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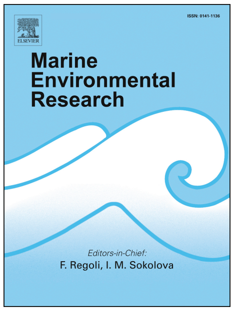

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Filling the gap: Using fishers' knowledge to map the extent and intensity of fishing activity.

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Abstract

Knowledge of the extent and intensity of fishing activities is critical to inform management in relation to fishing impacts on marine conservation features. Such information can also provide insight into the potential socio-economic impacts of closures (or other restrictions) of fishing grounds that could occur through the future designation of Marine Conservation Zones (MCZs). We assessed the accuracy and validity of fishing effort data (spatial extent and relative effort) obtained from Fishers' Local Knowledge (LK) data compared to that derived from Vessel Monitoring System (VMS) data for a high-value shellfish fishery, the king scallop (*Pecten maximus* L.) dredge fishery in the English Channel. The spatial distribution of fishing effort from LK significantly correlated with VMS data and the correlation increased with increasing grid cell resolution. Using a larger grid cell size for data aggregation increases the estimation of the total area of seabed impacted by the fishery. In the absence of historical VMS data for vessels ≤15 m LOA (Length Overall), LK data for the inshore fleet provided important insights into the relative effort of the inshore (<6 NM from land) king scallop fishing fleet in the English Channel. The LK data provided a good representation of the spatial extent of inshore fishing activity, whereas representation of the offshore fishery was more precautionary in terms of defining total impact. Significantly, the data highlighted frequently fished areas of particular importance to the inshore fleet. In the absence of independent sources of geospatial information, the use of LK can inform the development of marine planning in relation to both sustainable fishing and conservation objectives, and has application in both developed and developing countries where VMS technology is not utilised in fisheries management.

Introduction

Mapping temporal and spatial patterns of fishing activity is an integral part of marine spatial planning. This includes determining the spatial extent of the environmental impacts of fishing (Jennings & Lee, 2012) and the potential economic impacts of proposed management measures used to control fishing activities (Pederson *et al.*, 2009). Data for specific gears, at a relevant spatial scale is required in order to understand conflicting pressures on marine ecosystems (Campbell *et al*. 2014). In the absence of systems that gather fisheries management data, information can be gathered directly from fishers (Bergmann *et al.*, 2004; Drew, 2005; Hall & Close, 2007; Shepperson *et al.*, 2014). Previously, scientists have utilised Local Knowledge (LK) from fishers to: ascertain where fishing occurs; understand the seasonality of fishing; identify locations of potential gear conflict; place economic or perceived value on fishing grounds; aid the design and planning of Marine Protected Areas (MPAs); attain estimates of fishing intensity (Close & Hall, 2006; Lieberknecht *et al.*, 2011; Yates & Schoeman, 2013; Leite *et al.*, 2013). Fishers can have a greater ability to detect short-term trends in fisheries than the available scientific data and are able to provide information on year-to-year variability in fish stocks (Rochet *et al.*, 2008). Scientific surveys are often limited in temporal and spatial scales. However, experienced fishers interact with the fishery environment on a daily basis and can have years of knowledge and experience that can supplement modern data collection.

Nevertheless, there are limitations associated with spatial data gathered from fishers. For example, LK is not as precise as that obtained from vessel monitoring systems which can reveal the exact location of fishing activities (Shepperson *et al.*, 2014), and can be used to determine fishing tracks. However, LK data can provide a reasonable estimation of the spatial extent of fishing; verified by comparing maps of fishing effort derived from LK data to 100 % VMS coverage for a fleet (Shepperson *et al.*, 2014). Aggregation of data at a finer scale provides a more accurate representation of the spatial extent of the fishery. However, when using LK to estimate fishing intensity the accuracy increases with the proportion of the fleet sampled and aggregation of the data at a coarser scale (Shepperson *et al.*, 2014). In some cases fisher knowledge represents the best, or only, available data. In the UK, the value of LK to inform the spatial management of inshore fisheries is recognised. Comparable projects to ascertain spatial patterns of fishing activity and the economic value of fishing grounds have been undertaken in Scotland (Kafas *et al.*, 2014), Ireland (Yates & Shoeman, 2013), England

(Turner *et al.*, 2015) and North Wales ('Fish Map Môn' project, des Clers *et al.*, 2008). In particular, data from the ScotMap project has been useful in marine spatial planning in areas where multiple uses such as renewable energy and conservation features co-occur (Kafas *et al.*, 2014).

Mapping fishing activity

VMS data are gathered primarily for fisheries management and enforcement purposes, and the data are frequently used to analyse spatial fishing patterns and estimate fishing effort (e.g. Mills *et al.*, 2007; Hintzen *et al.*, 2010; Lee & Jennings, 2010; Gerritsen *et al.*, 2013). In the European Union, VMS has been compulsory for all commercial fishing vessels >15 m LOA since 2005 and for vessels >12 m LOA since 2012. However, >90 % of registered fishing vessels in England and Wales are ≤15 m LOA (MMO, 2012), which means that there is a lack of spatial effort data for this sector of the fleet.

Scallop vessel fleets are often defined into two categories; 'inshore', and 'offshore' (Palmer, 2006; Howarth & Stewart 2014). The UK offshore fleet, comprises vessels that are typically >15m LOA (vessels of this size are not permitted to fish within 6 NM of the coast) and the inshore fleet (vessels typically <15 m LOA) that operate closer to shore. There is no VMS coverage for the majority of the inshore fleet, of which *c*. 50% are <12 m LOA. In the absence of VMS data, other methods have been employed to describe the location and intensity of inshore fishing activity, such as combining environmental data with expert information on the location of fishing to estimate the area of sea impacted (Dunn *et al.*, 2010). Breen *et al.* (2014) used records of observed fishing activity from fisheries enforcement data to calculate sightings-per-unit-effort (SPUE) as a measure of relative fishing intensity. In the latter study, although correlation with VMS data (where this was available) was high, limitations included a low density of sightings data, compromised positional accuracy in some areas, the sporadic nature of data collection and gaps in the data set for areas not visited by fisheries enforcement vessels.

In the present study we use a UK king scallop fishery as a case study due to its high economic value and spatial footprint. The physical impact of scallop dredging varies with seabed habitat, ranging from severe (Kaiser *et al.*, 2006) to that indistinguishable to impacts from natural disturbance (Sciberras *et al.*, 2013). In the UK scallop landings support the third most valuable fishery. However, at present, the lack of VMS data for the inshore scallop sector impedes our ability to understand the wider ecosystem effects of these fishing activities. Due to commitments under the EU Habitats Directive (92/43/EEC, Council of the European Union, 1992) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC, Council of the European Union, 2008) to develop networks of Marine Protected Areas (MPAs), coupled with the number of livelihoods reliant on inshore fisheries in the UK (Breen *et al.*, 2014), understanding the spatial distribution and intensity of inshore fishing activity is essential for marine spatial planning and the assessment of the compatibility of fishing activities with conservation features. There is currently no available resource that provides comprehensive coverage of inshore scallop fishing activity due to a lack of VMS data for this sector. The aim of the present study was to understand whether it was possible to fill data gaps (in a reliable manner) in relation to the spatial distribution and intensity of scallop dredging using the English Channel as a case study, by gathering LK from scallop fishermen that have been active during the last decade. The following objectives were addressed:

1. Map the spatial extent and relative intensity of inshore (≤15 m LOA vessels) and offshore (>15 m LOA vessels) king scallop (*Pecten maximus* L.) fishing activity in the English Channel.
2. Assess the validity of using fishers' LK to estimate the extent and relative intensity of scallop dredging by comparing maps of LK with VMS data (for vessels >15 m LOA).

Methods

Data for all UK vessels that landed king scallops from the English Channel (ICES sub-areas VIId and VIIe) in the eight years prior to this study were obtained from the Marine Management Organisation (MMO). The mean number of vessels that exploited the king scallop fishery annually in ICES sub-areas VIId and VIIe, between 2006 and 2013, was 155 (Table 1).

Table 1: Total number of vessels targeting king scallops ±S.E. (includes data from trips by vessels where king scallops were the main retained species, or king scallop dredges were used) caught in ICES sub-areas VIId and VIIe, split by vessel length.

Year	≤15 m LOA vessels	>15 m LOA vessels	Total vessels
2006	96	37	133
2007	111	31	142
2008	127	23	150
2009	125	28	153

2010	102	35	137
2011	132	41	173
2012	131	36	167
2013	142	39	181
mean 2006-2013	**121 (±5.7)**	**34 (±2.1)**	**155 (±6.2)**

A semi-structured questionnaire (appendix 1) was administered to scallop fishermen who were contacted via the UK Scallop Association, the South-West Fish Producers Organisation (SWFPO) and referrals provided by fishermen. All of the participants were full-time skippers of vessels that targeted king scallops for all or part of the year. The first section of the questionnaire involved a series of 39 quantitative and qualitative questions regarding vessel and gear characteristics, fishing habits, economics and opinions regarding the management of the fishery. Questions were either: closed; required an answer based on a Likert scale (Likert, 1932); or were structured in an open format to encourage greater sharing of information. The fishermen were not provided the questionnaire prior to the interview, as it was hoped that obtaining spontaneous answers to the questions would avoid bias. Much of the information given during the interviews was anecdotal and therefore not reported in the present study, in which we focus on the spatial distribution of fishing effort.

The mapping exercise involved fishermen identifying all locations in the English Channel where they had actively fished for king scallops with their current vessel, over the 10 year period prior to the date of the interview. This time period was used, as this was the maximum time period the authors expected to obtain reliable data, due to the information being reliant on the memory of the skipper on the day of the interview. All interviews were conducted in person, by the lead author (CLS), between March 2012 and March 2013, therefore the response periods range from March 2002-2012 to March 2003-2013. Fishing locations were identified either by drawing polygons directly onto a geo-referenced admiralty chart of the English Channel in ArcMap v.9.1, using software developed for the 'FisherMap' project (des Clers *et al.*, 2008), or by drawing directly onto an A3 sized printed admiralty chart. Some skippers had worked on the same vessel for the full 10 year period, while others had recently changed vessels, or were more recently qualified as skippers. Data for fishing locations was only recorded for the time period the interviewee had been the skipper of the vessel. This was to avoid any duplication of data if more than one fisher had skippered a particular vessel, which occurred a number of times. For each polygon drawn, participants were asked to indicate which months in the year they normally visited the location to fish, and on average how many days per month fishing activity occurred. They were also asked to indicate how many years in the last 10 (or as long as they had been skipper of the vessel, if <10 years) they had returned to fish within the specified polygon. Interviews were conducted with 19 skippers of vessels >15 m LOA (length overall) and 29 skippers of vessels ≤15 m LOA between summer 2012 and autumn 2013. Based on data provided by the MMO for scallop vessel activity in recent years (Table 1) this constituted approximately 54 % and 25 % respectively of the mean number of full and part-time scallop vessels operating in ICES sub-areas VIId and VIIe over the past decade. Full-time scallop vessels are defined as those that use only scallop gear throughout the year. Part-time scallop vessels are those that target scallops during certain times of the year but target other species with different gear (e.g. beam-trawl) the remainder of the year. There were more frequent opportunities to interview skippers of vessels ≤15 m LOA, as vessels of this size tend to return to port each day and are less able to fish in high wind conditions. There were fewer opportunities to interview skippers of larger vessels as they spend up to a week at sea per trip and after landing the catch often leave port immediately for the next fishing trip. There are 19 landing ports along the south coast of England (Figure 1). Interviews were conducted with skippers of vessels either registered at, or landing into 13 of these ports, to provide a representative spread of samples across the study area. This included English, Scottish and, to a lesser extent, Welsh owned vessels.

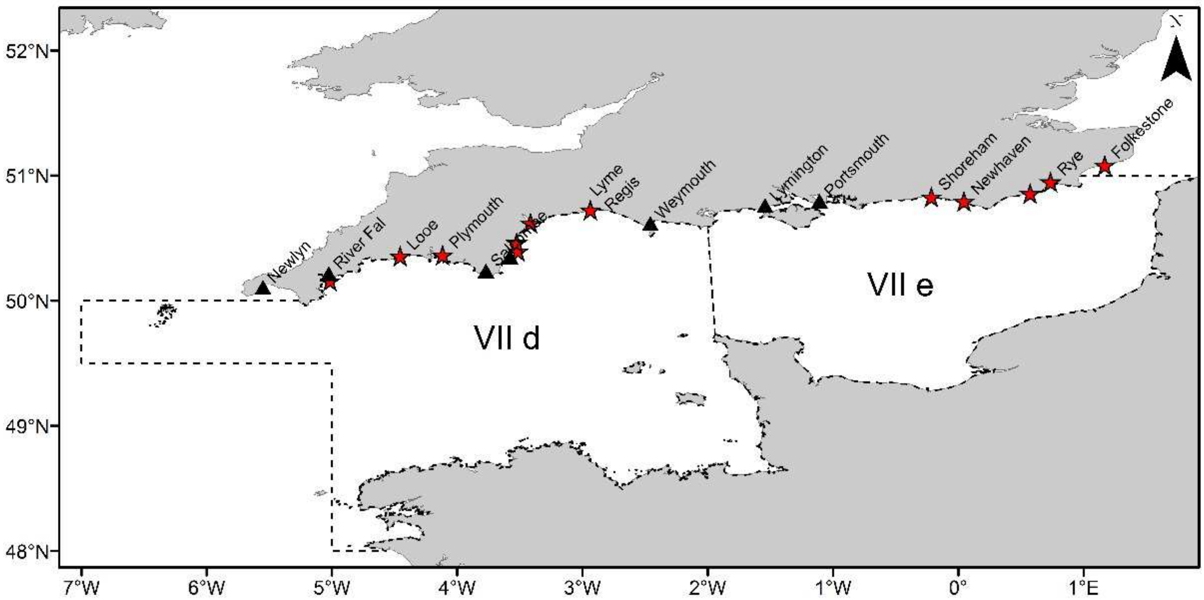

Figure 1: The location of English ports along the English Channel where king scallops are landed. Red stars indicate the home ports or landing ports of scallop fishermen that were interviewed. No scallop fishermen were interviewed from ports indicated by black triangles. The boundaries of ICES sub-areas VIId and VIIe are shown with dashed lines. Data provided by the Marine Management Organisation.

Data Analysis

Vessel characteristics

For the purposes of analysis, where skippers were unable, or chose not to provide an answer to a question, missing data was dealt with by entering the average response for vessels with similar characteristics. First, a Draftsman's plot was performed in PRIMER-E (Clarke & Gorley, 2006) to test for significant autocorrelation between the variables: total number of dredges; maximum hours fishing per day; total days fishing activity in last 12 months; minimum tow duration; maximum tow duration; minimum tow speed; maximum tow speed; minimum mean catch weight (king scallops) per day; maximum mean catch weight (king scallops) per day; minimum trip length (days); maximum trip length (days); maximum wind force fished; % grounds visited in last 12 months that have been fished previously; maximum distance travelled to fish; increase in distance travelled in last 10 years; vessel length; engine power; number of crew; minimum crew; maximum crew. To test the hypothesis that vessel characteristics and fishing behaviour differ between fleet sectors (dictated by vessel size), a multivariate analysis of vessel characteristics was performed using PRIMER-E. The data were normalised and a resemblance matrix of the similarity between vessels was created using Euclidean distance as the measure of the similarity. An ANOSIM test was used to ascertain whether characteristics were significantly different between vessels grouped by LOA ($\leq$15 m; >15m). The SIMPER function was used to ascertain the percentage similarity of characteristics within group and percentage dissimilarity between groups.

LK Fishing polygons

Fishing activity recorded during fisher interviews was weighted according to the frequency of use indicated by the interviewee, then aggregated by polygon to give an estimation of the relative fishing effort exerted across all fishing grounds over the total time period. The number of fishing days per year (days yr^{-1}) was calculated for each polygon by summing the number of days the area was visited over each 12 month period. To provide a relative value of fishing effort over the full 10 year period covered by the interview, a weighting (0-1) was then applied. For example, if a skipper had fished in a polygon area once in the previous 10 years, a weighting of 0.1 was applied to the total days per year; whereas if the area had been fished biennially (5/10 years), a weighting of 0.5 was applied. This enabled integration of data from all interviews, which covered varying time periods, to provide a measure of relative fishing intensity. Then all polygons were joined using the 'Union' tool, to produce a map of relative fishing effort over the 10 year period. Polygons for >15 m LOA and ≤15 m vessels were treated separately.

For each of the two length groups of vessels, fishing polygons were converted to a continuous raster layer using the mean of all values within a cell and the cell centre assignment method, with an output cell size of 0.025 decimal degrees (approximately 1.8 x 2.8 km at 50°N), as this was the scale at which the VMS data was aggregated (see below). If a skipper of an >15 m LOA vessel had drawn a polygon on the map that fell inside the 6 NM zone (0-6 NM from the shore) it was assumed to be a result of the coarse method of recording, rather than an intentional indication of fishing effort. To eliminate this error, the raster layer for the >15 m vessels was converted to a point grid layer of 0.025°. Points that fell inside of this zone were removed and the resultant point data were then converted back to a raster of cell size of 0.025° using a mean cell assignment type.

Comparison of VMS and LK data

To validate the accuracy of LK for the >15m vessels, the data were compared with the VMS data. The VMS data represent total fishing activity for the period (for vessels >15 m LOA), whereas the LK data were gathered from a sample of the fleet and therefore represent relative fishing effort. Our aim in this study is to highlight the distribution of effort in recent years, and the total spatial extent of fishing effort, therefore the discrepancy in the total time periods covered by the two datasets will not adversely impact the findings. Vessels >15 m LOA are not permitted to fish within 6 NM of the coastline in the English Channel therefore a 6 NM buffer was applied to the VMS data and only records outside of this zone were retained for the comparison of VMS with LK. Data from ICES sub-areas VIId, e and h (outside of the 6 NM mile zone) were included, as fisher polygons included fishing effort in all of these areas. Anonymised VMS point data (aggregated at a scale of 0.025°) for all UK and foreign scallop vessels, for the period 2005-2013 inclusive, were obtained. This time period was used as this was the data available in aggregated, anonymised format from the MMO, thereby fulfilling data confidentiality requirements. Scallop vessels are engaged in fishing activity at speeds of >2 knots (nautical miles per hour) and <3.5 knots (Lee *et al.*, 2010; Lambert *et al.*, 2012), therefore the dataset was filtered to include only records that fell within these margins. The sum of the time interval (total hours) between VMS transmissions was used as a measure of fishing effort over the time period and the point data were converted to a continuous raster in ArcMap v.10, using 0.025° grid cells. The VMS data were also aggregated using the 'Aggregate' tool, into grid cells of 0.1 and 0.3 decimal degrees (using the mean value) for comparison with the LK data.

The size of grid cell used for the aggregation of VMS data can over- or under-estimate the spatial extent and intensity of fishing activity (Piet and Quirjins, 2009; Gerritsen *et al.*, 2013). Therefore, vector analysis grids of differing cell sizes (0.1; 0.2; 0.25 and 0.3 decimal degrees) were created using the 'Create Fishnet' tool in ArcMap in order to visually assess the suitability of different scales. Due to the trade-off between resolution and accuracy and the distortion that occurs at the boundaries of the polygons, 0.3° grid cells were the largest size of cell used for aggregation. The 'Zonal Statistics as Table' tool was used to obtain mean VMS and LK fishing effort values for each fishnet polygon, at each spatial scale. The resultant tables for VMS and LK data were joined and the data points for each corresponding polygon plotted against each other. Correlations were tested for significance using a generalised linear modelling approach in R (R Development Core Team, 2008) and models were evaluated by checking for homogeneity of residuals. Visual assessment of frequency histograms of intensity values indicated that the data distribution was skewed towards low activity values. Aggregated relative fishing intensity data at each resolution were displayed on maps in seven breaks using the Jenks natural breaks classification (Jenks, 1967). This maximises the variation between groups in order to optimise visualisation of the relative spatial distribution of fishing activity. The maps representing aggregated raw LK data were sent to scallop fishermen that had taken part in the industry questionnaires, for visual validation.

Results

Vessel characteristics

A draftsman plot was used to investigate significant auto-correlation between vessel characteristics. Engine power and vessel LOA were significantly correlated (ρ>0.95) with the total number of dredges, therefore only the latter parameter (no. of dredges) was retained in the multivariate analysis (Clarke & Warwick, 2001). An MDS plot (2D stress=0.06; Figure 2) and accompanying ANOSIM test of normalised vessel characteristics indicated that vessels of different size (LOA of ≤15 and >15 m) displayed significantly different physical characteristics and fishing behaviours (ANOSIM: R=0.692, p=0.001). A summary of mean vessel characteristics, by group is given in appendix 2. SIMPER revealed high within group similarity for ≤15 m and >15 m LOA vessels (82.9 and 92.1 % respectively), and average dissimilarity between groups of 29 %. Hence, in further analysis and the discussion we continue to refer to two groups of vessels; 'inshore' (≤15m LOA) and 'offshore' (>15m LOA) vessels.

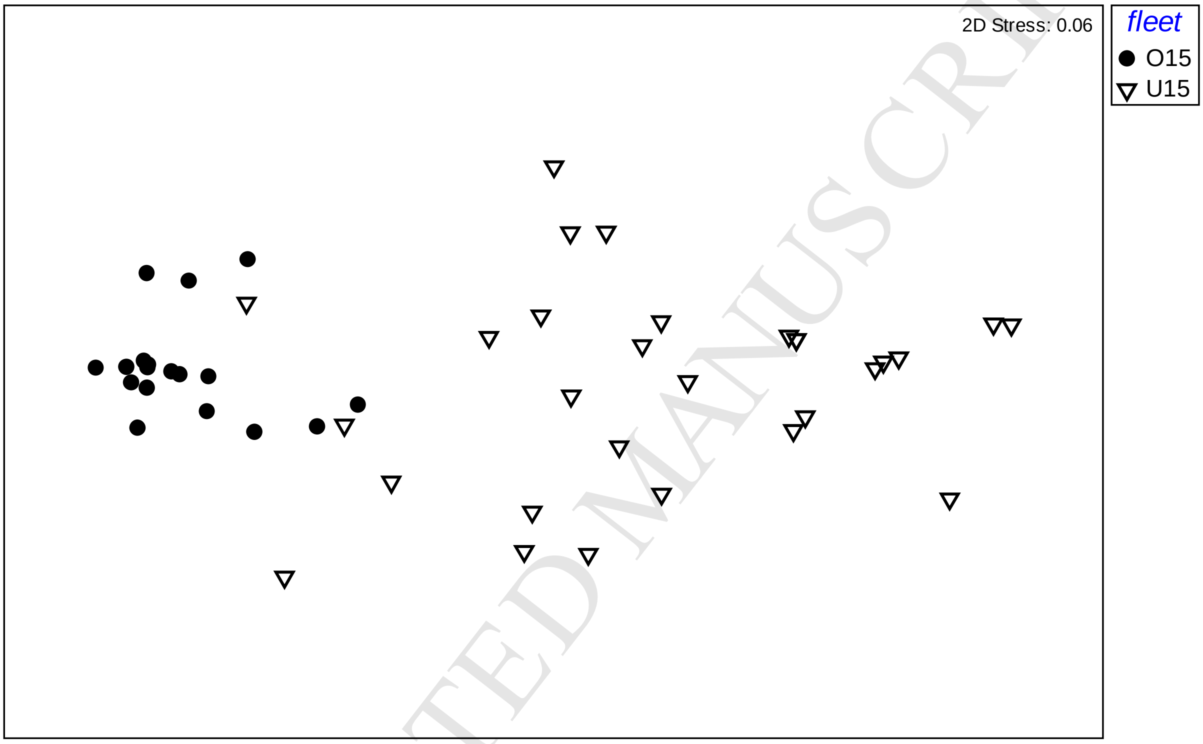

Figure 2: A multi-dimensional scaling plot of scores assigned to scallop vessel characteristics. Data was normalised prior to creating the resemblance matrix. Vessel characteristics included in the analysis are listed in the methods section. Symbols represent vessel LOA (solid circle >15m LOA; open triangle ≤15m LOA).

Fishing effort maps

When plotting the fishing effort data, the estimate of the total area of extent impacted increased with the grid cell size used for data aggregation. This effect was most pronounced for the VMS data, due to the high resolution of the original data set (Table 2). There was a marked increase in area of extent impacted for the offshore LK data when the grid cell was increased from 0.1 to 0.3 decimal degrees. In contrast, there was a slight decrease in the overall area of extent impacted for the inshore LK data when the grid cell was increased from 0.1 to 0.2 (Table 2).

As the grid cell size increased there was an increase in the correlation between relative fishing effort estimated from aggregated VMS and offshore LK data (Figure 3), however all correlations were significant (Table 3). As grid cell size increased so did the spatial boundaries of the fishery, and this effect was most evident using the VMS data (Figure 4). This resulted in grid cells covering areas that had not been identified as fishing grounds from LK polygons (Figure 4, 5). The boundaries of the data also became increasingly abstract.

Table 2: Estimate of the area of extent impacted by the king scallop fishery in the English Channel using VMS data and LK data for the inshore and offshore scallop fleets, with data aggregated at increasing grid cell sizes.

Data	Grid cell size (decimal degrees)	Area (km^2)	% increase in area of extent *c.f.* 0.025 degree cells
VMS	0.025 decimal degree cells	44,821	
	0.1 raster	83,326	86%
	0.3 raster	124,300	177%
LK offshore	raw polygons	81,636	
	0.1 raster	88,024	8%
	0.3 raster	110,489	35%
LK inshore	raw polygons	33,586	
	0.1 raster	39,848	19%
	0.2 raster	39,097	16%

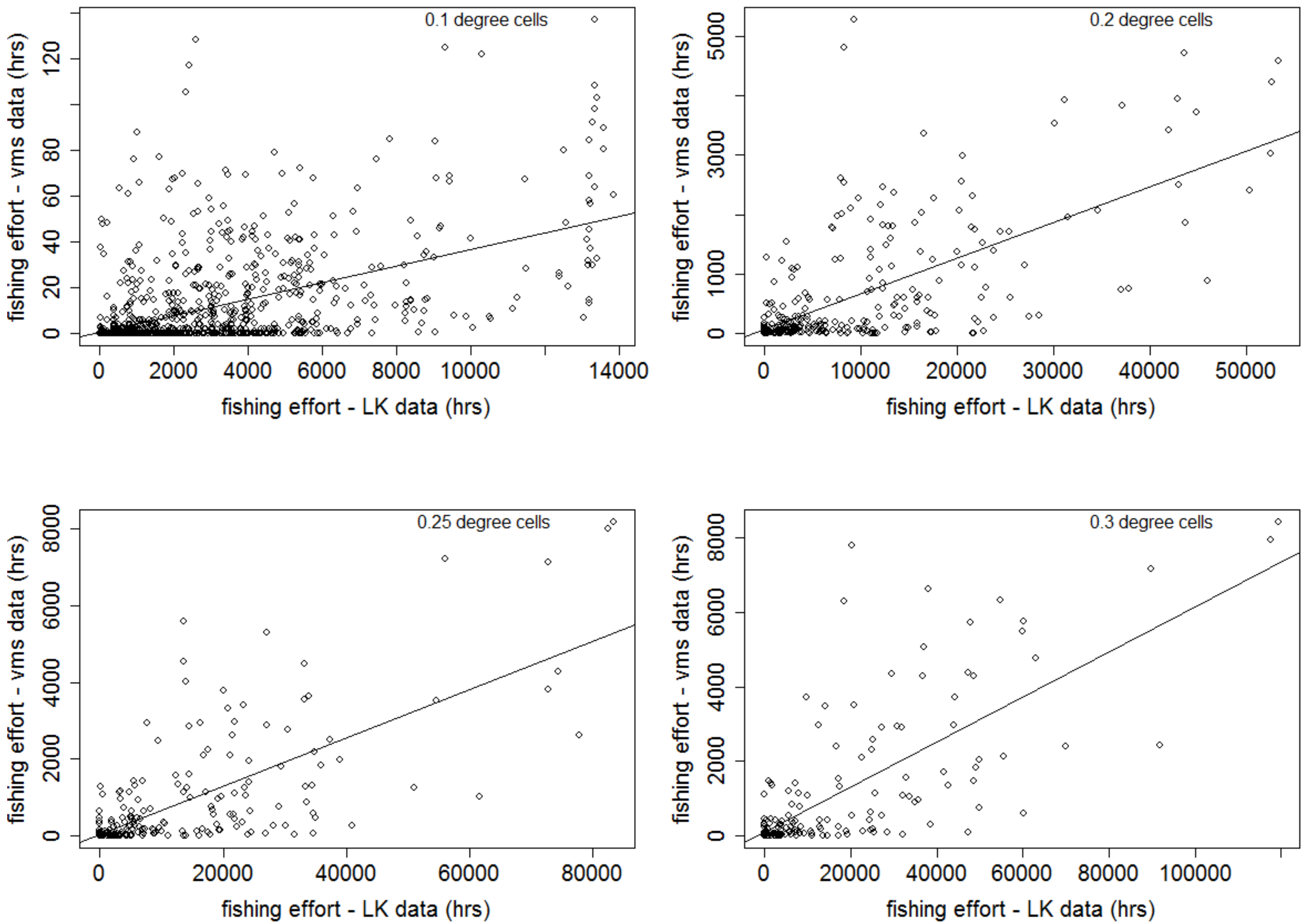

Figure 3: Plots of king scallop dredge fishing effort values derived from VMS data (2006-2013; >15m LOA vessels, total fleet) and fisher polygons (LK data; >15m LOA vessels, *c*. 50 % fleet sample) (2002-2013). Data points extracted at four different spatial scales: 0.1; 0.2; 0.25; 0.3 decimal degrees. Significant modelled linear regression lines are displayed. The r^2 and p values are given in table 3.

Table 3: Results of linear regressions for fishing effort data calculated from VMS data and fisher polygons (LK data) extracted at different cell sizes, d.f. = degrees of freedom.

Grid cell size (decimal degrees)	**cell dimensions**	**cell area**	**R^2 value**	**d.f.**	***p* value**
0.1	7.2 x 11.1	80 km^2	0.28	1, 1083	<0.001
0.2	14.4 x 22.2	320 km^2	0.45	1, 332	<0.001
0.25	18.0 x 27.8	500 km^2	0.51	1, 231	<0.001
0.3	21.0 x 33.0	693 km^2	0.53	1, 175	<0.001

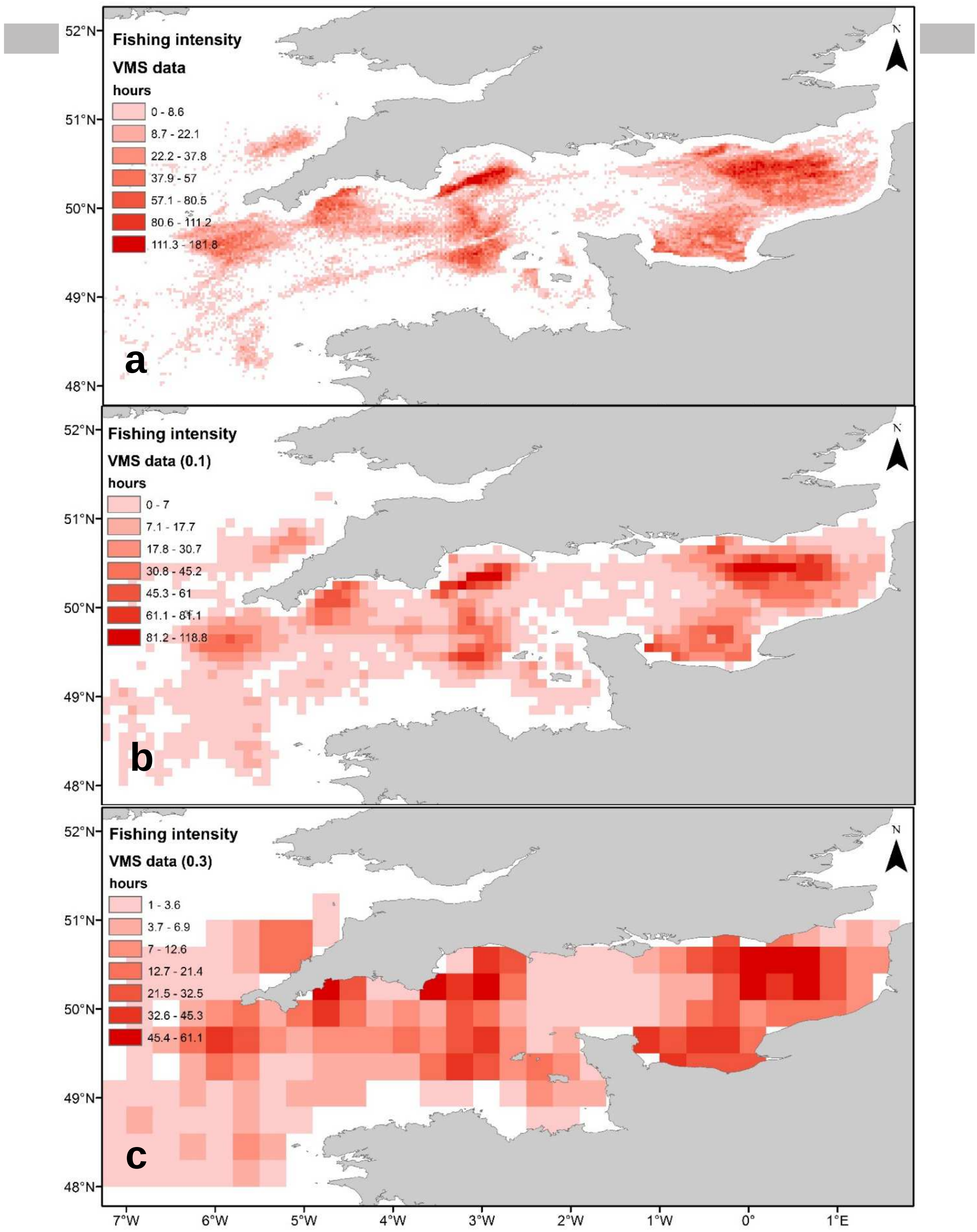

Figure 4: King scallop fishing intensity for all UK and foreign scallop vessels >15m LOA in the English Channel, expressed as the total number of hours fishing activity for the reference period 2006 to 2013, derived from VMS data for all UK and foreign vessels, aggregated at: a) 0.025 decimal degree grid cells; b) 0.1 decimal degree grid cells; c) 0.3 decimal degree grid cells. Darker shading indicates higher values of fishing intensity. Note the different scale applied to each figure.

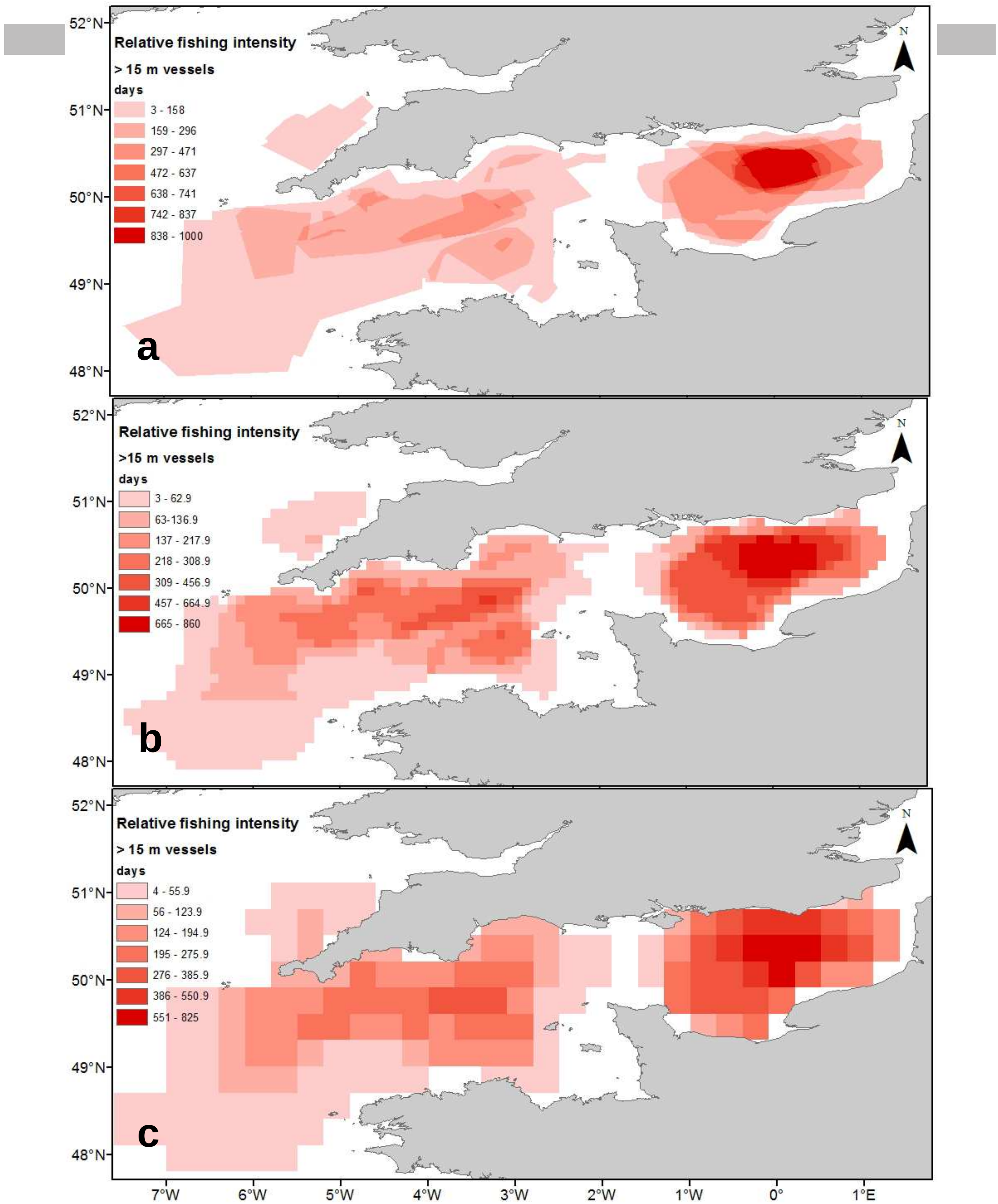

Figure 5: LK data for >15 m LOA scallop vessels in the English Channel, covering the period 2002-2013, displayed as: a) raw data (polygons); b) data aggregated at 0.1° grid cells; c) data aggregated at 0.3° grid cells. Although data values (days fished per year, weighted over a 10 year reference period) are actual values gathered during the study, these are qualitative and are intended to represent the relative number of vessel days (24 hour operations) fishing over a 10 year reference period, from a *c*.50 % fleet sample. Darker shading indicates higher values of fishing intensity. Note the different scale applied to each figure.

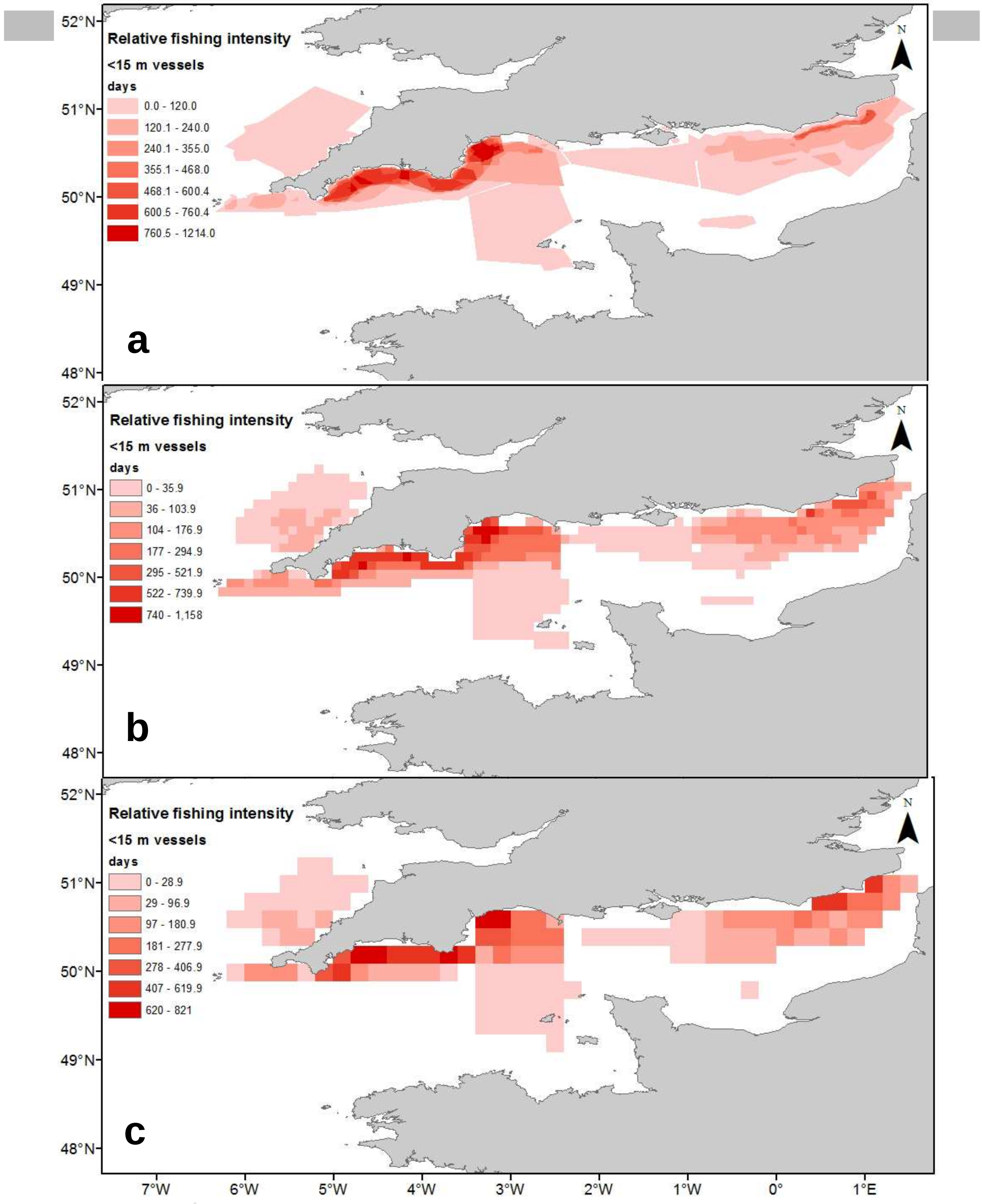

Figure 6: LK data for ≤15 m LOA scallop vessels in the English Channel, covering the period 2002-2013, displayed as: a) raw data (polygons); b) data aggregated at 0.1° grid cells; c) data aggregated at 0.2° grid cells. Although data values (days fished per year, weighted over a 10 year reference period) are actual values gathered during the study, these are qualitative and are intended to represent the relative number of vessel days fishing over a 10 year reference period, from a *c*.25% fleet sample. For vessels ≤15 m in length, total fishing time in a day varies from 8-24 hours. Darker shading indicates higher values of fishing intensity. Note the different scale applied to each figure.

Discussion

The value of local knowledge

Where electronic vessel tracking data and spatially resolved effort data for fleet activity are non-existent or not available for use, semi-structured interviews create open dialogue and offer opportunities for scientists and policy-makers to better understand socio-economic drivers of fishers' activities and inform long-term solutions to issues in fisheries management (Yates *et al.*, 2014). The reliability and accuracy of local knowledge (LK) varies with context and species (Gilchrist *et al*., 2005; O'Donnell *et al.*, 2012). However, for a species such as the king scallop that has a consistent association with seabed habitat, the reliability of LK data can be high (Shepperson *et al.*, 2014). In the present study, older fishers had fishing experience that spanned decades and were able to impart specific knowledge of the state of scallop stocks (relative to the past) for areas in which they had fished for many years; although shifting perceptions of baseline must be considered with such information (Pauly, 1995).

Validation of LK data with VMS data

Local knowledge derived from just over half (54 %) of the offshore fleet that operated in the fishery gave a good visual representation of the maximum spatial extent of fishing activity when compared to 100 % VMS coverage. However, the estimate of the total area of extent of seabed impacted was inflated, due to the coarse resolution of the LK polygons. LK data is limited by the precision at which individual fishers report fishing grounds and the overall accuracy is affected by sample size, and analysis grid resolution (Shepperson *et al.*, 2014). In relation to both the VMS and LK data, as the grid cell size used for aggregation increases, the border of the area of impact becomes increasingly abstract. This can be critical if overlaps between fisheries activities and conservation features (such as Marine Conservation Zones) need to be identified. Thus, the smallest feasible grid cell size may be useful when delineating fishing grounds. Using larger grid cells reduces the inherent variability in the data and mitigates against individual error in reporting. However, the extent of the area impacted by the fishery can be over-estimated, which may lead to inflated estimates of environmental impact (Shepperson *et al.*, 2014).

When data were aggregated into grid cells of 0.3 decimal degrees (the largest grid cell used) the estimate of the area of extent impacted by the offshore fishery increased by 35 % in comparison to the raw polygon data. If we assume the LK data to be a valid measure of fishing extent (discussed further on), this suggests that smaller grid cells (e.g. <0.1 decimal degrees) may provide more accurate maps of the area of impact. This is important to consider if such information is used in spatial management. For the inshore fleet, the estimate of area of extent impacted increased by 16 % when the data were aggregated using grid cells of 0.2 decimal degrees compared to the raw data. However, the increase was slightly greater (19 %) when aggregating at smaller (0.1 degree) grid cells, due to the data processing methods of the GIS software in formation of raster layers. Hence, there is a necessary trade-off when evaluating spatial patterns of fishing intensity, and the appropriate scale should be chosen depending on the intended use of the data.

When considering the distribution of fishing effort, there were significant correlations between the LK and VMS data (relating to vessels >15m LOA). Correlation of LK with VMS data increased with increasing cell size, with moderate, significant correlations (0.45; 0.51; 0.53) at grid cell sizes of 0.2, 0.25 and 0.3 decimal degrees, respectively. Using a larger grid cell size when assessing fishing intensity will buffer against inaccuracies in the data (Shepperson *et al.*, 2014). It is therefore suggested that a grid cell of between 0.1-0.2 decimal degrees (*c*. 80-320 km^2) provides the best trade-off between inaccuracies in LK data and the overestimation of total area for the offshore scallop fishery in the English Channel when compared to VMS data. A limitation of VMS data are the assignment of 'Unknown' gear type to a substantial proportion of records. For the full VMS dataset obtained for use in the present study, *c*. 70 % of records were classified as 'Dredge' gear, and *c*. 30 % as 'Unknown', thereby requiring an assumption of gear type and a decision on whether to include or exclude a large proportion of data (Szostek, 2015). The time interval between successive VMS transmissions can also be very variable. Both the latter issues hinder the accuracy of the analysis. However, VMS data still represent the most reliable and comprehensive source of fishing effort data for vessels >15m LOA, but can be enhanced when combined with other sources of fishing effort data (Russo *et al.*, 2016). In the study by Shepperson *et al.* (2014), grid cells of 25 km^2 were the largest used in analysis of scallop fishing activity around the Isle of Man (Irish Sea) and gave the highest agreement between LK and VMS data. In the present study, the smallest grid cells used were substantially larger (approximately 80 km^2), therefore we consider that the scale of analysis of LK data will yield reasonable accuracy for the English Channel scallop fishery.

Shepperson *et al*. (2014) also found that a larger sample size of the fleet increased the accuracy of estimated fishing intensity. A subsequent reduction in sample size from 100 % of the fleet to 33 % led to a 9 % reduction in the Kappa agreement statistic, which accounts for the likelihood of chance agreement between datasets (Cohen, 1968). In the study by Shepperson *et al*., the resultant Kappa value based on a 33 % sample of all scallop fishing vessels was 0.57, using a 25 km^2 grid cell, This value falls just below the threshold Kappa value of 0.6 that is considered to indicate 'substantial agreement' between data sources (Landis & Koch, 1977). Although the Kappa statistic could not be assigned in the present study due to the different units used in analysis of VMS and LK data, for the offshore fleet in the present study, of which 54 % were sampled, the largest grid cell (693 km^2) is considered to provide a reasonably accurate estimation of the distribution of fishing effort.

Assessing confidence in LK data

Although it was not possible to validate the inshore LK data with VMS data, the significant correlations found between the offshore LK and VMS data increase our confidence in the LK dataset as a whole. Visual assessment of the aggregated LK data by fishers that had taken part in the original questionnaire, also confirmed that they were a good representation of real effort distribution. Therefore, we are confident that the maps of inshore scallop fishing activity produced using LK data are an accurate representation of reality. The detailed maps of inshore fishing activity across the entire UK coast of the English Channel we present (Figure 6) are the first of their kind and can be used to highlight areas of economic importance, particularly in the consideration of marine spatial planning.

Individuals demarcated fished areas with varying levels of precision; inshore fishermen frequently drew small polygons in specific locations, whereas offshore skippers tended to map their activity with few polygons, covering a larger area. In the western English Channel, offshore fishing activity is sparse (indicated by discrete patches of low intensity VMS data). However, offshore skippers drew polygons that covered large areas of the western English Channel to reflect the maximum range that they had travelled to fish in the previous 10 years. Hence, the LK data failed to represent the fine scale detail in fishing activity that can be revealed by VMS data and led to an overestimation of the total seabed area impacted by the offshore fleet. It also resulted in many zero hour VMS records lying within low intensity LK polygons, thereby reducing the overall correlation between the two datasets. Thus, it appears that using LK to represent the extent of the offshore fishery is a precautionary method in terms of describing potential impact. There was greater visible correlation between the VMS and LK data in areas of concentrated fishing intensity; therefore the LK is likely to be more accurate where fishing activity occurs most frequently.

It was not possible within the scope of the study to interview skippers at every single port, however interviews were conducted at a range of landing ports along the coast to ensure the inshore activity recorded was representative across the full spatial extent of the fishery. Although skippers may have different home ports, fishing grounds indicated by skippers from nearby ports frequently overlapped, indicating that many skippers visited the same traditional fishing grounds. For example, although no inshore skippers from Southampton were interviewed, fishing grounds to the east of the Isle of Wight were identified by a Welsh skipper that had fished in that area. The scallop fishery in this area is limited; a byelaw in the Southern IFCA district restricts vessels to 12 m LOA or less, towing 3 or 4 dredges in total and there were only 5 or 6 vessels landing scallops into Southampton at the time of this study (Neil Richardson, Southern IFCA, pers. comm.). An increased sample size would increase the accuracy of estimates of relative fishing intensity but is unlikely to significantly alter the predicted spatial extent of inshore fishing activity.

In the process of aggregating data from all interviewees, ‘hotspots’ of scallop fishing activity were highlighted by the inshore LK map, reflecting traditional fishing grounds along the coast. There is less inshore scallop activity in the eastern English Channel; however the highest levels of activity are concentrated close to the Sussex shoreline (Vanstaen *et al.*, 2010; Vanstaen & Silva, 2010). Areas of lower activity for the inshore fleet tend to be in locations that are further from shore or landing ports, or are only visited during extended periods of good weather, such as the Channel Islands (as smaller vessels are more vulnerable at exposed locations such as these).

The precise location of inshore fishing activity is pertinent when considering the designation of Marine Conservation Zones (MCZs), which contribute to the UK’s network of marine protected areas to meet commitments under the Convention on Biological Diversity, and achieve ‘Good Environmental Status’ under the EU Marine Strategy Framework Directive (JNCC & Defra, 2012). Such areas have been implemented to conserve sensitive seabed features and habitats but can also lead to cultural, social and economic impacts (Whitmarsh *et al.*, 2002).

Socio-economic considerations

Many factors can influence patterns of fishing activity and fleet dynamics (Putten *et al*., 2012). There has been a reduction in the spatial footprint of the offshore scallop fleet in recent years, observed in the raw data in the present study and by Campbell *et al.* (2014). This is due in part to a restriction on annual fishing effort (measured as kW days) for the >15 m fleet in ICES area VII. Of those interviewed, 85 % of offshore skippers fished in both areas VIId and VIIe. This is in contrast to inshore skippers, of whom the majority fished in either area VIId, or VIIe exclusively (depending on the location of their home port), while just 24 % fished in both areas. This confirms the anecdotal observation that >15 m LOA vessels tend to be nomadic while ≤15 m vessels are more locally restricted in areas where they fish (pers. comm. Jim Portus, CEO, Southwest Fish Producers Organisation).

Legislation such as area closures and effort restrictions inhibit activity of both the inshore and offshore fleets. Ground closures displace the impacts of fishing to other locations (Greenstreet *et al*., 2009), with financial and socio-economic impacts on fishers. Skippers of inshore vessels reported that in recent years their fishing had been impacted by area closures including the special area of conservation (SAC) in Lyme Bay, Marine Conservation Zones (MCZs) in Falmouth Bay (Reker, 2015) and recent closures around the Isle of Wight, Start Bay, Torbay, Falmouth, the Scilly Isles (all in the English Channel) and Cardigan Bay and Caernarfon Bay (in Welsh waters) as a result of habitat conservation measures. Due to these closures, 28 % of inshore fishers reported having to travel further from their home port to fish, while 72 % travelled the same distance to fish as 10 years ago. This has resulted in more time spent at sea, increased fuel expenditure and greater vulnerability to weather conditions (closures generally occur in areas close to shore that are less exposed to extreme weather conditions).

Therefore, when proposing sites to meet conservation objectives, careful consideration should be made of potential impacts on fleet behaviour. Currently, the total area of MCZs (designated under the Marine and Coastal Access Act 2009 (Hill *et al.,* 2010)) and Special Areas of Conservation (SACs) in the UK is 20,425 km^2, of which 3145 km^2 is in the English Channel (data from http://jncc.defra.gov.uk/) (Figure 7). Thus, 9% of the inshore scallop fishing grounds (calculated from LK data), and 7% of the offshore scallop fishing grounds, could potentially be affected by MCZ management measures (Figure 7).

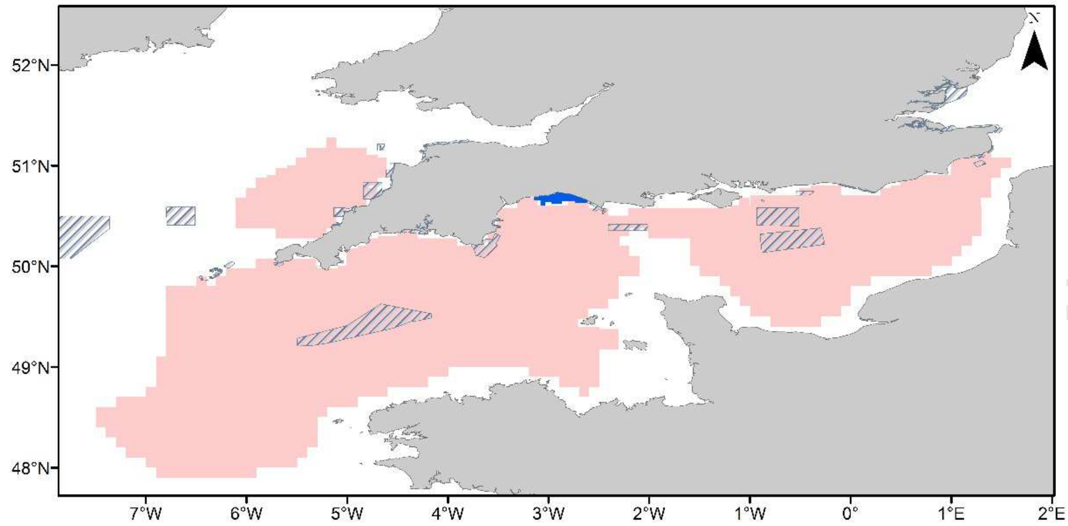

Figure 7: Location of designated Marine Conservations Zones (MCZs) in the English Channel and north of Cornwall (shown with hatching). The Lyme Bay Special Area of Conservation (SAC) is indicated in blue. Data from http://jncc.defra.gov.uk/. Scallop dredging grounds identified from LK data are shown in pink.

Conclusions

The extent to which LK data reflect empirical measures of fishing effort can vary with fishery, fleet sector, sample size, and scale of aggregation. Therefore it is important to assess each metier individually. In the present study we have demonstrated an example, in a high-value shellfish fishery, of where LK can be used to reliably inform development of fishing effort data for the purposes of management. A suite of environmental and socio-economic factors influence king scallop fishing activity. The inshore king scallop fleet fish on traditional grounds in the English Channel and is impacted considerably by ground closures, including existing MCZs and SACs. In comparison to this, the offshore fleet has access to large areas of productive fishing ground, but economic drivers have reduced the spatial extent of activity in recent years.

The LK data in the present study have certain limitations; <100 % fleet coverage and a trade-off between scale and accuracy. However, LK data provide a tangible alternative in data deficient situations and have been demonstrated to be accurate for other king scallop fisheries (Shepperson *et al.*, 2014). However, for management decisions that require more precise estimates of fishing effort, sampling the entire fleet is desirable (Shepperson *et al.*, 2014). Insight gained from fishers could be incorporated into the development of future management plans for an economically and environmentally sustainable fishery. The present study represents a useful resource for fisheries managers, in defining the spatial and temporal utilisation of fishing grounds frequented by the scallop dredge fleet across the English Channel. The data can be overlaid with habitat and stock information to help evaluate potential benefits and conflicts of alternative management options.

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Appendix 1

English Channel Scallop Fishery Survey

Thank you for participating in this questionnaire. The aim is to increase knowledge about the English Channel scallop fishery and the information will be used to support the Scallop Association and its members in the sustainable management of the fishery.

Do you have any questions before we begin........?

Gear information

1. **Gear type used:** Newhaven / other (***please specify***)…………………

What is the:

- Gear width...
- No. of dredges used...
- Dredge tooth spacing..
- Belly ring size...
- Tooth length..

2. Do you plan to increase or decrease **engine size** in next 12 months? **Y/N** (please give details)

………………………………………………………………………………………

3. Have you increased or decreased **engine size** in the last 10 years? **Y/N** (please give details)

………………………………………………………………………………………

4. Do you plan to increase or decrease no. of dredges used in next **12 months**? (please specify)

………………………………………………………………………………………

5. Have you increased or decreased no. of dredges used in the last **10 years**? (please specify)

………………………………………………………………………………………

Please answer the following questions in relation to your fishing habits in 2011:

6. On average, how many hours a day did you fish?........................hours
7. Approximately how many days did you fish?..............................days
8. What is your average tow time? ....mins
9. What is your average tow speed? ....knots
10. What was your average catch per day (bags)?......................................
11. What was the average bag weight/size?..
12. What was your average trip length (days)?....................................days

Location of fishing

Fish Map software used to record areas fished and number of days per month, main by-catch landed no. of years fished, importance of grounds.

13. What are the three most important factors that influence **where** you decide to fish?

For example: Weather (e.g. strong winds), vessel's total catch in that area in previous year, Condition of scallops, Distance from port, Cost of fuel, Number of other fishing vessels present on grounds

i. …………………………………………………………

ii. ………………………………………………………….

iii. …………………………………………………………

14. What wind strength prevents you from fishing?..

15. How do you decide **where** you will fish? (*Please tick all that apply*):
    - Skippers knowledge/experience...
    - Sharing knowledge with other boats/fishermen.........................
    - Prospecting for new grounds..
    - Other (*please specify*)..

16. Approximately what percentage of your fishing each year is in the **same** areas as the previous year, and what percentage is in **new / different (occasional)** areas?

    Same: ....% **New / different areas**: ....%

17. If you fish in **different** grounds to ‘normal’, what are the 3 main **reasons** for this (*in order)?*
    i. …………………………………………………………………………………
    ii. …………………………………………………………………………………
    iii. …………………………………………………………………………………

18. Do you spend time **prospecting for new scallop beds?** If yes, approximately how many days per year do you spend doing this?
    Yes / No **Number of days per year**…………………………………….

19. If there are grounds that you fish on a rotational basis e.g. once every 2 or 3 years, what are the reason(s) for this?
    …………………………………………………………………………………
    …………………………………………………………………………………

20. In the last **10 years** have there been any **area based** legislative reasons (e.g. area closures) that have affected **where or how** you would normally fish?
    - Location(s)..
    - Why/how affected?..
      ....
      ....
      ....

21. In the last **10 years** have there been any **technical** legislative reasons (e.g. gear/engine size/effort restrictions, curfews) that have affected **where or how** you would normally fish?
    - Location(s)?..
    - Why/how affected?..
      ....
      ....
      ....

22. Thinking about the last 10 years, how far would you **normally** travel from your home port to fish? (*please state a range e.g. 50-200nm*) ....**nm**

23. What is the maximum distance you are **willing** or **able** to travel to fish?..............................**nm**

24. In the last **10 years** have you **needed** to travel **further than normal** from your home port to fish?

No 0-12nm 12-50nm 50-100nm 100-200nm >200nm

When and why? (*e.g. fuel cost / scallop abundance/ restrictions)*

....

....

....

If yes, where did you go?...

25. Where do you do the majority of your fishing? **0-3nm 3-6nm 6-12nm 12+nm**

26. Has the way you fish for scallops changed in any other way over the last **10 years**?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Catch composition & condition

Please indicate on the paper map if you are aware which month(s) spawning occurs in a particular area and provide the following information if possible:

27. Does spawning occur at the same time of year in the area?

    a) Yes it varies by less than a week
    b) No, it can vary by 2 or 3 weeks
    c) No, it can vary by a month or more

28. Do the majority of scallops in this area all spawn at approximately the same time or does it occur over a longer time period?

a) Yes, most scallops spawn within a day or two of each other
b) Most scallops spawn within a week of each other
c) No, the spawning carries on for longer than a week

29. Are there any apparent triggers for spawning? (*e.g. light, temp, sediment, water clarity, tides*)
…………………………………………………………………………………………
…………………………………………………………………………………………

30. Does the timing of spawning influence where you decide to fish? (*Please state how/why*)
…………………………………………………………………………………………
…………………………………………………………………………………………

Landings & Profitability

30. In the last **10 years** has your **overall catch** increased or decreased?

>50% less ***0-50% less*** ***same*** ***increased 0-50%*** ***increased >50%***

Please give possible reasons for this……………………………………………………..
…………………………………………………………………………………………
………

31. If possible please say **which years** were:
particularly **good** (large catch):……………….........
particularly **poor** (small catch):……………………

32. In the last **10 years** has your average **catch weight per tow** of MLS scallops increased or decreased?

>50% less ***0-50% less*** ***same*** ***increased 0-50%*** ***increased >50%***

Please give possible reasons for this……………………………………………
…………………………………………………………………………………………

33. What is your **minimum** commercially viable catch rate?

   a. Bags per trawl...........................

   b. Bags per day.............................

***By answering the following questions you will help place an economic value on the areas that you fish*:**

34. For your fishing activity in **2011** please give an indication of:

- your annual gross **landings** (tonnes)……………………........./ prefer not to answer
- the value of your annual **landings** (£)……………………….../ prefer not to answer
- your annual **profit** (£)……………………………………….../ prefer not to answer

35. Please estimate the percentage (%) difference between **2011** and **2001**:

- % change in your annual gross **landings** (tonnes)……............% increase / decrease
- % change in the value of your annual **landings** (£)……………% increase / decrease
- % change in your annual **profit** (£)……………………………% increase / decrease

Management

36. Please answer these 3 statements questions using the following scale:

Strongly disagree ***Disagree*** ***Neither agree or disagree*** ***Agree*** ***Strongly agree***

   i. The fishery is currently fished at a sustainable level.......................................

      Please give a reason for your answer...

   ii. The fishery is **at risk** of being overfished...

      Please give a reason for your answer...…

37. In your opinion, please indicate the **three most effective** ways of conserving scallop stocks for the future (i.e. fishing sustainably), in order of effectiveness (1-3):

- Dredges per side limits.......
- New dredge design.........
- No. of teeth........
- Belly ring size........
- Vessel size limits........
- Engine size limits........
- Minimum landing size.......
- Permanent closed areas.......
- Seasonal closures.....
- Curfews.......
- TACs........
- Restricted effort........
- Caps on licences.........
- Other (*please specify*)..

38. Do you disagree with any of the current management measures in the English Channel?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

39. Are there any other comments you would like to make? (*Continue on separate sheet if necessary*)

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Appendix 2

Summary of vessel characteristics. Vessels are grouped by length (≤15 m; >15 m LOA). S.D. = one standard deviation of the mean.

	≤15 m LOA			**>15 m LOA**		
	min	**max**	**mean (S.D.)**	**min**	**max**	**mean (S.D.)**
total dredges	6	16	9.86 (2.5)	16	36	27.2 (6.55)
hours per day	8	24	15.2 (5.5)	24	24	24 (0.0)
days fished scallops in last 12 months	0	337	118.6 (75.8)	100	320	194.7 (67.1)
min tow duration (minutes)	15	100	50.3 (19.0)	30	90	55.0 (13.3)
max tow duration (minutes)	40	180	82.0 (38.8)	45	120	75.9 (22.2)
min tow speed (knots)	1.5	3.0	2.4 (0.38)	1.9	3.0	2.4 (0.3)
max tow speed (knots)	1.5	3.5	2.7 (0.47)	1.9	3.5	2.6 (0.5)
min trip length (days)	1	5	1.2 (0.77)	2	7	5.8 (1.3)
max trip length (days)	1	5	1.2 (0.77)	4	8	6.4 (1.1)
max wind (knots)	4	6	5.38 (0.62)	5	10	7.8 (1.5)
% same ground fished each year	20	100	87.6 (16.34)	0	100	78.3 (24.9)
max distance travelled	9	1000	300.8 (385.15)	150	1000	880.6 (278.2)
vessel length (m)	9.8	15.0	11.7 (2.0)	18.3	40.0	28.8 (5.9)
engine power (kW)	93	300	154.7 (61.7)	221	880	595.8 (186.5)
min crew	1	4	2.2 (0.7)	3	7	5.0 (1.0)
max crew	1	6	3.0 (1.1)	4	9	6.4 (1.1)
skipper age	27	64	48 (11.9)	24	57	43.3 (9.6)

Highlights

- Local Knowledge (LK) from fishers can provide a reliable source of fishery spatial data
- LK data highlights important fishing grounds in the absence of empirical data sources
- A trade-off between accuracy and error reduction is required in analysis grid cell size