captured at the south end of the Faial-Pico channel by deepwater handlining (kitefins) and heavy tackle angling (sixgills). Handlining was similar to that traditionally used in the Azorean bottom fishery. The fish were hauled slowly (ca. 0.2 m/second) and restrained alongside the boat in order to induce tonic immobility. selected for acoustic telemetry were surgically implanted with an ultrasonic transmitter (V16-4H, Vemco Ltd., Halifax, Nova Scotia) in the peritoneal cavity, had the hook removed and released at the point of capture upon regaining of tonic signs (e.g. Afonso et al., 2011). All sharks were measured, sexed and tagged with an external "spaghetti" dart tag (Hallprint, Australia) for external recognition if recaptured by fishermen. A total of 25 kitefin sharks (13 male of 102-121 TL in size, 12 female of 127-158 cm TL) were tagged in 2010-2013, and eight sixgill sharks (1 male of 319 TL in size, 7 female of 380-420 cm TL) tagged in 2015. Fish were implanted with acoustic transmitters that randomly emit a coded signal every 60 to180 seconds. Four of the kitefins and three sixgills were tagged with transmitters equipped with a pressure-sensor (V16P) that measures the depth of the animal at the time of transmission. Transmitters had an average battery life of 1305 (kitefins) and 1785 (sixgills).

To monitor the presence of the tagged shark at the platform and slopes of the Faial and Pico islands and the neighbouring seamounts, an acoustic listening receiver (Vemco VR2W or VR4-UWM 69 kHz single frequency) network was deployed and maintained throughout the study period (2010-2018). These receivers continuously monitored the presence of any coded transmitters in their vicinity, logging the exact time/date and code of a given tag when in range. Receivers were moored about 2.5 metres above the seafloor at shallow depths (ca. 30 mt.) or in deepwater between 200- 500 m depth. To allow recovery of the deep receivers, the moorings were rigged with an acoustic release (Edgetech ORE or AR50 Sub Sea Sonics, San Diego, USA) and two 28 cm wide floats mounted vertically 2 m above the receiver. Stations were retrieved every 6 to 12 months to download stored information. Long-term monitoring data were initially screened for spurious detections. These may occur whenever signals from different coded transmitters emit simultaneously and collide within the same detection range, resulting in "false" signals. For this study, detections were considered spurious if only a single detection occurred on either receiver over a 24-hour period. Data were subsequently analysed for individual and overall residency (site attachment) of shark at each of the stations for the study period, and for individual movements between stations.

Results and discussion

1) Species distribution and potential overlap with fishing

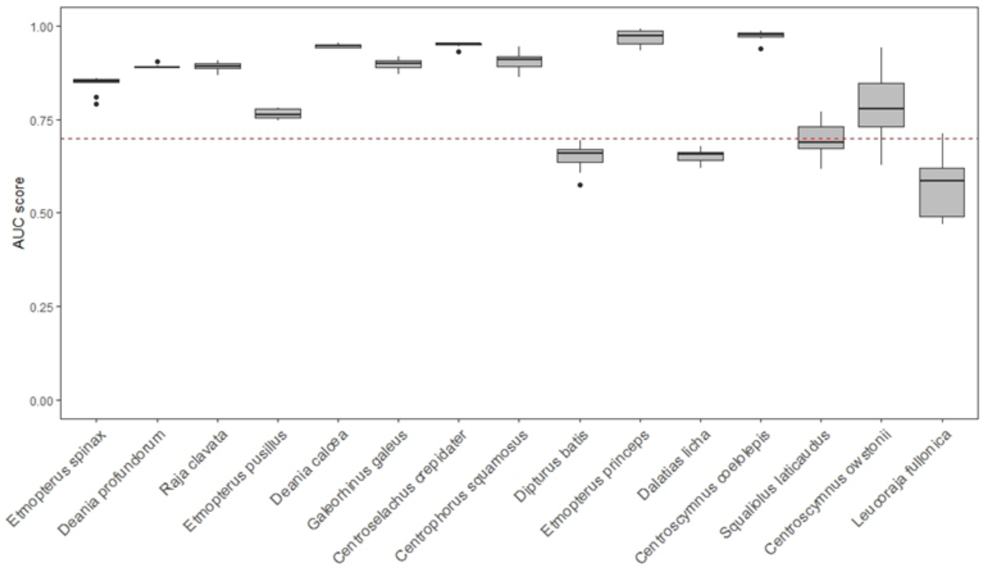
a. Species Distribution Models

Model selection and model fit

Random forest models performed well (>0.25 of explained variance) for 5 species among the ones with the highest number of occurrences (in green in table 3), while they performed more poorly (between 0.05 and 0.19) for 5 other species (in orange in table 3). For the remaining 5 species, mainly those with the lowest number of occurrences, negative values of explained variance were obtained (in red in table 3). Results from those 5 species were thus not considered relevant and were not shown in the following results. Models could be improved for those species, by including occurrence data from other data sources and evaluate other potential environmental variables that could explain the habitat suitability for those species. The AUC gives the same species with bad predictions, while the Kappa gives poor predictions for 4 additional species (figure 3). Results for those species are shown in the following section, however those are preliminary results that must be interpreted carefully.

Table 3. Summary of the random forest model performance for all selected species

Species name	Explained_Var	Kappa_mean	Kappa_sd	AUC_mean	AUC_sd
Etmopterus spinax	0.27	0.40	0.039	0.84	0.024
Deania profundorum	0.30	0.43	0.015	0.89	0.005
Raja clavata	0.27	0.38	0.023	0.89	0.012
Etmopterus pusillus	0.08	0.20	0.021	0.76	0.013
Deania calcea	0.36	0.49	0.027	0.95	0.004
Galeorhinus galeus	0.29	0.45	0.032	0.90	0.016
Centroselachus crepidater	0.15	0.32	0.061	0.95	0.007
Centrophorus squamosus	0.05	0.29	0.076	0.91	0.024
Dipturus batis	-0.004	0.10	0.027	0.65	0.035
Etmopterus princeps	0.12	0.43	0.061	0.97	0.021
Dalatias licha	-0.06	0.05	0.019	0.65	0.018
Centroscymnus coelolepis	0.19	0.43	0.081	0.97	0.013
Squaliolus laticaudus	-0.07	0.08	0.042	0.70	0.049
Centroscymnus owstonii	-0.02	0.14	0.046	0.79	0.098
Leucoraja fullonica	0.02	0.14	0.112	0.57	0.085



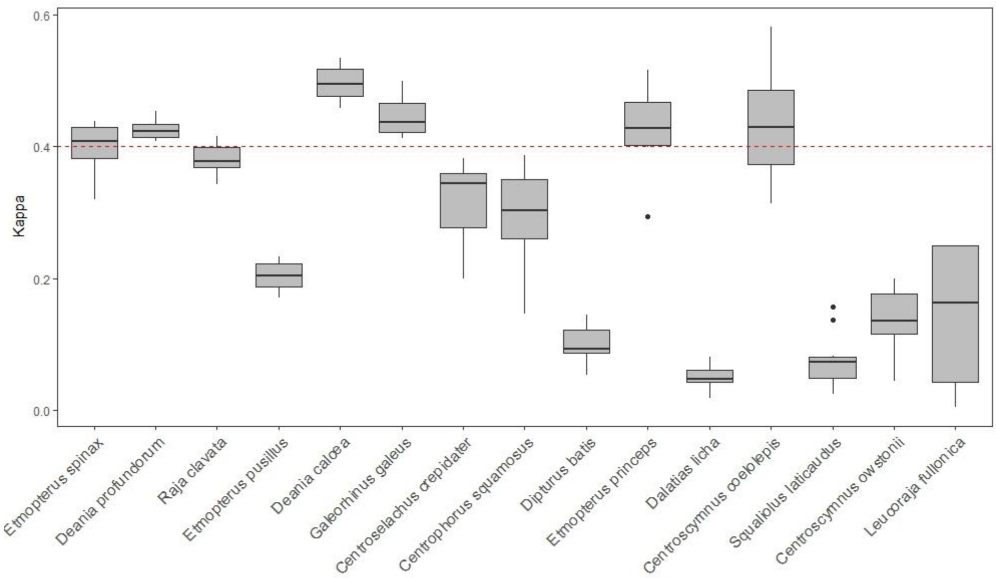


Figure 3. Performance of the model for each species based on (top) AUC, with values above 0.7 (dotted line) showing good predictions, and (bottom) Kappa, with values above 0.4 showing good predictions. Species were sorted by total number of individuals caught from survey data.

Retained predictors were depth, slope, aspect, bathymetric position index (BPI), nitrates, particulate organic carbon (POC) flux, and fishing effort. Depth was the most influential variable of species distribution, being a significant predictor in all models fits, the most important for 7 species, the second for the 3 remaining species (table 4). Aspect (northness / eastness) and nitrates rare also significant predictors for many species. Table 4 summarizes the importance of the predictors and their main effects on the probability of presence. The summary of the relative importance of all variables and partial plots of all models can be found in Appendix 1.

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Table 4. Retained predictors for each model, rank of the predictor within the model, and main trend of probability of presence with an increase in the predictor (only a difference of >0.1 probability of presence was considered an actual increase/decrease). Species are sorted from the shallowest to the deepest range based on survey data.

	DEPTH	NORTHNESS	EASTNESS	NITRATES	BPI	SLOPE	POC FLUX	EFFORT
Galeorhinus galeus	↓ 1	4	6	3 ↓	↓ 2	7	5	↑ 8
Raja clavata	↓ 1	5	4	2 ↓	~ 3	7	6	↑ 8
Etmopterus spinax	↑ 1	7	na	↑ 2	↓ 3	~ 4	5	↑ 6
Etmopterus pusillus	↑ 2	4 ~	6 ~	↑ 1	~ 3	↑ 8	~ 5	↑ 7
Deania profundorum	~ 1	5	6	↑ 2	~ 3	7	4	8
Deania calcea	↑ 1	4	3	2	↓ 5	7	6	8
Centroselachus crepidater	↑ 1	2	3	6	↓ 4	na	5	7
Centrophorus squamosus	↑ 1	2	3	4 ~	5	7	6	8
Centroscymnus coelolepis	↑ 3	2	1	5	4	8	6	7
Etmopterus princeps	↑ 3	1	2	5	↓ 4	na	7	6

Predictive distribution maps

Given that the depth is the predominant environmental variable affecting the distribution of most species, it appears logical that preliminary results of the species distribution models show a clear distinction between the species that occur in shallow waters, such as *Galeorhinus galeus* and *Raja clavata*, which habitat range is very reduced with presence exclusively restricted to coastal areas (figure 4), as opposed to the species that occur in deeper areas and for which potential habitat ranges are much wider, eg. *Deania calcea, Etmopterus princeps.* Some of the deepest species such as *Centroscymnus coelolepis* or *Centroselachus crepidater* have however a potential habitat range more restricted to the fewer areas with the most appropriate habitat characteristics.

Those results have to be interpreted carefully thought because the models explain a little part of the variance. Those results are also very sensitive to the selected threshold. Maps displaying probability of presence for each species are shown in Appendix 2.

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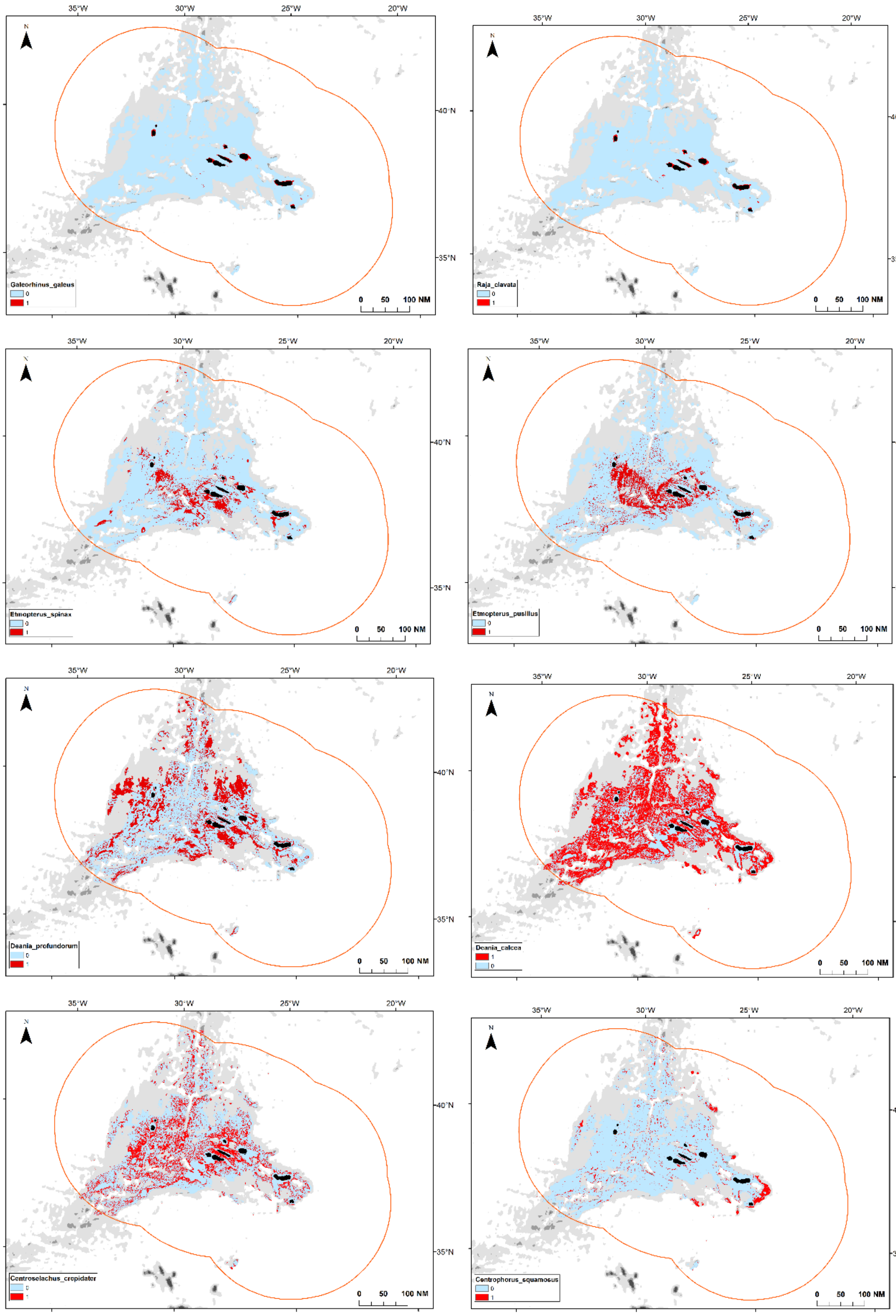
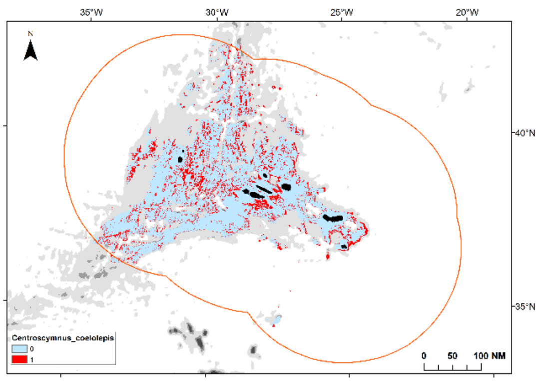


Figure 4. Predicted presence/absence map for each species. Species are sorted from the shallowest to the deepest average depth from survey data



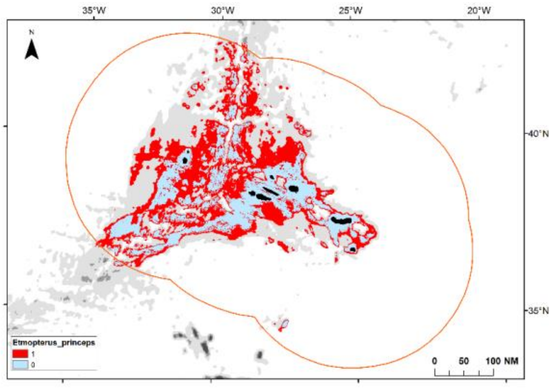


Figure 4. (cont.)

Preferential habitat model maps of deep-water sharks are presented in figure 5.

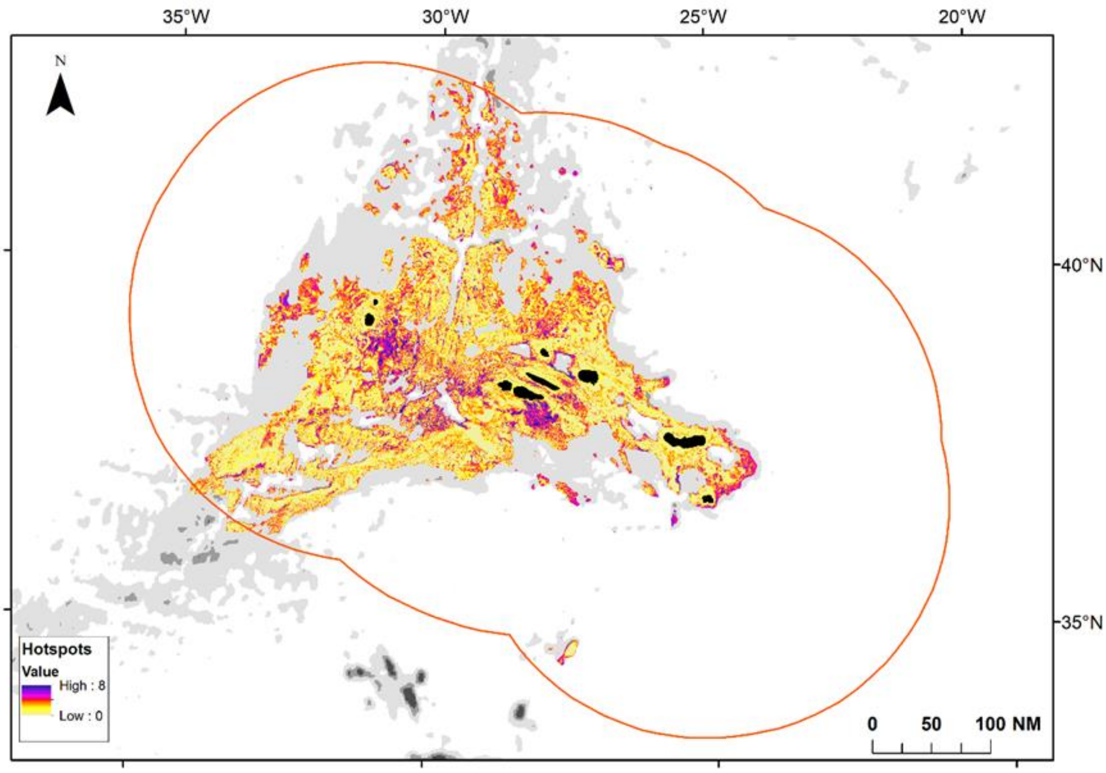


Figure 5. Deep-water elasmobranchs hotspots based on presence / absence distribution of the 10 selected species.

Maps of the main TAC 0 species caught by the two deep-water fisheries are displaying in figure 6 and 7. Those results are discussed in the final section about potential mitigation measures.

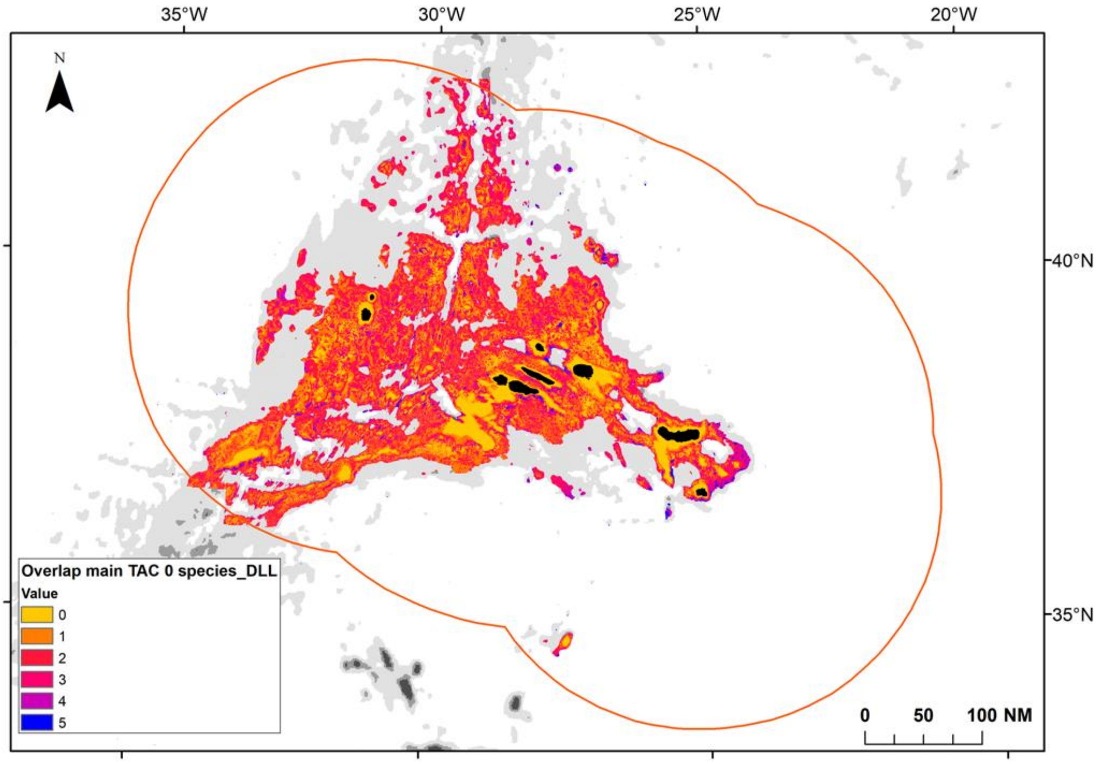


Figure 6. Hotspots of the main TAC 0 species caught by drifting deep-water longliners.

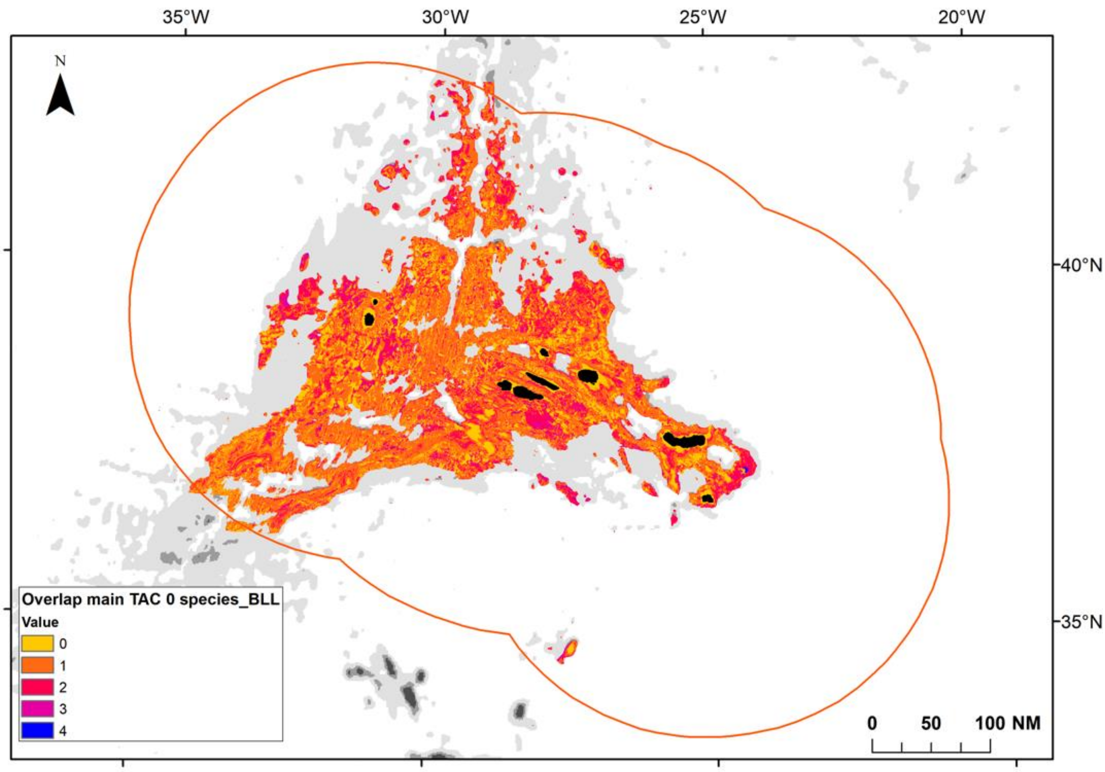


Figure 7. Hotspots of the main TAC 0 species caught by deep-water bottom longliners.

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a. Mapping Fishing Effort

Despite the large size of the Azores EEZ, the surrounding great depths and lack of continental shelf greatly limits the potential fishing areas. The fishing areas the most used by bottom longliners are mostly restricted to the coastal areas around the islands and the few shallowest seamounts around (figure 8).

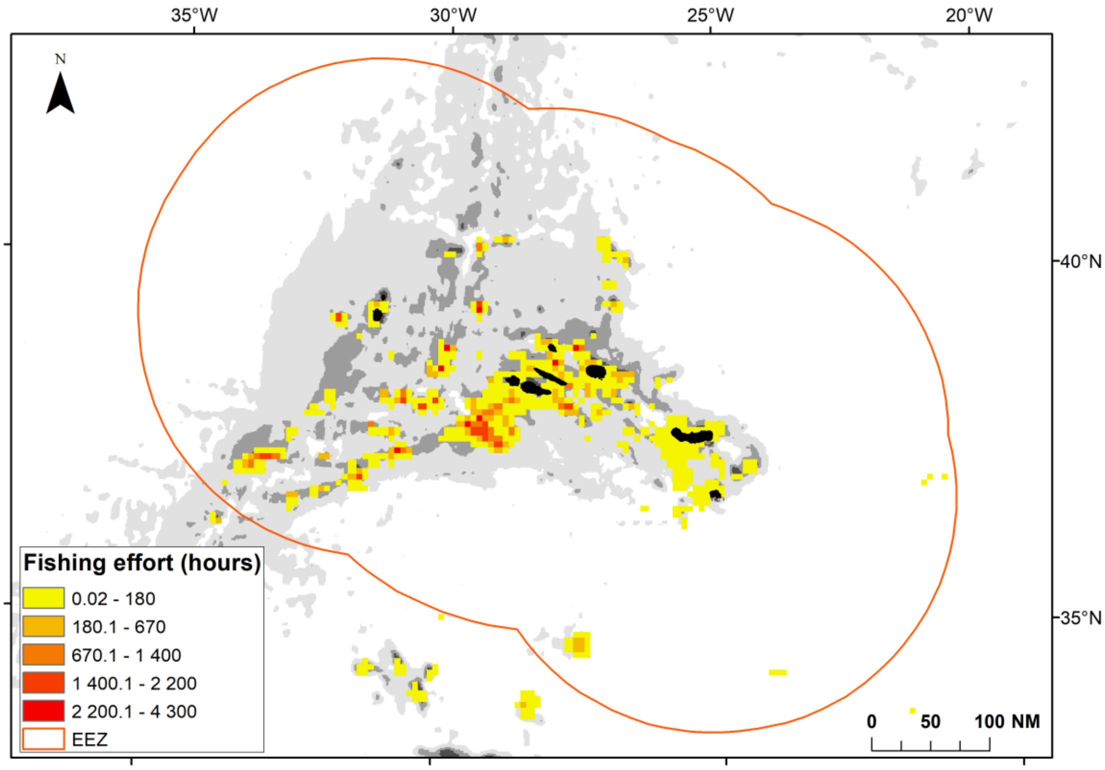

Figure 8. Distribution of the fishing effort (in number of hours fished) of bottom longliners based on VMS data.

2) <u>Fine-scale patterns using telemetry experiments</u>

We found kitefin shark to be quite resident in the overall study area, particularly the Faial/west Pico island slopes and the neighbouring Condor bank MPA (Figure 9). Overall, the Faial/Pico channel area appeared to be the habitat of higher use, with over 85% of total detections. A few animals eventually ventured into the S. Mateus bank south of Pico and nearby small peaks (Figure 10). Thus, this species apparently uses a large home range when compared to many other fish species, but is still resident in its range and most possibly uses intensively a particular core area within it. This finding is somewhat surprising if we compare this pattern with other studies skarks (e.g. tiger shark).

The sixgill shark showed a similar overall residency pattern, with the eight animals detected in the same receivers than kitefin skark. However, there was a contrasting behavioural difference in that sixgills apparently moved much more within their home range than kitefin sharks, as most animals were detected in the majority of the stations, including those around the islands of Faial and Pico.

Another interesting aspect is the diel pattern shown in the vertical habitat use of both species. Both kitefin and sixgill sharks spend some time in shallower (300-100 mt) waters during the nightime, meaning they eventually venture into the deep circalitoral habitats on the island shelves (Figure 11). However, again there is an acute difference in that kitefin sharks show a very marked diel pattern, animals going deep during the daytime, eventually becoming undetectable to the acoustic receivers. Sixgills, on the contrary, appear very 'stable at middle depths (300-400 mt) during daytime, also showing a curious expanded vertical niche at night. This might indicate that both species are mostly nightime active, and that kitefin sharks may take refuge at great depth from large predators, including sixgill sharks, during the daytime.

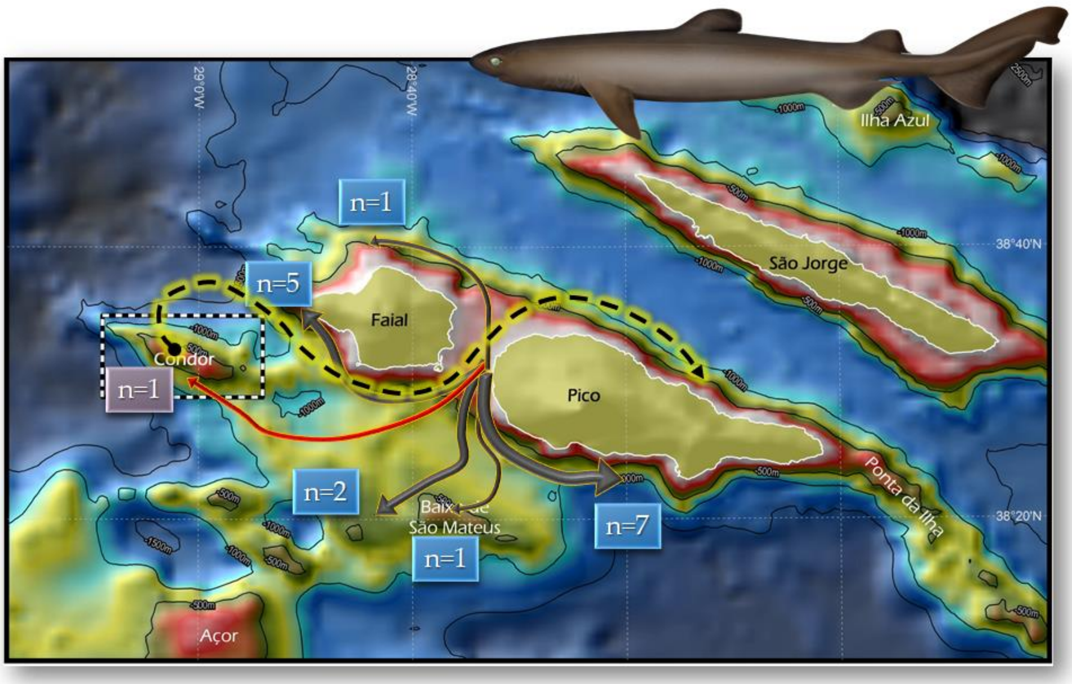

Figure 9. Graphical representation of the movement ranges of individual kitefin sharks tagged with acoustic transmitters at the south of the Faial-Pico channel and monitored using deepwater acoustic receivers in the islands' slopes and neighboring seamounts; boxes represent the number of sharks undertaking a particular movement.

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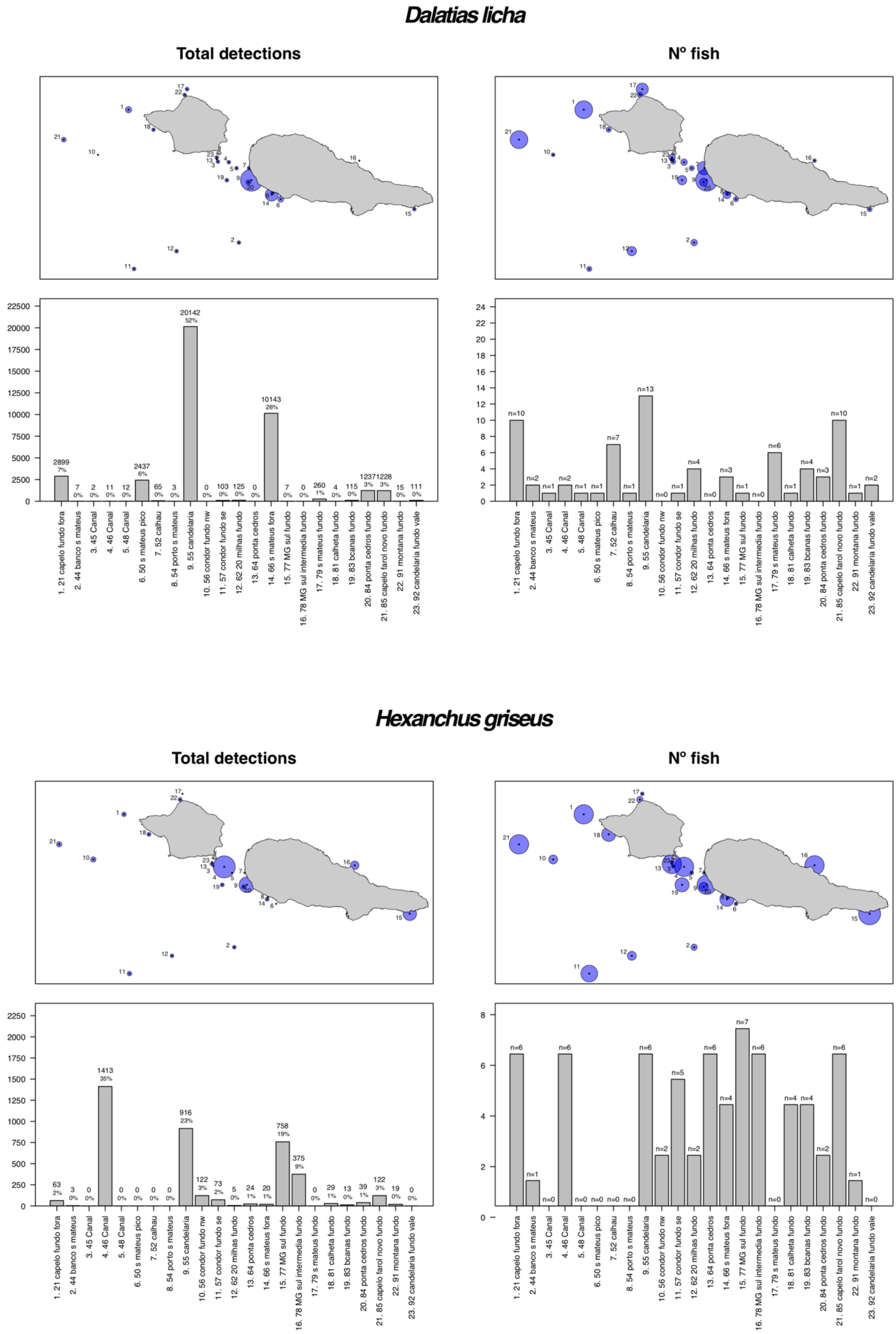

Figure 10. Total number of detections (A), number of fish detected (B), average of relative detection frequencies (C) and co-occurrence frequencies (D) per acoustic receiver of kitefin shark (upper panel) and sixgill shark (lower panel)

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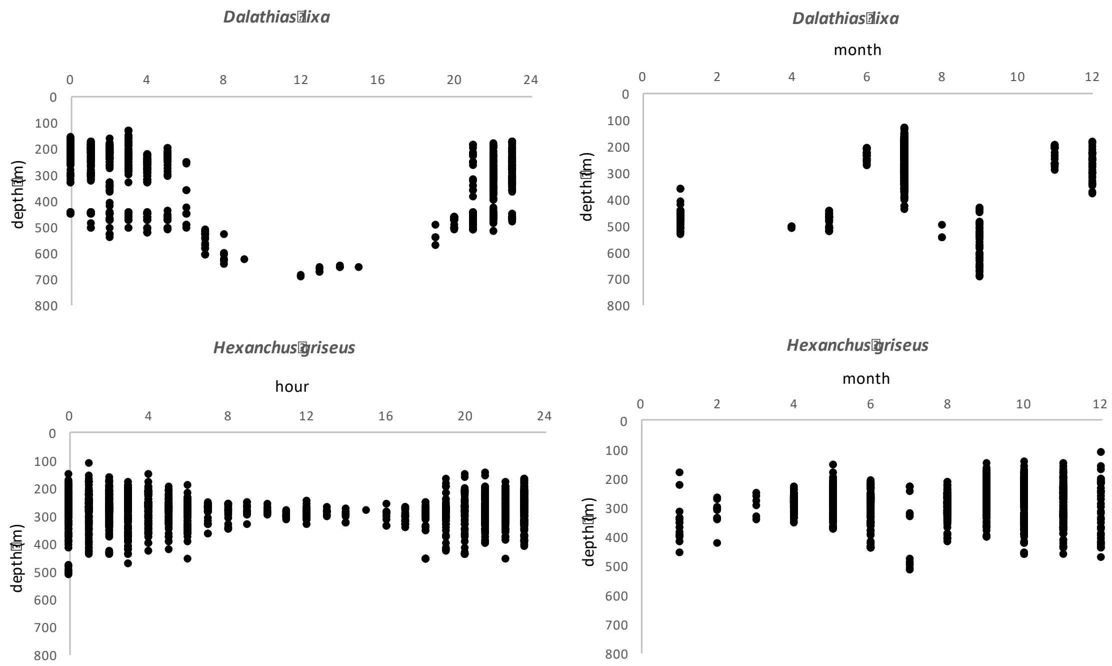

Figure 11. Diel (left) and seasonal (right) patterns of the depth at which kitefin sharks (Upper) and sixgill sharks (lower) were detected at the acoustic receivers.

Implications for shark bycatch mitigation measures

The ecological and fisheries effort data combined presented in this report are an update to the local knowledge of deepwater sharks and the potential vulnerability they face with regards to the interaction with local hooks and lines fisheries. It also allows us to draw some conclusions with regards to the potential of spatial and technical mitigation measures that can reduce the interaction with sharks and thus their by catch in Azorean fisheries. Nevertheless, it also needs to be acknowledged that the conclusions to be drawn from the spatial data presented here must be taken with caution because of the data limitations themselves.

Spatial mitigation measures – Areas to avoid fishing

The SDM models using the fishery survey data were, in various cases, not enough to produce robust enough results, even if they provide interesting indications. This was most evident in species for which there was not enough data. However, our results show some clear and useful trends.

When we consider the hotspots from the composite occurrence for the TAC 0 shark species ensemble that are caught by the bottom fishery, and compare it with the fishing effort hotspots (figure 8), an apparent mismatch becomes clear. In fact, the former are localized in deeper sections of the EEZ (greater than 800 m) when compared to the shallower fishing hotspots, as the bottom fishery targets essentially the seamounts down to the 600-700-800 m depth. This might also explain the relatively low overall levels of shark bycatch in the Azorean bottom fishery (Fauconnet et al. unpublished data). Thus, the current relatively small overlap appears to be beneficial in terms of keeping the main fishing effort away from the main deepwater shark hotspots, even if no other spatially-based measures are put in place to prevent catching those species. If that would be the case, then restricting fishing on the areas southwest of Pico and Flores, and northeast of Sta. Maria, could potentially reduce the interaction and bycatch. A different situation occurs with regards to the drifting deepwater longline, as it would be expectable that such fishery would target deeper areas, precisely at the depth ranges where most deep-sea sharks occur. However, this fishery has not gone over the experimental level in the region, therefore representing very small effort levels. However, a future shift in fishery trends might substantially alter this panorama. In particular, this could be the case if the deeper fisheries which have been exploratory so far (i.e. targeting black scabbardfish and common mora *Mora mora*), become more intense in the future.

Also, some species of sharks are still by-caught by the bottom fishery at higher levels, as they tend to inhabit shallower habitats. This is the case of the lantern sharks, the kitefin shark, and the sixgill shark. We provide data from telemetric experiments on the two latter. Our observer results and the models show those are not the most important species in terms of by-catch. Yet, if this is certainly the case for sixgill shark, it may not be so for kitefin shark, a species that occupies a shallower habitat envelope than most of the other by-caught sharks, and is most probably the species that interact the most with the handline and longline bottom fishery (occurred in 15% of the fishing operations sampled by onboard observers). Our acoustic telemetry data provides novel evidence that the spatial ecology of kitefin shark, with its apparent high residency, renders it an increased vulnerability to localized fishing and a plausible explanation for the putative collapse that the species went through in the 1980's after an intensification of the fishery. The results from the SDM for this species also appear to be in agreement with this evidence, although they did not provide a robust model. Taken together, these findings may imply that closing relatively small areas on each island/seamount is most probably not going to offer full protection to this species, which uses a larger home range across the year. Nevertheless, the increased use of some specific (core) areas within islands (and possibly seamounts) as found here shows that there might be particular functions associated to it, and that kitefin sharks should become more vulnerable to fishing in these areas. This seems to be the case of the area in the south slope of the Faial-Pico channel, which is an MPA under the regional law and also an OSPAR MPA. Therefore, the use of off-fishing areas for this species could still hold some promise if these are located on such hotspots and are of a size compatible with the increased habitat use. However, it is not yet clear if the essential habitat includes both the island slopes and the seamounts. Modelling the results of satellite and acoustic telemetry combined could provide the answer to this question.

The case of sixgill shark is different. This species is only occasionally caught in Azorean fisheries, and has no zero-quota imposing rule. The interaction with the fishery most probably occurs with minimal levels of immediate mortality, but delayed mortality caused by ingested hooks should not be discarded. This top predator is apparently less site attached within its home range than kitefin shark, which probably means that restricting its interaction with fishing gear would require larger off-fishing areas than those for the latter.

Technical mitigation measures

Another possibility is to orient fishing techniques using the species behaviour to avoid catching sharks. For example, the sharp diel behaviour shown by kitefin shark, whereby animals move to shallower areas during nightime and deeper grounds during daytime, may provide a solution based on the times of fishing. Handlining on the island slopes and shelves on areas of increased

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activity (see above) could be restricted to daytime if one would be to avoid interacting with the vertically migrating kitefin sharks. This type of measure could be combined with other measures concerning the gear (e.g. using nylon leader only) on those hotspot areas to, in combination, reduce the bycatch of unwanted sharks. A similar approach should be undertaken with the other key species, for which virtually nothing is known with regards to their individual behaviour and vertical envelopes.

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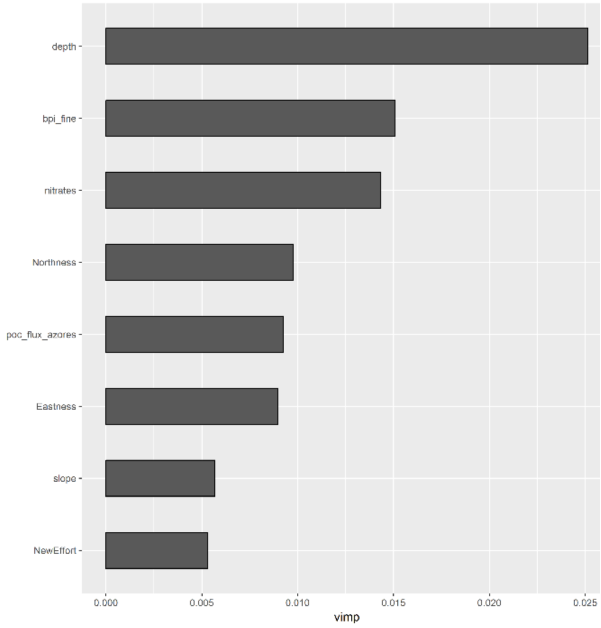
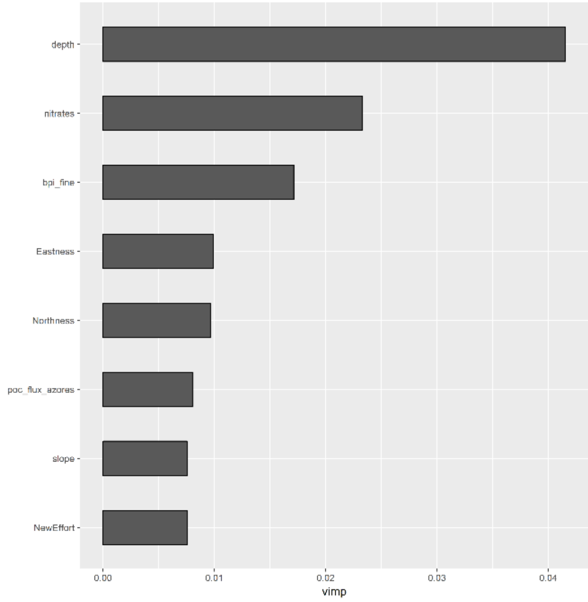
Appendix 1 – Variable importance by species for the binomial models. Species are sorted from the shallowest to the deepest average depth from survey data.

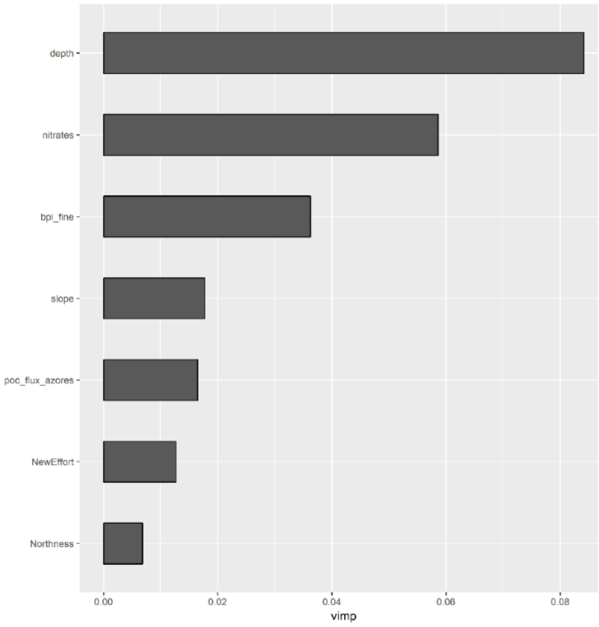
Galeorhinus galeus



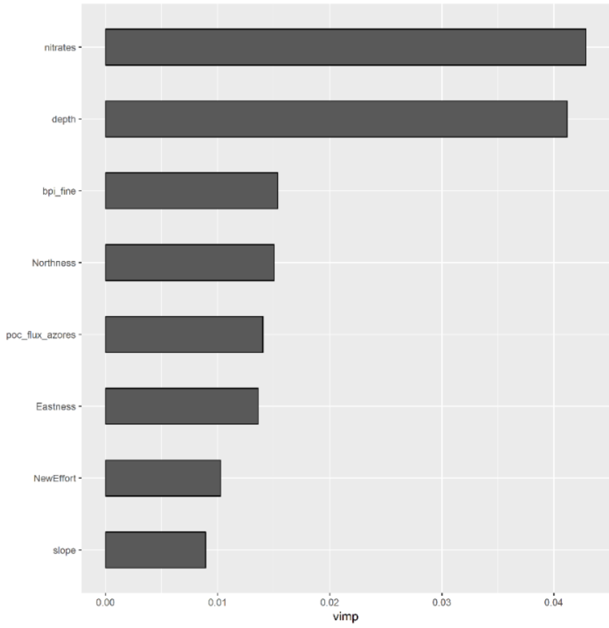
Raja clavata



Etmopterus spinax



Etmopterus pusillus



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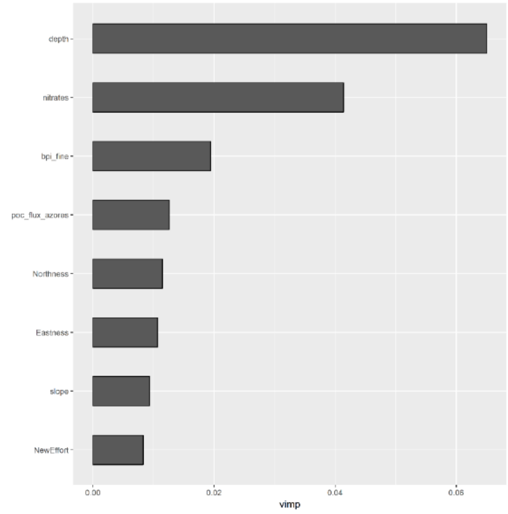
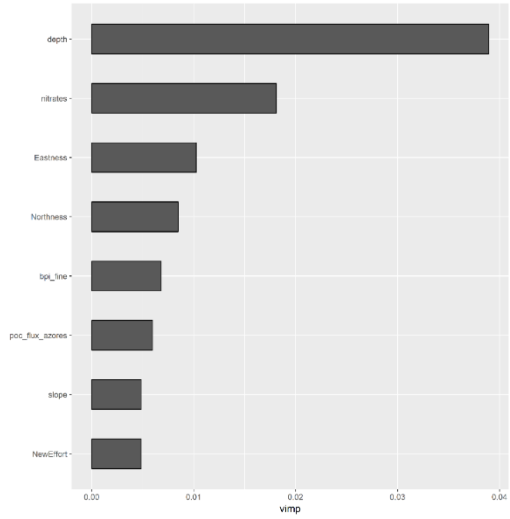
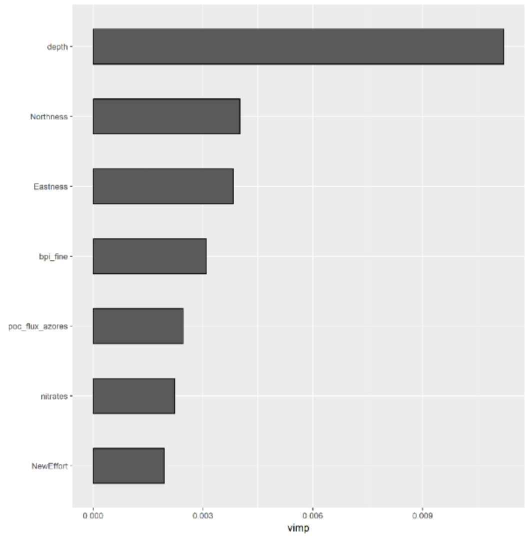
Deania profundorum



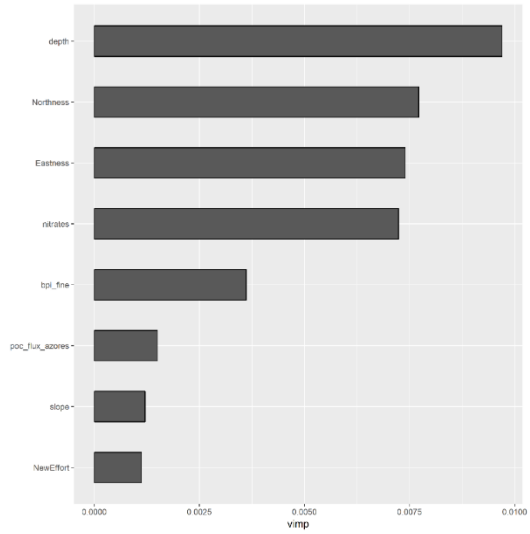
Deania calcea



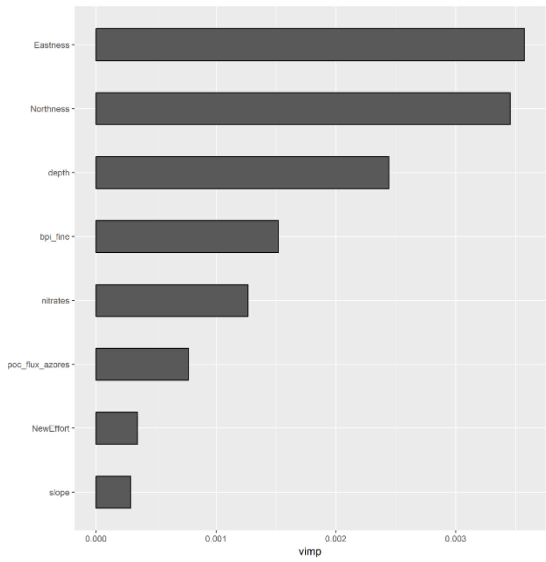
Centroselachus crepidater



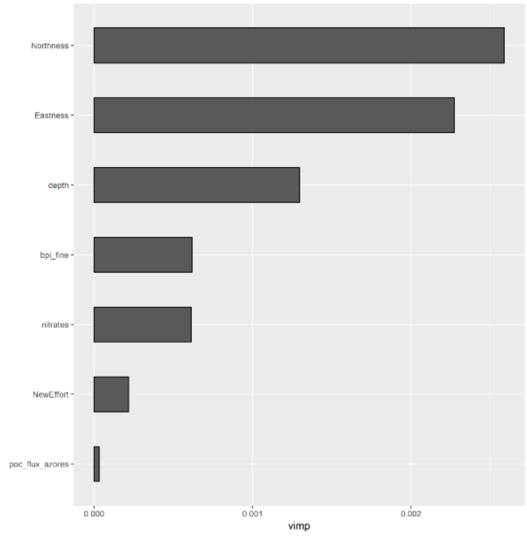
Centrophorus squamosus



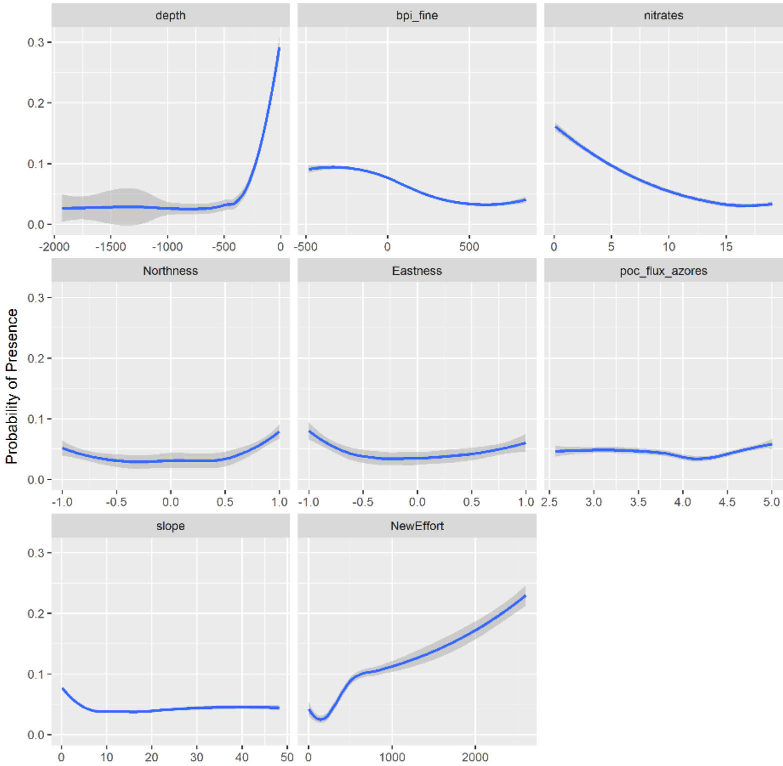
Centroscymnus coelolepis



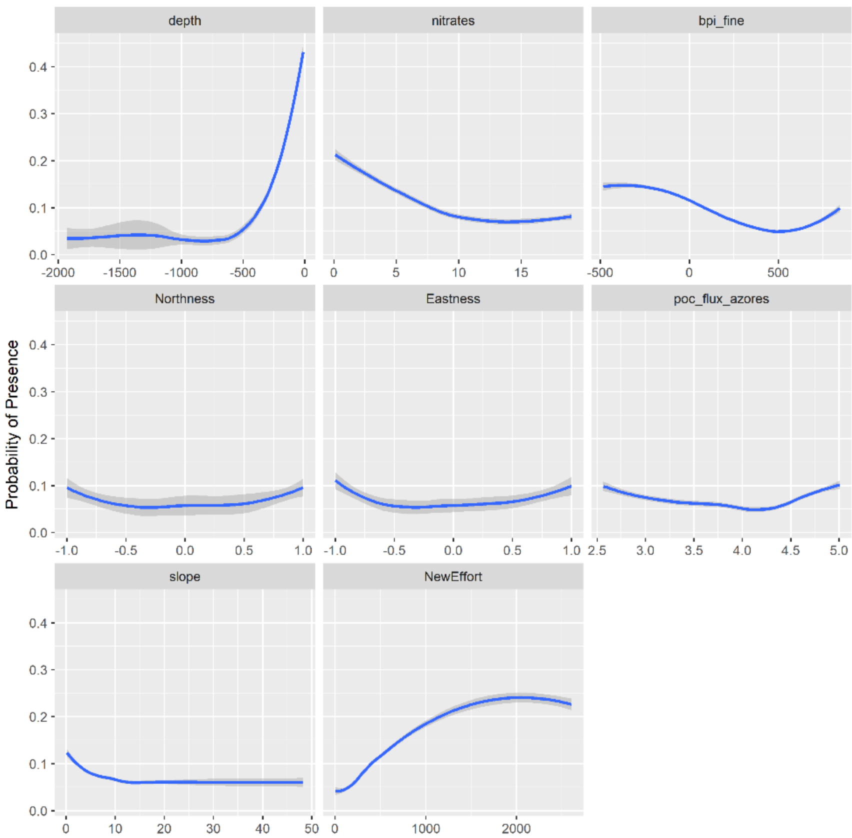
Etmopterus princeps



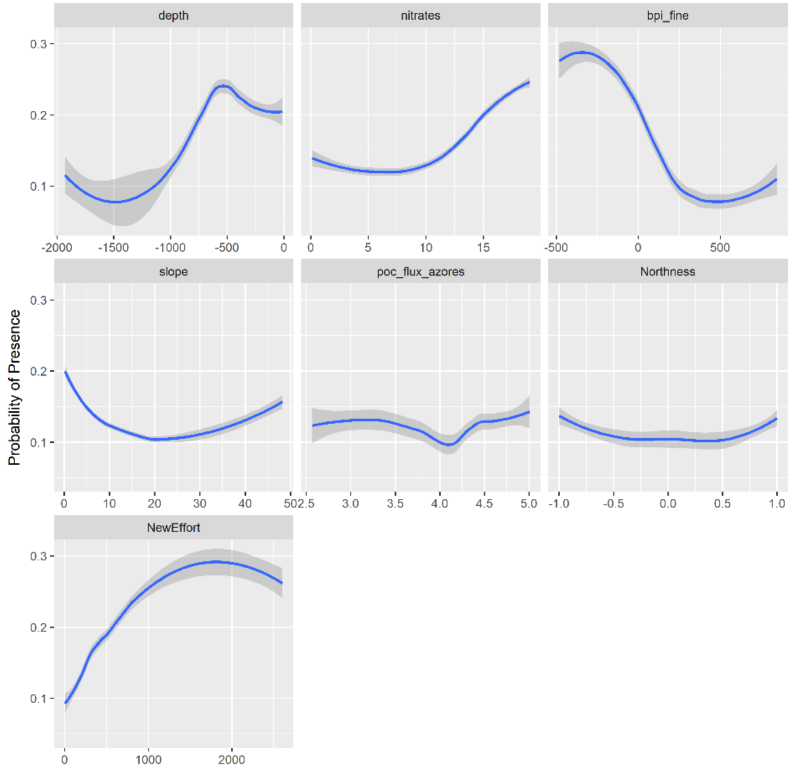
Galeorhinus galeus



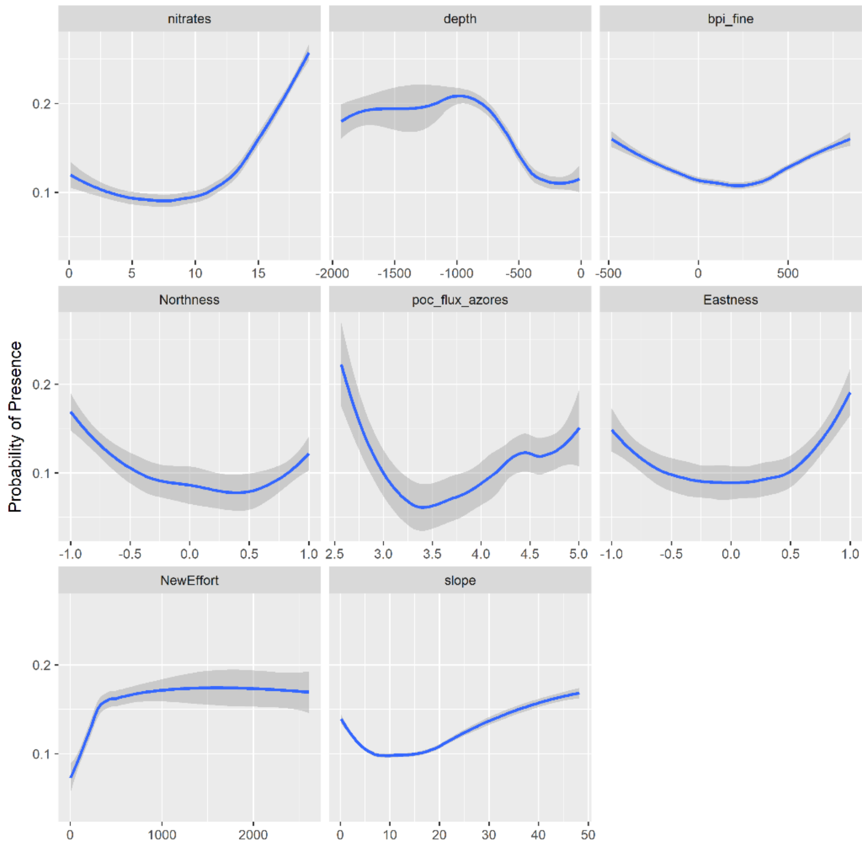
Raja clavata



Etmopterus spinax



Etmopterus pusillus



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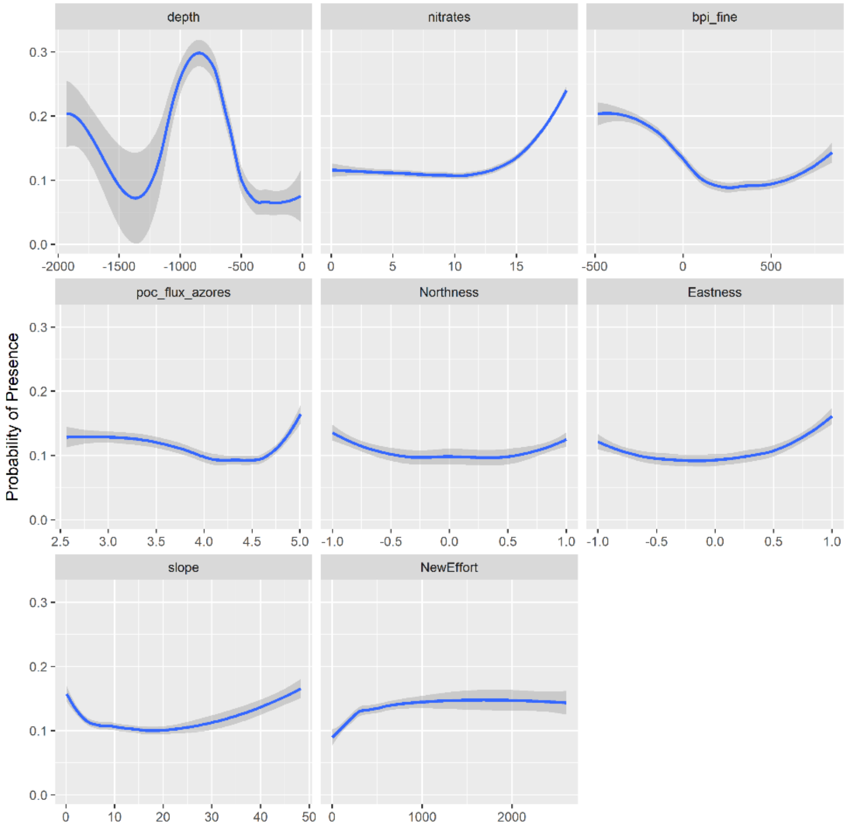
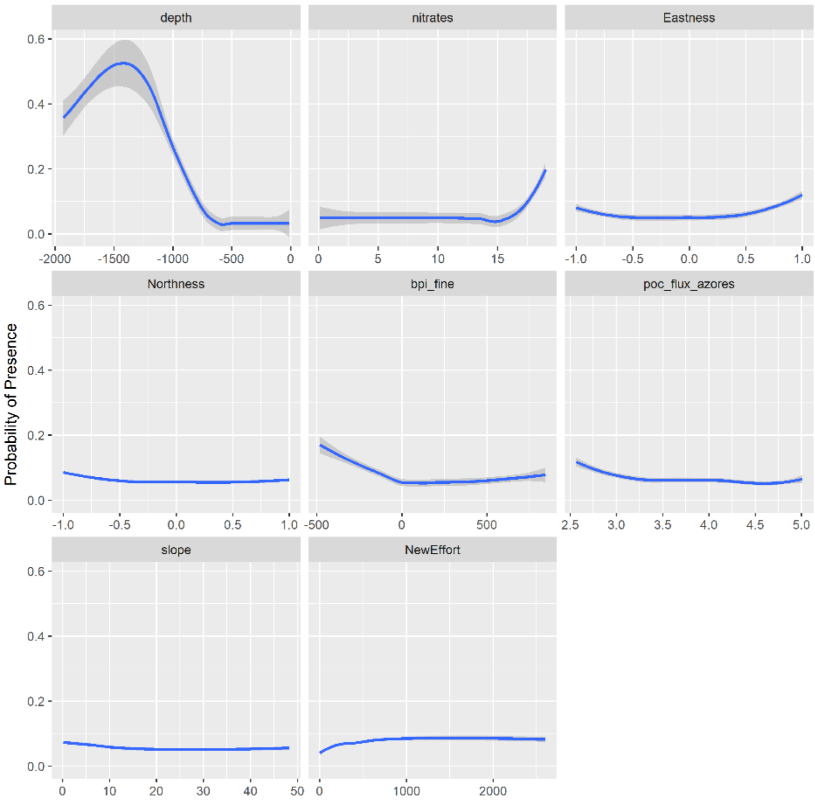
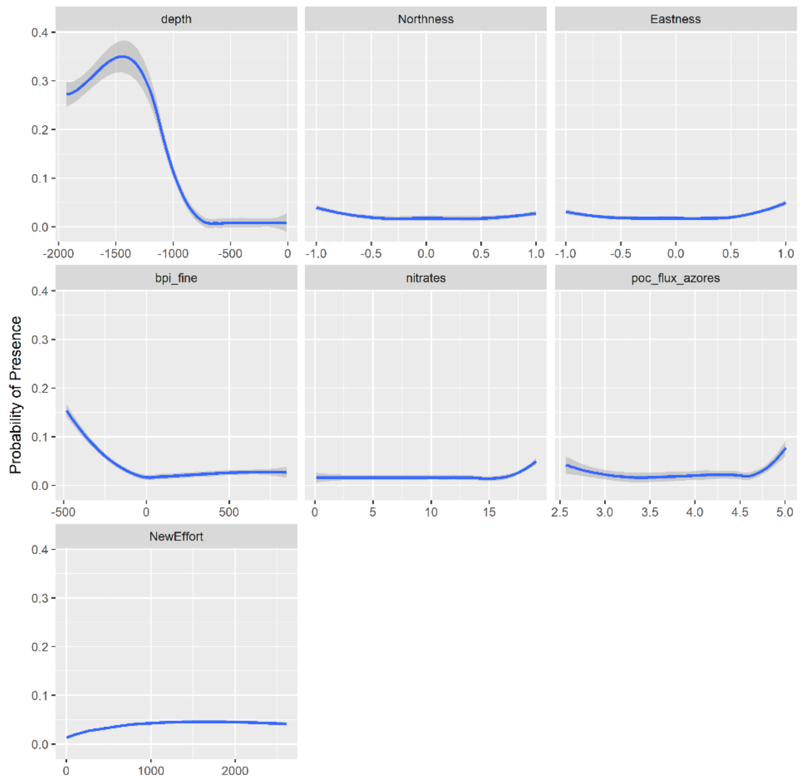


Deania profundorum

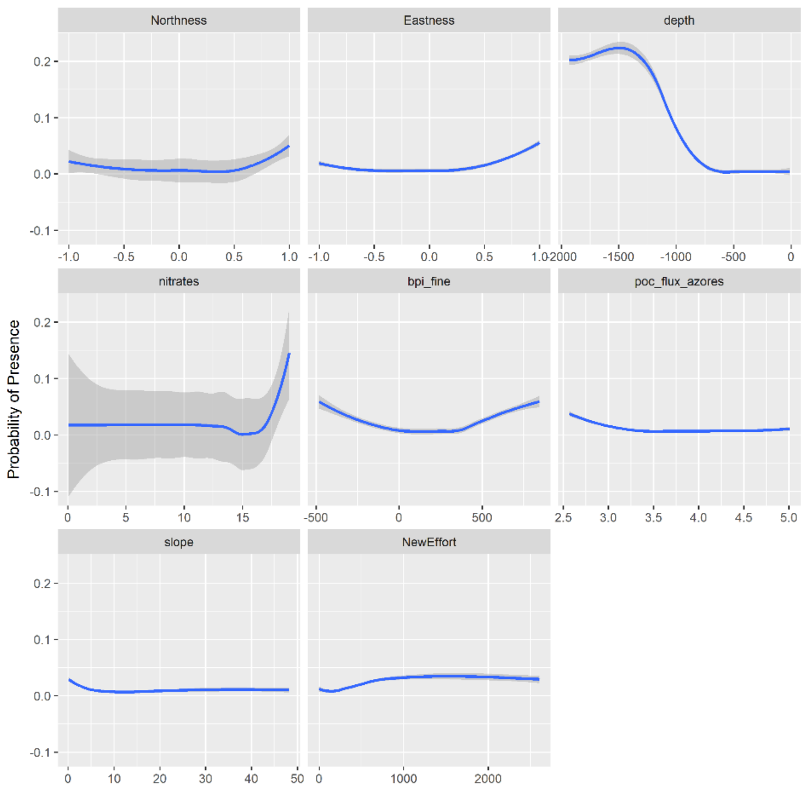
Deania calcea



Centroselachus crepidater

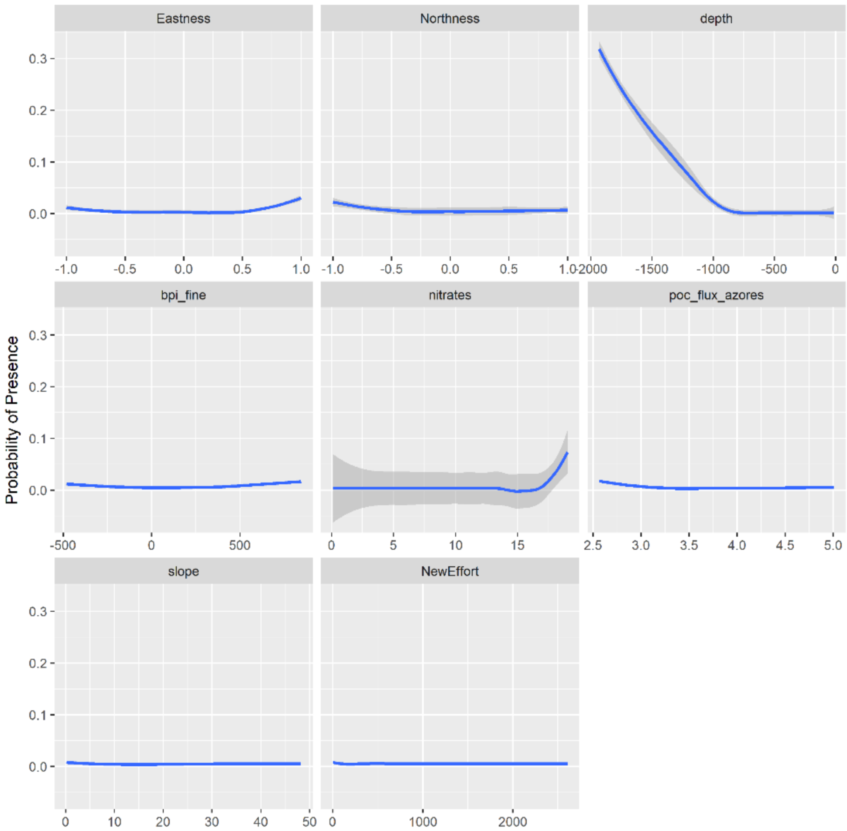


Centrophorus squamosus

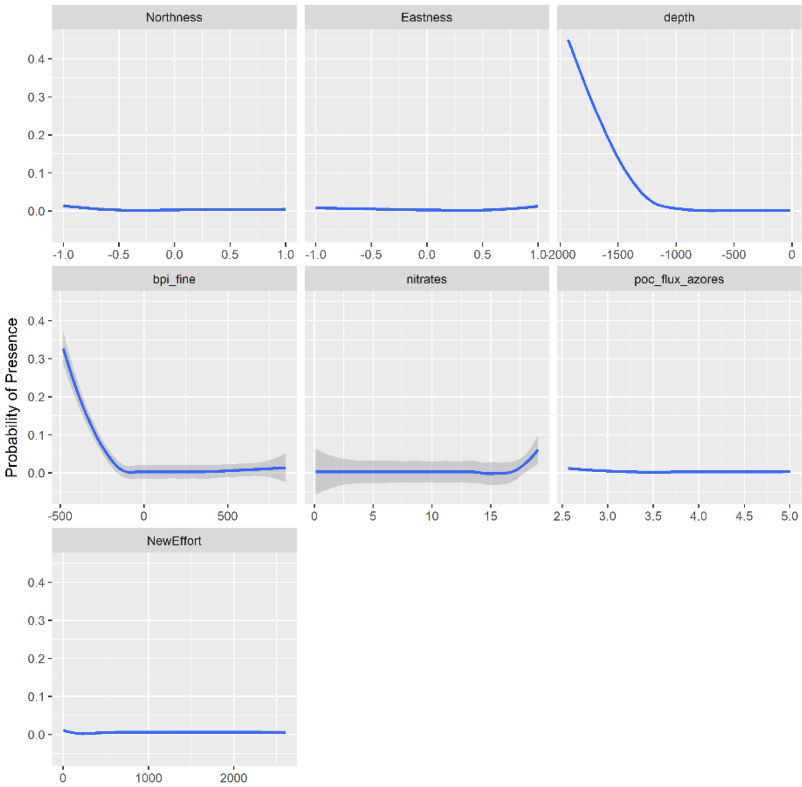


This project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement no. 633680

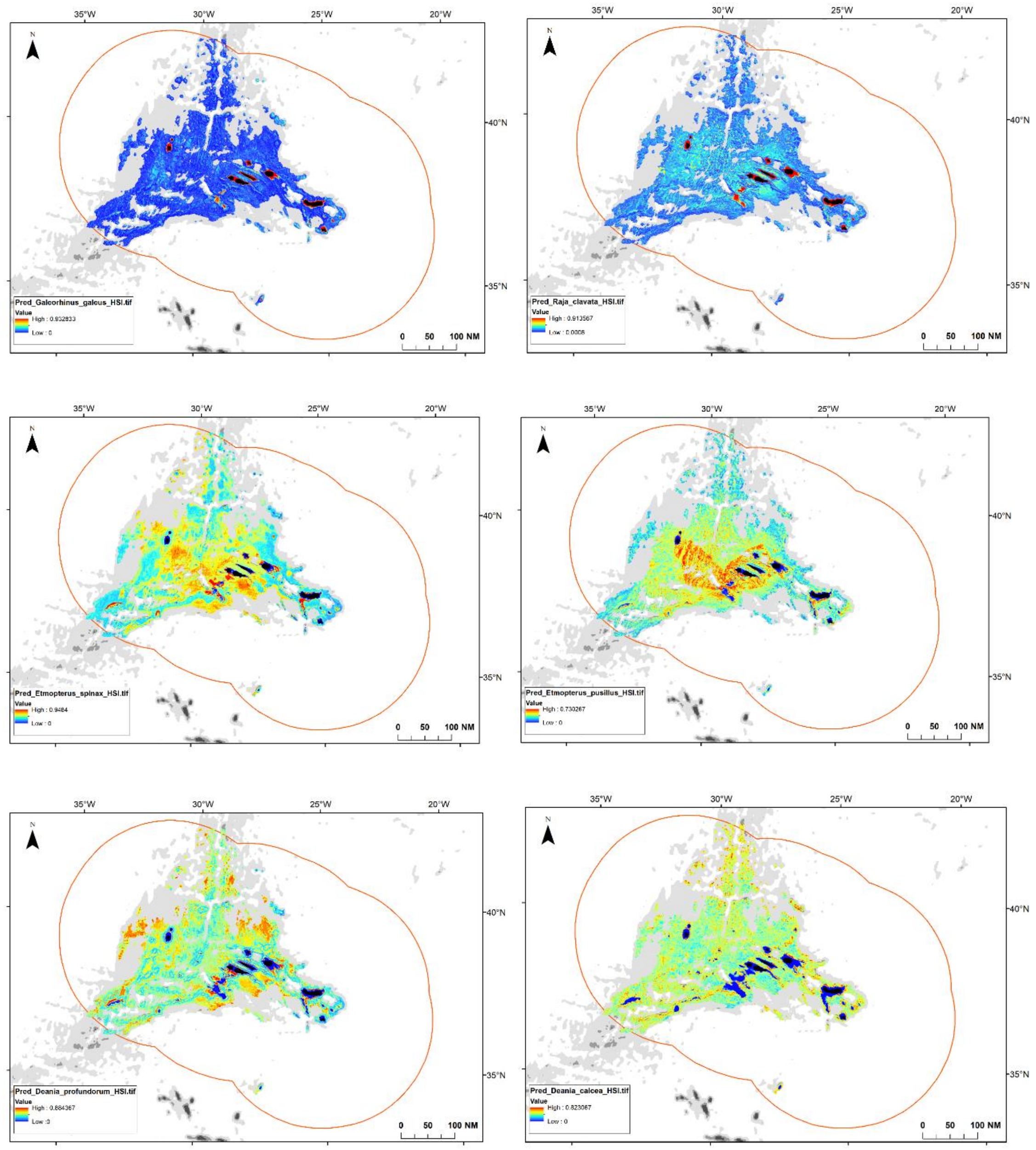
Centroscymnus coelolepis

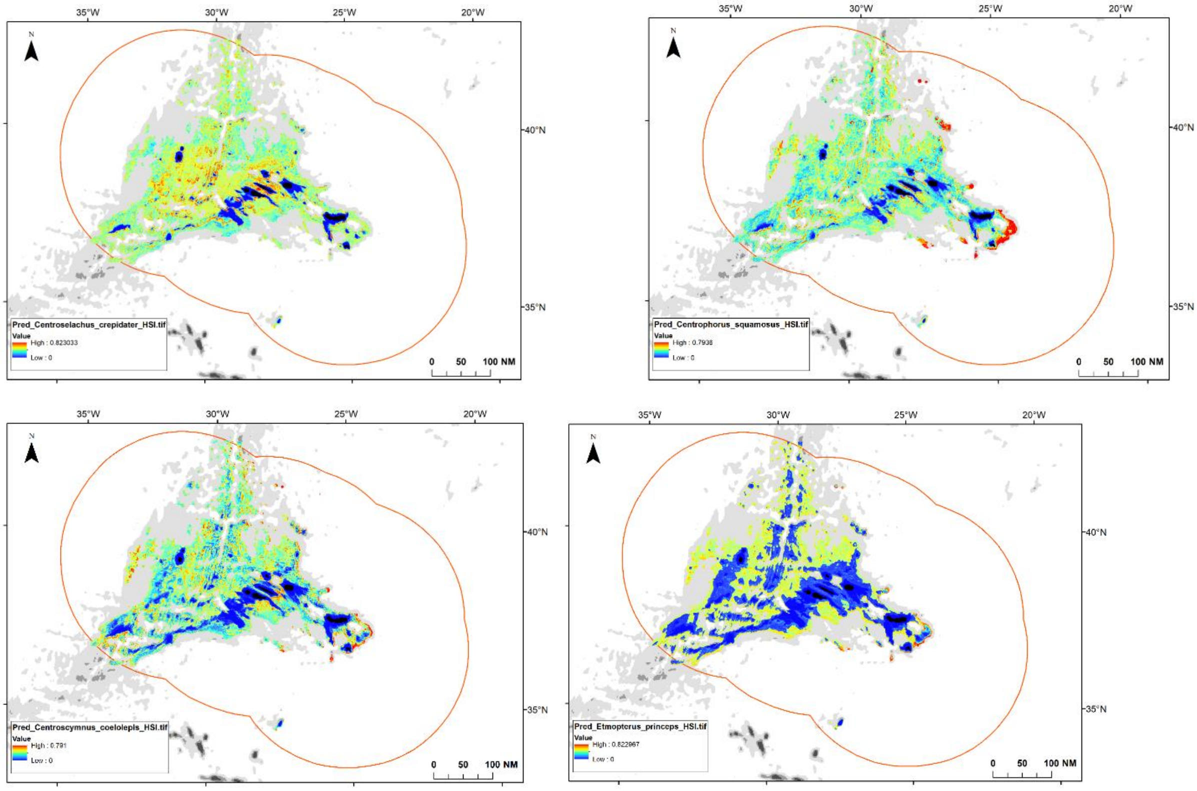


Etmopterus princeps



APPENDIX 2. Maps of predicted probability of presence for each species. Species are sorted from the shallowest to the deepest average depth from survey data.




35°W
30°W
25°W
20°W
40°N
35°N
Pred_Centroselachus_crepidater_HSI.tif
Value
High : 0.823033
Low : 0
0 50 100 NM
Pred_Centrophorus_squamosus_HSI.tif
Value
High : 0.7938
Low : 0
Pred_Centroscymnus_coelolepis_HSI.tif
Value
High : 0.791
Low : 0
Pred_Etmopterus_princeps_HSI.tif
Value
High : 0.822967
Low : 0

Chapter 13. Eastern Mediterranean - documenting suggested discard reduction fishing practice

George Triantaphyllidis and Ioanna Argyrou - NAYS

Eastern Mediterranean case study

Scientists in the Eastern Mediterranean and in the Mediterranean Sea in general, tend to highlight the fact that there is largely an apparent fisheries mismanagement in this area (Tsikliras 2014, Damalas 2015, Vasilakopoulos, et al. 2014). Overall, the Mediterranean is among the most overfished European seas, well beyond EU overfishing rates in the Atlantic or in the Baltic Sea. Between 1994 and 2014, Mediterranean catches declined from 1.020.000 to 800.000 tons, an impressive 20% reduction in just 20 years. All recent scientific reports in the Mediterranean present alarming data for the status of fish stocks:

- On average, 85% of assessed stocks are overexploited (FAO/GFCM 2016) (96% of EU stocks and 91% for stocks shared with non EU countries (EC 2016)).
- The General Fisheries Commission for the Mediterranean (GFCM) and the EU Scientific, Technical and Economic Committee for Fisheries (STECF) regularly assess the status of fish stocks in the Mediterranean. Out of 440 assessments published between 2007 and 2015, as much as 400 revealed fishing exploitation rates well beyond sustainable levels, 128 of which with rates five times higher than biologically sustainable limits.

Discard management plans for the EU Mediterranean fisheries under the reformed Common Fisheries Policy seems to be a mission impossible (Damalas 2015).

The MEDAC recommendation that has been adopted by the European Commission on 20.10.2016 with the Commission Delegated Regulation C (2016) 6606 final (EC 2016b), establishing a discard plan for certain demersal fisheries in the Mediterranean Sea, has been criticized in numerous meetings and open discussions. Many fisheries scientists caught in surprise and despite the fact that the competent authority for reviewing the Mediterranean JRs (STECF) concluded that none of them can be assessed, due to lack of information regarding the volumes of landings and discards, the European Commission adopted the plan. For many fisheries scientists, going through the text of the submitted JRs it becomes obvious that the essence of the regulation has been misrepresented by fishers who perceived the exemptions provided, as an escape-way from the obligation to land all catches and continue business as usual (Damalas 2015).

Commission Delegated Regulation (EU) No 1392/2014 established a discard plan for certain small pelagic fisheries in the Mediterranean Sea. That discard plan applies to small pelagic fisheries using pelagic mid-water trawl and/or purse seins (fisheries for anchovy, sardine, mackerel and horse mackerel). In order to avoid disproportionate costs of handling unwanted catches, it allows the discarding of a small percentage of catches of species subject to minimum sizes as referred to in Annex III to Council Regulation (EC) No 1967/2006 ('de minimis exemption'). Delegated Regulation (EU) No 1392/2014 expired on 31 December 2017 and was replaced by Delegated

Regulation (EU) 2018/161 of 23 October 2017 establishing a de minimis exemption to the landing obligation (LO) for certain small pelagic fisheries in the Mediterranean Sea.

In addition, Scientists express concerns for the new CFP and the LO in the Mediterranean (Bellido et al 2011, Sarda et al. 2015, Damalas 2015). For many Meditreeanean based scientists, the CFP was designed based on characteristics and needs of the Atlantic and North Sea fisheries, not considering the peculiarities of the Mediterranean fisheries (Machias et al 2017). The main differentiation of the Mediterranean fisheries are:

1. The Mediterranean EU fisheries production represents about 10.5% of the total fisheries production of the EU. However, this production derives from the 46% of the EU fishing vessels and more than 50% of the EU fishers. This is due to the fact that more than 80% of the Mediterranean fisheries fleet are less than 12 m LOA (Machias et al 2016).
2. The Mediterranean has an extensive coast line (more than 16.000 Km in Greece alone). This means, in combination with the above fleet characteristics and the market, that every spot in the coastline is a potential landing site. On the contrary in the Atlantic, there are defined places for landing fish and markets. This fact has as a result, in the Mediterranean the logistics of gathering the discards from numerous places difficult and with a high cost.
3. The Mediterranean has a small fisheries production but a rich biodiversity (catches are composed of numerous species many of which are not edible). These species are mainly of small size, with small life duration and usual high commercial values (Vassilopoulou et al., 2007). On the contrary, in North Europe are targeted relatively fewer species and their larger sizes, as fisheries management is through Total Allowable Catches (TACs) or fishing opportunities, i.e. catch limits (expressed in tonnes or numbers) that are set for most commercial fish stocks. TACs are shared between EU countries in the form of national quotas. Quotas promote high grading which is a practice of selectively harvesting fish (i.e. the larger ones) so that only the best quality fish are brought ashore.
4. In the Mediterranean there is a big differentiation in the types of the various fishing vessels, activities and metiers. This often results in acute competition between fishers and between fisheries activities.
5. The larger fisheries production in the Atlantic and the North Sea is due to the fact that the waters there are mesotrophic and the continental shelf is extended. On the contrary in the Mediterranean the waters are in general oligotrophic and the continental shelf is limited (Sarda et al 2015).
6. Despite the fact that in the EU Member States the participation of the fisheries in the GDP ranges between 0.01-0.2% without having a distinct differentiation between North Europe and the Mediterranean, many scientists consider that the socioeconomic importance of fisheries is higher in Greece and perhaps in the Mediterranean (Vassilopoulou et al 2007).

In the Mediterranean, fisheries management is done with technical measures (prohibition of using certain fishing gears in some areas, depths and seasons closures (e.g. in Greece), minimum conservation size) that often do not have a sound scientific basis (Stergiou et al 1997).

Many scientists believe that for the same reasons the LO is rather irrational for the Med (see Machias et al., 2017). They believe that the discards LO will not affect the quantities fished as in the Med there are no quotas (with the exception of Blue Fin Tuna and from now on for swordfish). Moreover, dietary habits in the Mediterranean, are different compared to North Europe and small (even undersized fish) is considered as a delicacy (gourmet). It is well known that there is an illegal market of fish below MLS. With the previous CFP it was considered illegal to have on board undersized fish (in order to prohibit to enter in the markets), an enforcement measure that is well adapted to the characteristics of the Mediterranean fisheries. There are fears that the discards LO will further increase this illegal market of undersized fish as now it will be allowed to the vessels to have the undersized fish on board (Machias et al., 2017).

Most scientists, agree and share the fishers' story and the technical difficulties that a landing obligation is about to bring. In brief, these difficulties mainly refer to the reduction of the vessel's storage capacity, the increase of handing costs and the lack of incentive to land discards. The first two conditions also hold for the infrastructure, facilities, capacity and staff availability at the landing port, which at the moment are completely insufficient to accommodate and handle increased amounts of landed quantities (Sarda et al. 2015).

For Mediterranean fisheries, the LO has the advantage of providing information for the actual quantities of unwanted catch that has been removed from the sea to fisheries and ecosystem models. In other words the once missing information of discards, which could have led to underestimation of total catch, is no longer missing. This will improve accuracy and predictive ability of stock assessment and will benefit fisheries management and marine policy but could have been acquired if a better system of monitoring fishing activities (mainly catches and discards) existed. The LO could also potentially benefit the aquaculture industry as large amounts of unwanted biomass would now be landed and be available at relatively lower cost to the fish farms.

The ecological disadvantage of the LO is that it does not provide any solution to the actual removal of undersized fish from the sea (Sarda et al 2015). One of the main issues in fisheries science and the targets of fisheries management has never been "what to do with the unwanted catch" but rather "how to avoid unwanted catch" and "select what we need from the sea" with respect to fish species and sizes within stocks. In a way, the LO provides an alibi for never resolving the unwanted catch issue and does not benefit the fisher or the marine ecosystem. It also serves the concept of "balanced" harvesting (Froese et al 2016), which has generated a serious debate in fisheries management (for a critique see Froese et al. 2016). Most scientists in the Mediterranean have been fighting for more selective fishing gears for decades and are rather skeptical with respect to enforcing the LO in the multi-specific Mediterranean fisheries.

Finally, eliminating discards may cause ecological cascading effects (Heath et al. 2014) because the discarded catches are a food source for scavenging species. Landing the entire catch may affect the populations of seabirds, marine mammals and seabed fauna, and has absolutely no benefit to fish stocks because fishing continues as usual. In contrast, if landing obligations are enforced together with regulations in fishing practices to limit the capture of unwanted fish the populations of seabirds, mammals and most fish stocks will be benefited (Heath et al. 2014).

Concluding, Scientists believe that the CFP has not succeeded in improving the state of European Mediterranean commercial fish stocks over the past two decades, in contrast to the European NE Atlantic stocks (Vasilakopoulos 2014). The increasing trend of exploitation rate observed in the Mediterranean, is particularly alarming because it is probably affecting many more stocks and species than the ones examined in this meta-analysis, due to the multispecies nature of the Mediterranean fisheries.

Conclusively, it has been identified that the current long-standing legislative framework (COM 1626/1994, COM 1967/2006), tailored to deal with the 'peculiarities' of Mediterranean fisheries by establishing an effort-based management scheme, has now become an immovable obstacle towards dealing with unwanted catches. Mediterranean stakeholders will have to decide if it is worth moving from an effort-based to a catch-based management system, or if the benefits realized by the former would be difficult to be counterbalanced under any other system (Damalas 2015).

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