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Report of the Workshop on the utility of commercial CPUE and VMS data in assessment (WKCPUEFFORT)

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International Council for the Exploration of the Sea
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Executive summary

The Workshop on the utility of commercial CPUE and VMS data in assessment (WKCPUEFFORT) was held at ICES headquarters 5-7 April, 2011. The workshop was chaired by Norman Graham, Marine Institute, Ireland and attended by twelve participants. The objective of the workshop was to review and consider the utility of vessel monitoring systems (VMS) and other novel data acquisition systems and how these could be used to improve the utility of CPUE data for assessment purposes. VMS and other electronic monitoring systems are relative new developments and are largely used for compliance purposes. However, the integration of VMS and commercial catch data provides the opportunity to provide fine scale spatial distribution maps of fishing effort and catch distribution maps. Much of the most recent work has focussed on the interpretation of VMS data to separate fishing from non-fishing activity and integration of VMS with landings data. Research beyond the production of mapping is only now beginning to emerge from the scientific community but in many respects the use of spatially refined catch data for scientific and management purposes is still in its infancy. VMS data, in combination with other data sources such as information from fishery independent surveys are now being used for the evaluation of spatial and temporal closures, but the use of VMS for traditional stock assessment purposes is hampered by the lack of time series and that many assessment techniques lack spatial considerations beyond stock boundary definition. The workshop considered the output from a recent EU funded project "Development of tools for logbook and VMS data analysis" and concluded that the common data format proposed should be used to ensure data and exchange compatibility. The work presented shows how VMS data can be used in conjunction with logbook data to spatially identify strata where linked VMS and logbook data was used to spatially refine commercial LPUE indices. Indices can be biased if the spatial distribution of fishing effort changes over time. Identifying strata based on homogenous, spatially refined catch composition data, can be used to provide an unbiased LPUE trends, contrasting stratified LPUE and non-spatially refined LPUE for some species shows marked differences. As time series of VMS data increases, spatially refining commercial tuning fleets using such approaches should be considered during stock benchmarks. Recognising that species distribution is strongly influenced by habitat type, the workshop considered the data types required to generate standardised abundance indices not only based on spatial distribution, but also to incorporate habitat type. The workshop was asked to provide guidelines on when to use commercial catch data. While identifying the main potential sources of bias, the workshop concluded that the decision to include or exclude commercial catch data is one best left to individual stock coordinators and that many of the issues are compliance rather than scientifically related. The workshop then considered how VMS and new monitoring systems could be useful in terms of providing better estimators of effort and how more systematic and widespread data collection of fishing gear parameters would help refine effort metrics. For example instead of estimating effort in terms of time, trawl sensors could be used to quantify swept volume or area. A potential statistical method for standardisation of effort and CPUE is presented. The workshop concluded that while the use of VMS data has been limited in terms of assessment purposes, the increasing time series and access to VMS and other novel data systems warrants more detailed investigation and this would be best achieved through the formation of a dedicated research projects.

1 Introduction – the problem with commercial CPUE data

Catch and effort data are routinely collected for almost all species and fisheries. Hilborn and Walters (1992) note that it is "simply irresistible to try to use catch per unit effort data to estimate or as an index of fish abundance". In principle, commercial CPUE data can provide useful indices of population trends in abundance provided that changes in CPUE are proportional to changes in stock size. The supposition of linearity or proportionality between CPUE and stock status is based on the assumption that catchability of the fleet remains constant over time and that recorded or apparent effort is stable and reflective of actual or effective effort.

In practice, these assumptions are violated due to changes in catchability associated with technological creep, resulting in improvements in gear efficiency and the ability of fisheries to maintain catch rates even when the overall abundance declines, by targeting 'hot spots'. This non-proportionality, where the assumption of a linear relationship between CPUE and abundance are violated, can lead to hyper-stability, where CPUE remains 'high' but abundance declines leading to an over estimation of biomass and underestimation of fishing mortality (Hilborn and Walters, 1992). Furthermore, in many fisheries, it is often the landings rather than the catch that is actually monitored, more correctly we should use the term landings per Unit of Effort (LPUE). Where discarding contributes a significant source of mortality and, more critically, discarding profiles vary, LPUE estimates may suffer a degree of bias. Hilborn and Walters (1992) provide several examples where actual declines in stock abundance were masked due to hyper-stability in CPUE indices e.g. North Sea herring and Peruvian anchoveta as well as marine mammal declines e.g. sea otter and Alaskan fur seal.

Walters (2003) notes that using non-spatially refined CPUE data, where no consideration is given to spatial activity can lead to biased perceptions of true population trends. Rose and Kulka (1999) note that the misinterpretation of commercial CPUE data in the Northern Cod stock in Newfoundland contributed to incorrect management actions due to incorrect inferences of hyper-stable CPUE indices due to hyper-aggregation of cod and associated contraction of fishing effort. Failure to recognise that the distribution of the fleet had changed (concentrated) with the hyper-aggregation of the target species, resulted in biased assumptions that the stock was 'healthy' whereas in reality it was on the verge of catastrophic collapse.

While improvements in technological efficiency and changes in abundance result in changes in catchability, failure to adequately measure fishing effort/activity can also result in bias. For example while changes in technology can improve catching efficiency for a given unit of time other operational changes that result in increases in gear deployment e.g. increases in towing speed, increases in the amount of gear deployed can all result in effort creep that can be masked if the measure of effort does not consider gear or operational aspects e.g. days at sea, or if only attributes of the vessels combined with activity are used e.g. kW.days.

Due to the biases in commercial catch data there has been a general decline in the use of fishery dependent CPUE indices for stock assessment purposes. However, with the rapid advances in electronic and satellite monitoring and data acquisitions systems being used primarily for control and enforcement purposes, it is possible now to accurately monitor the spatial distribution of fisheries and to help refine effort estimators. Furthermore, many fisheries are subject to observer programmes and there is potential to use such programmes to collate more detailed information on vessel and gear attributes that may provide better insight into technological creep thus offering data that could be used to estimate changes in catchability.

In this workshop we have considered the data needs required to allow the possibility to account for technical changes in fleets and how more spatially refined CPUE indices can be developed through linking commercial catch data to VMS. It should however be noted that the data from VMS and other new fisheries information acquisition tools are relatively new to the scientific community. Much of the recent focus has been on the development of techniques and routines to integrate such data and it is only relatively recently that the scientific community has started to use such data in a quantitative sense and go beyond the production of fine scale fisheries distribution maps.

The workshop provided the opportunity to present some examples of where more spatially refined catch and effort data are now being used and some discussion is given to potential developments in the future. It should be noted that due to the relatively short time series of VMS data, the application of spatially refined catch data has been limited and at this stage the workshop was only able to review some examples of where VMS data has demonstrated its potential rather than be able to provide definitive guidelines. It is also noted that there are a number of good examples where VMS linked with commercial landings and survey data for evaluating the impacts of spatial management measures e.g. Evaluation of closed areas in the Kattegat (unpublished Danish report presented at STECF 2010) and for the assessment of the potential impacts of the UK Real Time Closures as part of the UK conservation credits scheme (Needle and Catarino, 2011). Unfortunately these and other similar studies were not presented to the workshop, but it is noted that these represent significant advances in the use of VMS data for the evaluation of more spatially refined management approaches.

The report is divided into two areas. The first part presents a series of abstracts covering the work presented during the workshop with the second section covering the principle findings and conclusions.

2 ToR 1– Develop Guidelines

a) *Develop guidelines on the types of data and information that need to be supplied, and the relevant factors that need to be taken into account, in order to maximize the utility of commercial CPUE and VMS data as inputs to assessment models.*

In this section we focus on data exchange and compatibility between different countries, provide examples of how VMS can be used to spatially refine LPUE indices and consider how to monitor for operational changes that can cause unforeseen changes in catchability and effective effort using VMS and other monitoring tools.

2.1 Improving the utility of VMS data – Data exchange and compatibility

Much of the recent work on using VMS and logbook data has focussed on the technical integration of the two data sources but the use of the data has largely been limited to the spatial mapping of fishing activity and the spatial distribution of landings. Research beyond the production of mapping is only now beginning to emerge from the scientific community but in many respects the use of spatially refined catch data for scientific and management purposes is still in its infancy. Use of VMS data for traditional stock assessment purposes has been limited due to the relatively short time series of VMS data and accessibility issues between different countries. In a European context there are few (if any) examples in multi-national fisheries where both commercial landings and VMS data have been collated. For any given fishery, having VMS linked logbook linked data from only part of the fleets undermines the utility of this potentially valuable data source considerably and has probably limited the utilisation from an analytical stock assessment perspective, coupled to the fact that the majority of assessments lack any spatial considerations, other than the current stock boundary definitions.

Ensuring common data collection formats is essential to ensure that data from different sources are compatible and facilitate the production of global views of spatial activity and catches. The workshop was given a presentation on the recent EC funded project "Development of tools for logbook and VMS data analysis".

The **vmstools** library is an open source R package developed under the EU call for tenders No MARE/2008/10 Lot2: Development of tools for logbook and VMS data analysis. The package and a wiki can be found at http://code.google.com/p/vmstools.

The tools developed for analyzing and linking the logbook and VMS data are generic and uses common data formats (EFLALO2 for logbook data and TACSAT2 for VMS data) as input.

R scripts can be found in the vmstools package to:

- Classify logbook data into DCF métiers.
- Distinguish fishing activity from non-fishing activity
- Link logbook trips with VMS trips
- Allocating the landings by species to the VMS pings
- Calculate effort

- Tools for aggregating the effort and species landings data into grids and displaying them on maps
- Exporting aggregated data (0.05 x 0.05 degrees grid) in a format that the regional database FishFrame can import
- An interpolation algorithm to create tracks from VMS data
- Calculate DCF indicators 5, 6 and 7

Methods are described in the project report (Beare *et al.*, 2011), in Bastardie *et al.* (2010) and in Hintzen *et al.* (2010).

The common database format used as input for the methods developed in the Lot 2 project for logbook and VMS data analysis are provided below. These are based on the EFLALO format developed under the CAFE project, but modified to include the information relevant for the Lot 2 project.

There are two datasets:

- EFLALO2: Effort and landings, based on combined log-books, vessel register and sales slips
- TACSAT2: VMS data

The data should be saved in a .csv format (comma separated file). When information is missing, an empty zero-length string should be added between the commas.

However, WKCPUEEFORT notes that while the above exchange format should be promoted, it should also be recognised that the analytical approaches may differ between regions depending on the structure of the fishing sector. For example in Mediterranean fisheries are relatively unique compared to other EU fishing regions (i.e. Atlantic Ocean or North Sea), primarily due to the high number of artisanal fishing activities, the low presence of industrial fishing, the high variety of fishing gears used, the multi-species targets, and the high number of species accepted by the markets. The particular nature of Mediterranean fisheries imposes calibrated procedures and methodological approaches that could differ from that of other regions. The mean temporal length of fishing trip is shorter than 1 day: for instance the Italian fishing fleet is characterized by vessels of small or medium size that perform their activities mostly within the 12 miles. Fishing trips last about 12 hours on average (source Italian National Programme 2009/2010).

Some procedures have been developed to take into account these aspects. Namely:

- Russo *et al.*, 2011a improved the interpolation method proposed by Hintzen *et al.*, 2010, also extending the applicability to all the possible métiers;
- Russo *et al.*, 2011b introduced a method to directly identify fishing activity at level 6 métier by processing VMS data through an artificial neural network.

EFLALO2 format

Type	Variable	Code	Format/Unit
Vessel	Vessel ID	VE_REF	20 character string
	Fleet	VE_FLT	DCF regulation
	Home country	VE_COU	ISO 3166 – 1 alpha-3 codes.
	Vessel length	VE_LEN	Oal (m)
	Vessel power	VE_KW	kW
	Tonnage	VE_TON	GT *(optional)*
Fishing trip	Fishing trip reference number	FT_REF	20 character string
	Departure country	FT_DCOU	ISO 3166 – 1 alpha-3 codes.
	Departure harbour	FT_DHAR	International harbour codes. UN LOCODE
	Departure date	FT_DDAT	DD/MM/YYYY
	Departure time	FT_DTIME	HH:MM
	Landing country	FT_LCOU	ISO 3166 – 1 alpha-3 codes.
	Landing harbour	FT_LHAR	International harbour codes. UN LOCODE
	Arrival date	FT_LDAT	DD/MM/YYYY
	Arrival time	FT_LTIME	HH:MM
Log event	Log event ID	LE_ID	25 character string FT_REF_number (1,2,3,etc.)
	Catch date	LE_CDAT	DD/MM/YYYY
	Log event start time	LE_STIME	HH:MM *(Optional)*
	Log event end time	LE_ETIME	HH:MM *(Optional)*
	Log event start position latitude	LE_SLAT	Decimal degrees *(Optional)*
	Log event start position longitude	LE_SLON	Decimal degrees *(Optional)*
	Log event end position latitude	LE_ELAT	Decimal degrees *(Optional)*
	Log event end position longitude	LE_ELON	Decimal degrees *(Optional)*
	Gear	LE_GEAR	3 character string. DCF metiér level 4

Type	Variable	Code	Format/Unit
	Mesh size	LE_MSZ	mm stretched mesh
	ICES rectangle	LE_RECT	37F5, NA=unallocated
	ICES division	LE_DIV	10 character string (see codes in annex 1)
	Fishing activity (metier)	LE_MET	FishFrame level 6 code
	Fishing activity from cluster analysis	LE_MET_CLUST	
	Landing weight estimate of species SP1 (FAO species codes)	LE_KG_<SP1>	Kg
	Landing value of species SP1 (FAO species codes)	LE_EURO_<SP1>	EURO
	…	…	…
	Landing weight estimate of species SPn (FAO species codes)	LE_KG_<SPn>	Kg
	Landing value of species SPn (FAO species codes)	LE_EURO_<SPn>	EURO

TACSAT2 format (VMS data)

Type	Variable	Code	Unit
Vessel	Vessel ID	VE_REF	20 character string
Sighting operation	Latitude	SI_LATI	Decimal degrees
	Longitude	SI_LONG	Decimal degrees
	Date	SI_DATE	DD/MM/YYYY
	Time	SI_TIME	HH:MM
	Instant speed delivered	SI_SP	Knots
	Instant heading delivered	SI_HE	Degrees
	At Sea/In Harbour	SI_HARB	0: In harbour 1: At sea
	Fishing/Steeming	SI_STATE	0: Steaming 1: Fishing
	Fishing trip reference (FT_REF)	SI_FT	20 character string

Annex 1: ICES Division codes from FishFrame

Code	Description
2a	Norwegian Sea (Division IIa)
2b	Spitzbergen and Bear Island (Division IIb)
3a	Skagerrak and Kattegat (Division IIIa)
3b	Sound or the Transition Area (Divisions IIIb)
3c	Belt Sea or the Transition Area (Divisions IIIc)
3d	Baltic Sea (Division IIId)
4a	Northern North Sea (Division IVa)
4b	Central North Sea (Division IVb)
4c	Southern North Sea (Division IVc)
5a	Iceland Grounds (Division Va)
5b	Faeroes Grounds (Division Vb)
6a	Northwest Coast of Scotland and North Ireland or as the West of Scotland (Division VIa)
6b	Rockall (Division VIb)
7a	Irish Sea (Division VIIa)
7b	West of Ireland (Division VIIb)
7c	Porcupine Bank (Division VIIc)
7d	Eastern English Channel (Division VIId)
7e	Western English Channel (Division VIIe)
7f	Bristol Channel (Division VIIf)
7g	Celtic Sea North (Division VIIg)
7h	Celtic Sea South (Division VIIh)
7j	Southwest of Ireland - East (Division VIIj)
7k	Southwest of Ireland - West (Division VIIk)
8a	Bay of Biscay - North (Division VIIIa)
8b	Bay of Biscay - Central (Division VIIIb)
8c	Bay of Biscay - South (Division VIIIc)
8d	Bay of Biscay - Offshore (Division VIIId)
8e	West of Bay of Biscay (Division VIIIe)
9a	Portuguese Waters - East (Division IXa)
9b	Portuguese Waters - West (Division IXb)
14b	Southeast Greenland (Division XIVb)

2.1.1 WKCPUEEFFORT Comments

The workshop considers this as an important development and **recommends** that the common data format proposed by vmstools package should be used to guarantee the interexchangeability of outputs. To facilitate the use of vmstools a vms user list should be developed to promote collaboration and exchange ideas and methodologies between scientists and recommends that ICES should establish a training programme for vmstools.

2.2 Improving the utility of VMS data - Spatial refinement of CPUE indices

If the fishing activity of a fleet moves between areas it can be expected that the LPUE of that fleet changes, even if the overall abundance of fish does not (unless the LPUE is uniformly distributed in space). This may be addressed by splitting the commercial data into a number of fleets based on their target species. However this can be problematic in mixed fisheries where there often is no single dominant species in the landings. Also, a fleet may target the same species in different areas with different catch rates.

This problem is addressed in WD 1 (Gerritsen) which outlines a method that accounts for the bias in LPUE resulting from changes in the spatial distribution of the effort by using integrated logbook and VMS data. The analysis showed that there was a strong spatial structure in the species composition of the landings and that there were major shifts in the spatial distribution of the fishing effort throughout the time-series. In order to address this problem, the area was divided into a number of spatial strata that showed more-or-less homogenous species compositions of the landings of otter trawlers. These spatial strata were based on a cluster analysis of landings compositions. Next the LPUE was calculated for each of the strata and finally a stratified overall estimate of LPUE was obtained by weighting the LPUE of each of the strata by its surface area. This resulted in an LPUE trend which is unbiased with respect to changes in the distribution of fishing activity (it essentially re-distributes the effort evenly over the whole area). An example was presented for four species (cod, haddock, whiting and *Nephrops*) in the Celtic Sea. It was shown that the *Nephrops* LPUE was generally overestimated, particularly in the third quarter of the year when most of the effort was focussed on one of the *Nephrops* grounds. LPUE of gadoids was generally under-estimated as the majority of vessels in this area were targeting *Nephrops*, rather than whitefish and therefore were not fishing in areas where the whitefish catch rates were highest.

A variation on this approach was presented in WD 2 (Silva & Afonso-Dias). The crustacean fishery in Portugal is conducted by 30 trawlers operating off the Southwest and South coasts of Portugal, corresponding to the *Nephrops* Functional Units 28 and 29, respectively. There are two main target species in this fishery, the deepwater rose shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*), sharing partly the same grounds.

The trips were classified according to their target species using a non-hierarchical clustering algorithm (Kaufman and Rousseeuw, 1990; Abad *et al*., 2007; Silva *et al*., 2009) on landings value, based on the assumption that the revenue obtained with the catch is the best descriptor for the activity of the fleet (ICES, 2003). In years of high abundance of the rose shrimp, a clear cluster directed at this species was identified and a second one, not well defined, directed at a mixture of crustacean species that includes rose shrimp, *Nephrops* and red shrimp. When the rose shrimp abundance decreases, although the rose shrimp cluster is still present, the second cluster is better defined and directed at *Nephrops*.

The landings of the fishing trip types were combined with fishing trips and hauls identified by the project GeoPescas, with the software GeoCrust 2.0 (Afonso-Dias *et al.*, 2002; Afonso-Dias and Pinto, 2008). This project used VMS records from the period 1998-2004, with a 10-min lag between two sequential records. The merged information provides estimates of fishing effort (in hours of trawling) and CPUE/LPUE. In the case of the crustacean species, taking into account their market value and onboard sampling information, one can assume that what is landed is what is caught.

Geo-referenced data are particularly useful in the case of this fishery. *Nephrops* stocks of these Functional Units (FUs) are assessed within the WGHMM. At present the two FUs are assessed together due to lack of information on the fishing grounds at landings. All the crustaceans species caught in this fishery are recorded and sold in a specific auction fishing harbour. The use of the VMS data will allow the identification of the landings origin, providing the basis for separate assessments by FU. Based on these data, the present model for CPUE standardization could be improved by the inclusion of other variables as depth and fishing area (Silva and Cardador, 2010).

It is expected that a more detailed analysis of the trips landing a mixture of crustacean species, using VMS haul information and data from logbooks will help to identify hauls directed at different species within the same trip and provide a better definition of these trips.

2.2.1 WKCPUEEFORT Comments

From the work presented, it is clear that spatial refinement of commercial LPUE information can significantly alter LPUE estimates. WKCPUEEFORT notes that while the work presented has primarily focussed on LPUE indices, spatial refinement of commercial tuning fleets should be routinely considered as part of any benchmark procedure where appropriate.

2.3 Improving the utility of other data sources – Incorporating habitat dependency into CPUE/LPUE indices

The spatial distribution of species is strongly influenced by habitat features and species' inherent biology (including their life-cycle). The density dependent habitat selection theory (i.e., the ideal free distribution theory) predicts differences in species' density among areas postulating that individual animals aggregate in various patches proportionately to the amount of resources available in each patch (Fretwell and Lucas, 1970). While the underlying assumption of an "ideal" assessment of patch quality by animal and a "free" capability to move from one patch to the other are considered to be most often violated (as well as caution must be taken when dealing with spatial variation without taking into account proxies for species' fitness, Shepherd and Litvak, 2004), there are clear evidences of the habitat dependent distribution of marine species. Indeed individuals exhibit heterogeneous distribution, being some habitats characterized by high densities compared to other, where densities are lower or individuals are even not present. The environmental features that characterize species' habitat include, among others, depth, oceanographic parameters (seawater temperature, salinity, oxygen concentration, primary production, etc.), sediment grain size, sea bottom geomorphology, benthic assemblage composition.

The relevance of the habitats that support species' life cycle has been summarized in the concepts of Essential Fish Habitat, that has been incorporated into management in the USA by the Magnuson-Stevens Fishery Conservation and Management Act in 1996, that recognizes that fish stocks depend on healthy ecosystems and requires that fishery managers expand their management regimes to include the very basis of healthy fisheries—the habitat itself (Rosenberg *et al.*, 2000). The definition of the habitat dependent use of different species is therefore an important element to be taken into account in order to increase the potential of the uses of CPUE data for assessment purposes, especially for demersal species. Indeed, since species' abundance varies according to habitat, CPUE data will differ across a region according to species' habitat preferences. This would result in the presence of spatial autocorrelation in CPUE data belonging to the same habitat (patch) that should be taken into account. Modeling CPUE data without taking into account species habitat preferences could exclude a relevant explanatory variable, thus partially hampering the potential use of CPUE data as proxies for abundance as well as the interpretation of CPUE trends over time. The integration of oceanographic data, sea bottom features (e.g. geomorphology) and sediment distribution (Valavanis *et al.*, 2004), as well as benthic fauna data (Ellis *et al.*, 2000) with data from trawl-surveys or ad hoc sampling activities (Hinz *et al.*, 2006) might serve for the purposes of identifying species' habitat (Figure 2.3.1). Trawl surveys data, being fishery-independent and standardized in terms of sampling gear/protocol, could be also useful to be compared/integrated with the CPUE/VMS data recorded in the same period (season) when experimental trawling is carried out, allowing one to compare CPUE among metiers over the same habitats. It is also worth noting that trawl-surveys data may be useful to address density dependent/independent habitat selection in species (Tamdrary *et al.*, 2010), another factor that might be taken into account when dealing with CPUE data.

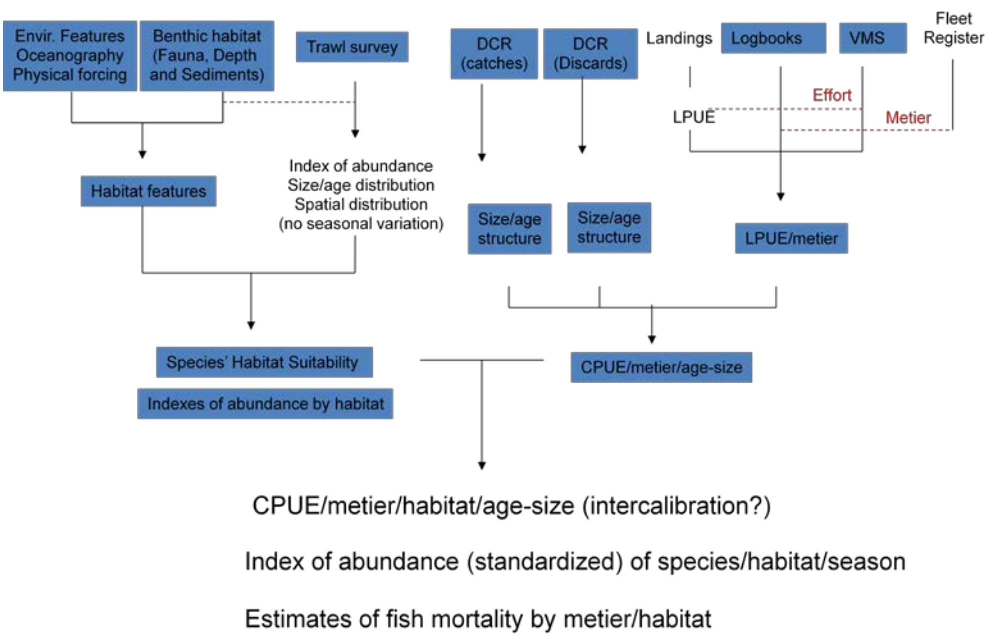

Figure 2.3.1 Schematic view of integration of data sources for the provision of spatially and habitat specific CPUE indices

2.4 Improving the utility of Effort Information – Data requirements for gear metrics

The availability of VMS data has lead to an increasing amount of time series data of high temporal and spatial resolution of a vessel in a single fishing activity. The high resolution data has lead to that the effort data given in logbooks in terms of hours fished could be validated or/and refined. However, the information that is available on gear specific details are usually rough estimates and does not invite to scale down the fishing operation to the same level of resolution as the spatiotemporal position of the fishing activity itself. In many jurisdictions, fishing activity or fishing effort is regulated in some way, for example through days at sea allocations to individual vessels or allocations of effort allocations to fleets or countries. Such regimes are likely to incentivise technical and tactical developments to maximise catches for a given amount of effort. Studies conducted in the Faroe Islands have shown that fishermen increased efficiency by increasing tow duration allowing longer fishing time and less gear handling time and towing speed had increased increasing swept area. Recent work by Reid *et* al (in press) and the ICES Study Group on Gear and Effort Metrics (ICES, 2009) have shown that the relationship between vessel power and the size of fishing gear deployed is complex. SGGEM compared vessel power vs fishing circle [a measure of swept volume] and vessel power vs ground gear length [a measure of trawl swept area] using a segmented regression (Muggeo, 2003). For the fishing circle the breakpoint was at 934 hp (Figure 2.4.1), for the ground gear the breakpoint was at 418 hp (Figure 2.4.2). These indicate that while there is a close correlation between vessel power and gear size, also observed by Eigaard *et al.* (2011) when contrasting gear size and power in the *Pandalus* fishery, the interesting observation is that above a certain power, the relationship breaks down. ICES (2009) noted that this could imply that there is potential latent capacity within the fleet as some of the more powerful vessels are using trawls that are well below the size that they are potentially capable of towing.

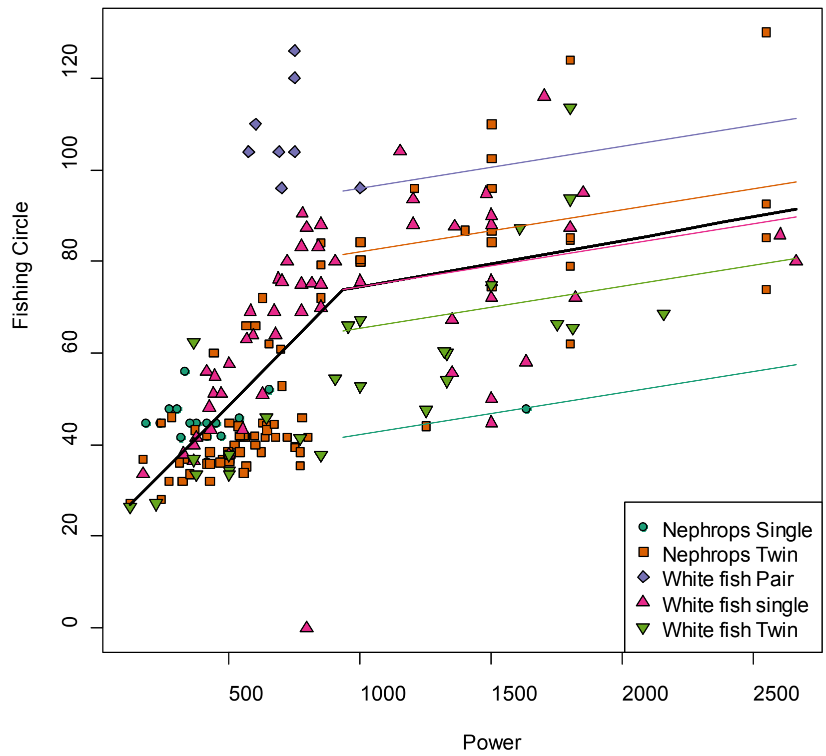

Figure 2.4.1 Relationship between fishing circle and vessel power. The black line is the segmented regression, the coloured lines show the glm fitted to data above the breakpoint.

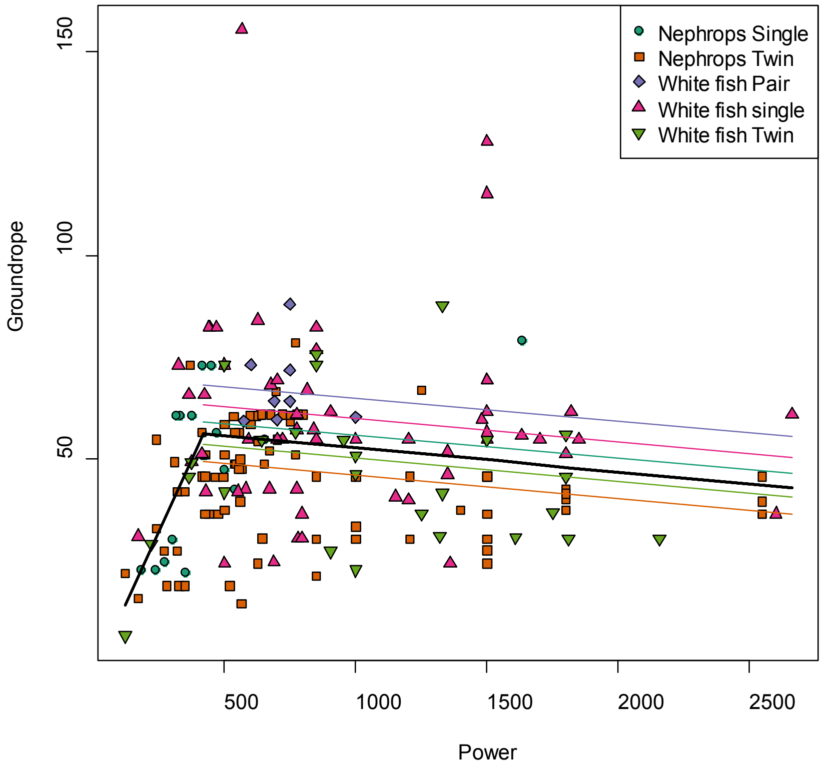

Figure 2.4.2 Relationship between ground gear and vessel power. The black line is the segmented regression, the coloured lines show the glm fitted to data above the breakpoint.

Small vessels clearly show a relationship between power and fishing circle and between power and ground gear but for vessels with engine sizes larger than the breakpoint this relationship breaks down. GLMs were fitted (with a Gaussian error distribution and an identity link function; McCullagh and Nelder, 1989), using the data above the respective breakpoints only. The full model had de following form:

glm(circle ~ power * sector)

glm(groundgear ~ power * sector)

where sector is the fishing sector (*Nephrops* Single; *Nephrops* Twin; White fish Pair; White fish single; White fish Twin). A stepwise selection procedure was applied to determine which of the variables contributed significantly to the model. For both the fishing circle and groundgear models, the interaction was dropped. For the fishing circle model the power variable was not significant (p=0.08, Chisq) but retaining power resulted in a small reduction in AIC. Sector was highly significant (p=0.01, Chisq). For the groundgear model the power variable was significant - but with a negative slope - (p=0.04, chisq) and the sector variable was highly significant (p<0.001, chisq)

A more detailed level of information of the fishing gear is also essential in order to track changes in the gear effectiveness that potentially could flaw the relationship between the catch and effort (CPUE) known as the technological creep. The potential for deploying more and larger fishing gear for the same amount of nominal effort could violate the relationship between fishing effort and catch over time. The knowledge of any changes in the fishing gear that affect the CPUE is an essential knowledge especially for commercial fleets that are used as tuning fleets in stock assessments. In addition, detailed information about the fishing gear allows you to estimate for example the swept area by a fishing operation. If then the swept areas by haul are increased due to an increase in the time of the haul (effort creeping) or/and an increase in the size of a gear, this can be detected and evaluated. The same arguments stated above holds for passive gears where there is a lack of detailed gear specific information. The following list is a **recommendation of data** associated to vessel and fishing gear that should be gathered by onboard observers

<u>Vessel</u>

Engine power	(kw)
Kort Nozzle	(yes, no)

<u>Towed gears.</u>

Trawling time	(minutes)
Mesh size in codend	(mm)
Wire length	(m)
Trawl type	
Panels	
(distance from codend, mesh size) (m,mm)	
Door spread	(m)
Wing spread	(m)
Speed through the trawl	(Knots)
Sweep length	(m)
Extension length	(m)
Number of meshes	
in trawl opening	(#)
Trawl height (opening)	(m)
Length of headline	(m)
Length of ground rope	(m)
Twin thickness	(mm)
Thickler chains	(yes, no)

<u>Passive gears (Nets)</u>

Gear type	(Trammel, Gill…..)
Mesh size	(min, max, mm)
Net length	(m)
Soaking time	(hours)
Twin thickness	(mm)

<u>Passive gears (Longlines)</u>

Number of hooks	(#)
Distance between hooks	(m)
Hooks size	(mm)
Hook Type	(XX)
Bait type	(xx)
Time fishing	(h)

Encircling gears (Purse seines)

Searching time	(h)
Time fishing (setting/handling the net)	(...)

2.4.1 WKCPUEEFFORT Comments

In order to provide better insight into the relationship between nominal effort, in terms of fishing time and how this relates to size and amount of gear deployed, WKCPUEEFORT **recommends** that details on the size and amount of gear deployed is collected under the auspices of national at sea observer programmes.

2.5 Improving the utility of Effort Information – using VMS and other data acquisition systems to estimate effort

The coupling of information from the vessel monitoring system (VMS) and landing from logbooks makes it possible to create fine-scaled information on the spatial distribution of the landings for a specific metier segment or fishing fleet. Using this information, possibly to estimate LPUE or spatially explicit fishing effort one should bear in mind that part of the fleet under investigation may not be equipped with a vessel monitoring system (as of 2011 boat length below 15 m). Since the introduction of the vessel monitoring system in EU, there has been a gradual increase in the number of vessels being monitored, due to a vessel length based time lag in the implementation of the VMS-regulations. As from 2012 all vessel above 12 m length should be equipped with vessel monitoring system. Analysis presented by Gerritsen (WD1; Figure 2.1.1) shows that while there is obviously a difference in absolute effort levels, when contrasting effort reported in EC logbooks, as these contain effort data vessels <15m, it is interesting to note that effort estimated from VMS based on fishing speed 1.5-4.5 knots and the reported fishing time in the logbooks are very similar. This supports the view that for vessels >15m at least, VMS can provide a precise estimate of fishing time or where there is concern regarding the accuracy of effort reported in EC logbooks, then VMS provides a useful alternative.

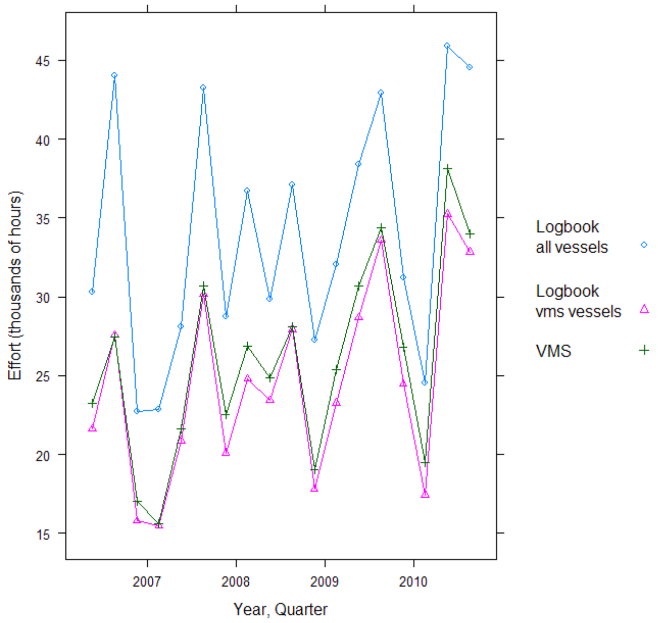

Figure 2.1.1. Comparison of fishing effort in VIIg from the logbooks database (circles) and effort estimates from the VMS data (crosses). For comparison, the logbook effort is also shown for vessels that have VMS only (triangles).

While fishing activity in terms of time fished, may be an appropriate proxy for effective effort in some fisheries, using reported effort in static gear fisheries may not necessarily be appropriate. The use video-based electronic monitoring systems are increasing (Figure 2.1.2).

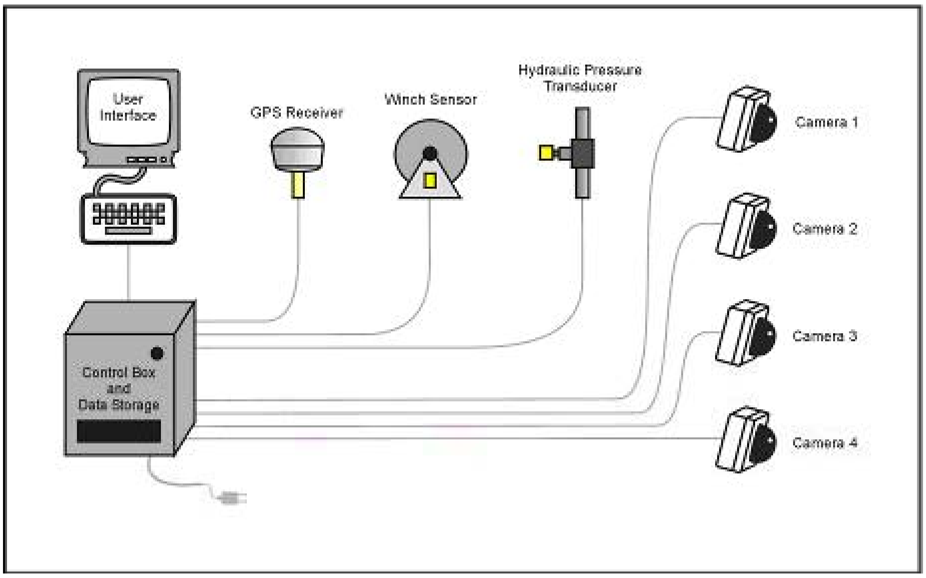

Figure 2.1.2 Schematic of electronic monitoring system.

In Europe several countries are now trialling the use of on-board monitoring systems or fully documented fisheries (Kindt-Larsen *et al.*, 2011). Vessels using such systems (McElderry, 2008) are allocated additional fishing opportunities if both landings and discards are counted against individual vessel allocations. These multi-sensor systems are primarily video observation systems that are used to observe the catch handling and processing systems onboard. However, the system also includes a range of other sensors e.g. monitoring winch and hydraulic activity and pressure that indicate what particular process is occurring at a given time e.g. hauling or deploying gear and for how long. Such detailed information has the potential to accurately estimate fishing effort (Figure 2.1.3).

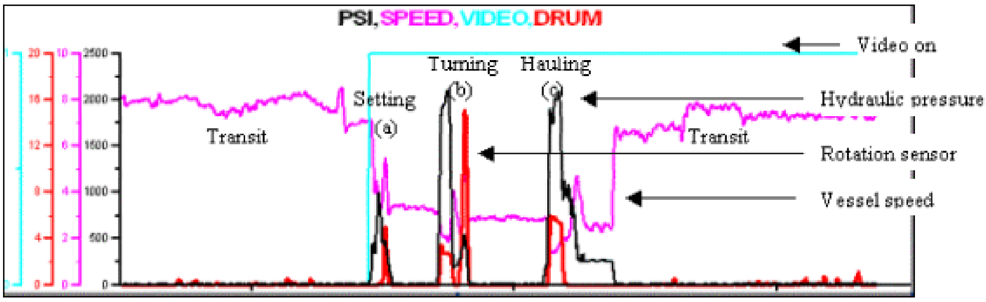

Figure 2.1.3 EM time series graph of sensor values showing a typical trawl fishing event: transit to grounds, setting gear (a), turning the vessel (b), hauling gear (c), and transit back to port. Shown are net drum rotation sensor (red), hydraulic pressure (black), vessel speed (purple), and image recording (turquoise) (data from McElderry *et al.*, 2005).

While speed and heading filtered VMS data can also provide robust effort estimates for mobile gears, the use of VMS recording of nominal effort purely in terms of time, is not necessarily meaningful for static gears. On-board monitoring systems however, provide an opportunity to estimate effective fishing time (soak time) for static gears, one of the primary effort metrics often not recorded.

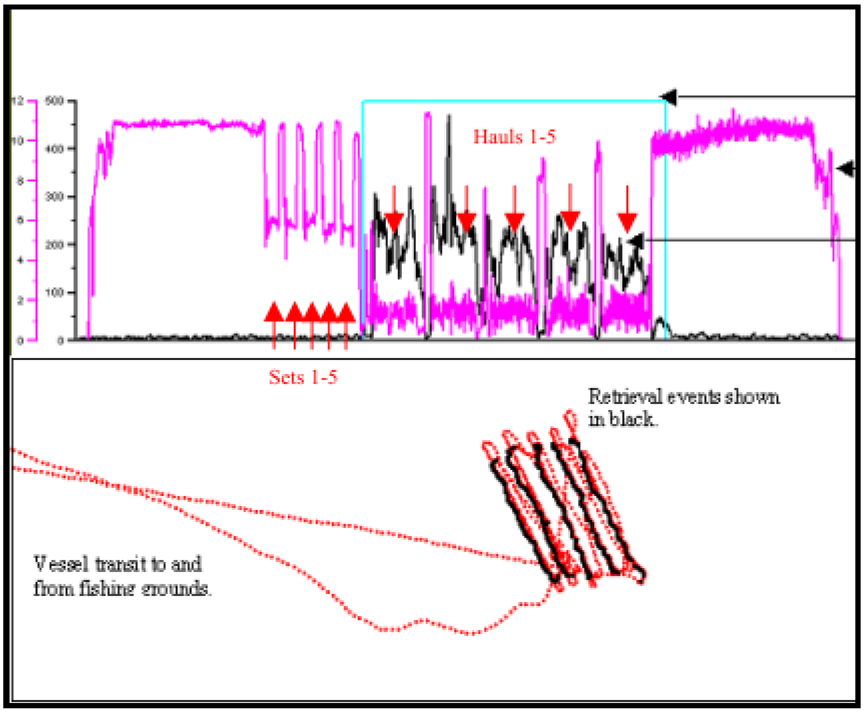

Figure 2.1.4 Plot showing setting and hauling activities on a groundfish longline vessel. Top is time series graph of sensor values and bottom shows GIS plot of setting and hauling (from McElderry *et al.*, 2004).

When creating time-series of specific metrics or presenting spatially refined information from part of a fleet there you need to take into account how representative your input data are. It might not be possible to account for the part of the fleet not using VMS but at least some basic information like percentage of landings and effort in fishing hours (or kWh) of the fleet segment without VMS could be calculated. In addition some metric on the spatial overlap could be provided, e.g. a comparison of effort and or landings per ices rectangle between VMS equipped vessels and vessels not using the system. In cases where the extended logbook is used, the spatial overlap of set positions of individual hauls between boats above and below the VMS limit length can be used. According to Council Regulation (EC) No 199/2008, fishing vessels above 15 m length must as from 31 May 2014 be fitted with Automatic Identification System (AIS). This system will provide fishery managers and researchers with high frequency data complementing the VMS system. It is important that these data are stored and made available also to fishery researcher. Care must be taken to ensure that data from AIS is stored in a way accessible and usable to researcher. Preferably no data should be discarded since there is a lack of estimates of the required frequency to successfully resolve fishing activity for different gear types.

2.6 Improving utility of landings data – Linking sampling events to activity

Collection and analysis of biological data from port sampling of commercial landings is time consuming and expensive. Therefore the best use should be made of this information by adding spatial information that describes where the catch was made. This could be particularly important for species where there are life history traits are spatially dependent e.g. depth dependent growth. This has particular relevance for megrim as it is known to grow faster in shallow water of approx. 100m compared to deeper waters of 200-250m (Gerritsen *et al.*, 2010). Therefore, the length at age distribution for this species will differ depending on the depth that it was caught. Identifying the location of samples would facilitate the development of depth specific Age Length Keys (ALK) which would improve the stock assessment by increasing the accuracy of the raising procedures to generate the catch numbers at age (CNAA). WD3 describes a successful attempt to link the sample date and vessel name to VMS data using the logbook information to provide a start and end date for the fishing trip. However there were some practical problems involved in linking the sampling, logbook and VMS databases. These problems include:

1) Errors in vessel names or absence of vessel names in the sampling database
2) Samples taken from multiple vessels landing on the same date
3) Mismatch between the trip departure and arrival dates in the logbooks with the dates of fishing activity in the VMS database
4) Lack of VMS data for vessels <15m

Despite the relative success of linking the samples to the spatial component of the fishing trip, the end result of the analysis was disappointing as there were no major differences found between the ALKs from the different depth categories. However, an important side note from this analysis is that the deeper fishing activity for megrim is underrepresented in the current port sampling programme. Only two trips with average depth greater than 150m were found. Such a bias in the sampling can have important consequences on the stock assessment as applying ALKs that are not representative of all the catches will result in increased uncertainty in the results due to depth related differences in length being accepted into the age structure of the assessment model. Greater sampling effort should be focused on the deeper fishing trips so that more accurate and realistic ALKs can be constructed for the stock assessment model.

Some of these issues can be resolved by improving quality control during sampling (e.g. vessel names) while others are inherent while using commercial data (e.g. mixed vessel landings). The advent of electronic logbooks may help to resolve some of these issues, as sampling events can be related to logbook and/or VMS events almost in real-time.

There are several problems in calculating the effort and hence also the CPUE of static gears. If there is reliable data in the logbook about the time that the gear is deployed in the water (soaking time) and data on the number of hooks or meters of length, estimates of LPUE or if data on discard is available also CPUE can be calculated. However, several countries have problems with that the data is not reported and/or that the quality of the data is poor. If there is a lack of logbook data described above, the inclusion of data with the spatial and temporal resolution of the VMS would not improve the probabilities to achieve CPUE estimates from static gears. The information that could be obtained from VMS signals is of help in order to get information about the fishing ground and data on how long time the vessels have spent on the sea. The fully documented fishery provides tools that can be used as estimators for CPUE for static gears. Firstly, the fully documented fishery will supply data on the total catch of the vessel i.e. catch per unit of effort instead of landings per unit of effort can be calculated. From analysing data from fully documented fishery, data for the time that the gear is deployed in the water and also the number/meters of gears used in the fishery.

3 ToR (b) Guidelines on when to use commercial catch data

b) *Develop guidelines for when to use commercial fleet data for determining fishing mortality or tracking stock abundance*

Commercial data (logbooks, VMS) are a very rich source of information. In many cases the data consist of a census of all activity or landings and in other cases the vast majority of activity or landings are recorded. For this reason alone, the utility of these data should be maximised. The accuracy of the data has improved in recent years with stricter enforcement and VMS data have made it possible to analyse the data in a spatially explicit way. However the main drawback for the use of commercial data remains the lack of discard information. There are only a small number of stocks for which discarding is insignificant or well monitored. It is not possible to define generic guidelines as to when and where to use commercial catch data (and when to ignore it!). Here we simply articulate the potential sources of bias, it is more a task of individual stock coordinators to make a judgement as to the utility of landings and discard data for any given stock. For many stocks, there have been general concerns about the accuracy of landing data, particularly since TAC's became restrictive, this led to misreporting of landings, either by area, by species or absence. Since the introduction of more stringent *landings* controls, there is a tacit view that accuracy of landings data has improved and for several stocks, have been reintroduced into the assessment. It is interesting to note that in some cases the age structure of the discarded portion of the catch has changed e.g. VIa Cod. It is possible that what was being misreported before is now being discarded.

3.1 Quality flags for use of commercial fleet data for determining fishing mortality or tracking stock abundance

Commercial LPUE data are often provided to stock coordinators for potential inclusion into a stock assessment model as a tuning fleet or as a direct index of abundance. The quality of tuning data is generally investigated by examining the residuals of single fleet runs. However, each commercial LPUE dataset should be thoroughly examined for possible sources of bias before it is submitted to the stock coordinator. The main possible sources of bias are:

1) Changes in the spatial distribution of effort
2) Changes in targeting behaviour (other than spatial changes)
3) Technological creep
4) Effort creep
5) Changes in misreporting of the landings (or effort)
6) Changes in discarding

Most of these changes occur in response to new management measures so it is of vital importance to have an insight into the consequences of these measures when interpreting trends in LPUE. If any of these sources of bias are known to occur but cannot be quantified, they should at least be flagged. If the bias can be quantified, the LPUE trends may be standardised using modelling techniques that account for the sources of bias.

4 ToR (c) Estimation Methods to Standardize Effort and to Track Stock Abundance

c) *Define necessary criteria and suggest estimation methods to derive proper and standardized time series of effort to be used for determining fishing mortalities in stock assessments taking all new electronic opportunities into account (e.g. VMS, electronic logbooks, automatic electronic monitoring)*

The standardization of effort is the same thing as the standardization of CPUE to obtain and index of relative abundance, since if U is a standardized CPUE series then C/U, where C is catch (or landings), gives the standardized effort. Also, a CPUE standardization model is equivalent to a purely catch-based model where effort is used as another predictor on the right-hand side of the equation or as an offset (e.g. Bishop *et al.*, 2008, Tascheri *et al.*, 2010). The standardized CPUE or catch series is a time series where factors affecting CPUE or catch other than fish abundance are thought to be removed, leaving an annual effect that serves as a proxy of relative abundance (Maunder and Punt, 2004). From a conceptual point of view the essential feature of CPUE standardization is that fish abundance is a latent predictor of catch or CPUE, and this is the reason why the year effect acts as a proxy of fish abundance. The other factors affecting the catch or the CPUE are generally selected from two categories of factors, namely factors related to the fishing strategy and fishing power and factors related to fish seasonality and spatial distribution, and these other predictors are observed. Standardized CPUE or catch series are used as information to influence the results of stock assessment models such as biomass dynamic models (a.k.a. non-equilibrium production models) and statistical catch-at-age models. These series should provide abundance trend information and be weighted against other sources of information contributing into an integrated stock assessment model (Maunder and Langley 2004). In addition, catch and effort information can be used directly to assess stocks, independent of the assessment of these stocks by recourse to population dynamics models. Consequently this section is organized in two parts. First we suggest data needs and statistical modelling techniques to standardize CPUE in order to produce proxies of relative stock abundance, and how VMS data can be used to refine the spatial component of CPUE. Secondly, we present a new approach to track stock abundance using catch and effort data and how VMS data clarify the interpretation of model parameters.

This subject was quite comprehensively covered by Maunder and Punt (2004) and other articles in the same issue of Fisheries Research. It is recommended that that article be consulted for an informed decision on how to set up a standardization model. Here we identify criteria for data collection and suggest additional modelling approaches that seem relevant to the European situation.

The most important practical issue in modelling CPUE or catch to derive a useful proxy of relative stock abundance is the level of aggregation of the data. In general statistical models are more useful when the basic data is less aggregated because in this case the statistical model is easier to define, the risk of model mis-specification is reduced, and the degrees of freedom to estimate parameters from the data are fully preserved. Ideally, in the context of CPUE standardization, the data should be at the maximum level of resolution of the individual fishing event, such as the individual trawl or the longline or gillnet set, by the individual ship. As the data becomes more aggregated such as per day or per fishing trip it loses degrees of freedom and then it becomes less powerful in discerning the proxy of relative stock abundance. This is a serious problem in European databases because the logbook data is often aggregated when it become available for modelling. In our view, efforts should be made to rebuild existing logbook databases to the maximum resolution of the individual fishing event and/or to start building logbook time series that fully account for all individual fishing events. A recent example of using individual data to standardize CPUE in the European context is Lorance *et al*. (2010). This example indicates that in principle it should be possible to rebuild existing databases to the maximum resolution of the fishing event by mining skipper's personal records of fishing. This rich source of information should not be lost to European fishery science, especially with the aim of obtaining a long-term view of stock abundance. If re-building is not feasible, then modern electronic means of data collection such as electronic logbooks should be structured in a manner that preserve the individual fishing event for modelling. Another important practical issue in fisheries data collection to model CPUE or catch is the amalgamation of logbook data that pertains to the same stocks from fleets of different countries or regions. It is often the case in European databases that logbook data from fishing activities in the same fishing grounds coming from fleets of different countries or regions is not consistent in the level of resolution. The article by Lorance *et al*. (2010) is again a relevant example. The authors use haul-by-haul logbook data to build a proxy of relative blue ling abundance from the French skippers only. Other fleets fish on the same fishing grounds but the corresponding haul-by-haul data were not available. For CPUE or catch standardization it is not essential that the logbook data be exhaustive: the proxy of relative stock abundance can be built with partial data. Nevertheless it is undoubtedly better to carry out the modelling having all the available data in the model. In standardization modelling, VMS data is useful to associate potential explanatory factors to the individual fishing event. An obvious item is the spatial location (latitude and longitude) of the fishing event. For example, in haul-by-haul logbook data the catch or landing associated to an individual fishing event can be corroborated by checking that the landed total of the fishing trip equates to the sum of the catch of the individual fishing events. No such checking can be carried out with location. Then VMS data may become the reliable source of information about the location of individual fishing events. Likewise, potential explanatory variables such as depth and habitat type can be obtained from bathymetric and habitat maps once the location data has been validated with VMS data. In the modelling of CPUE or catch data for standardization there are a number of approaches that can be undertaken. The first aspect to consider is whether the response variable is the catch or the CPUE. If the relation between catch and effort is assumed to be linear with a known coefficient then the choice does not matter and the effort of the individual fishing event may divide the catch in the right hand side of the equation (a CPUE model) or may be moved to the right hand side of the equation as an offset (e.g. Tascheri *et al*., 2010). However, if the relation between catch and effort is suspected to be nonlinear because of effort saturability or effort synergy (Bannerot and Austin, 1983, Quinn and Deriso, 1999) then the choice matters, because in the CPUE model the effort data should go on both sides of the standardization model. For example, if the nonlinear relation between catch and effort is power,

$$(1) \quad C = f(E^{\alpha}, \boldsymbol{X})$$

where C is catch, E is effort, and X is a vector of further explanatory variables, then the CPUE model should be

$$(2) \quad U = f(E^{\alpha-1}, \boldsymbol{X})$$

where U is the CPUE. An example of this approach modelling the catch is Bishop *et al*. (2008), where the γ parameter in their eq. (1) equals α-1 in our eq. (2).

Once the decision has been made whether to use the catch or the CPUE as the response variable, it is necessary to choose the distribution of the response and the mathematical structure of its dependence with the predictors. The simplest but nonetheless still useful approach is to assume a lognormal distribution of the catch or CPUE data and then model the logarithm of the response variable in a linear dependence structure with respect to response variables (e.g. Bishop *et al*., 2008). The underlying model is a multiplicative effects model. It should be noted that this structure is not equivalent to a generalized linear model in the Gaussian family with a log link (see Venables and Dichmont, 2004). Actually, this latter option is not recommended because it assumes homocedasticity, whereas catch and CPUE data often exhibits increasing variance with increasing mean.

The simple multiplicative model with a lognormal distribution is equivalent to a generalized linear model of the log(catch) or the log(CPUE) with a normal distribution and an identity link. Probably the most pressing problem with this approach is the fact that the catch and CPUE data is usually populated by a more or less extensive subset of zeroes when the data is dis-aggregated to the maximum resolution of the individual fishing event, as it is recommended here. One solution to this problem is simply to ignore the zeroes and then the model yields a proxy of relative stock abundance that is conditional on the catch being positive. However, the proportion of catches that are positive may carry information on the stock relative abundance trends so it may be desirable to account for the zero catches in the standardization model. The nature of this modelling problem is better grasped by considering that the choice of the distribution for the response variable may be such that zeroes are not allowed, such as in the case above with the normal distribution of log(catch) or log(CPUE) or with other choices within the generalized linear modelling paradigm, such as the exponential and the Gamma. In general, there are two statistically valid approaches to account for zero catches: a separate model for the binary result of fishing (i.e. 0 for zero catch and 1 for a positive catch) or the choice of a distribution that allow for zeroes. The first solution is known as a hurdle model in statistics, and a delta model in fisheries. It has been extensively applied to model catch and CPUE (e.g. Tascheri *et al.*, 2010, Roa-Ureta and Niklitschek, 2007).

The second solution has apparently not been employed extensively (but see Tascheri *et al.*, 2010). A simple alternative in this case is to employ a generalized linear model in the Poisson family. The Poisson distribution allows for zeroes but then the catch has to be transformed into counts, instead of being modelled as biomass. An obvious transformation is to divide the catch in biomass by the biomass capacity of a standard fish box. For example in the Basque trawler fleet the standard fish box contains 15 kg of fish. This is not as unnatural as it seems because experience tells that skippers often count fish boxes as the result of an event of fishing and then the catch in biomass units is obtained afterwards by multiplication. Another more complex modelling approach is to model the response variable with a distribution in the Tweedy family (Tascheri *et al.*, 2010, Lorance *et al.*, 2010) or with a zero-inflated Poisson distribution, among other options. When the catch and effort data are recorded at the individual fishing event level, the multivariate nature of the catch becomes evident. This means that the catch is a catch vector with as many components as there are fish species in the assemblage caught by the gear, and because of fisher targeting behaviour and natural ecological processes, the components in the vector are correlated random variables. Faced with this multivariate response variable the usual approach is to model the catch of the species of interest separately, and take into account the targeting behaviour by using the catch of the other species as predictor co-variables (e.g. Tascheri *et al.*, 2010) or by setting percentage cut-off points to define a targeted fishing event to a given stock (Lorance *et al.*, 2010). A statistically more appropriate method is to model the whole multivariate structure of the catch simultaneously with multivariate linear models or multivariate generalized linear models. The outcome of such a modelling would be a simultaneous multivariate time series of relative abundance proxies for all species composing the catch. A number of software tools have been developed recently to fit multivariate generalized linear models, among them the R package MCMCglmm (Hadfield, 2010), which includes families of distributions of special interest in CPUE standardization. The existence of databases with a resolution defined at the individual fishing event allows better modelling of the spatial component, especially when the location of each fishing event has been validated by analysis of VMS data. Currently, a common approach is to define an area factor with a few levels that are cells in a coarse spatial grid (Lorance *et al*., 2010, Tascheri *et al*., 2010). A more appropriate statistical modelling approach is to model the spatial correlation of the catch and CPUE individual fishing event data with geostatistical tools (Nishida and Chen, 2004).

Using Catch and Effort Data Directly for Stock Assessment

Probably one of the most serious issues affecting the utility of a CPUE index of fish abundance as a source of information of stock trends in stock assessment models, is the existence of hyper-stability and hyper-depletion (Harley *et al*., 2001). This occurs when there is a nonlinear relationship between CPUE and fish abundance, such as in

$$(3) \quad U = f\left(E^{\alpha-1}, N^{\beta}, \boldsymbol{X}\right)$$

where N is fish abundance and β is the hyper-response parameter. This phenomenon cannot be accounted for in a CPUE standardization model because in that type of model fish abundance is a latent variable, a non-observed predictor. The way to deal with hyper-stability and hyper-depletion is to consider a different class of models where fish abundance is an explicit predictor of catch rate.

Let the catch rate be defined as

$$(4) \quad \frac{dC}{dt} = f(E, N)$$

Assuming a linear function of the form *f(E,N)=qEN*, where q is a scaling constant, a solution of (4) is

$$(5) \quad C(t=\tau) = q\int_0^{\tau} E(t)\,N(t)\,dt = q\int_0^{\tau} E(t)\left(N_0 e^{-Mt} - \int_0^{\tau-\delta t} C(t)\,e^{-M(t-\delta t)}\,dt\right)dt$$

for a very small δt, M the instantaneous natural mortality rate (assumed the same for all $0 \le t \le \tau$), and N_0 the initial abundance in numbers. Since the observations of catch and effort come in discrete time steps, the model in (5) can be simplified to

$$(6) \quad C_t = q\,E_t N_t e^{-M/2} = q\,E_t\left(N_0 e^{-Mt} - e^{-M/2}\sum_{i<t} C_i e^{-(t-i-1)M}\right)e^{-M/2}$$

This discrete model is the Leslie-Davies-Chapman (LDC) depletion model (Leslie and Davies, 1939; Chapman, 1974; Rosenberg *et al*., 1990; McAllister *et al*. 2004; Roa-Ureta and Arkhipkin, 2007). The LDC depletion model is a stock assessment model that only allows for regular losses and that assume a linear relation between catch and its causative variables, nominal effort and fish abundance. To make it useful to model stocks in the presence of hyper-stability and hyper-depletion, and also to model nonlinearities in the relation between catch and effort, a simple approach is to assume a power nonlinear model for both, effort and abundance. In addition, to allow for fish recruitment events or fish emigration events and/or movements of the fleet that make new parts of the stock accessible to the fishing gear, pulses of positive or negative abundance can be added at specific time steps. These three generalizations lead to the following basic stock assessment model based on catch and effort data,

$$(7) \quad \begin{gathered} C_t = q\,E_t^{\alpha} N_t^{\beta} = q\,E_t^{\alpha}\left(N_0 e^{-Mt} + \sum_{i=1}^{t} P_i^{-M(t-i)} - e^{-M/2}\sum_{i=1}^{t-1} C_i e^{-M(t-i-1)}\right)^{\beta} e^{-M/2}, \\ t>0, C_t \ge 0, E_t \ge 0, q>0, N_0>0, \alpha>0, \beta>0, M>0, P \in \mathbb{R} \end{gathered}$$

where P_i are the episodic pulses (assumed to occur exactly and completely at the start of a single time step), $P_i>0$ for episodic additions, $P_i<0$ for episodic losses, and $P_i=0$ for most of the time steps. This latter condition makes the model identifiable. In addition, it is necessary to assume that the time steps when the P_i are not zero are known as well. Under the model in eq. (7) and the assumptions just described, the model has free parameters $\theta = \{q, \alpha, \beta, N_0, M, \{P_i\}\}$.

The pulses of abundance can be interpreted as being caused by the fish or by the fleet. This is where VMS data is useful. If the fleet location data show that part or all the fleet moved to new fishing grounds around the time step where a pulse is observed, then the pulse has been caused by the addition of a part of the stock that had been fished in the previous time steps. Alternatively the VMS data may show no change in the spatial distribution of effort and thus the pulse shall be attributed to new stock recruiting to the fishing grounds. In the model shown on eq. (7) the data demands are high frequency records of catch and effort, ideally at the maximum resolution of the individual fishing event, and if the catch is reported in biomass, then it is also necessary to have records of the mean body weight at the same time scale as the records of catch an effort, to transform catch in biomass to catch in numbers.

To fit the model to data it is necessary to adopt a probability model for the data. Two obvious options are an additive structure with a normal deviates, and a multiplicative structure with lognormal deviates,

$$X_t = qENe^{-M/2} + \epsilon, \quad \epsilon \sim N(0, \sigma^2)$$
$$X_t = qENe^{-M/2} e^{\epsilon}, \quad \epsilon \sim N(0, \sigma^2)$$

Fig. 1 shows the application of a multi-fleet version of the model to the greater forkbeard stock fished in the Celtic Sea and the Bay of Biscay by the Spanish fleet, assuming an additive normal probability model. In this case observations of mean body weight were not available because the stock is of little commercial importance and thus no program of biological sampling is carried out. Thus the model was also modified to account for natural changes in growth during each time step. The model however, did not account for pulses during the season and the presence of large positive outliers is evident. Details can be seen in a working document attached to the final report of ICES WGDEEP 2010. For all three fleets the model estimated a $\beta<1$ showing hyper-stability, whereas the situation was different for α depending on the fleet: trawlers had a nearly linear parameter ($\alpha \approx 1$) whereas gillnetters and longliners showed gear saturation ($\alpha<1$). Although the abundance parameter estimate looked reasonably good, these results shall not be interpreted as formal stock assessment results but rather as exploratory assessments.

Fig. 2 shows the application of model in eq. (7) to the redfish stock around Iceland and Greenland for the Spanish fleet in 2002, assuming an additive normal probability model. This model was run with catch in numbers. We show two model fits, one without any pulse and another one with one pulse at day 189 of the year. For each model four plots are shown, including model fit to data (left upper panel), residual distribution (right upper panel), residual scatterplot (left lower panel), and Q-Q residual plot (right lower panel). In this case, the estimated $\alpha>1$ indicates gear synergy whereas the estimated β was slightly higher than 1 indicating proportionality or a small degree of hyper-depletion. These results shall also be considered as exploratory.

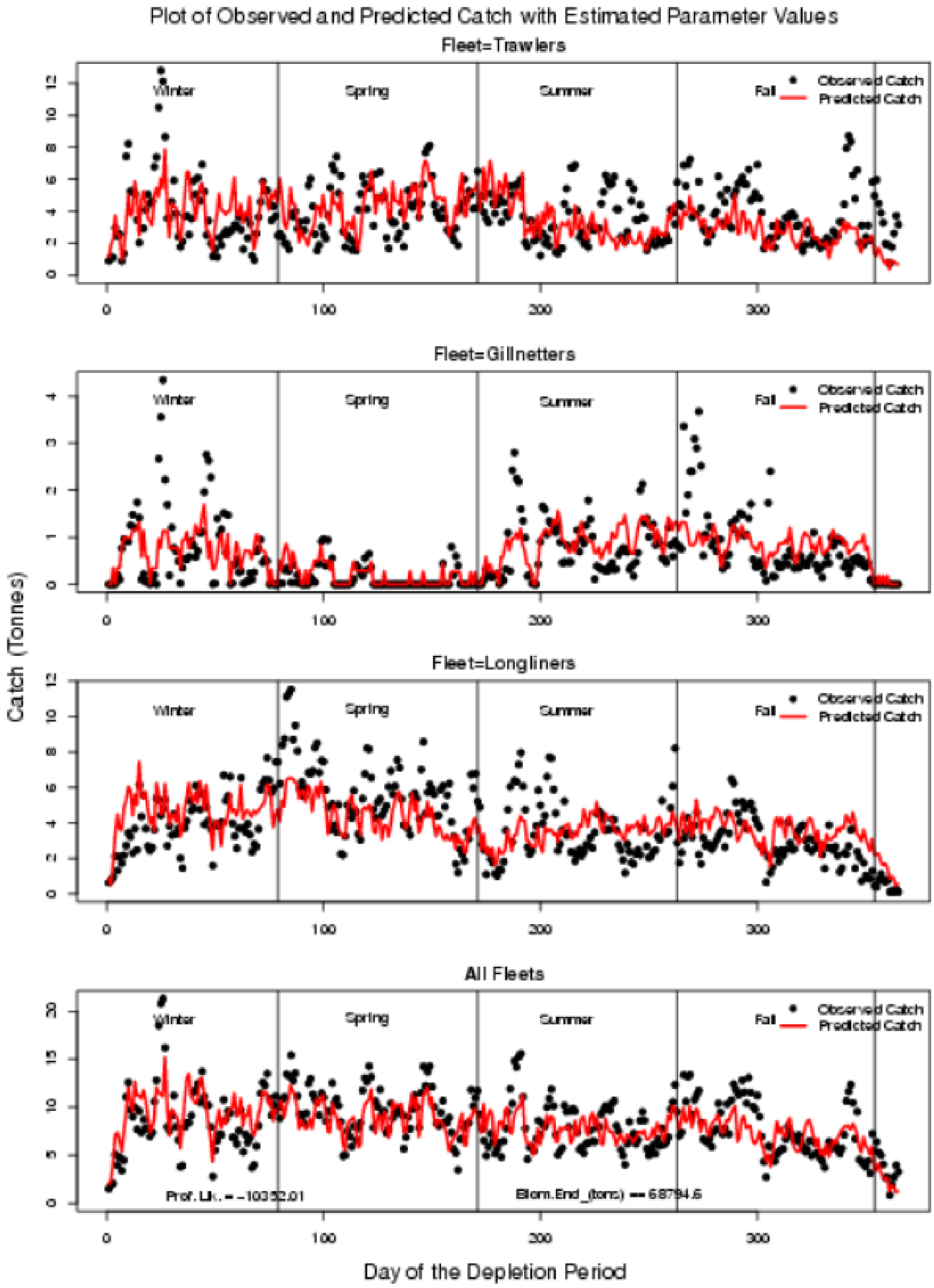

Figure 1. Phycis blennoides in the Celtic Sea and Bay of Biscay. Observed catch and predicted catch by the daily catch dynamics (generalised depletion) model in 2003.

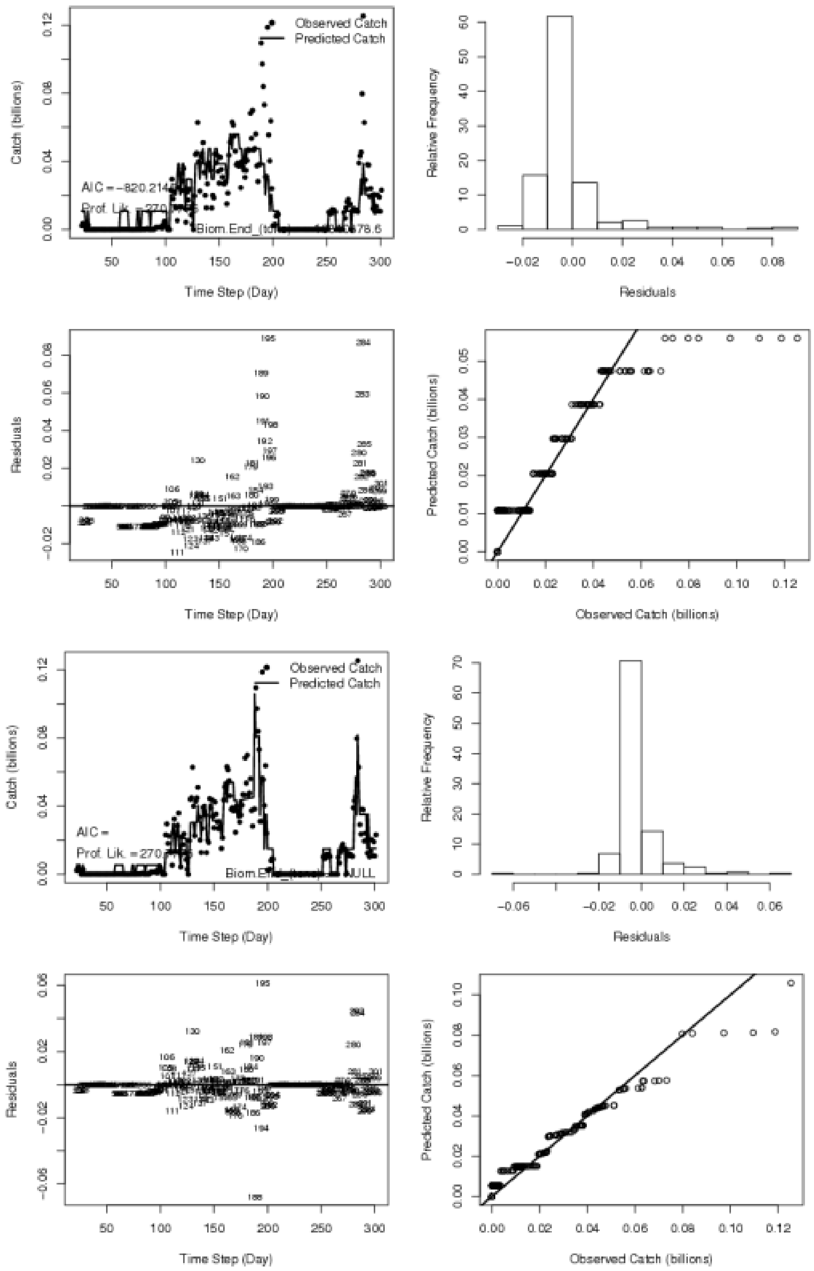

Figure 2. Sebastes mentella in the North Sea. The four panels show the model fit, a histogram of the residuals, a residual scatterplot, and Q-Q residual plot. The lowest four panels show the improved model with one pulse at day 189 of the season in 2002.

References

Abad, E., I. Artetxe, F. Cardador, J. Casto, R. Duarte, D. Garcia, C. Hernández, M. Marín, A. Murta, A. Punzón, I. Quincoces, M. Santurtún, C. Silva, L. Silva, 2007. Identification and Segmentation of Mixed-Species Fisheries Operating in the Atlantic Iberian Peninsula waters (IBERMIX project). Final Report. Contract Ref.: FISH/2004/03-33. 256 p.

Afonso-Dias, M., J. Simões, C. Pinto and P. Sousa, 2002. Use of satellite GPS data to map effort and landings of the Portuguese crustacean fleet. Final Report ECDGXIV/STUDY/99/059 http://w3.ualg.pt/~madias/geocrust/FinalReport_GeoCrust.pdf

Afonso-Dias, M. e C. Pinto, 2008. Análise da Distribuição Espacial do Esforço e Rendimentos de Pesca das Frotas Portuguesas de Arrasto Costeiro (Projecto GeoPesca). Relatório Final do Projecto MARE 22-05-01-00025. Universidade do Algarve, Faculdade de Ciências do Mar e do Ambiente, Faro. 171 p.

Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J., Degel, H., 2010, Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location, Fisheries Research, 106, 41-53,

D.J.B. Beare, N.T. Hintzen, G.J. Piet, Clara Ulrich Rescan, Colm Lordan, Fabrizio Manco, Francois Bastardie , Hans Gerritsen , Josefine Egekvist, Martial Laurans, Neil Campbell, Nicolas Deporte, Rasmus Nielsen, Ryszard Grzebielec, Stephanie Mahevas, Sebastien Demaneche, Stuart Reeves, 2011 Development of tools for logbook and VMS data analysis Studies for carrying out the common fisheries policy (No MARE/2008/10 Lot 2)

Bishop J, Venables WN, Dichmont CM, Sterling DJ. 2008. Standardizing catch rates: is logbook information by itself enough? ICES Journal of Marine Science 65:255–266.

Bannerot SP, Austin CB. 1983. Using frequency distributions of catch per unit of effort to measure fish stock abundance. Transactions of the American Fisheries Society 112:608-617.

Chapman, D. G. 1974. Estimation of population size and sustainable yield of sei whales in the Antarctic. Report of the International Whaling Commission, 24: 82–90.

Eigaard, O.R., Rihan, D., Graham, N., Sala, A. and Zachariassen, 2011. Improving fishing effort descriptors: Modelling engine power and gear-size relations of five European trawl fleets. Fisheries Research, 110, 39-46.

Ellis J.R., Rogers S.I., Freeman S.M., 2000. Demersal assemblages in the Irish Sea, St George's Channel and Bristol Channel. Estuarine, Coastal and Shelf Science, 51: 299-315.

Fretwell S., Lucas H., 1970. On the territorial behaviour and other factors influencing the distribution of birds. I. Theoretical development. Acta Biotheor, 19: 16-36.

Gerritsen, H.D., McGrath, D., Lordan, L. And Harlay, X., 2010 Differences in habitat selection of male and female megrim (Lepidorhombus whiffiagonis, Walbaum) to the west of Ireland. A result of differences in life-history strategies between the sexes? Journal of Sea Research, 64, 487-493.

Hadfield, JD. 2010. MCMC methods for multi-response generalized linear mixed models: the MCMCglmm R package. Journal of Statistical Software 33:1-36.

Harley SJ, Myers RA, Dunn A. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Science 58: 1760–1772.

Hilborn, R. And Walters, C.J., 1992. Quantitative fisheries stock assessment: Choice; dynamics and uncertainty, Chapman and Hall, pp 558

Hinz, H., Bergmann, M., Shucksmith, R., Kaiser, M. J., and Rogers, S. I. 2006. Habitat association of plaice, sole, and lemon sole in the English Channel. e ICES Journal of Marine Science, 63: 912-927.

Hintzen, N.T., Piet, G.J., Brunel, T., 2010. Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. Fish. Res. 101, 108–115.

ICES, 2003. Study Group on the Development of Fishery-based Forecasts. ICES CM 2003/ACFM:08.

ICES. 2009. Report of the Study Group on Combining Gear Parameters into Effort and Capacity Metrics (SGEM). ICES Document CM 2009/FTC: 11. 28 pp.

Kaufman, L. and P. J. Rousseeuw, 1990. Finding Groups in Data. An Introduction to Cluster Analysis. J. Wiley & Sons, Inc. 342 p.

Kindt-Larsen, L., Kirkegaard, E. and Dalskov, J., 2011. Fully documented fishery: a tool to support a catch quota management system. ICES Journal of Marine Science; doi:10.1093/icesjms/fsr065

Leslie, P. H., and Davis, D. H. S. 1939. An attempt to determine the absolute number of rats on a given area. Journal of Animal Ecology, 8: 94–113.

Lorance P, Pawlowski L, Trenkel, VM. 2010. Standardizing blue ling landings per unit effort from industry haul-by-haul data using generalized additive models. ICES Journal of Marine Science 67: 1650–1658.

Maunder, MN, Langley, AD. 2004. Integrating the standardization of catch-per-unit-of-effort into stock assessment models: testing a population dynamics model and using multiple data types. Fisheries Research 70:389-395.

Maunder, MN, Punt, AE. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

McAllister, M. K., Hill, S. L., Agnew, D. J., Kirkwood, G. P., Beddington, J. R. 2004. A Bayesian hierarchical formulation of the DeLury stock assessment model for abundance estimation of Falkland Islands' squid (Loligo gahi). Canadian Journal of Fisheries and Aquatic Sciences, 61: 1048–1059.

McCullagh, P., and Nelder, J. A. 1989. Generalized Linear Models. Chapman and Hall, London. 511 pp. (Monographs on Statistics and Applied Probability).

McElderry, H., J. Illingworth, D. McCullough, and J. Schrader. 2004. Electronic Monitoring of the Cape Cod Haddock Fishery in the United States – A Pilot Study. Unpublished Report Prepared for the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), Chatham, MA, USA by Archipelago Marine Research Ltd., Victoria, BC, Canada. 37

McElderry, H., 2005a. Report for Electronic Monitoring in the Antarctic Longline Fishery. Archipelago Marine Research Ltd. Unpublished Report Prepared for the Australia Fisheries Management Authority, Canberra, ACT, Australia by Archipelago Marine Research Ltd., Victoria, BC, Canada, 11p.

McElderry, H., 2008. At-Sea observing using video based electronic monitoring, proceedings of Electronic Monitoring Workshop, July 2008, NPFMC/NOAA/NPRC,

Muggeo, V.M.R., 2003. Estimating regression models with unknown break-points. Statistics in Medicine, 22: 3005-3071

Needle, C., L. And Catarino, R., 2011. Evaluating the effects of real-time closures on cod targeting. ICES Journal of Marine Science; doi:10.1093/icesjms/fsr092

Nishida T, Chen D-G. 2010. Incorporating spatial autocorrelation into the general linear model with an application to the yellowfin tuna (Thunnus albacares) longline CPUE data. Fisheries Research 70:265– 274.

Reid, D. G., Graham, N., Rihan, D.J., Kelly, E., Gatt, I.R., Griffin, F.D., Gerritsen, H.D. and Kynoch, R.J., (in press) Do big boats tow big nets? ICES Journal of Marine Science.

Roa-Ureta, R. and Arkhipkin, A. I. 2007. Short-term stock assessment of Loligo gahi at the Falkland Islands: sequential use of stochastic biomass projection and stock depletion models – ICES Journal of Marine Science, 64, 3–17.

Roa-Ureta R, Niklitschek E. 2007. Biomass estimation from surveys with likelihood-based geostatistics. ICES Journal of Marine Science 64: 1723-1734.

Rose, G. A., and Kulka, D. W. 1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua)* declined. Canadian Journal of Fisheries and Aquatic Sciences, 56(Suppl 1): 118 - 127.

Rosenberg, A. A., Kirkwood, G. P., Crombie, J. A., and Beddington, J. R. 1990. The assessment of stocks of annual squid species. Fisheries Research, 8: 335–350.

Rosenberg, A.A.; Bigford, T.E.; Leathery, S.; Hill, R.L.; Bickers, K. (2000). Ecosystem approaches to fishery management through essential fish habitat Bull. Mar. Sci. 66(3): 535-542

Russo, T., Parisi, A., Cataudella, S., 2011a. New insights in interpolating fishing tracks from VMS data for different métiers. Fish. Res. 108, 184–194.

Russo, T., Parisi, A., Prorgi, M., Boccoli, F., Cignini, I., Tordoni, M., Cataudella, S., 2011b. When behaviour reveals activity: Assigning fishing effort to métiers based on VMS data using artificial neural networks. Fish. Res. (2011), doi:10.1016/j.fishres.2011.06.011

Shepherd T.D., Litvak M.K., 2004. Density-dependent habitat selection and the ideal free distribution in marine fish spatial dynamics: considerations and cautions. Fish and Fisheries, 5: 141–152.

Silva, C. and F. Cardador, 2010. Effects of using new standardized CPUE series in the assessment of FU 28-29 Nephrops. Working document presented to WKSHAKE2, Lisbon, 22 – 26 November.

Silva, C., A. Murta and F. Cardador, 2009. Segmentation of the Portuguese bottom-trawl and purse-seine fleets based on the analysis of landings composition by trip. Relat. Cient. Téc. IPIMAR, Série digital (http://inrb.pt/ipimar) nº 51, 20pp.

Tamdrari H., Castonguay M., Brèthes J.C. Duplisea D., 2010. Density-independent and -dependent habitat selection of Atlantic cod (*Gadus morhua*) based on geostatistical aggregation curves in the northern Gulf of St Lawrence. ICES J. Mar. Sci., *67(8): 1676-1686.*

Tascheri, R, Saavedra-Nievas, AC, Roa-Ureta, R. 2010. Statistical models to standardize catch rates in the multi-species trawl fishery for Patagonian grenadier (*Macruronus magellanicus*) off Southern Chile. Fisheries Research 105:200-214.

Valavanis V.D., Georgakarakos S., Kapantagakis A., Palialexis A., Katara I., 2004. A GIS environmental modelling approach to essential fish habitat designation. Ecological Modelling, 178: 417–427.

Venables WN, Dichmont CN. 2004. GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. Fisheries Research 70:310-337.

Walters, C., 2003. Folly and fantasy in the analysis of spatial catch rate data, Can. J. Fish. Aquat. Sci. 60: 1433-1436

5 Conclusions from WKCPUEEFORT:

Much of the recent work on using VMS and logbook data has focussed on the technical integration of the two data sources but the use of the data has largely been limited to the spatial mapping of fishing activity and the spatial distribution of landings. Research beyond the production of maps is only now beginning to emerge from the scientific community but in many respects the use of spatially refined catch data for scientific and management purposes is still in its infancy. A number of presentations were made during the workshop that provided examples of how spatially refined data presents clear benefits in terms of both the provision of scientific advice and how such data could be used for more spatially refined fisheries management.

WKCPUEEFORT acknowledges the availability of the vmstools and considers that this should be used as the basis for future work and such work could also contribute to the development of the vmstools package. WKCPUEEFORT recommends that the common data format proposed by vmstools package should be used to guarantee the inter-exchangeability of outputs. To facilitate the use of vmstools a vms user list should be developed to promote collaboration and exchange ideas and methodologies between scientists and recommends that ICES should establish a training programme for vmstools.

Work presented on CPUE indices for Celtic Sea haddock (VIIb-k) has shown that VMS data can be used to spatially refine CPUE (LPUE) indices from commercial fleets and that such spatial refinement can have significant impacts on CPUE trends. Integration of VMS and logbook data together with data on habitat type will allow for the development of habitat specific CPUE indices for demersal species. Further work of this type is encouraged and should be considered during ICES benchmarking process.

Logbook databases should be maintained at an individual fishing event level e.g. haul-by-haul level and ideally should be built on a regional scale. With the addition of data on fishing gear metrics, WKCPUEEFORT concluded that it is possible to significantly refine estimators of nominal effort by improving data on gear metrics. WKCPUEFFORT recommends that additional metrics on fishing gear construction be gathered under the Data Collection Framework by observers engaged in national 'at sea' sampling programmes. The integration of VMS, vessel and fishing gear characteristics will allow the refinement of effort estimators for example the estimation of swept area by metiers. The collection of gear metrics offers the potential to systematically record and estimate technological creep allowing for derivation of quantitative correction factors that could potentially be applied to CPUE indices.

There is evidence that shows that under management systems that regulate fishing effort, fleets can respond with tactical adaptations that can negate adjustments in fishing effort. These tactical adaptations include the increase in towing speed and reductions in the daily frequency of fishing operations reducing the time required to deploy and retrieve fishing gear. This 'effort creep' can occur within the 'headroom' of existing management units e.g. kW.days. Both VMS and data from fully documented fisheries data could be used to monitor for the possibility of effort creep.

Management measures can have significant impacts on fishermen's behaviour that could influence the CPUE index. VMS could assist in identifying spatial changes in fleet activity in response. VMS data can be used to check suitability of sampling relative to the spatial distribution of the fishery. The use of CPUE as a measure of abundance is limited by the lack of discard data and in practice is Landings per Unit Effort (LPUE). This significantly limits the utility of CPUE as an abundance indicator.

VMS data can be used to directly estimate effort independent of logbooks for mobile gears and can help refine estimators of nominal effort. Work presented showed that VMS effort estimated for vessels over 15m achieved high correlation with effort data reported in logbooks for towed gears. This indicates that in situations where there is concern regarding the reporting of nominal effort, cross references between the two data sets could confirm or exclude this possibility. If no correlation is found it is considered that the VMS data could be used as an alternative as an effort estimator.

VMS data is limited as an indicator of fishing effort in static and surrounding fisheries and needs to be supplemented with additional sources of data e.g. onboard monitoring systems used in fully documented fisheries. Providing reflective estimators of nominal effort has always been problematic in static gears as effort is related not only to the size of gear, but also soak time. The integration of VMS and onboard monitoring equipment could result in significant improvements in the provision of more precise estimators of nominal effort by including information on soak time. Alternatively, recording of set-by-set data in logbooks together with location, gear size and shooting and hauling time would achieve an even higher level of precision.

Relatively new data source for science but accessibility to the scientific community is variable. WKCPUEEFORT agrees with the conclusions from vmstools that, in general, the frequency of VMS transmissions is too long and greater utility (precision) could be achieved with increased ping frequency. WKCPUEEFORT recommends that the ping rate should be set at a maximum of 30 minutes.

Lack of VMS and logbook data from vessels <15m limits the availability for spatially refined CPUE and catch data. WKCPUEEFORT recommends that vessels under 12m should be encouraged to use equipment that can provide spatially refined activity maps. AIS system may present high frequency spatial coverage in coastal areas and this data should be made available for scientific purposes.

WKCPUEEFORT **recommends** the formation of a dedicated R&D project to develop further the scientific and management use of spatially refined catch and effort data and other sources of 'new' technologies.

Annex 1: List of participants

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Annex 2: Agenda

WKCPUEEFORT 2011

ICES, Copenhagen

09:00 Hrs 5 April - 15:00 Hrs 7 April

AGENDA

1) Welcome and Introduction

2) Background and ToR's

3) Case studies

   a) Development of tools for logbook and VMS data analysis, Francois Bastardie, DTU-Aqua, Copengahen,

   b) Spatially explicit LPUE indices of Mixed Fisheries in the Celtic Sea using VMS and Logbook data – Hans Gerritsen, MI, Galway

   c) Using VMS to check depth dependent sampling bias in Megrim – Eoghan Kelly, MI, Galway

   d) Improving fishing effort descriptors: modelling engine power and gear-size relations of five European trawl fleets, Eigaard *et al.*, 2010.

   e) CPUE – Technology and changes in q and does the effort matter?

4) General discussion – identifying where VMS can be used – disentangling science from management

5) General discussion – factors affecting CPUE – accounting for changes in q and 'headroom' in effort - how can new tools help?

6) General discussion – maximising CPUE/VMS in assessment procedures – guidelines, data requirements and utility

7) When to use commercial catch data?

8) Data requirements and estimation methods for standardisation of effort

9) Task allocation for WKCPUEEFFORT report

Annex 4: Recommendations

Recommendation	Adressed to
1. Consideration should be given to the use of VMS and landings data to spatially refine tuning fleets used for assessment purposes	ICES – Benchmark Expert Groups
2. The list of technical details of fishing gears contained in WKCPUEEFORT should be collected routinely as part of sea-going observer programmes	PGCCDBS/DCF
3. Dedicated R&D project to develop further the scientific and management use of spatially refined catch and effort data and other sources of 'new' technologies	ICES/EU
4. The common data format developed by the MARE/2008/10 Lot 2 VMS tools project should be promoted to ensure inter-exchanability	SGVMS
5. To facilitate the use fo VMS tooks a vms user list should be developed to promote collaboration and exchange ideas and methodologies	SGVMS
6. ICES Should establish a training programme in the use of VMS tools	ICES

Annex 5: Working Documents

Working Document to the

Workshop on the utility of commercial CPUE and VMS data in assessments

(WKCPUEffort)

Copenhagen, 5-7 April 2011

Spatially explicit LPUE indices of mixed fisheries in the Celtic Sea using VMS and Logbook data

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Abstract

Lpue estimates from commercial fisheries may be biased if the spatial distribution of fishing effort changes over time. A method is presented to identify spatial strata with homogenous catch compositions using hierarchical cluster analysis. These strata were then used to estimate a stratified lpue trend which is unbiased with respect to changes in the distribution of fishing activity.

Introduction

Fisheries in the Celtic Sea are mainly of a mixed nature; although certain species may be targeted, the by-catch of other commercially valuable species is generally substantial. However, even within this mixed fisheries, there is considerable spatial structure in the species composition of the landings (Figure 1). For this reason, the lpue indices from mixed fisheries are sensitive changes in the distribution of fishing effort over time. The aim of the present analysis is to:

a) Identify spatial areas with homogenous catch compositions.
b) Use these areas to stratify the commercial lpue data and obtain an unbiased lpue index.

Methods

Developments in the methodology for integrating landings statistics from the EU logbooks with VMS data have made it possible to estimate catch and effort data at a very fine spatial resolution. Following the method described by Gerritsen and Lordan (2011), each VMS location of Irish Otter trawlers was allocated an effort value, which is the time since the previous VMS record (generally 2 hours; records with time intervals of more than 4.5 hours were omitted). Next, the VMS data were filtered for vessel speeds between 1.5 and 4.5 knots in order to select records corresponding to fishing activity. The daily catch data were then allocated equally to the remaining VMS records for each vessel and date and aggregated to the grid of

0.10° longitude * 0.05° latitude. Data were available for the period of 1 Jan 2006 to 31 Aug 2010.

A Hierarchical Cluster Analysis (HAC) was performed to identify areas with similar species compositions. The species compositions of the 10 most abundant species in the landings were converted to proportions in each grid cell. (These species constitute 90% of the total landings; all deepwater species were grouped into one species-class). Next a matrix of the Euclidian distance between the species compositions in the cells was calculated. This matrix was used as input for a hierarchical cluster analysis, using Ward's minimum variance clustering algorithm (Gordon, 1987).

Eight clusters were identified and these were used to define 35 spatial strata. The spatial distribution of these clusters was used to manually draw the boundaries of the strata. The distribution of fishing effort and depth contours were also taken into account when drawing the boundaries.

The present analysis was limited to the main strata covering ICES Division VIIg (Celtic Sea). The landings and effort in each of these strata were extracted on a quarterly basis from the integrated logbooks and VMS databases. The lpue was estimated for four species (cod, haddock, nephrops and whiting) for each stratum and the overall lpue was estimated by calculating the average lpue weighted by the surface area of the strata to obtain an unbiased, stratified, estimate of lpue:

$$L = \frac{\sum L_s \cdot A_s}{\sum A_s}$$

Where L is the stratified lpue of the whole region, s is the stratum number 1,2,3…n, L_s is the lpue in stratum s and A_s is the surface area of stratum s.

Results and Discussion

The number of clusters resulting from the HAC was chosen, somewhat arbitrarily, to be eight. This number resulted in spatially discrete clusters that appeared to match known spatial patterns in the fisheries. Even though the location of each cell was not taken into account in the analysis, a clear spatial pattern emerges when the clusters are mapped in space (Figure 2). The borders around the clusters was drawn in manually, creating 35 distinct strata. For convenience each of the strata was given a name of a nearby fishing ground or geographical feature (Figure 2). The present analysis was limited to the area of ICES Division VIIg. The strata do not follow Division boundaries but the main strata in this area (Cork, Galley, Labadie1, Labadie2, Nymphe and Smalls) were selected (Figure 3).

A time-series of the species composition in the selected strata is shown in Figure 4. Most strata have a reasonably consistent species composition but the Smalls ground has a strong seasonal pattern.

The effort estimated from VMS in these selected strata showed a nearly identical trend to the effort in VIIg, estimated from the logbooks, particularly when only vessels that have VMS were included (Figure 5). The VMS effort is a bit lower than the overall logbooks effort, the main reason is probably that the VMS data are restricted to vessels of 15m and over. The fishing effort by stratum (estimated from VMS records) is shown in Figure 6. The figure clearly shows that the spatial distribution of fishing effort varies considerably over time.

The stratified estimates of lpue (mean lpue of the strata, weighted by surface area) are shown in Figure 7. The figure also shows the logbook estimates. The lpue estimates for cod were similar for both methods, probably because the majority of the catches are located in a small area. Stratified lpue estimates for haddock were consistently higher than those from the logbooks. This suggests that the haddock landings are not a driver for the distribution of the effort. In other words, if the effort was distributed evenly throughout the area, haddock landings would be higher (not taking into account changes discarding that may take place). Nephrops show the opposite effect, this indicates that the distribution of the effort is so that nephrops lpue is higher than expected from a random spatial distribution. The VMS lpue also has much less of a seasonal signal, which appears to be caused by the seasonal change in effort on the Smalls grounds (Figure 6). The whiting lpue has a strong seasonal signal which is apparent in both the VMS and logbook estimates. The lpue tends to peak in the 4th quarter of each year, perhaps reflecting recruitment into the fishery of young fish.

Conclusions

a) The cluster analysis resulted in a reasonably unambiguous division of the fishing grounds around Ireland into a number of spatial strata with reasonably homogenous catch compositions.
b) These areas can be used to estimate a spatially stratified lpue time-series which is less sensitive to bias caused by changes in the spatial distribution of effort over time.
c) Currently, the time-series of VMS data is quite short (2005 onwards for vessels >15m) but nevertheless it can provide useful insights.

References

Gerritsen, H.D. and Lordan, C., 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 J. Mar. Sci., 68(1): 245-252.

Gordon, A.D., 1987. A review of hierarchical classification. JSTOR, 150(2): 119-137.

Figures

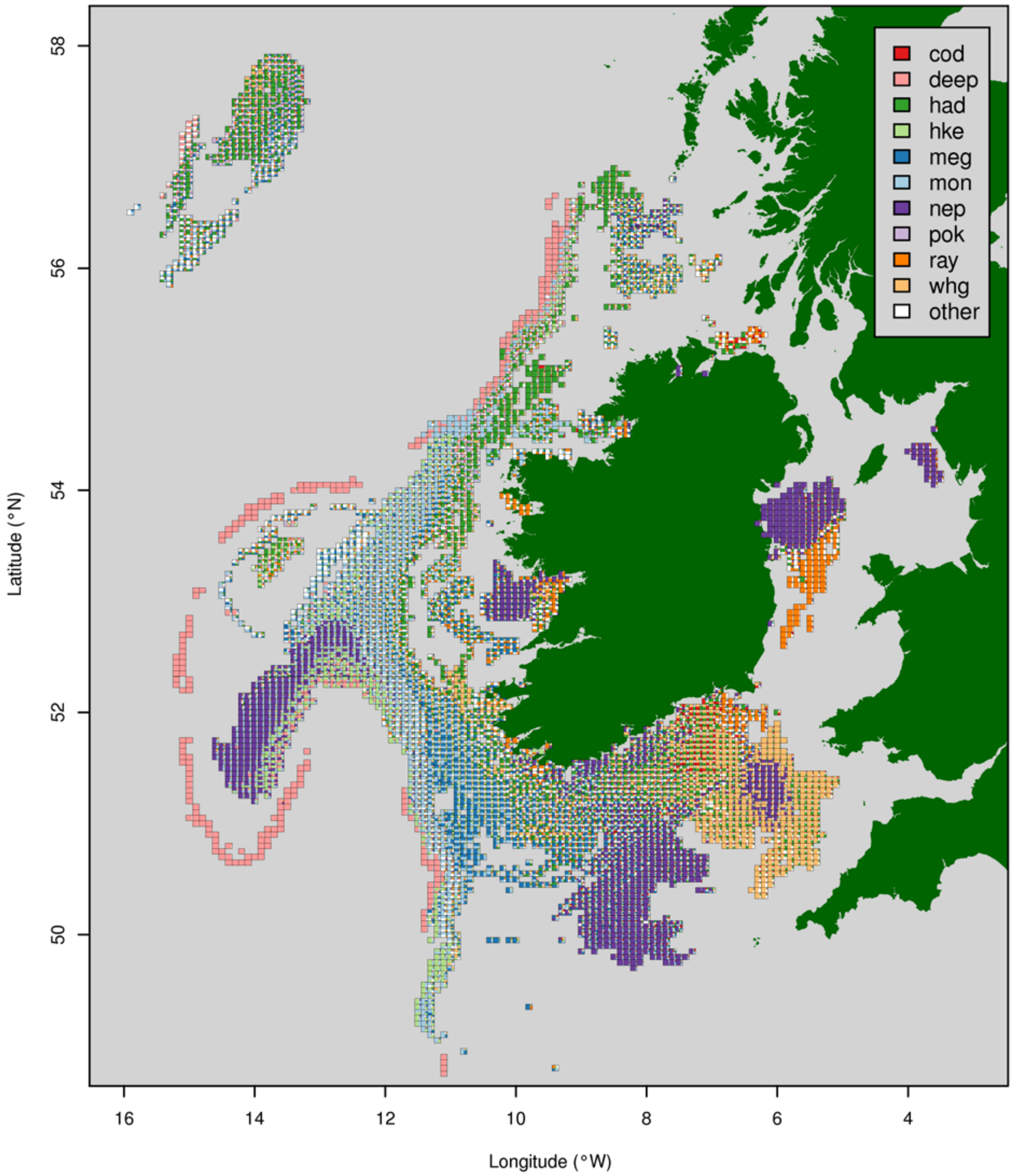

Figure 1. Species composition of the landings of Irish otter trawlers during 2006-2010. Each cell is 0.10° longitude * 0.05° latitude and the area of each colour with the cell is proportional to the species composition in the landings (by weight)

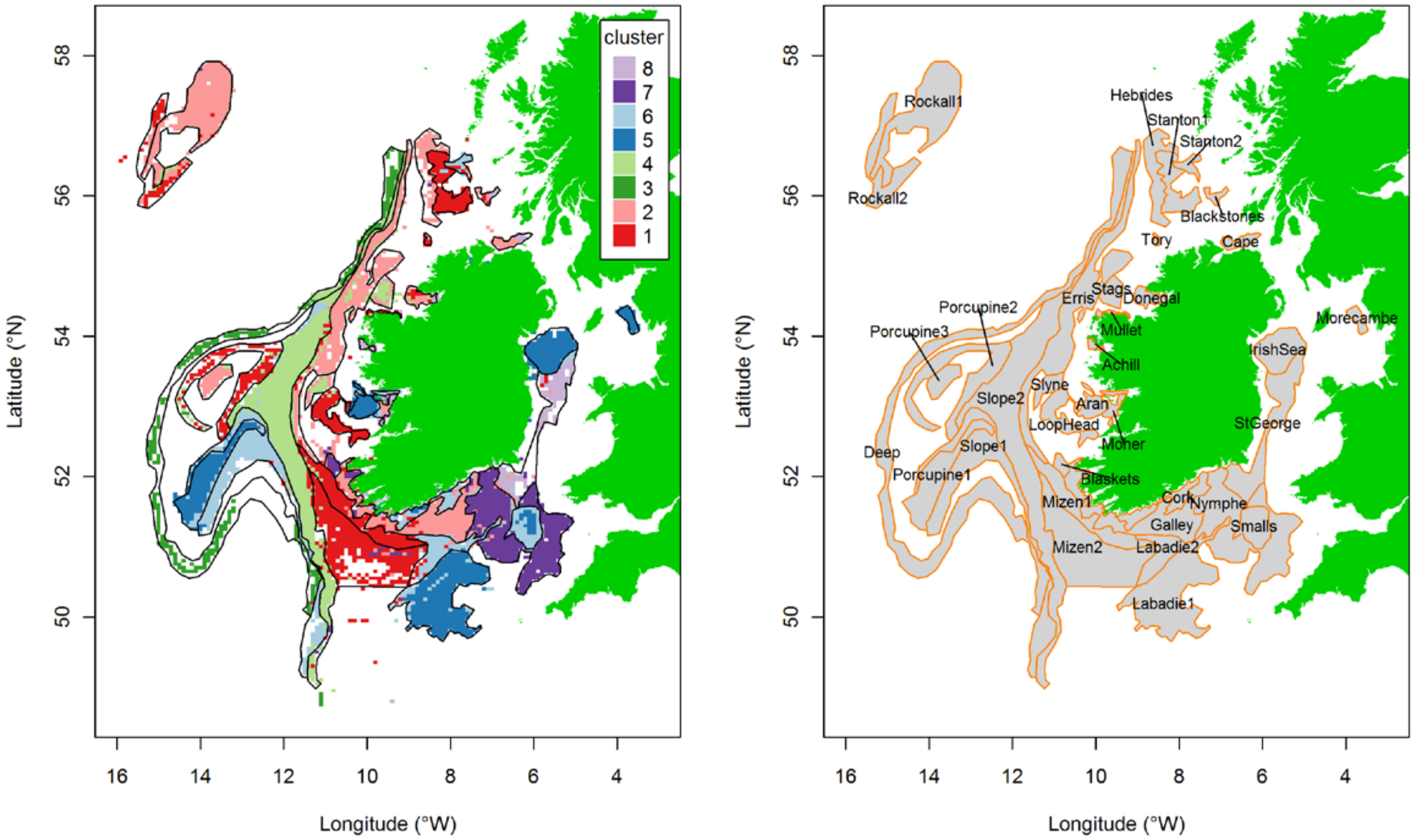

Figure 2. Results of the hierarchical cluster analysis; 8 clusters were identified which showed clear spatial patterns (left panel). The 8 clusters resulted in 35 distinct strata (right panel).

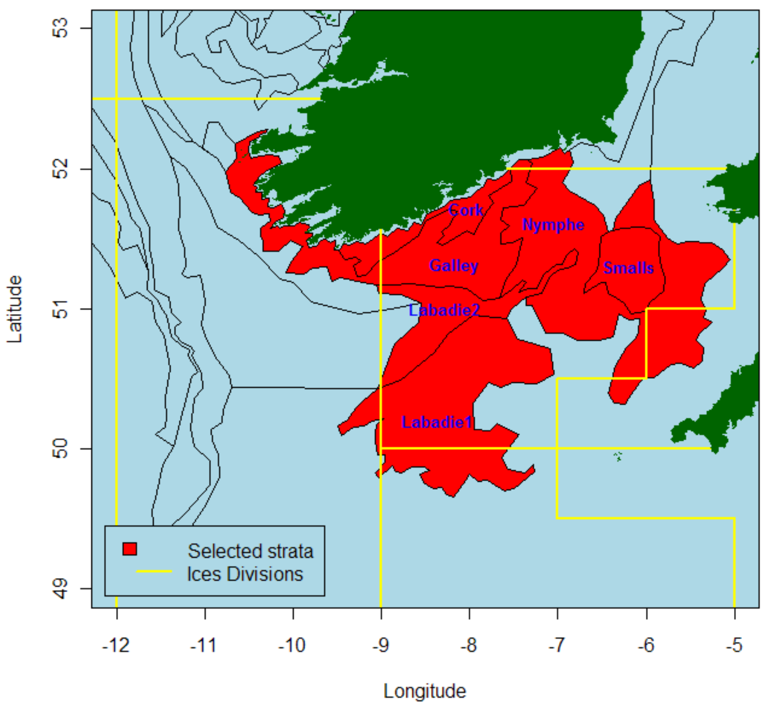

Figure 3. The six main strata covering ICES Division VIIg were selected for the current analysis (Cork, Galley, Labadie1, Labadie2, Nymphe and Smalls)

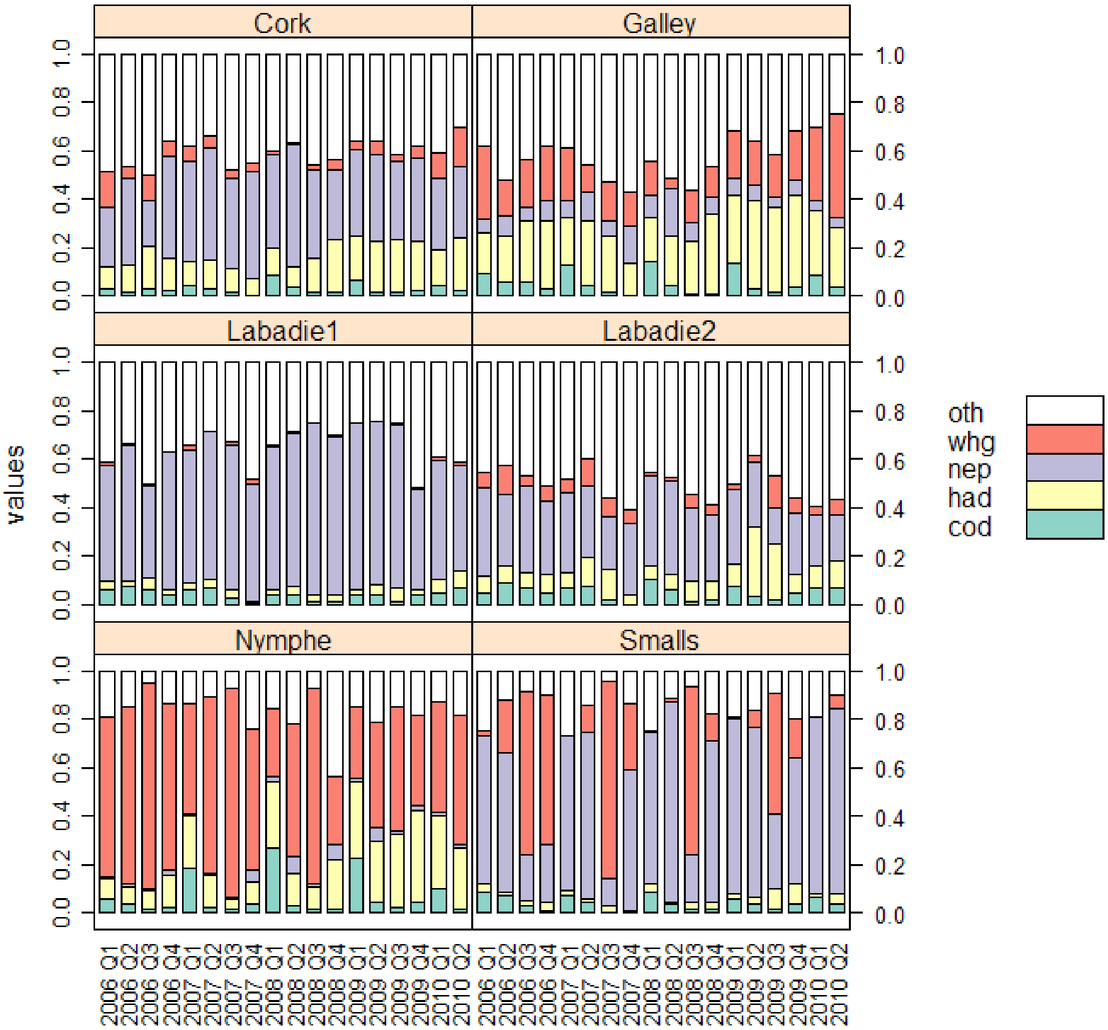

Figure 4. Species composition over the time series in the selected strata for cod, haddock, nephrops, whiting and other species.

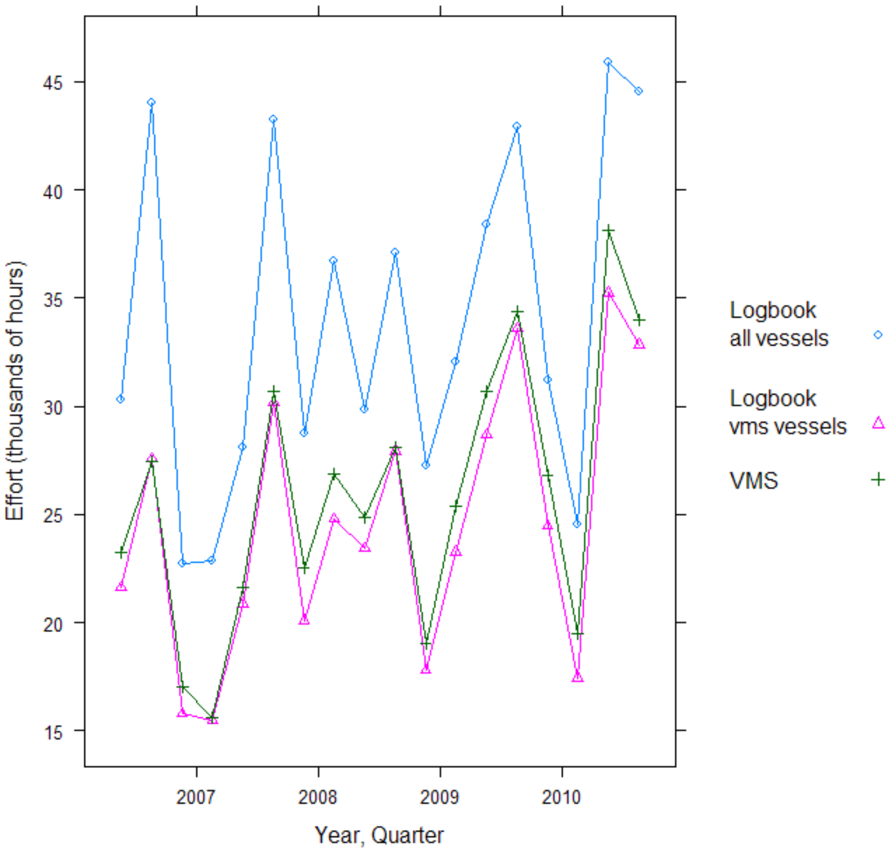

Figure 5. Comparison of fishing effort in VIIg from the logbooks database (circles) and effort estimates from the VMS data (crosses). For comparison, the logbook effort is also shown for vessels that have VMS only (triangles).

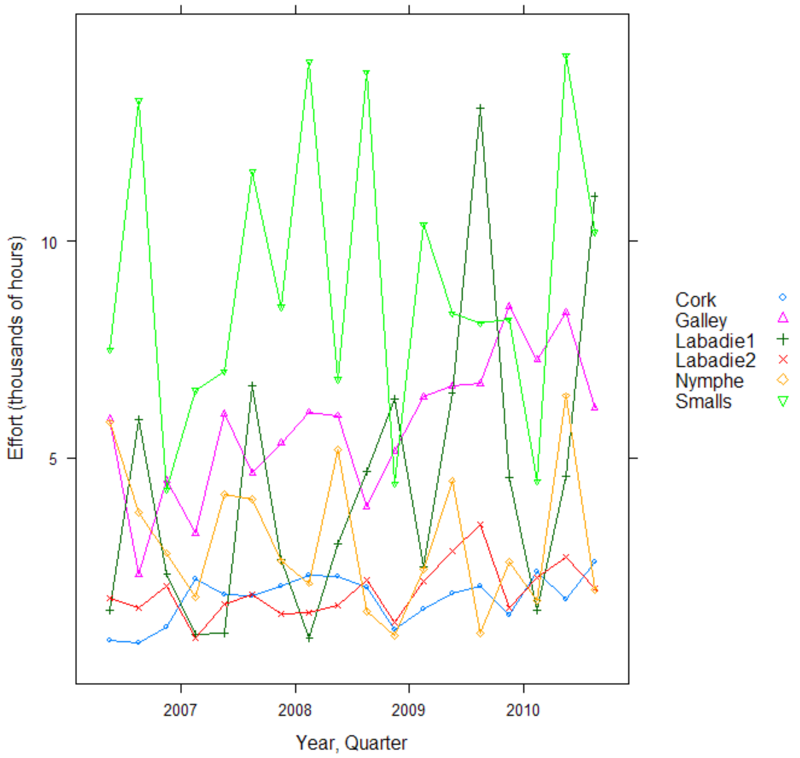

Figure 6. Fishing effort in the selected strata (estimated from VMS records).

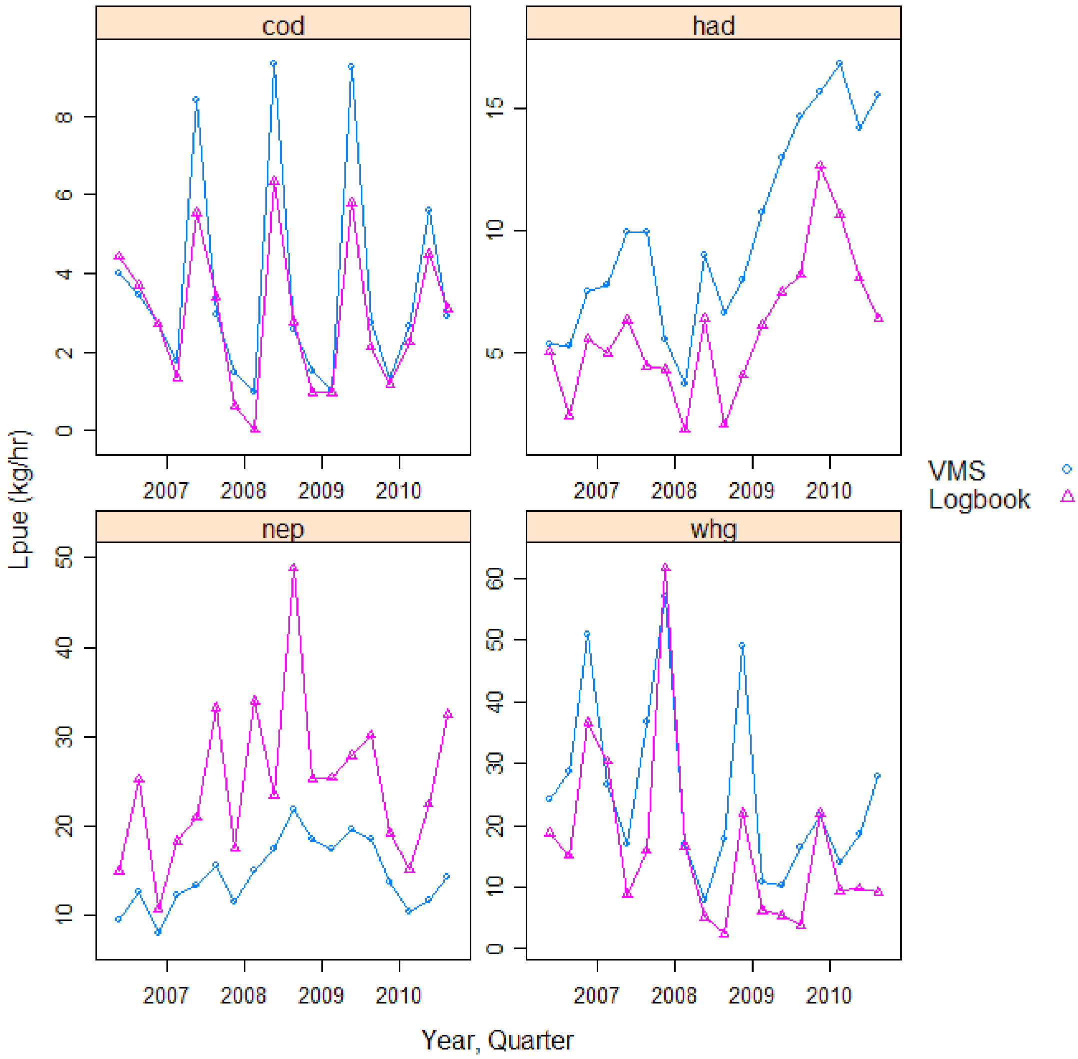

Figure 7. Lpue of cod, haddock, neprhops and whiting, estimated using the stratified VMS data and using the standard logbook method.

Working Document to be presented at the Workshop on the utility of commercial CPUE and VMS data in assessments (WKCPUEFFORT), Copenhagen, 5 – 7 April, 2011

The use of VMS data for the *Nephrops* CPUE standardization

in the Portuguese Crustacean Trawl Fishery

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Introduction

The Portuguese crustacean fishery takes place off the southwest and south coasts of the Portuguese continental waters (ICES Division IXa – Functional Units FU 28 and 29). The fishery is conducted by 30 trawlers, which are in average 25 meters of overall length and 411 kW of engine power. This fleet accounts for 93% of deep crustacean landings from Portuguese continental waters. There are two main target species in this fishery, the deepwater rose shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*), sharing partly the same grounds. Although their distribution areas overlap at depths 200 – 500 m, rose shrimp highest yields occur at depths below 400 m whereas Norway lobster highest catch rates are at 500 – 600 m. Due to the high market value of rose shrimp and to the fact that its fishing grounds are closer to the coast, in periods of high abundance of rose shrimp the vessels spend less effort on *Nephrops*. Taking into account the target species, the vessels of this fleet are licensed for mesh sizes of 55 and ≥70 mm, for shrimps and *Nephrops*, respectively.

Attempts have been made to standardize *Nephrops* CPUE using GLM. Considering the behaviour of the fleet in periods of high abundance of rose shrimp, variables related to the daily catches of this species and the proportion of *Nephrops* in the total daily catch were incorporated in the model together with *year* and *month* (ICES 2010a, 2010b). Other variables related to fishing grounds (zone, ICES square) were not used due to deficiencies in the logbooks data. The final model explains 45% of the total variability, with the proportion of *Nephrops* in the total daily catches as the most important factor (Silva and Cardador, 2010).

However, other factors as fishing ground and depth could be important for this standardization and for the separation of data from the two FUs. At present, all the crustacean landings from trawl are recorded and sold in only one fishing harbour, located at south Portugal, and hence *Nephrops* stocks in these FUs are assessed together.

The aim of this communication is to discuss what improvements can be introduced in the CPUE standardization using the VMS information.

VMS

VMS records (including vessel code, position, time and speed in 10-min intervals) were processed using the package GeoCrust 2.0 in the project GeoPescas (Afonso-Dias and Pinto, 2008). These records correspond to the period 1998-2004, when the data were transmitted each 10 minutes. The fishing hauls and trips were semi-automatically identified based on a speed criterion for each of the crustacean trawlers, the landing date and the judgement of an operator. In average, the trawl speed ranged 2.3 – 3.5 knots.

In the whole period, 12855 fishing trips were considered, 76% of which were tagged as valid and 61270 hauls were identified.

The identified hauls have associated the haul duration in minutes and the trawled distance in nautical miles. The VMS data from the second half of the year 2004 were not completely processed.

In 2005, the time interval to transmit the data increased from 10 minutes to 2 hours, creating problems to the hauls identification. Figure 1 shows a simple simulation exercise on the possible consequences of the time interval increase. Data were taken from a real trip of the year 2003. In this specific case, assuming that the trawling speed is 3 knots, the total effort time estimated from identified hauls is 42.22 fishing hours, directly from VMS records with 10-min interval is 42.55 hours and from 2-hour interval is 40.72 hours. Depending on the first point sampled, the estimated total time may be different.

Landings data

Data on landings in weight and value by species, trip and vessel were provided by the Portuguese Fisheries Administration (DGPA). Given that fishing is highly driven by the market value of the product, it was assumed that the revenue obtained with the catch would be the best descriptor for the activity of the fleet (ICES, 2003). Fishing activities were identified using a non-hierarchical clustering algorithm PAM (Partitioning Around Medoids) and its variant CLARA (Clustering Large Applications) to classify the landing profiles (Kaufman and Rousseeuw, 1990; Abad et al, 2007; Silva et al, 2009).

Two main clusters were identified for each year. In the period 1995-2003, when the abundance of rose shrimp was very high, one cluster was directed at rose shrimp (DPS) and the other, not well defined, at a mixture of crustacean species (MIXC), i.e. rose shrimp, Norway lobster and red shrimp (*Aristeus antennatus*). In 2004-2007, the abundance of rose shrimp decreased and the fleet start to direct its activity also to *Nephrops*. In this period, there was still a cluster directed at rose shrimp but a cluster directed at *Nephrops* (NEP) was clearly defined. In 2008-2009, rose shrimp abundance increased again and the fishery reverted to the previous situation with mostly of the trips directed at rose shrimp and the remaining trips at mixed crustaceans. In 2004, some few trips were classified as directed at the giant red shrimp (*Aristaeopsis edwardsiana*) (Silva, pers. com.).

Linking trips and VMS

A trip is limited by the vessel departure date from the harbour for fishing and the next arrival for landing. The hauls identified within the trip are linked with the corresponding landings, based on the vessel identifier and landing date.

The hauls for the period 1998-2004 identified with the software GeoCrust were linked to the corresponding landings and trips classification. As this classification was based on landings value, trips from the freezer vessels (14% and 9% of valid hauls in 2003 and 2004, respectively) were not used. These vessels sell directly their products and do not land their catches.

Depth distribution

Depth data for each haul operation was estimated overlaying the VMS data on a 1-minute depth grid (extracted from global seafloor topography from satellite altimetry and ship depth soundings, http://topex.ucsd.edu/cgi-bin/get_data.cgi). Figure 2 shows the hauls depth distribution by trip type and zone.

As expected, the highest density of hauls directed at rose shrimp is in areas shallower than 400 meters while the depth distribution of the trips directed at mixed crustaceans (MIXC) and *Nephrops* look similar and more concentrated at 500-700 meters. It is important to note that the trips classified as MIXC may include hauls in different areas and depths. A deeper analysis of these trips based on VMS data and logbooks, not only on landings, may help to clarify their fishing pattern and separate the hauls directed at the different species.

Catch and effort estimation

For the purpose of this document, data were aggregated to a grid of 0.05º longitude by 0.05º latitude (Figure 3). The median area of the cells is 24.3 km^2.

Figures 4 to 6 show the distribution of the crustacean fleet fishing effort by fishing trip types in the period 1998-2004.

In the specific case of this fishery, crustacean species are too valuable to be discarded. Therefore, one may consider that the landings of these species correspond to catches. The same is not true for fish species. Dividing the landings equally by the number of hauls in a trip will give a CPUE estimate for the crustacean species but only LPUE for the others.

Another approach could be to link the classified fishing trips and hauls with the logbook data, to determine the fishing ground and depth and introduce these variables in the CPUE standardization model. This work is still in progress.

Apart from the hauls identification, the analysis was carried out in R (R Development Core Team, 2010, Bivand *et al.*, 2008).

Issues to discuss

- This work was carried out with VMS records in 10-minutes interval. With 2-hour interval, which is the average now, what is the effect in the effort estimation and its precision?
- It is expected that the entry in force of the electronic logbook fill some gaps of the information from the present paper logbook. Position data are recorded in the logbook by the captain or automatically recorded? Is this information sufficient to estimate effort? VMS data are still needed to map the fishing grounds and area estimation.

Acknowledgements

This report makes use of the trips identified in the project GeoPescas (MARE 22-05-01-00025), based on data provided by DGPA/SIFICAP-MONICAP (Sistema integrado de Informação e apoio à vigilância, FIscalização e Controlo da Actividade da Pesca). Trips classification was based on landings data provided by Portuguese Fisheries Administration (DGPA).

References

Abad, E., I. Artetxe, F. Cardador, J. Casto, R. Duarte, D. Garcia, C. Hernández, M. Marín, A. Murta, A. Punzón, I. Quincoces, M. Santurtún, C. Silva, L. Silva, 2007. Identification and Segmentation of Mixed-Species Fisheries Operating in the Atlantic Iberian Peninsula waters (IBERMIX project). Final Report. Contract Ref.: FISH/2004/03-33. 256 p.

Afonso-Dias, M. and C. Pinto, 2008. Análise da Distribuição Espacial do Esforço e Rendimentos de Pesca das Frotas Portuguesas de Arrasto Costeiro (Projecto GeoPesca). Relatório Final do Projecto MARE 22-05-01-00025. Universidade do Algarve, Faculdade de Ciências do Mar e do Ambiente, Faro. 171 p.

Bivand, R. S., E. J. Pebesma and V. Gómez-Rubio, 2008. Applied Spatial Data Analysis with R. Use R! Series. Springer. 378 p.

ICES, 2003. Study Group on the Development of Fishery-based Forecasts. ICES CM 2003/ACFM:08.

Kaufman, L. and P. J. Rousseeuw, 1990. Finding Groups in Data. An Introduction to Cluster Analysis. J. Wiley & Sons, Inc. 342 p.

R Development Core Team, 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org/.

Silva, C., A. Murta and F. Cardador, 2009. Segmentation of the Portuguese bottom-trawl and purse-seine fleets based on the analysis of landings composition by trip. *Relat. Cient. Téc. IPIMAR*, Série digital (http://inrb.pt/ipimar) nº 51, 20pp.

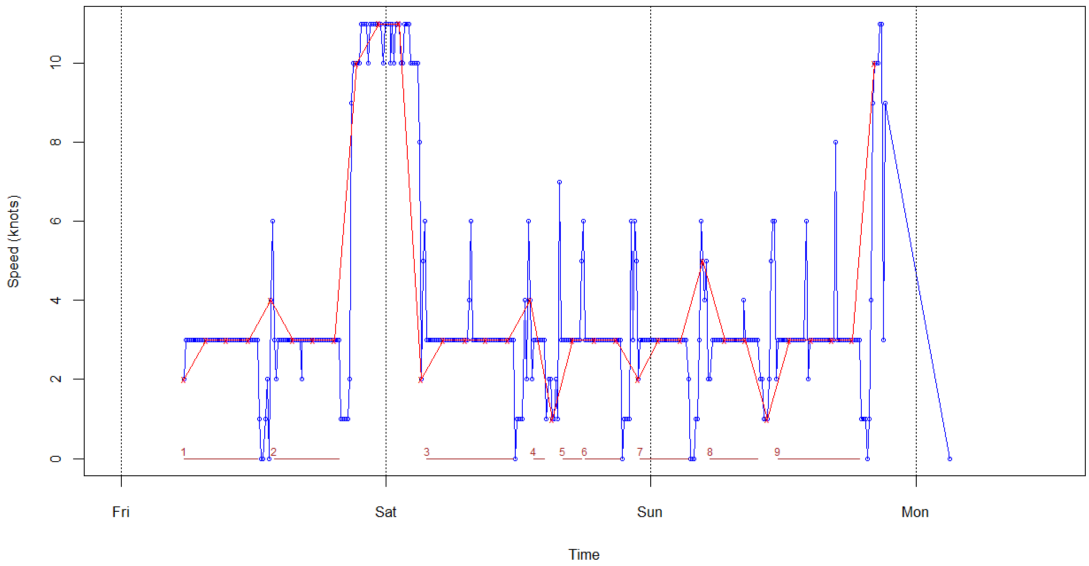

Figure 1. Blue line: 10-min interval VMS records of an identified trip. Red line: VMS records sampled from the same trip, taking the first record in each group of 12 (approximately 2-hour interval). Brown lines and numbers: Hauls identified with GeoCrust 2.0. Data taken from a real trip of the year 2003.

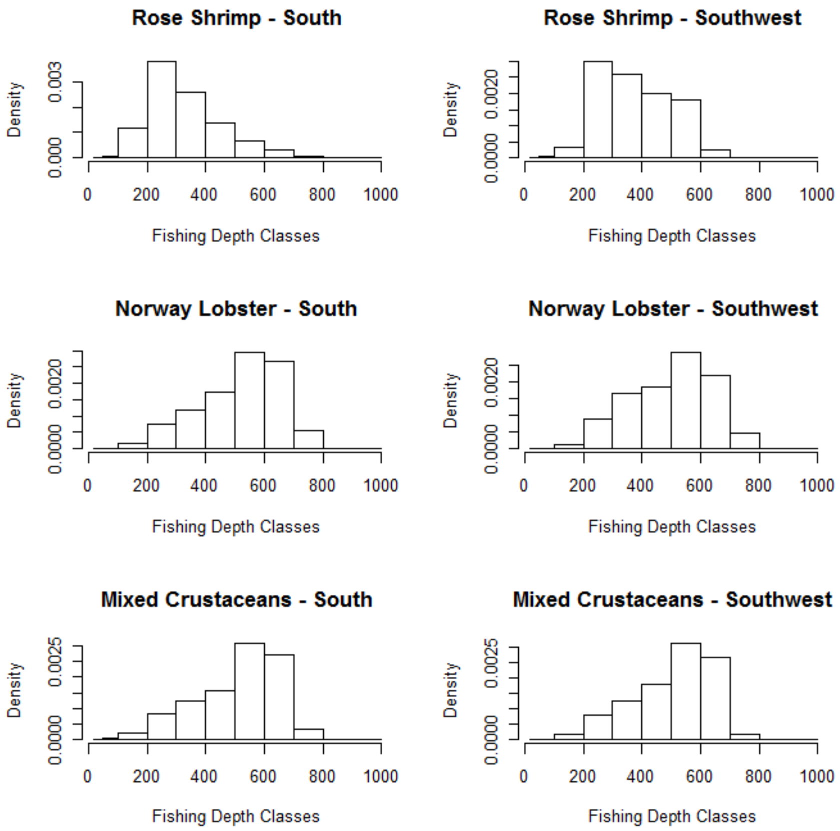

Figure 2. **Density of trawl hauls for the clusters directed at rose shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*) and mixed crustaceans off the South (FU 29) and Southwest (FU28) coasts of Portugal.**

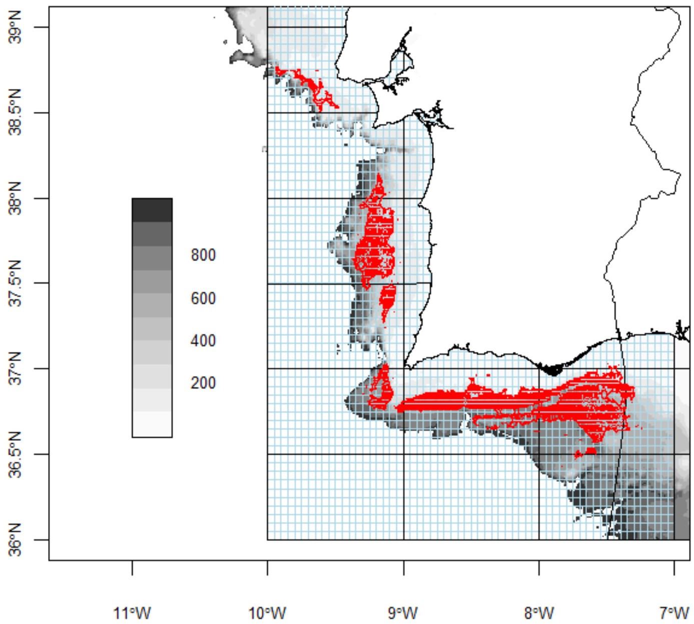

Figure 3. **Crustacean fishing grounds (in red) off Southwest and South coasts of Portugal, with a 0.05º x 0.05º grid, ICES squares and depth (grey scale) overlays.**

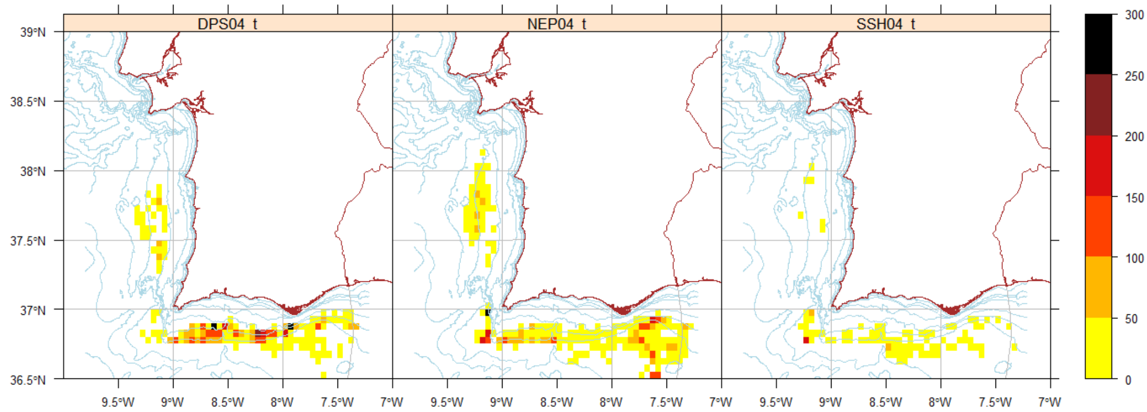

Figure 4. Effort distribution (in hours trawling) for the year 2004 for the trips directed at rose shrimp (DPS), *Nephrops* (NEP) and giant red shrimp (SSH) . Note: The year 2004 was not completely covered.

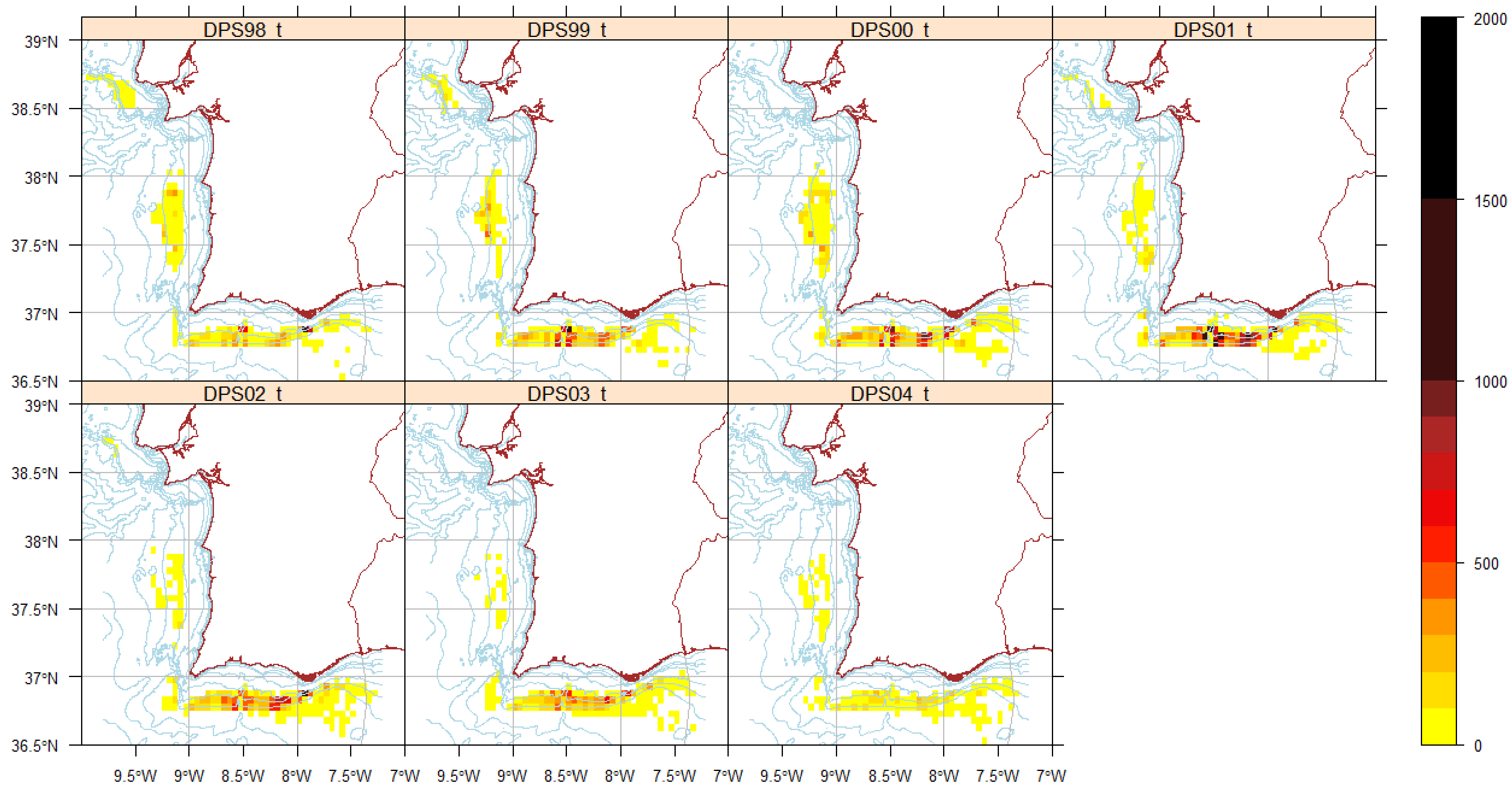

Figure 5. Effort distribution (in hours trawling) for the cluster DPS directed at rose shrimp, in the period 1998-2004. See note from Figure 4.

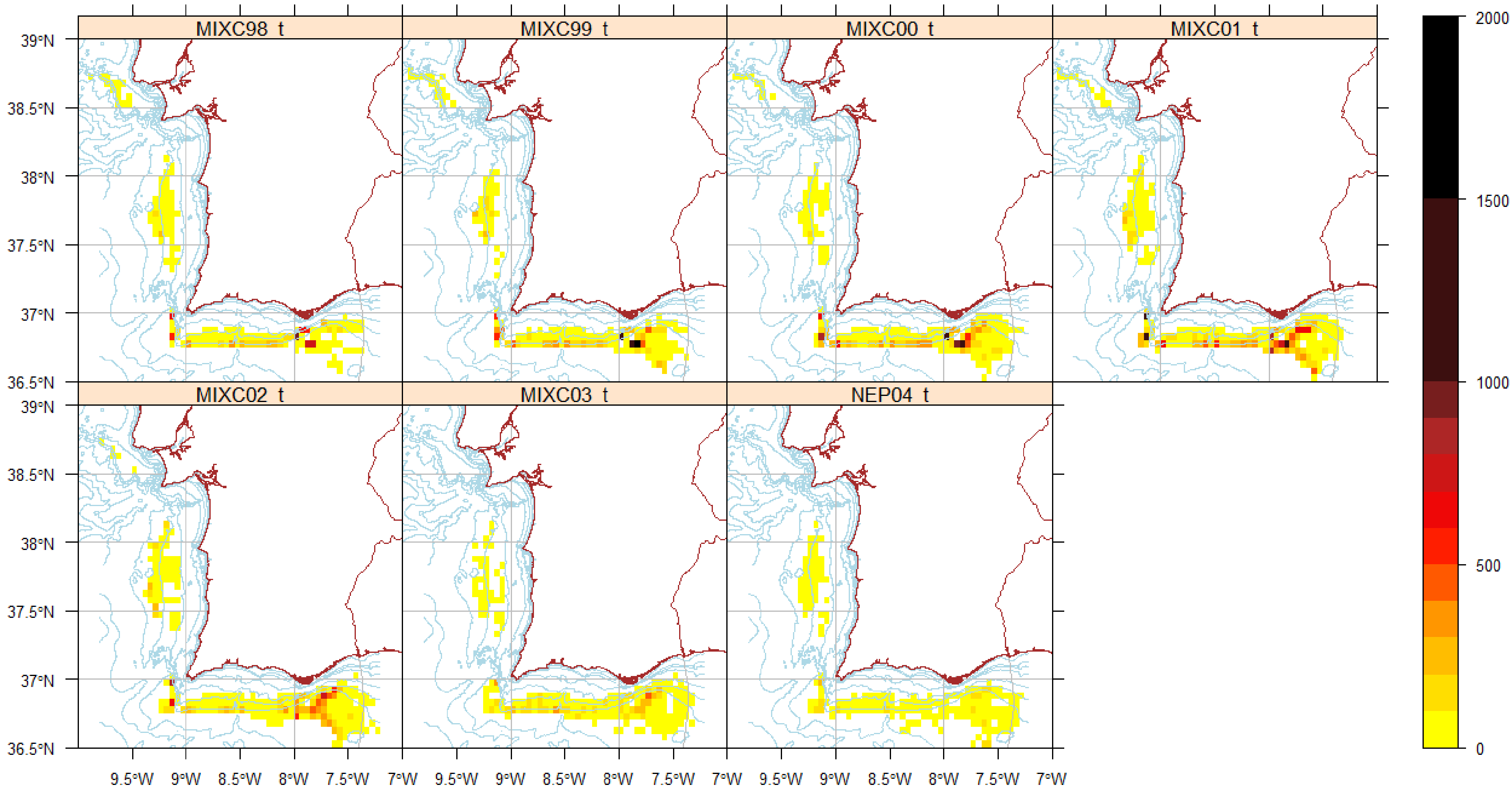

Figure 6. Effort distribution (in hours trawling) for the fishing trips directed at mixed crustaceans (MIXC) for the period 1998-2003 and *Nephrops* (NEP) in 2004. See note from Figure 4

Working Document for WKCPUEffort

Title: 'Spatially resolving megrim length and age information from sampling program using logbook records and VMS data'

Authors: Eoghan Kelly and Hans Gerritsen

Introduction

At present biological information, such length and age, is collected by the Marine Institute by sampling the landings from commercial vessels at various ports. However, the origin of these catches is not spatially resolved. This has particular relevance for megrim as it is known to grow faster in shallow water of approx. 100m compared to deeper waters of 200-250m (Gerritsen *et al.*, 2010). Therefore, the length at age distribution for this species will differ depending on the depth that it was caught. Identifying the location of samples would facilitate the development of depth specific Age Length Keys (ALK) which would improve the stock assessment by increasing the accuracy of the raising procedures to generate the catch numbers at age (CNAA). Furthermore, if the sampling effort is to representatively cover the spatial distribution of the catches, it is necessary to know the location of the samples.

Methods

During port sampling by Marine Institute staff information on the name of the vessel and the landing date is recorded where possible. This information was used to construct a query in MS Access to return the matching records from the logbook database so a start and finish date for each fishing trip could be compiled. The sampling date and landing date were not always equivalent as vessels often landed days before being sampled. To account for this mismatch in dates a series of queries were carried out with differences in sampling and landing dates of up to 8 days. The occurrence of subsequent landing events resulted in duplicate records which were removed. The final dataset for the fishing trip included vessel name, vessel ID, start date and end date. This was then linked with the

Vessel Monitoring (VMS) database, using the method of, to provide spatial information for the samples. Fishing activity was distinguished from non-fishing activity using a speed criterion of 1.5-4.5 knots (Gerritsen & Lordan, 2011). This criterion worked well except for near port activity when the speed was reduced to within the range associate with fishing. To overcome this problem a minimum hauling depth was extracted from the Marine Institute's discard database. No hauls containing megrim were observed below 30m, thus it was assumed that no fishing activity occurred in water less than this depth. Average, minimum and maximum water depths were then calculated for each fishing trip sampled.

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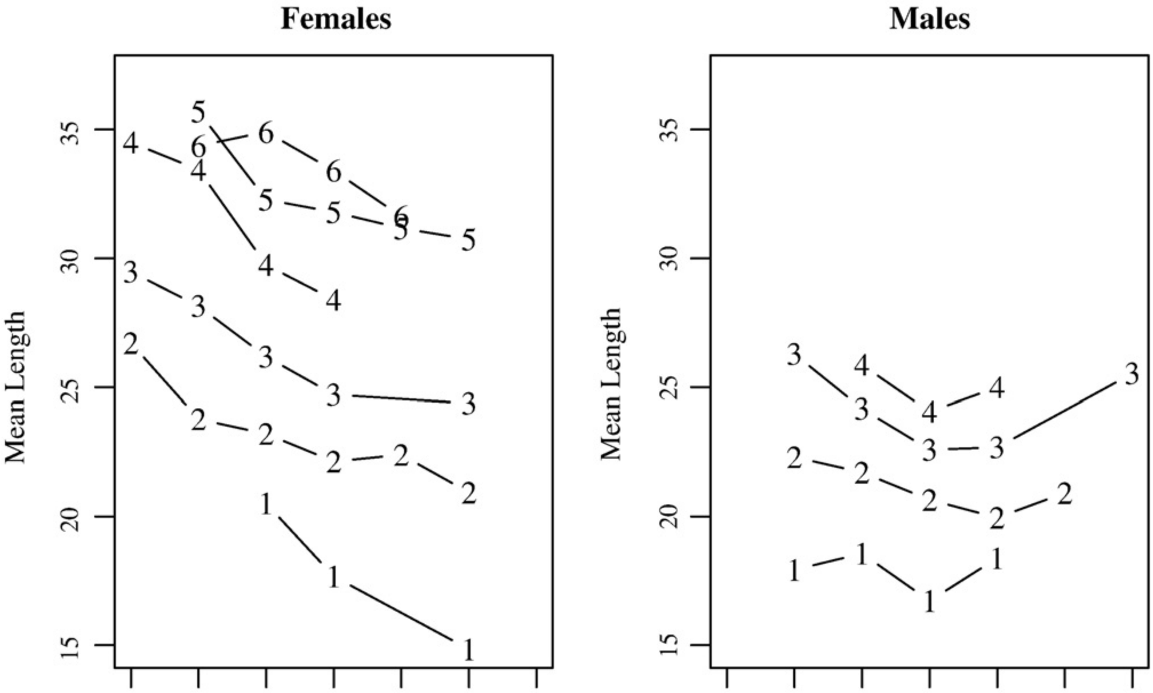
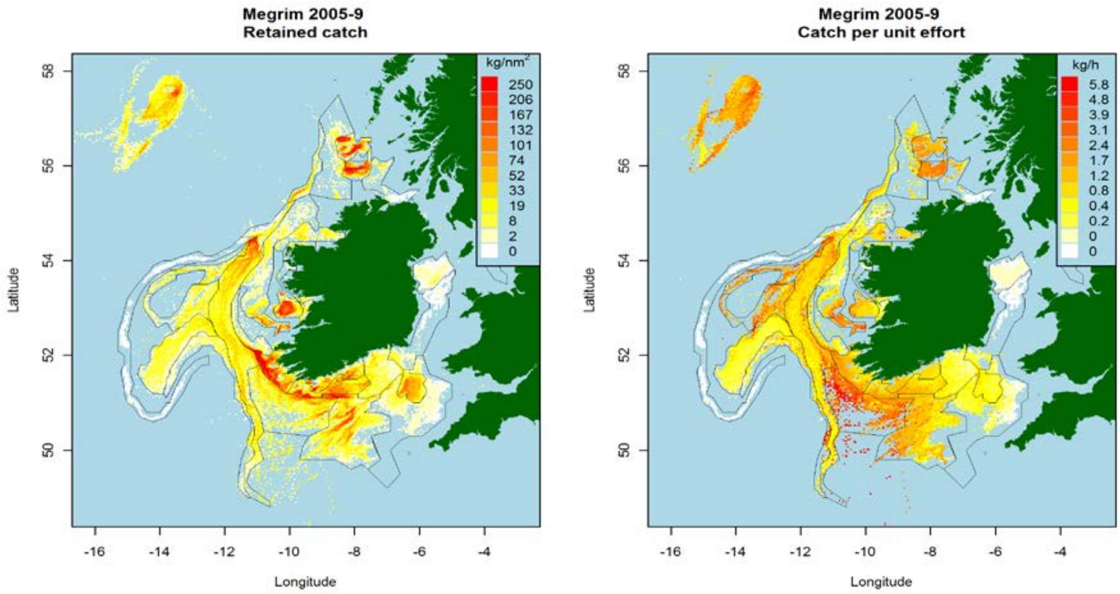
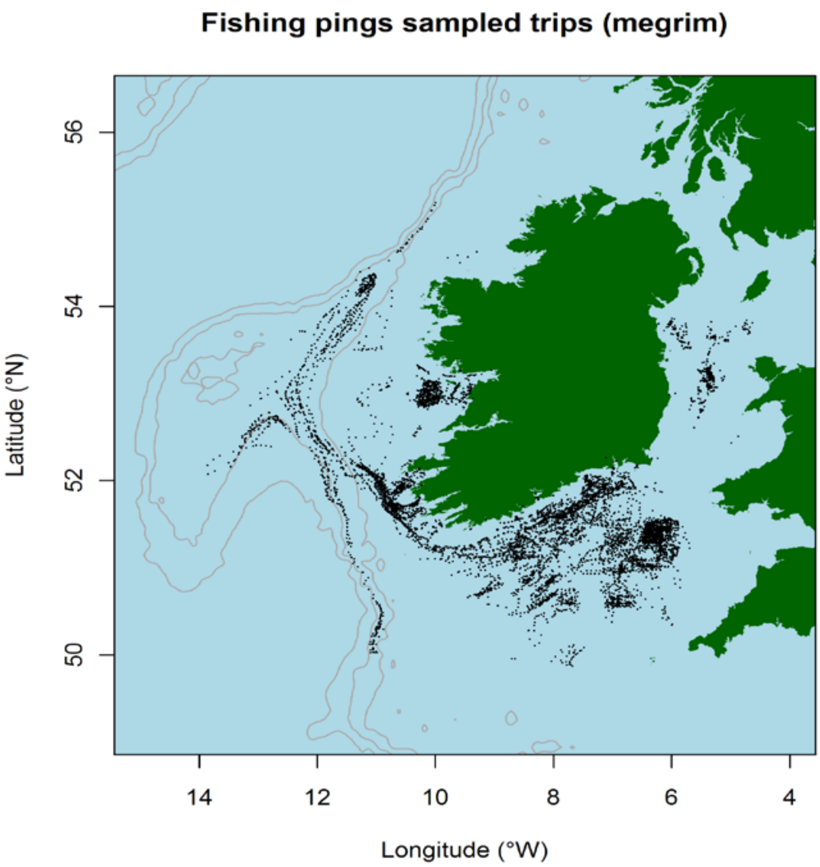




Megrim 2005-9
Retained catch
kg/nm^2
250
206
167
132
101
74
52
33
19
8
2
0
Latitude
Longitude
Megrim 2005-9
Catch per unit effort
kg/h
5.8
4.8
3.9
3.1
2.4
1.7
1.2
0.8
0.4
0.2
0
0
Latitude
Longitude



Fishing pings sampled trips (megrim)
Latitude (°N)
Longitude (°W)

Results

The initial query on the sample database requested age and length records for megrim from 2006 onwards in ICES Divisions VII b-k and VII b,c,d. This query returned 140 samples and 3870 records. The next query linked the sampling dates to landing dates from logbook database and returned 126 samples and 3598 records. Finally, the vessel name, start date and end date of fishing trip was linked to the VMS database and returned 86 samples and 2435 records. From the initial query to the final query, 54 samples (39%) and 1435 records (31%) were lost.

Of the 2435 records in the spatially resolved sample database, 2260 (93%) were sexed and 85% were female. Due to the small number of males (350) in the database, the age length analysis could not be carried out by sex and a combined sex key was constructed instead.

Assuming a no-fishing cut off depth of 30m the megrim samples ranged from a minimum of 33m to a maximum of 370m. The greatest spatial resolution of the sample was at the trip level, as it was not possible to determine which haul the samples originated. In order to more accurately assign the length and age information to depth strata it was necessary to minimise the range of depths that hauls were conducted at during the fishing trip. Plotting the average, minimum and maximum depths by fishing trip (Figure 2) it is apparent that the deeper trips generally had larger depth ranges. This is not surprising as fishing trips to deeper waters will usually include shallow trawls on the way out or back. A sub-selection of the fishing trips was made by limiting the depth range to 50% of the average depth (trips excluded from further analysis are plotted in red in Figure 2). This reduced the number of trips in the analysis from 86 to 66 and the number of records from 2435 to 1931.

From Figure 2 it is also apparent that there is a rough distinction between fishing trips below and above 100m. Consequently, this point was used for depth stratification and ALKs were constructed for 40-100m and 100-150m (Annex I). The outlying deep fishing trip, with an average depth of 297m, was assessed separately.

Modal lengths per age class were extracted from the ALK for each depth stratum (Table 1) and plotted (Figure 3). No clear distinction was apparent between the three depth strata although the deepest sample had the lowest length at age. Surprisingly growth at 40-100m was slower than at 100-150m.

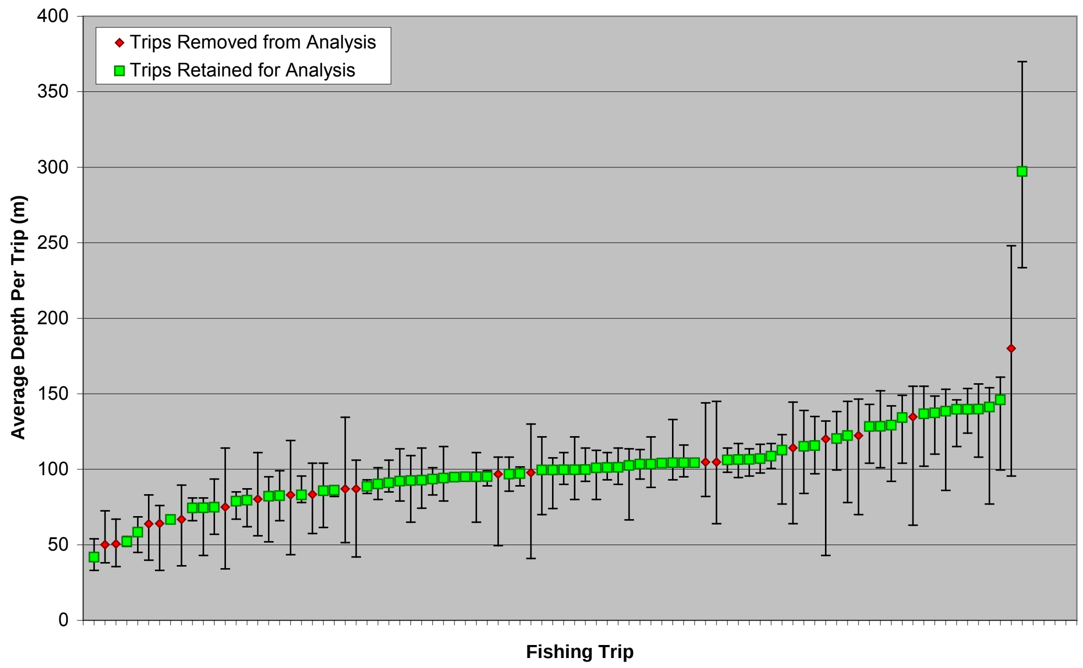


Figure 2: Average depth per fishing trip with minimum and maximum error bars

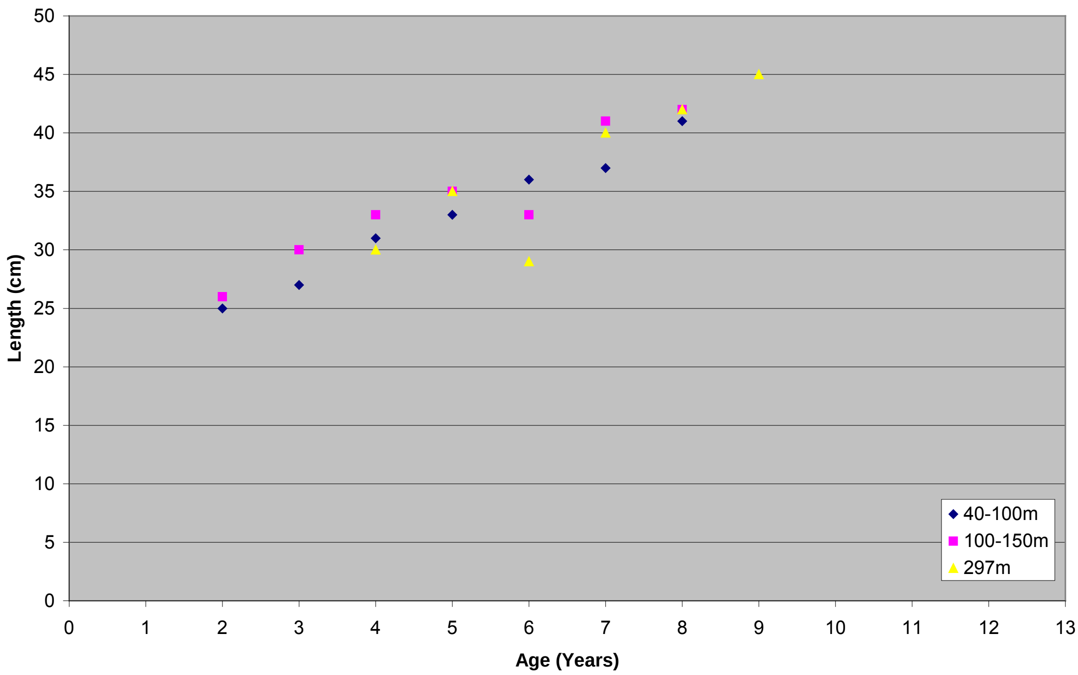


Figure 3: Modal length at age for eachdepth strata

Age	2	3	4	5	6	7	8	9	10	11	12
Length at 40-100m (cm)	25	27	31	33	36	37	41	-	-	-	-
Length at 100-150m (cm)	-	26	30	33	35	33	41	42	-	-	-
Length at 297m (cm)	-	-	-	30	35	29	40	42	45	-	-

Table 1: Modal Length (cm) at Age for different depth categories

Conclusions and discussion

Collection and analysis of biological data from port sampling of commercial landings is time consuming and expensive. Therefore the best use should be made of this information by adding spatial information that describes where the catch was made. This working document describes a successful attempt to link the sample date and vessel name to VMS data using the logbook information to provide a start and end date for the fishing trip. Nevertheless, 39% of the samples and 31% of the length and age records were lost from the initial to the final query. These losses occurred for several reasons e.g. inability to link the sample information to the logbook database because of errors in or absence of vessel names, samples taken from multiple vessels landing on the same date or the dates for the fishing trips not matching those in the VMS database. It is also possible that samples were taken from vessels <15m, for which there are no VMS data. Some of these issues can be resolved by improving quality control during sampling (e.g. vessel names) while others are inherent while using commercial data (e.g. mixed vessel landings). The advent of electronic logbooks should help to resolve some of these issues.

Despite the relative success of linking the samples to the spatial component of the fishing trip, the end result of the analysis was disappointing as there were no major differences found between the ALKs from the different depth categories. However, an important side note from this analysis is that the deeper fishing activity for megrim is underrepresented in the current port sampling programme. Only two trips with average depth greater than 150m were found and this finding also explains the underrepresentation of males (35%) as they are associated with deeper water of >200m (Gerritsen *et al.*, 2010). Such a bias in the sampling can have important consequences on the stock assessment as applying ALKs that are not representative of all the catches will result in increased uncertainty in the results due to depth related differences in length being accepted into the age structure of the assessment model. Greater sampling effort should be focused on the deeper fishing trips so that more accurate and realistic ALKs can be constructed for the stock assessment model.

Annex I

	AGE											
LENGTH	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
20	2											**2**
21	2	1										**3**
22	5	1	1		1							**8**
23	6	6	4	1								**17**
24	4	10	5	1								**20**
25	6	18	9	3	1							**37**
26	5	15	9	4	3							**36**
27	5	19	14	5	1							**44**
28	2	16	18	8	2							**46**
29	4	17	25	11	5							**62**
30	1	13	22	12	5	2						**55**
31	1	7	27	11	4	2		1				**53**
32	2	8	25	13	5	2						**55**
33		7	22	21	6	3	2					**61**
34		6	17	22	10	2	1					**58**
35		2	17	20	11	6	1					**57**
36	1	1	11	15	13	6	3	1				**51**
37		1	8	16	14	11	1					**51**
38		2	6	14	11	6	2					**41**
39			4	11	14	6	2	2				**39**
40			4	8	12	9	5	1				**39**
41			1	7	7	7	8	1				**31**
42			1	2	6	7	3					**19**
43				1	6	3	3		1			**14**
44				2	4	3	4	2	1			**16**
45			1	1	2	6	2	2				**14**
46					2	3	1		1			**7**
47						2	1	2				**5**
48					1		4	1			1	**7**
49								1	1			**2**
50					1							**1**
51												**0**
52							1	1				**2**
53							1					**1**
54												**0**
55												**0**
56												**0**
57												**0**
58												**0**
Total	**46**	**150**	**251**	**209**	**147**	**86**	**45**	**15**	**4**	**0**	**1**	**954**

Table 2: Age Length Key for samples from 40-150m

	AGE											
LENGTH	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
20	1											**1**
21	1											**1**
22	1	1										**2**
23	3	5	2		1	2						**13**
24	2	11	6	4	3	2						**28**
25	2	12	8	5	4	4						**35**
26	2	15	9	7	5	1	2					**41**
27	2	10	13	8	7	3						**43**
28	2	11	14	6	6	1						**40**
29		10	18	10	6	6	1					**51**
30	1	10	22	9	7	5	1					**55**
31	1	6	21	11	6	6	3	1				**55**
32		3	18	14	5	7	2	1				**50**
33		2	18	20	9	10	1					**60**
34		3	14	18	5	4	3	2				**49**
35			11	18	17	5	3					**54**
36		1	5	18	16	9	4					**53**
37		1	2	14	10	6	6	3				**42**
38			2	8	13	10	5	4	1			**43**
39			1	7	8	8	2	5				**31**
40		1	2	3	8	8	7	2	2			**33**
41			1	5	2	9	7	3	1			**28**
42				1	3	6	4	7				**21**
43			1	1	5	7	5	2	2	1		**24**
44					4	6	8	1	1			**20**
45					2	4	4	2	1	1		**14**
46					1	2	6		3			**12**
47						3	2	2			1	**8**
48					2		2			1		**5**
49									2			**2**
50						1	1	3				**5**
51										1		**1**
52								1	2			**3**
53						1	1		2			**4**
54												**0**
55												**0**
56												**0**
57												**0**
58							1					**1**
Total	**18**	**102**	**188**	**187**	**155**	**136**	**81**	**39**	**17**	**4**	**1**	**928**

Table 3: Age Length Key for samples from 100-150m

	AGE											
LENGTH	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
20												**0**
21												**0**
22												**0**
23												**0**
24												**0**
25					1							**1**
26												**0**
27			1	1								**2**
28				1	1	1						**3**
29					1	1						**2**
30				1	1							**2**
31				1	1	1	1					**4**
32		1			1		1					**3**
33				1	1	1						**3**
34					1	1	1					**3**
35					1							**1**
36					1	1						**2**
37					1	1			1			**3**
38					1	1	1			1		**4**
39					1	1	1					**3**
40							1					**1**
41						1	1	1		1		**4**
42								1				**1**
43								1				**1**
44									1			**1**
45								1				**1**
46							1	1				**2**
47							1					**1**
48									1			**1**
49												**0**
50												**0**
51												**0**
52												**0**
53												**0**
54												**0**
55												**0**
56												**0**
57												**0**
58												**0**
Total	**0**	**1**	**1**	**5**	**13**	**10**	**9**	**5**	**3**	**2**	**0**	**49**

Table 4: Age Length Key for sample from 297m

References

Gerritsen H.D. & Lordan C. 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.

Gerritsen H.D. , McGrath D. , Lordan C. & Harley X. 2010. Differences in habitat selection of male and female megrim (*Lepidorhombus whiffiagonis*, Walbaum) to the west of Ireland. A result of differences in life-history strategies between the sexes? *Journal of Sea Research*, 64(2010), 487–493.