Fisheries Research 219 (2019) 105310

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Defining métier for the Celtic Sea mixed fisheries: A multiannual international study of typology

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ARTICLE INFO

Handled by Bent Hermann

Keywords:
Metier
Multivariate analysis
Cluster
Mixed fisheries
Celtic Sea
Technical interactions
EBFM

ABSTRACT

There is growing international focus on ecosystem based fisheries management. Within the EU this has manifested in the provision of mixed fisheries advice, using the FCube model. The operational implementation and accuracy of this model relies on accurate identification of the technical interactions between fleets, gears and the resulting composition of species in the retained catch. These interactions are defined using units of fishing activity based on gear type and target species assemblage, but with no consideration for spatiotemporal heterogeneity. We assess the relevance of the fishing units used in relation to the spatial and temporal trends in retained catch within the Celtic Sea. To achieve this multivariate analysis (principal component and hierarchical clustering) were conducted to identify homogenous groupings of fishing activity using 5 years of international Celtic Sea retained catch data. The groupings identified demonstrate that a fairly simplistic structure of fishing activity units (country of provenance, fishing location, gear and target species) can effectively describe the complex mixed fisheries scenarios being executed within the Celtic Sea consistently across multiple years. This international and multiannual analysis improves our understanding of the mixed fisheries scenarios within the Celtic Sea and reveals a multifaceted spatial structure in the species assemblages landed, indicating the presence of several distinct mixed fisheries within the region appropriate for mixed fisheries analyses.

1. Introduction

The heterogeneity of abundance, distribution and stock status of demersal fisheries poses many challenges to their successful management. This heterogeneity is reflected in the combination of species fished, gears, vessels, and seasonal dynamics in fisher behaviour. Not accounting for this heterogeneity can result in flawed stock assessment and unsuccessful management (Hilborn and Walters, 1992). This is particularly true in the case of mixed fisheries where any haul or fishing operation will result in a combination of species which are managed under different and often conflicting single-species quota regimes. This may result in the most quota limited species becoming a choke species for the fishery with the potential to stop fishing in an area or risk substantial discards (Ulrich et al., 2011). As a result there is an increasing international push towards an ecosystem based fisheries management (EBFM), where multi-species and multi-fleet interactions can begin to be taken account of in management (ICES, 2013).

An ecosystem based approach to fisheries management is a goal now enshrined in European law, including the Common Fisheries Policy (EU, 2013a) and Marine Strategy Framework Directive (EU, 2008a). As a result, there is a growing number of ecosystem models in which fishing effort is being incorporated (e.g. ICES, 2017a). This is also reflected in management measures, with mixed fisheries catch options now being provided for a number of ecoregions, including the Celtic Sea (ICES, 2017b) using the Fleet and Fisheries Forecast model (FCube) (Ulrich et al., 2011; Ulrich and Reeves, 2008). The operational implementation and utility of FCube, and other mixed fisheries/ ecosystem based models, relies on the accurate identification of fishing units at an appropriate scale which properly identify differences in catch composition created from the technical and biological interactions between fleets, gears, and species (Ulrich and Andersen, 2004). Within the literature these units of fishing activity are defined in many

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https://doi.org/10.1016/j.fishres.2019.105310
Received 12 November 2018; Received in revised form 3 June 2019; Accepted 15 June 2019
Available online 20 June 2019

ways including; métiers (i.e. Marchal and Horwood, 1996), fishery (i.e. Lewy and Vinther, 1994), and fishing tactics (e.g. Pelletier and Ferraris, 2000). These definitions have evolved over time, but the most recent official definition of units of fishing activity used by the European Commission (EC) Data Collection Framework is that of métier as a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern (EU, 2016). By aggregating fishing activity into these homogenous fishing units, it is possible to reflect the true nature of a fishery (ICES, 2003). Homogeneity within unit of fishing activity can provide more effective estimates of catch per species, directed fishing effort and partitioning of fishing mortality (Pelletier and Ferraris, 2000). However it is important to ensure that the unit selected correctly captures the fishing activity within an area and that the right level of contrast is used to capture both spatial and temporal differences between the fishing units (Holley and Marchal, 2004; Mateo et al., 2017). Understanding this level of contrast is now particularly critical within Europe due to the implementation of the landings obligation (EU, 2013b), where poorly specified units of fishing activity could result in inaccurate assessments and forecasts, increasing the risk of "choking" fleets (Mortensen et al., 2018).

The Celtic Seas (ICES Division 7bc,e–k, excluding 7d) are an area of highly mixed fisheries, targeting a range of species with different gear types (ICES, 2017a). To capture this diversity in fishing activity, retained catch data is submitted by Member States to the International Council for Research of the Sea (ICES) in units which are consistent with DCF métier level 6 (2010/93/EU Appendix IV) and incorporate the additional information of vessel length. This results in retained catch being aggregated to a fishing's unit which incorporates the key trip variables of gear, mesh size, target assemblage, and vessel length. Since 2015, the FCube forecast has been produced using fishing activity in units which are consistent with DCF level 5 (2010/93/EU Appendix IV), which describes fishing activity using key trip variables of gear and target assemblage. However, the relevance and effectiveness of DCF level 5 to describe the diverse heterogeneous fishing activity within the Celtic Sea has not previously been evaluated. Therefore, this established ICES data call and mixed fisheries framework provide a valuable opportunity to test the assumptions of fishing activity categorisation.

The objectives of this analysis were to: (i) assess the relevance of the current units used to describe fishing activity within the Celtic Sea; (ii) explore possible improvements to this typology based on spatial and inter-annual temporal trends in retained catch; (iii) and finally to explore refining these definitions with a view to improving mixed fisheries modelling capability. The utility and application of this work will be discussed in terms of our understanding of mixed fisheries within the Celtic Sea and wider implications for management.

2. Materials and methods

2.1. Data

This analysis is based on international retained catch data submitted to the ICES Working Group on Mixed Fisheries (WGMIXFISH) in 2016, which consisted of data from six countries (Belgium, Ireland, France, Scotland, England (inc. Wales) and Northern Ireland) from 2011 to 2015. This data contains effort and retained catch information for vessels operating in the Celtic Sea (VII bc,e–k). The retained catch component of the data is summarised to a single categorical variable consistent with DCF métier level 6 (2010/93/EU Appendix IV), containing three key trip variables: gear type; target assemblage; and mesh size. These three key trip variables are then combined with country (flag of vessel provenance), area (ICES Division), vessel length class, and year of retained catch. Therefore providing a description of fishing activity which is aggregated to the level of year and ICES Division.

Prior to analysis, data was subjected to initial screening to remove unusable records. Fishing units that were considered unrepresentative of the demersal fishery in the Celtic Sea were removed, i.e. fishing units which contained very low retained catch volumes (< 1% of cumulative tonnage of the data submission), or fishing units which contained > 80% of the species category "other". Catch of pelagic species and non-quota demersal species are reported to WGMIXFISH under the species category of "others". Removal of this species category reduces the data set by 64% of the original total catch.

The final data set included 8 gear types (trammel nets (GTR), gill nets (GNS), longliners (LLS), bottom otter trawler (OTB), mid water otter trawler (OTM), multi-rig otter trawler (OTT), seine nets (SCC), and beam trawler (TBB)). Which were further divided into target assemblages of demersal (DEF), crustacean (CRU), finfish (FIF) or molluscs (MOL), resulting in a total of 17 unique units of fishing activity. In the case where gear or target assemblage were not declared, this miscellaneous fishing unit was labelled as "MIS_MIS". This dataset covered 8 ICES divisions, with retained catch that totalled 2,031,379 tonnes over the 5 years. All analyses were performed within the R language and environment for statistical computing (R Core Team, 2017). The analysis focussed on 14 main demersal species: monkfish (ANF, *Lophius piscatorius* and *Lophius budegassa*), cod (COD, *Gadus morhua*), haddock (HAD, *Melanogrammus aeglefinus*), hake (HKE, *Merluccius merluccius*), megrim (LEZ, *Lepidorhombus whiffiagonis* and *Lepidorhombus boscii*), ling (LIN, *Molva* spp.), *Nephrops* (NEP, *Nephrops norvegicus*), plaice (PLE, *Pleuronectes platessa*), pollack (POL, *Pollachius pollachius*), saithe (POK, *Pollachius virens*), aggregated ray and skate species (RJA), aggregated dogfish species (SDV, *Squalidae* spp.), sole (SOL, *Solea solea*) and whiting (WHG, *Merlangius merlangus*). All remaining species were grouped together into one "other" group (OTH). The other group consisted of a wide range of species types including teleost fish, cephalopods, elasmobranchs, and molluscs.

2.2. Fishing unit descriptions

A multivariate clustering framework was applied to identify groups of homogeneous métiers that describe fisheries currently being executed in the Celtic Sea based on proportions of species in retained catch and key trip variables provided. The framework builds on the approach taken by Pelletier and Ferraris (2000) and developed by a number of other authors (Davie, 2013; ICES, 2003; Ulrich and Andersen, 2004). This framework combines the use of quantitative multivariate analysis of retained catch data with qualitative expert knowledge, avoiding prior assumptions on homogenous groupings. Firstly, trends in the percentage composition of species within retained catch profiles were identified using non-normalised Principal Component Analysis (PCA) allowing for species dominance. PCA reduces the dimensionality of a dataset and identifies the main reoccurring species combinations that explain the greatest variation. Components are presented in order of importance, with the greatest variation described by the first component (Fowler et al., 2004). Secondly, a Hierarchical Agglomerative Cluster analysis (HAC, utilising Euclidean distance and Ward's algorithm (Ward, 1963)) was run on the principal components outputted from the PCA, to create successive clusters based on previously identified clusters, building a hierarchy from individuals to a single group (Davie and Lordan, 2011; Holley and Marchal, 2004; Pelletier and Ferraris, 2000). Determination of the appropriate number of clusters to employ was considered to be the level at which the increase in the proportion of variance explained levelled off (Ulrich and Andersen, 2004). Some clusters were then pooled using expert knowledge to avoid unnecessary complexity and excessive disaggregation. This pooling was necessary in a small number of cases to retain important information on the structure of the dataset whilst preserving integrity for future analysis (Anon, 2005).

This multivariate analysis was run nine times, each run incorporating different key trip variable combinations currently available to WGMIXFISH. Four key trip variables were available to test: gear;

Table 1
The structure and results of the six principle component (PCA) analysis runs on Celtic Sea retained catch profiles. The fishing activity executed in each analysis is aggregated to a different level based on the included key trip factor variables. The optimum run (6) has been highlighted and underlined.

PCA	Key Trip Factor Variables		PCA Results		
	Variables Included	Variables excluded	Clusters	Variance explained by 4 components	No. of clusters required to explain > 90%
1	Country + Year + ICES Division + Gear + Target spp. + Mesh Size + Vessel Length	0	19	73%	8
2	Country + Year + ICES Division + Gear + Target spp. + Mesh Size	Vessel Length	18	75%	7
3	Country + ICES Division + Gear + Target spp. + Mesh Size	Year + Vessel Length	18	77%	7
4	Country + ICES Division + Gear + Target spp. + Mesh Size + Vessel Length	Year	24	73%	8
5	Country + Year + ICES Division + Gear + Target spp.	Mesh Size + Vessel Length	20	79%	7
6	**Country + ICES Division + Gear + Target spp.**	**Mesh Size + Vessel Length + Year**	**19**	**82%**	**6**
7	Country + ICES Division + Gear	Mesh Size + Vessel Length + Year + Target spp.	17	62%	14
8	Country + Gear	ICES Division + Mesh Size + Vessel Length + Year + Target spp.	17	70%	16
9	ICES Division + Gear	Country + Mesh Size + Vessel Length + Year + Target spp.	17	73%	16

target assemblage; mesh size; and vessel length. Additionally, a temporal variable of catch year and spatial variable of ICES Division were tested. The country of provenance was included as a variable in eight of the nine runs as it provides an important economic identifier which is required in the production of advice and the distribution of quotas. The run, and key trip variables, which explained the most variation in the retained catch data were then subsequently described with expert knowledge and proposed as an appropriate framework for defining fishing activity units in future Celtic Seas mixed fisheries modelling.

3. Results

Each of the nine runs varied in the number of clusters produced and in the level of variation they explained (Table 1). Run 1 incorporated all four fishing activity descriptors (gear; target assemblage; mesh size; vessel length) and explained the least variation in the data set (73% variation explained in first four components; Table 1). Run 6 incorporated two fishing activity descriptors, fishing gear and target assemblage and explained the most variation in the retained catch (82% variation explained in first four components; Table 1), and was therefore considered to be the best descriptor of the trends in the dataset and the focus of this paper.

Run 6 excluded the descriptive variables mesh size, vessel length, and year, as they were not found to be drivers of clustering in the other runs, and were therefore not considered key drivers of fishing activity in the Celtic Sea. Run 6 utilises two just fishing activity descriptors, fishing gear and target assemblage. The first four components of the run 6 PCA were considered as a relevant description of the relationship between species compositions of retained catch profiles (82% variation). A bi-plot showing the first and second PCA components, explaining 34% and 18% of the variance respectively, is driven by a separation of *Nephrops* into the top right hand corner, with additional separation of monkfish and then “others” (Fig. 1a). The third and fourth components explain 17% and 13% of the variance respectively, across these components separation of monkfish and hake occurs (Fig. 1b). These same separations can be clearly identified in the results of the HAC.

The HAC in run 6 resulted in 19 clusters, each cluster accounted for a wide range in the weight of retained catch, from 2 to 117 tonnes, with a varying number of fishing activities per cluster (1–13). Due to the low retained catch weight of cluster 13 (2 tonnes) it was recombined with cluster 12, which showed similar fishing activity characteristics in area, gear, target assemblage and retained catch profiles. This resulted in 18 clusters, each representing a homogeneous grouping of fishing activity. Some clusters included fishing activity executed by multiple nations, across a number of ICES Divisions, while others were nation or area specific. Using expert knowledge each cluster was described in terms of fishing activity and retained catch profiles, to determine the homogeneous unit of fishing activity that it represents (Table 2). The distinct characteristics of these clusters were mapped to visualise the spatial trends in key trip variables and clusters (Fig. 2).

Each cluster is considered to represent a homogenous unit of fishing activity within the Celtic Sea. Many of these homogenous units are executed by multiple countries across multiple regions and can be defined as truly mixed fisheries. The majority of the Celtic Seas retained catch from 2011 to 2015 were caught in ICES Division VIIe (37,818 t/yr). More than 90% of this retained catch is captured by two distinct fisheries, the French Channel fishery (15,649 t/yr)(cluster 11, Table 2d, Fig. 2a) and the French hake directed set net fishery (23,543 t/yr) (cluster 17, Table 2a)(Fig. 2a). Both of these fisheries are characterised by mixed gears, with the landings from the French Channel fishery being dominated by the “other” species (50%) category (most likely dominated by molluscs and cephalopods), while the French hake directed set net fishery represents being dominated by one species (90%) (Table 2a).

This analysis revealed a high diversity in set net fisheries (Table 2a).

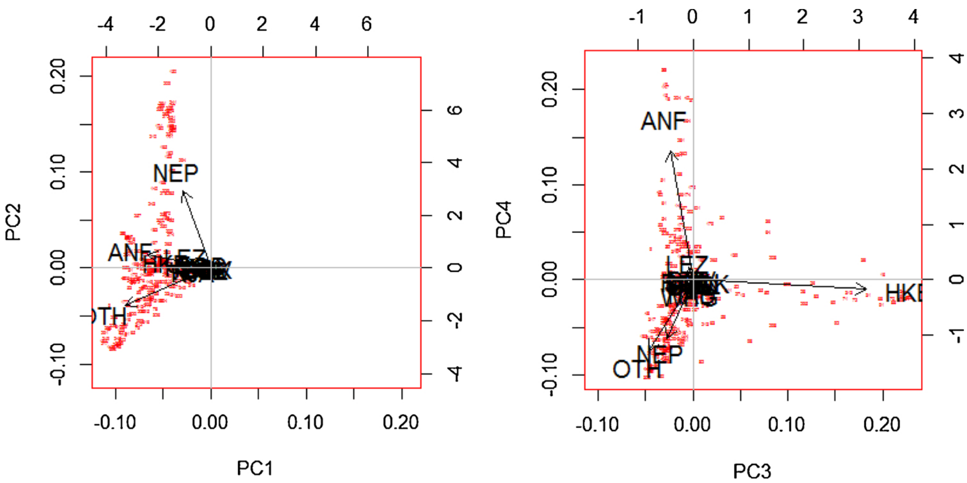


Fig. 1. Principle Component Analysis scores of (a)(left) the first and second components, and (b)(right) the third and fourth components of the analysed landings profiles. The species are labelled to demonstrate their influence on the variation in this data set. *Nephrops* (NEP) and general category of other species (OTH) are the main driving force in the grouping of landings profiles across the first and second principle components. While monkfish (ANF) and hake (HKE) present as the diving force in grouping across the third and fourth component.

Despite spatial overlap in these fisheries (clusters 1,2,3,4,6,17, Fig. 2a) there is a distinct separation in the fishing activity based on MS fishing behaviour, resulting in distinct patterns in catch assemblage. The gear group with the highest diversity in fishing activity is that of bottom trawlers, with ten distinct clusters of fishing activity (Table 2d). Within this gear grouping there are two distinct *Nephrops* fisheries, one mixed *Nephrops* and demersal fishery (cluster 7), which is dominated by France and Ireland; and one directed *Nephrops* fisheries executed by Ireland only (cluster 18). The remaining diversity of fishing activity in the bottom trawl gear grouping is separated out based on very distinctive wanted catch compositions: An English flatfish and ray fishery (cluster 13); a mixed monkfish and megrim targeted by both a French mixed demersal fishery (cluster 5) and a mixed gadoid and slope fishery (cluster 14); a whiting directed fishery executed by Ireland only (cluster 10), a mollusc and cephalopod fisheries (cluster 11 and 16); and finally a number of mixed demersal fisheries, which are grouped by very on specific MS behaviours separating France (cluster 8), Ireland (cluster 10 and 15). Thus demonstrating how variations in MS behaviours can result in varying catch composition despite similar gears and geographical locations. The only cluster dominated by the Belgium fleet was that of the beam trawls (Table 2c), where they are responsible for 82% of the catch.

4. Discussion

Our study reinforces the perception that the Celtic Sea is an area of highly mixed demersal fisheries, whose management is complicated by the wide variety of gear, mesh size, vessel power, fishing behaviours and Member States involved in the fishery. This analysis has succeeded in categorising this diverse array of fishing activity into appropriately sized units which best capture the pattern in retained catch in the Celtic Sea. A total of 18 homogenous groups of fishing activity were identified. These groups of fishing activity were found to persist throughout the study period, at the spatial resolution of ICES Division. The impacts of these findings in relation to sampling programme design, data call structure, and management advice are considered here.

4.1. Identification of homogenous métiers

Four key trip variables were found to describe trends in fishing activity and their resulting retained catch. These four key trip variables are consistent with those currently used in the production of mixed fisheries advice for the Celtic Sea: country, ICES Division, gear and target assemblage (ICES, 2017b). Although this analysis was conducted using highly aggregated annual scale, the findings concur with those of Marchal (2008) who conducted a similar analysis on haul data from the French fleet. The highly aggregated data used in this study facilitated the inclusion of multiple member states in the analysis, thus provided an aggregated but more complete view of fishing behaviour in the Celtic Sea. Therefore, this analysis supports the current descriptors employed to model mixed fisheries interactions in the Celtic Sea, and demonstrates the importance of target assemblage in defining realistic fleet behaviour and relevant fleet groupings for future ecosystem modelling of the Celtic Seas.

Three key trip variables were not found to be drivers of clustering in the Celtic Sea: year, mesh size, and vessel length. Each of these variables have been employed and found to be useful descriptors in other regions (i.e. north-west Spain (González-Álvarez et al., 2016), North Sea (Ulrich and Andersen, 2004)) and at other spatial scales within the Celtic Sea (Davie and Lordan, 2011; Holley and Marchal, 2004; Mateo et al., 2017). Year was excluded as its inclusion decreased the explained variation in the clustering due to the episodic fluctuations in recruitment of a number of commercial species within the Celtic Sea, particularly the main gadoid stocks of cod, haddock and whiting (ICES, 2017c).

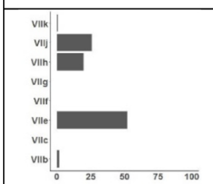
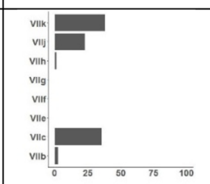
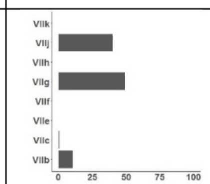
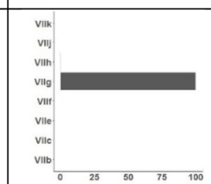
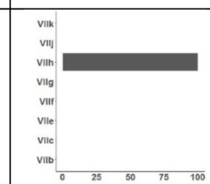
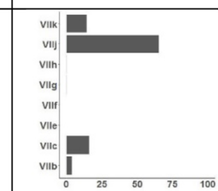
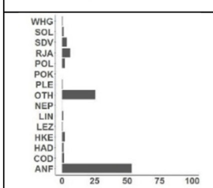
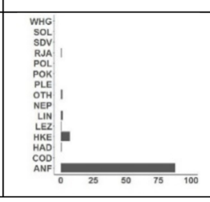
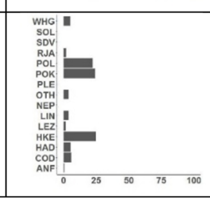
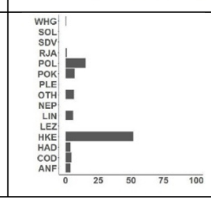
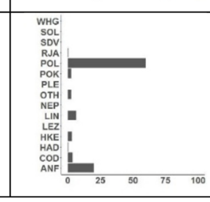
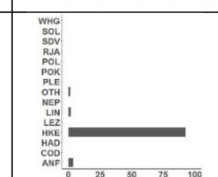
This analysis has provided valuable information by which to describe fishing activity in the Celtic Sea. However, it is important to note that these 18 homogenous units only describe part of the story, as the authors only had access retained catch for the main TAC species which was submitted as part of an ICES datacall, all other landed species were grouped as "other" by MS prior to data submission. Access to complete catch profiles would provide valuable information on the patterns of discarding within the fishery, and the true extent of mixing. Additionally, this analysis could be improved by access to seasonal information, from which it would be possible to follow the shifting behaviour of fleets over the year, which has proven effective in other studies (Silva et al., 2002; Tzanatos et al., 2006) and would provide a very valuable management tool. However, this data is not currently freely available at this international level. Using a different metric for landings, such as landings value per species may also provide a different perspective on the metier composition – as the relative importance of species may change. For example, lower volume but high value trawl fisheries in the Channel may be more disaggregated (e.g. inshore sole and plaice vs offshore anglerfish and megrim fisheries). Although this analysis is restrained by the limitations of the data, it still effectively describes fisher intention and behaviour through the landings of wanted catch.

4.2. Limitations of spatial resolution

Theoretically both mesh size and vessel length should impact the results within this study, where vessel length impacts whether a fishing activity takes place either inshore or offshore (González-álvarez et al., 2016) and the mesh size impacts the species composition and age

Table 2
Summary of cluster characteristics in terms of key trip factors and species composition. The graphical descriptions of each cluster have been weighted by within cluster landings for each variable. The fishery represented by each cluster has been defined and described by expert knowledge and grouped into four overall gear groupings: a) set nets, b) seine nets, c) beam trawls, d) bottom trawls.

a) Set Net Clusters

French Monkfish Directed Set Net Fishery:	Scottish Monkfish Directed Set Net Fishery:	Irish Mixed Demersal Set Net Fishery:	English Hake Directed Set Net Fishery:	English Pollack Directed Set Net Fishery:	French Hake Directed Set Net Fishery:
French (98%) set net fishery (GTR 60%, GTR 12%), targeting monkfish (50% landings), resulting in a demersal target assemblage (100%), accounted for 30936t. (Cluster 1)	Scottish (75%) set net fishery (GNS 83%), targeting monkfish (80% landings), resulting in a demersal target assemblage (100%), accounted for 5458t. (Cluster 2)	Irish (100%) set net fishery (GNS 100%), landing a mixture of gadoids and rays, resulting in a demersal target assemblage (100%), accounted for 11047t (Cluster 3)	English (100%) set net fishery (GNS 99%), tageting hake and landing a mixture of other gadoids, resulting in a demersal target assemblage (100%), accounted for 4486t (Cluster 4)	English (100%) set net fishery (100%), tageting pollack and landing a mixture of other gadoids, resulting in a demersal target assemblage (100%) accounted for 3322t. (Cluster 6)	French (89%) set net fishery (65%) and longline (35%) fishery, targeting hake (90% landings), resulting in a demersal target assemblage (100%), accounted for 70250 (Cluster 17)
					
					

b) Seine Net Clusters

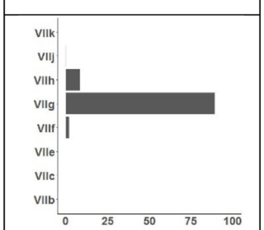
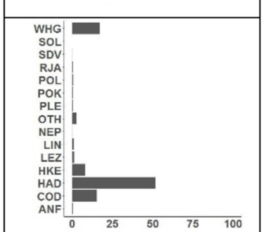
Mixed Whitefish Fishery:
French (58%) and Northern Irish (42%) seine net (92%) fishery, landing a mixture of whitefish species, resulting in a demersal target assemblage (100%), accounted for 3657t. (Cluster 9)



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Table 2 (*continued*)

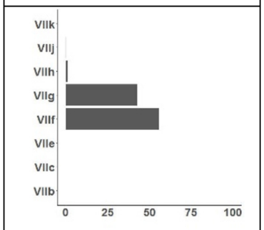
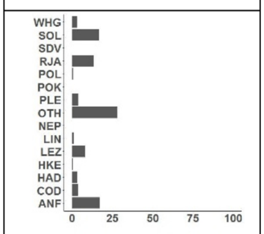
c) Beam Trawl Clusters
<u>Mixed Demersal Fishery:</u> Belgian (82%) beam trawl fishery, landing a variety of demersal species, resulting in a demersal (50%) or miscellaneous (50%) target assemblage, accounting for 27701t. (Cluster 12)



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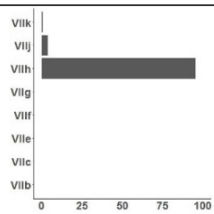
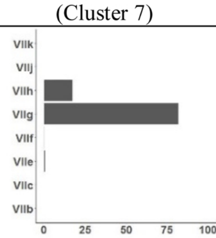
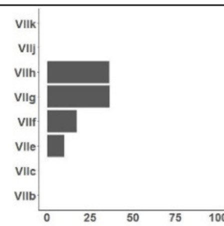
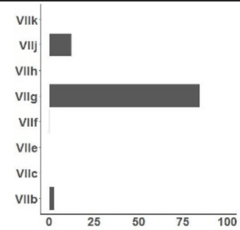
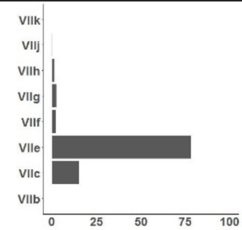
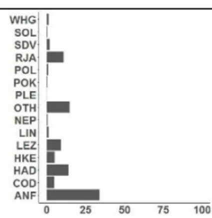
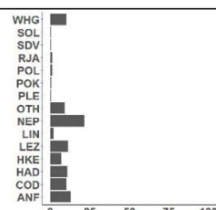
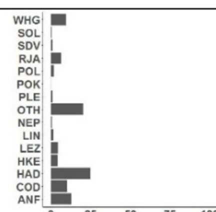
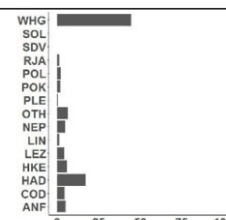
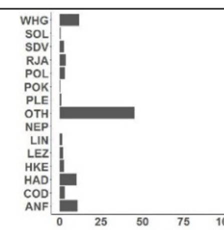
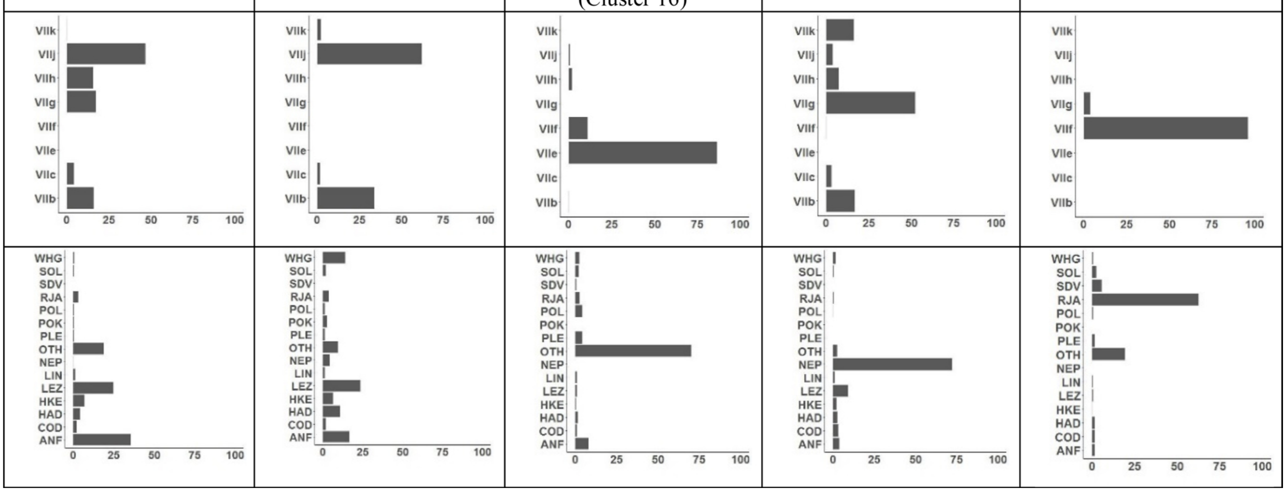
Table 2 (*continued*)

d) Bottom Trawl Clusters				
French Mixed Demersal Fishery: French (92%), multi-rig otter trawl (OTT, 89%) fishery, landing a mixture of demersal species, resulting in a demersal (100%) target assemblage, accounting for 43475t. (Cluster 5)	**French Mixed Demersal – Nephrops Fishery:** Irish (53%) and French (42%), multi-rig otter trawl (OTT, 90%) fishery, landing a mixture of demersal species, including *Nephrops*, resulting in a demersal (50%) or crustacean target assemblage (50%), accounting for 18527t. (Cluster 7)	**French Mixed Demersal Fishery:** French (92%) , bottom trawl (OTB 75%) fishery, landing a mixture of demersal species, resulting in a demersal (100%) target assemblage, accounting for 99117 t. (Cluster 8)	**Irish Whiting Directed Fishery:** Irish (99%), bottom trawl (OTB 60%) and siene net (SSC 40%) fishery, targeting whicting (50% of the landings), resulting in a demersal (100%) target assemblage, acounting for 55270 t. (Cluster 10)	**French Channel Fishery:** French (99%), bottom, trawl (OTB 90%) fishery, targeting non-demersal species such as molluscs and ceplapodes, along with a mixture of demersal species, resulting in a demersal (100%) target assemblage, accounting for 78247t. (Cluster 11)
				
				

(*continued on next page*)

Table 2 (*continued*)

d) Bottom Trawl Clusters				
Mixed Gadoid and Slope Species Fishery:	**Irish West Coast mixed Demersal Fishery:**	**English Channel Fishery:**	**Irish *Neprophs* Directed Fishery**	**English Ray and Flatfish Directed Fishery**
English (43%), French (36%), Irish (14%) and Scottish (7%) bottom trawl (OTB 72%) and beam trawl (TBB 23%) fishery, tageting monkfish and megrims and gadoids, resulting in a demersal (100%) target assemblage, accounting for 81938t. (Cluster 14)	Irish (100%), bottom trawl (OTB 75%) and multi-rig otter trawl (OTT 25%), landing mixed demersal species, resulting in a demersal (100%) target assemblage, accounting for 24385t. (Cluster 15)	English (91%), bottom trawl (OTB 45%), beam trawl (TBB 40%) and gill net (GNS 25%) fishery targeting non-demersal species such as molluscs & ceplapodes, along with a mixture of demersal species, resulting in a demersal (100%) target assemblage, accounting for 117717 t. (Cluster 16)	Irish (96%), bottom trawl (OTB 55%), multi-rig otter trawl (OTT 45%) fishery targeting *Nephrops*, resulting in a crustacean (100%) target assemblage, accounting for 31944 t. (Cluster 18)	English (100%), bottom trawl (90%) fishery targeting Rays and flatfish, but given a crustacean (100%) target assemblage, accounting for 3133 t (Cluster 13)



structure of the retained catch (Davie and Lordan, 2011). However, these studies were conducted at a finer spatial scale than ICES Division. Work by Gerritsen et al. and Mateo et al. (2017) illustrates the spatial complexity in patterns of retained catch data within the Celtic Sea at the finer spatial resolution by combining logbook and vessel monitoring systems (VMS) data. This finer spatial resolution revealed regions defined by distinct homogenous composition of retained catches, which is in agreement with our study where clusters contain many ICES Divisions, with clusters occurring in many ICES divisions (Fig. 2a), therefore indicating a finer spatial resolution then the level of aggregation of ICES Division.

Finer spatial resolution may allow for the impact of ground type, habitat and gear specification to be detected and associated catches described. While gross spatial resolution such as ICES Division, results

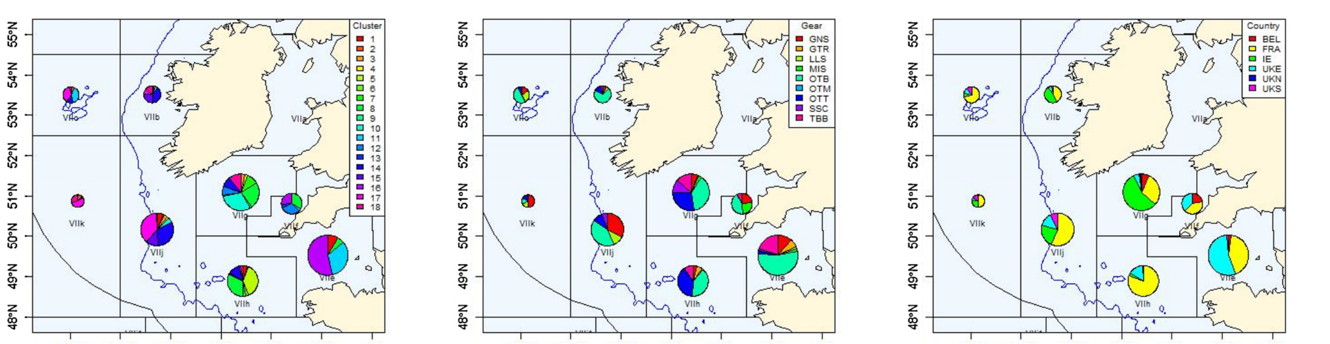


Fig. 2. Shows the distributions of landings weight in tonnes within the Celtic Sea between 2011–2015 in relation to a) cluster number, b) gear type and c) country. The 200 m contour line is marked in blue, identifying the continental shelf and raised sea mounts such as the porcupine bank (VIIc). The ICES divisions are defined by the black, with VIIk and VIIj being further segmented by a curved EU boundary line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in a smoothing and dilution of this signal. However, access to high resolution information (i.e. integrated VMS, daily logbook or haul by haul data) is generally restricted to the national administration or fishing organisation and was not available for the purposes of this study.

4.3. Sampling programme design

This analysis highlighted the subjectivity associated with the categorisation of the variable target assemblage, and the importance of consistency between Member States. Within this analysis target assemblage was found to be an important driver of clustering of the retained catch profiles, however there are variations in how MS have defined it. Some variation in the labelling of target assemblage between MS is to be expected as at a national level a combination of a methods are used to allocate fishing operations to metier level 5 units of fishing activity (RCG, 2018). These variations are a direct result of varying sampling plans, levels of availability of quality information and implementation of localised expert knowledge (RCG, 2018). However, it important to note that there are still some major inconsistencies in how MS are defining target assemblage. One example of this mislabelling can be seen in this analysis, where the English flatfish and ray directed fishery (cluster 13, Table 2d) was labelled with a crustacean target assemblage. Therefore, like Deporte et al. (2012) this study shows the importance, but also the weakness and potential pitfalls of including target assemblage within mixed fisheries analysis. The evident inconsistency in categorising effort by target species or assemblage is a direct result of there being no clear definition of target within the literature or the fisheries legislation (e.g. 2010/93/EU Appendix IV). Target species or assemblage could be defined as the fisher's intentions before leaving the port and despite the potential value of this socioeconomic variable it is not currently required by regulation to be recorded in European logbooks (EU, 2006, 2005; Marchal, 2008). Different countries employ a variety of 'input' and 'output' methods to classify the key trip descriptor of target assemblage (Marchal, 2008; RCG, 2018). This variation in how target assemblage is defined at a national level could create a number of pitfalls for later mixed fisheries analysis including the incorrect partitioning of effort and catches between fleets. This dilution of métiers into merged DCF métiers or the homogenous groups of fishing activity defined here could potentially undermine the utility of mixed fisheries forecasts, advice and management, and hugely limit practical implementation of ecosystems based fisheries management. It is clear from this analysis that steps need to be taken at an international level to agree the best approach for defining mixed fisheries units. Deporte et al. (2012) suggest that target assemblage when be combined with mesh size may result in more homogenous categories and reduce the impact of misspecification of target assemblage. However, in our analysis the addition of mesh size range reduced the variation that could be explained by the cluster analysis (Table 1), which may be an artefact of the low spatial resolution. Ultimately, our ability to incorporate mesh size range into any analysis is hindered by the issue of misreporting of these ranges in logbooks, which are the sole source of this information. There is ongoing work by ICES and the Regional Coordination Groups (RCG) to improve this.

4.4. Application in fisheries advice

The outcomes of this analysis have direct application for both single species and mixed fisheries assessment. This work demonstrates the importance of certain key trip variables as units of aggregation with which fishing activity within the Celtic Sea can be accurately defined. Therefore, providing scientific support to allocation procedures which are currently used to raise sampling data to an international level, and are subsequently utilised in stock assessments and advice. Additionally, this analysis demonstrates the effectiveness of this framework in interrogating the level of aggregation and detail required the description of a fisher behaviour, which if applied can be used to avoid over stratification of samples by stock coordinators during the international allocation procedure.

Currently Celtic Sea mixed fisheries advice only incorporates three gadoid species: cod, haddock and whiting (ICES, 2018). The results of this study indicate the importance of expanding these simplistic mixed fishery forecasts to include a number of other species including hake, *Nephrops*, megrim and monkfish, all of which interact with the three gadoids across a number of clusters (Table 2). Additionally, this analysis shows a number of emerging fishing activities which have not previously been considered in the mixed fisheries analysis of the three main gadoid species, such as the whiting directed fishery (Table 2d, Irish whiting directed fishery). Ignoring these unique fishing activities in mixed fisheries forecasting could result in incorrect estimation of effort and ineffective management. For example, separating the directed whiting fishery from the mixed gadoid fishery may change our perception of the total effort likely to be deployed in the fisheries to catch available quota. Ensuring metiers are defined appropriately when used in mixed fisheries analyses is therefore vital to correctly identify choke problems. In addition, appropriately defined metiers can be used as a tool to understand how vessels change their fishing patterns in response to the landing obligation through changes in effort allocation among metiers. While its recognised that changing spatial effort allocation is possible, there is currently little analysis to the extent that this is possible and how far such changes are able to support adaptation to the landing obligation (Dolder et al., 2018). Therefore, the practical framework applied in this analysis could be employed annually at a national and international level to ensure continued consistency in the assumptions used in both raising the data and modelling the data.

In conclusion, this analysis demonstrates the true extent of fleet flexibility within the Celtic Sea, whereby multiple countries, gears and clusters being identified in each ICES Division (Fig. 2). This analysis also illustrates clearly the varying behaviours of Member State specific fleets across the entire Celtic Sea. Demonstrating the true value of regional sampling coordination, which provides a standardised framework in which to study multiannual and multi-country trends, therefore providing insights which can inform management. This framework demonstrates a practical method with which to analyse the structure and relevance of fishing activity units, which should be conducted prior to all mixed fisheries modelling, to ensure that any evolving activities are captured and unused categories are disregarded. This analysis isolated the key trip variables required to describe the complex fishing behaviours in this region, validating the current fishing activity units used in mixed fisheries analysis of the Celtic Sea, thus ensuring model efficiency. Finally, this work demonstrated a number of homogenous units of fishing activity, and emergent fishing activities were identified within this study, information which can now be employed to improve sampling programmes, data calls, and analysis. While we've demonstrated the importance of a rigorous multinational approach to analysing the typology of fisheries in the Celtic Sea, this approach is necessary in any area where technical interactions are considered important in management advice. For example, incorporation of fleet dynamics in management strategy evaluation can improve predictions of fishery catches (Marchal et al., 2013) and defining metier typology is a prerequisite for accurately characterising fleet dynamics.

Acknowledgement

The authors thank the Working Group on Mixed Fisheries Methods of the International Council for the Exploration of the Sea (ICES) for facilitating this research. We would also like to take this opportunity to thank our colleagues at this working group who participated in many discussions about this work, and proposed many helpful and constructive ideas. Finally, we would like to thank the reviewers for this invaluable input in developing this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2019.105310.

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