Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data

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Vessel monitoring systems (VMS) are used primarily for fisheries enforcement purposes, but also provide information on the spatial and temporal distribution of fishing activity for use in fisheries and environmental assessment and management. A reliable, repeatable, and accessible method using readily available software for estimating fishing effort from unprocessed VMS data is developed, tested, and applied. Caveats associated with the method are identified, and the biases introduced by our assumptions are quantified. Application of the method provides a high-resolution description of gear-specific fishing activity by UK vessels. An index is developed to describe variation in the spatial pattern of fishing effort generated by different gears. The proposed method for VMS analysis involves removing duplicate VMS records and records close to ports, calculating the time interval between successive records to identify periods of activity, linking each record to a vessel and gear type, differentiating fishing and non-fishing activity, and summing fishing records in time and space to estimate fishing effort. The approach is a step towards the development of standardized methods to facilitate wider exchange and use of European VMS data. A clear audit trail for the methods of VMS analysis already used to inform management needs to be documented.

Keywords: data, ecosystem approach, fishing activity, fishing impacts, spatial planning, vessel monitoring system, VMS.

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Introduction

Descriptions of the spatial and temporal distribution of fishing effort are used to assess fisheries interactions with target stocks and the environment (Rijnsdorp *et al.*, 1998; Kaiser *et al.*, 2000; Stefansson and Rosenberg, 2005; Hiddink *et al.*, 2007), to develop and apply indicators of fishing pressure (Anon., 2007; Piet *et al.*, 2007; European Commission, 2008a, b), to assess the displacement of fishing activity following changes in regulations, area closures, and fuel costs (Dinmore *et al.*, 2003; Murawski *et al.*, 2005; Arnason, 2007), to describe fishing behaviour and interactions among vessels (Mackinson *et al.*, 1997; Rijnsdorp *et al.*, 2000; Poos and Rijnsdorp, 2007), and to establish track records that the fishing industry can use when debating access rights and conflicts with other fishers and users of the sea (Eastwood *et al.*, 2007; Stelzenmüller *et al.*, 2008). Historically, data on fishing effort were compiled from information provided by fishing skippers, who were required to report their fishing locations in large statistical areas (such as the ICES rectangles of 0.5° latitude by 1° longitude). These data could not be used for high-resolution analyses (e.g. at scales of 1–10 km). Further, the records of fishing locations were not always reliable and were only confirmed for a small proportion of vessels by ship- or air-based surveillance.

The introduction of vessel monitoring systems (VMS) as a surveillance and enforcement tool has revolutionized the study of the spatial and temporal distribution of fishing effort, providing high-resolution real-time data for most of the larger fishing vessels. VMS are used by management authorities to check that a vessel is fishing at a time, and in an area, where it is allowed to fish. VMS have not entirely replaced existing monitoring arrangements, but help alert enforcement aircraft or vessels to potential infringements. The European Union adopted VMS to monitor the activities of all vessels $\geq$24 m long overall from 1 January 2000, and by 1 January 2005, had extended monitoring to all vessels $\geq$15 m long (European Commission, 2003). VMS will be extended to all vessels 12 m or longer overall from 1 January 2012 (European Commission, 2009). If VMS data are used to describe fishing activity, then their main drawback is that the transmitted data do not indicate whether vessels are in port, fishing, steaming, or underway but not making way.

Several methods have been developed and applied to VMS data to obtain estimates of fishing effort (Table 1). The diversity of these methods may, in part, reflect the different questions being addressed and the preferred scales of analysis. Many methods focus on trawled gears and use some form of speed-based differentiation to identify fishing activity. However, the results are not always tested against data on known fishing activity, and the procedures may not be documented in ways that allow the methods to be repeated. The development of rigorous, reliable, and repeatable methods of VMS analysis would be a significant step towards

Table 1. Review of published methods to estimate the spatial distribution of fishing from VMS.

Source reference	Gear	VMS interval (min)	Method of identifying fishing activity	Method of converting from points to surface showing effort	Resolution of estimate	Region
Rijnsdorp *et al.* (1998)	Beam trawl	6	Mean speed ± 2 knots	Points per grid cell (positional data from loggers not VMS)	3 × 3 miles	Netherlands
Dinmore *et al.* (2003)	Beam trawl	120	Speed ≤ 8 knots	Trawling frequency calculated as (number of points × estimated area disturbed per point)/area of cell	1 × 1 to 8 × 8 miles	UK
Deng *et al.* (2005)	Prawn trawl	1–120	Speed <4 knots, not at anchor (same location for several hours), not in port or seasonal closure	Tracks overlaid to give intensity of trawling; spatial resolution of output grids not stated	–	Australia
Murawski *et al.* (2005)	Otter trawl	–	Speed <3.5 knots	Points per grid cell	1 degree	USA
Salthaug and Johannessen (2006)	Bottom trawl	60	Not stated	Number of (VMS) hours spent in the specified area	Summary for specified polygon area	Norway
Eastwood *et al.* (2007)	Beam and otter trawl and dredge	120	Speeds, 1–6 knots for otter trawls and dredges, 2–8 knots for beam trawls	Following methods from Mills *et al.* (2007)	2 × 2 miles	UK
Harrington *et al.* (2007)	Scallop dredge	Not stated	Not stated	Points per grid cell and kernel density	250 m to 5 km	Tasmania
Mills *et al.* (2007)	Beam trawl	120	Speeds (2–8 knots) and turning angles	Tracks overlapped to give a footprint (no intensity), ellipses to represent uncertainty in paths between points	3 × 3 km	UK
Piet *et al.* (2007)	Beam trawl	6 and 120	Speed 3–6 knots for small vessels, 5–8 knots for large vessels	Points per grid cell (and swept-area estimates using average speed and gear width but not applied per grid cell)	1 × 2 min (∼1 × 1 mile)	Netherlands
Walter *et al.* (2007)	Scallop dredge	60	Speed <5.5 knots	Radial search, 1.9 miles from centre of grid cell	1 × 1 mile	USA
Witt and Godley (2007)	All gears, not differentiated	120	Speed (km h^{-1}) ≥ 3 and ≤ 10 (∼1.5–5.5 knots); aided by trip reconstruction	Hours at points per grid cell	3 × 3 km	UK
Fock (2008)	Gillnet, pelagic trawl, otter trawl, beam trawl	60	Otter and beam trawls, mean speed per vessel calculated from all speeds <8 knots, all points < mean speed + 2 knots classed as fishing; gillnets same as above, but 5 knots	Hours at points per grid cell, plus some value added to neighbouring cells to represent uncertainty in paths between points	0.05 × 0.1 degrees (∼3 × 3 miles)	Germany
Hintzen and Brunel (2008)	Beam trawl	6 and 120	Not stated	Cubic Hermite spline method used to interpolate between successive VMS points	Various	Netherlands
Stelzenmüller *et al.* (2008)	Beam and otter trawl, and dredge	120	Speed, values following Eastwood *et al.* (2007)	Tracks overlapped to estimate intensity of pressure	2 × 2 miles	UK
van der Hulst *et al.* (2008)	Beam trawl	120	Not stated	Following methods from Hintzen and Brunel (2008)	Various	Netherlands

Continued

Table 1. *Continued*

Source reference	Gear	VMS interval (min)	Method of identifying fishing activity	Method of converting from points to surface showing effort	Resolution of estimate	Region
Mullowney and Dawe (2009)	Traps	60	0.1–3.0 knots	Hours fished	10 min grid	Newfoundland and Labrador
Pedersen *et al.* (2009)	All gears, identified by vessel behaviour and EU vessel register	60	Following methods in Fock (2008); seines and pots using same method as for gillnets	Following method of Fock (2008)	0.05 × 0.01 degrees (∼3 × 3 miles)	Germany
Piet and Quirijns (2009)	Beam trawl	6 and 120	Speed 3–6 knots for small vessels, 5–8 knots for large vessels	Area trawled per grid cell calculated as (time × average speed × width of gear)	0.005 × 0.01 degrees to 0.5 × 1 degree, also a range of temporal resolutions	Netherlands

Note that miles refer to nautical miles.

condensing the vast quantities of data collected by management authorities into estimates of fishing effort that could be accessible to a wider scientific audience and of increasing value to stakeholders participating in debates about the use of the sea. Standardization of methods would also facilitate the sharing of data internationally, which is essential when several countries fish in the same areas and contribute to the overall fishing pressure. To ensure the widest application, fishing effort would be estimated from VMS data at the finest space and time resolutions useful to researchers and stakeholders, while recognizing the limitations imposed by the underlying positional data. Researchers needing effort estimates at coarser scales of time and space could then aggregate the fine-scale estimates as required.

Here, we develop and test methods for estimating fishing effort from VMS data for fishing vessels registered in the UK. We propose methods for identifying errors in unprocessed VMS data and investigate how the "cleaned" data can be used to estimate fishing effort with different gears, based on comparisons with known fishing activity. We discuss how our method can be applied to support international collaboration.

Methods

VMS identity, position, speed, and heading data from UK vessels fishing in all areas and from UK and non-UK vessels fishing in UK waters are transmitted to the Marine and Fisheries Agency (MFA) of the UK Department of Environment, Food and Rural Affairs. For this analysis, we used all available VMS records for UK vessels in an area from 24°W to 5°E and 47°N to 64°N and generated estimates of fishing activity at a 3′ grid resolution, giving a total of 197 200 grid cells. We chose to present data for UK vessels only because we have access to reliable and verifiable information on the fishing gear used by those vessels but cannot consistently obtain this information for non-UK vessels fishing in UK waters.

Unprocessed VMS data obtained from the MFA were screened to identify basic inaccuracies in vessel identity, position, speed, and heading. Duplicate data records (identical vessel, time, and location) and records from within 0.05° (∼3 nautical miles) of a port were removed. Then the interval between successive records was calculated. The required reporting interval is 2 h, but some records proved to be more or less frequent. When the time between successive records exceeded 4 h, the second record was assumed to represent the first location on a new episode of activity. Once the preliminary screening was complete, the remaining data were assumed to represent true records of vessel positions when either fishing or steaming and were used in subsequent analysis.

The fishing gear used by UK vessels that are monitored with VMS can be established by linking the VMS data to national logbook data using the vessel identifier and time. This can be done in research organizations such as that of the authors (Centre for Environment, Fisheries and Aquaculture Science, Cefas) that are permitted access to commercially sensitive logbook data for research purposes. Fishing vessels may be involved in non-fishing activity (e.g. guard duty on offshore installations), but may still return VMS positional information. This activity will not have any associated logbook information. VMS data falling into this unassigned gear code category may be useful for identifying unreported activity, but the focus of this research was to explore patterns of fishing effort so, if logbook information was unavailable for a particular period of activity, then the VMS data for that period were excluded from further processing. We assigned gear codes to vessels following the Level 4

Table 2. Classification of fishing gear by EU Data Collection Regulation (DCR) level.

Level 2 classification	Fishing gear included
Dredges	Boat dredges; mechanized (or suction) dredges
Hooks and lines	Hand and pole lines; set and drifting longlines and trolling lines
Nets	Driftnets; set gillnets; trammelnets
Seines	Fly shooting seines; beach-seines; boat-seines; pair-seines; anchored seines; surrounding (purse-) seines
Traps	Pots; traps; uncovered pound nets; fykenets
Trawls	Single otter trawls (pelagic and demersal); paired otter trawls (pelagic and demersal); multirig otter trawls; beam trawls

classification in the EU Data Collection Regulation (DCR; European Commission, 2008a, 2008b). Level 4 classification identifies the specific gear types employed, e.g. boat dredge or beam trawl, but does not detail the target species or mesh size employed. For the purposes of summarizing results, we aggregated the Level 4 data to provide a Level 2 classification (Table 2).

After screening the unprocessed VMS data and identifying links to logbook data to assign gear codes, fishing and non-fishing activities have to be distinguished before fishing effort can be estimated. Previous work on the development of methods for distinguishing beam trawling from non-fishing activity (Mills *et al.*, 2007) used information on the known activities of individual vessels that were also monitored with VMS. This information was obtained from the England and Wales discard monitoring programme, which places observers on fishing vessels to record the timing and location of fishing activity, catch rates, and discard rates. Between 0.5 and 1.0% of trips by English and Welsh vessels are monitored annually (Cotter *et al.*, 2006). Similarly, we used data from the discard monitoring programme for the years 2000–2005 to compare the distribution of vessel speeds associated with fishing and not fishing and to determine whether the differences in speed were sufficient to identify fishing activity from VMS speed records.

We report fishing effort as the time spent fishing per unit area per unit time. This approach is used principally to describe fleet activity, whereas the parameter area swept per unit time per unit area is used for assessment of links between effort and fishing mortality or fishing impacts on the seabed. The latter parameter can be calculated from the former for towed gears if the geometry of those gears and the speed of fishing are known (Dinmore *et al.*, 2003). For the current analyses, we focus on estimating the former parameter, i.e. the time spent fishing per unit area per unit time, based on a point summation method.

For point summation, VMS records associated with fishing were allocated to a 3-min grid (cell area $\sim$21 km^2 at 47°N to 14 km^2 at 64°N). We used a grid based on the units of latitude and longitude rather than a grid of equal areas, so that the cells mapped exactly to the ICES rectangles used for the logbook-based reporting of effort and landings data (200 × 3-min cells per rectangle). The implications of adopting different cell sizes for reporting fishing effort and assessing fishing impacts are discussed by Rijnsdorp *et al.* (1998), Dinmore *et al.* (2003), Mills *et al.* (2007), and Piet and Quirijns (2009). Cell-size configurations can be modified if equivalence of area with latitude is deemed more important or to address specific analytical needs when assessing fishing impacts. Within each cell, the number of VMS fishing records per unit time per gear class (DCR Level 2) was summed to estimate fishing effort. All analyses were conducted using the open source statistical language R and Esri ArcGIS v9.

To quantify the differences between the spatial patterns of fishing effort associated with different gears or for the same gears in different years, we developed an index of difference in spatial pattern. The proportion of effort in each cell was calculated, such that the sum of effort in all cells in UK waters was 1.0. To compare two maps, the per-cell absolute differences in the proportion of effort were calculated, summed for the entire grid, then divided by 2. This provides an index of difference in spatial pattern that varies from zero (spatial patterns identical for a given cell-size resolution) to one (spatial pattern maximally different, i.e. no effort in the same cells).

Results

Observations of fishing activity recorded by the England and Wales discard monitoring programme demonstrated that the distribution of vessel speeds associated with fishing with towed gear differed from speeds when not fishing (Figure 1). For beam trawls, most of the fishing activity was at speeds up to 7 knots, dredges fished at speeds up to 6 knots, whereas for otter trawls, fishing activity was at speeds up to 4 knots. Non-fishing activity is at speeds of 7 knots and above for dredges and otter trawls and at speeds of 5 knots and above for beam trawls. In these data, from which records close to port (within 0.05°) have been excluded, speeds of zero are evident for both fishing and non-fishing activities.

The distribution of vessel speeds associated with VMS records varied among gears (Figure 2). Distributions for all gears appeared to be bimodal, and followed similar patterns to those recorded in the observer data (Figure 1), with peaks associated with fishing and non-fishing activities. The breakpoint between the peaks was at speeds of 5–6 knots always. The observer data and the VMS data show records with a speed of 0; we excluded these from our analysis to minimize the risk of including areas where vessels were idling or waiting to return to port. The data indicated that the use of a 1–6-knot speed filter could provide an effective means of distinguishing most of the fishing activity for all gears. Local or sectoral differences in such speed rules would be expected. Therefore, if additional information were available on the dynamics of fleet activity, the simple speed rule could be refined.

Having adopted a 1–6-knot speed filter, VMS records were classified as fishing or not fishing, and the fishing records were used to estimate fishing effort. For static gears, the assumption is that the lower peak in the bimodal distribution of speed is indicative of gear being set and recovered. Using this method, it is not possible to determine the period during which the static gears were fishing, so, for those gears, the VMS analysis only provides an indication of the whereabouts and relative intensity of fishing.

The VMS data used to generate estimates of fishing effort and the effects of data processing are summarized in Table 3. Of the 4.09 million VMS records considered, some 18% were excluded from further analysis as being either duplicate points or in locations close to port, and a further 19% were excluded because no link to landings logbook data could be established. Using the speed range 1–6 knots to signify fishing, some 2.04 million (of the remaining 2.55 million) records were classified as fishing.

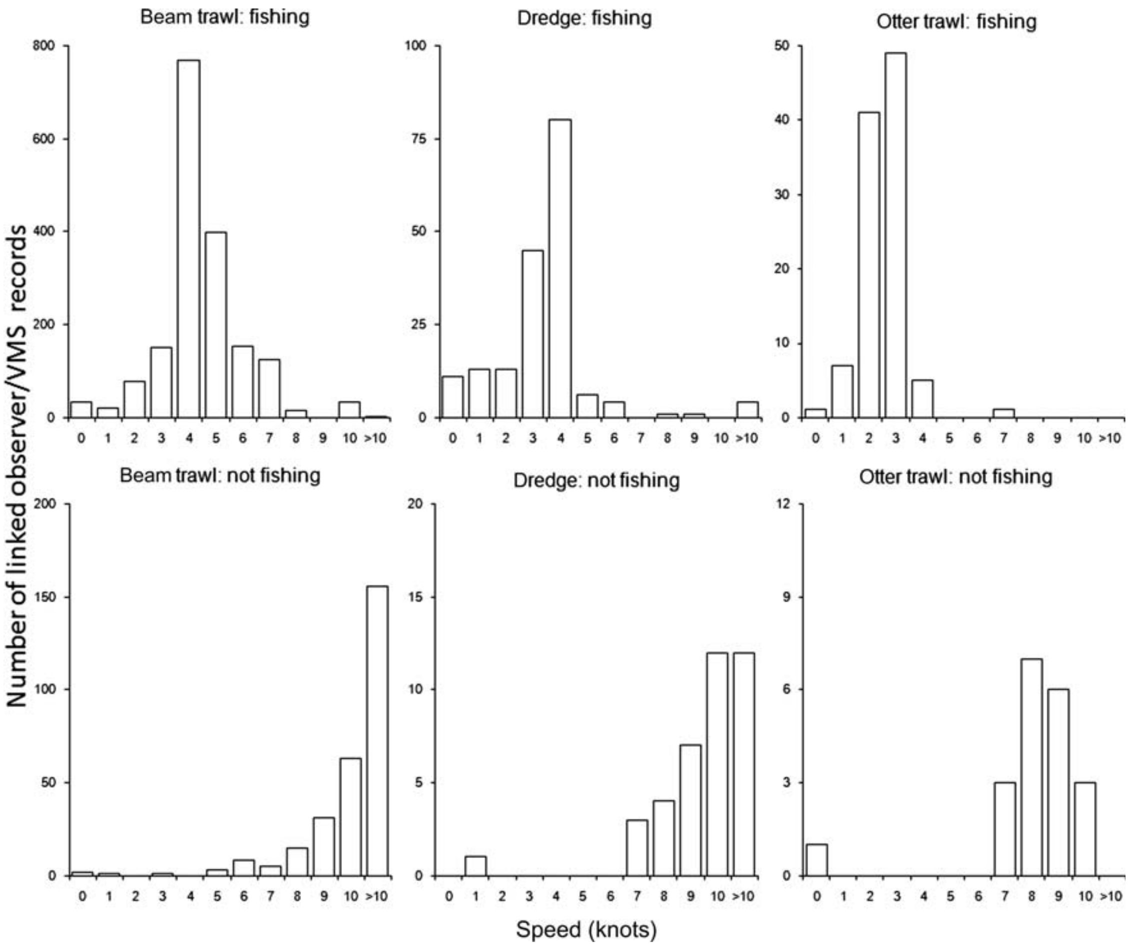

Figure 1. Transmitted VMS speeds of vessels verified as fishing/not fishing by UK discard observers, 2000–2005.

The proportion of data classified as fishing activity was consistent across the 2 years of the study.

The distribution of fishing effort varied among gears, but was relatively consistent within gears in 2006 and 2007. The spatial distribution of the effort by different gears is shown in Figure 3. Dredge effort was recorded in 2.28% of the total study area, whereas the effort for hooks and lines covered just 1.76% of the total study area. Netting effort was recorded in 2.43% of the study area and seining in 2.88%. Trap effort was recorded in 2.23% of the study area, whereas trawling effort accounted for the greatest proportion of total effort and was recorded in 16.46% of the total area. Our index of difference in pattern between gears in the same year ranged from 0.863 to 0.999 (Table 4, Figure 4a). Spatial patterns were more consistent within gear between years, ranging from 0.252 for the trawled gears (Figure 4b) to 0.568 for hooks and lines (Table 5).

As we summarized the results using DCR Level 2 gear classification, our results mask significant spatial differentiation in the distribution of effort attributable to specific types of gear. Further disaggregation of the trawl-effort data to beam and *Nephrops* trawls, demersal otter trawls, and pelagic otter trawls (Figure 5) showed the dominance of beam-trawl activity in southern UK waters, the concentration of pelagic otter trawling in western areas, and the more widespread use of demersal otter trawls.

To assess how the definition of speed rules might modify the predicted distribution of fishing effort, we compared the estimates of the area fished based on a range of plausible speed rules. An all-speeds rule was also used to include 100% of the VMS data for each gear group and to provide a comparative baseline for assessing the effects of other rules. For most gears, plausible changes to the speed rules do not greatly change the extent of the fished area (Table 6). For example, with trawling, the fished extent ranges from 86% of all possible cells using the broadest speed range of 1–8 knots to 73% of all possible cells using the most restricted speed range of 3–6 knots. For all gears, there was little difference in the spatial extent of the fished area when using the 2–7 and 1–6 knots rules. The gear group hooks and lines was most susceptible to the choice of speed rule, with a difference in area fished of 40% between the least and most restrictive rules (Table 6).

There is little empirical data available on fishing with static and set gears to help identify a preferred speed rule. Discussion with industry experts indicated that the spatial patterns of activity obtained using a range 1–6 knots is representative of fishing with those gear types (based on consultation in Plymouth on 6 January 2009).

As it was only vessels of ≥15 m overall length that were monitored with VMS in 2006 and 2007, this limits the proportion of total fishing activity that can be described using our approach.

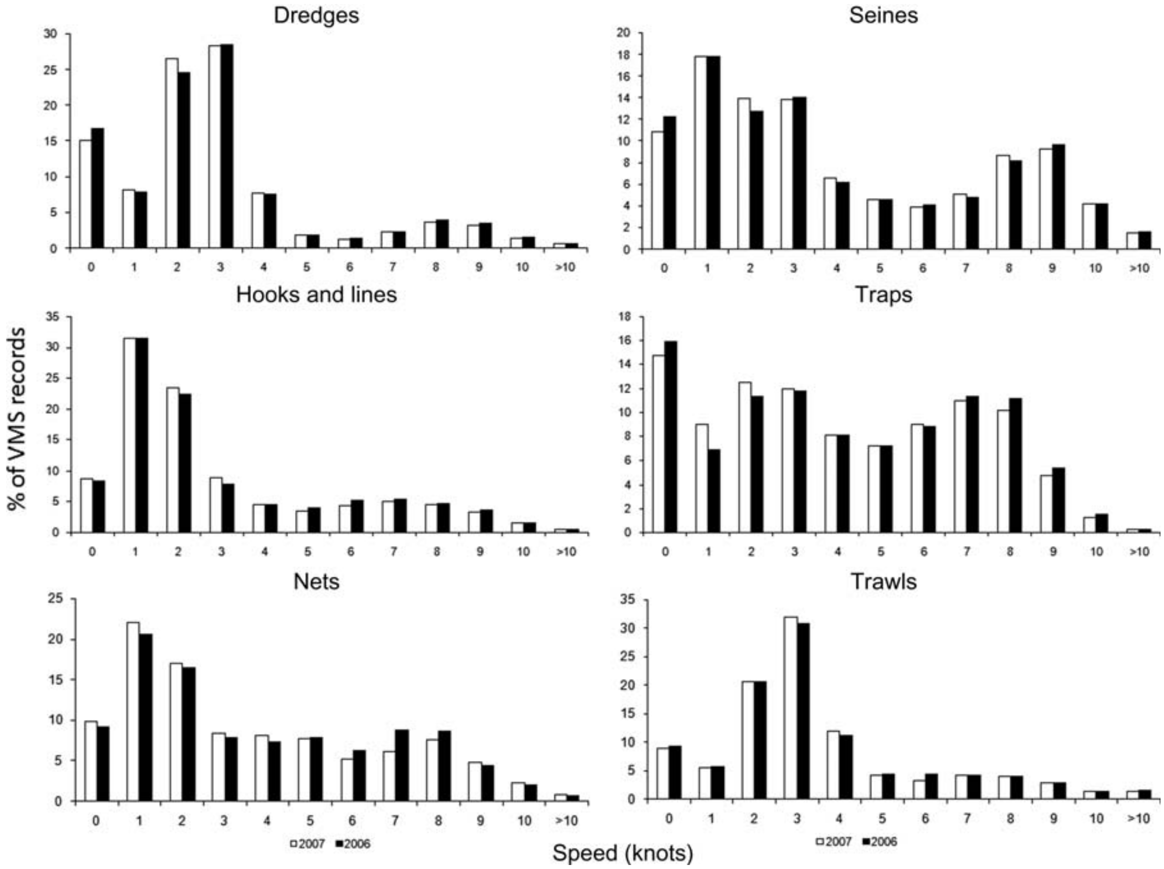

Figure 2. Transmitted VMS speeds of UK vessels, 2006 and 2007.

Table 3. Analysis of UK VMS data for 2006 and 2007.

Year	Number of raw VMS records within study region (×1 000)	Records removed as in port/duplicates (×1 000)	Records removed as no link to logbook data (×1 000)	Remaining VMS records (×1 000)	Records estimated as fishing (×1 000)	Records estimated as fishing (% of remaining)	Records estimated as fishing (% of raw VMS locations)
2006	1 963	363	376	1 224	969	79	49
2007	2 128	388	410	1 330	1 073	81	50
Both years	4 091	751	786	2 554	2 042	80	50

Total UK fishing effort, weight of catch, and value of catch (from logbook data that are submitted by all registered vessels of all lengths) were compared with effort, catch, and value by vessels $\geq$15 m to provide an indication of the proportion of fishing activity captured with VMS. The activity of seine-netters and trawlers is almost completely attributed to VMS vessels, but for other gears the proportion of activity attributed to VMS vessels is low and variable, ranging from 23% of landings for traps to 64% of landings for hooks and lines (Table 7).

Discussion

The development and application of a process for estimating fishing effort from unprocessed VMS data have provided a unique, high-resolution description of gear-specific fishing effort in UK waters. Based on the assessment of the data received from the management authority and the analyses conducted, we recommend a six-step process for estimating fishing effort from VMS data. These steps are (i) remove duplicate records, (ii) remove locations in or close to port, (iii) calculate the time interval between successive records, (iv) establish the fishing gear used by vessel and exclude (or categorize as Unassigned) any VMS locations for which fishing gear cannot be established, (v) differentiate between fishing and non-fishing records based on reported speed, and (vi) estimate the spatial distribution of fishing effort from these records. It is valuable to document the methods used for processing VMS data because subtle differences in methods will affect the output. Documentation of methods also contributes to an audit trail that is essential when VMS data are already being used to inform planning policy (Defra, 2007; Fock, 2008; Pedersen *et al.*, 2009).

The benefits of having a standardized grid and approach are that a large number of VMS records (>4 million in the present study) can be converted into smaller, gear-specific, spatially referenced files of fishing effort data that are tractable for further

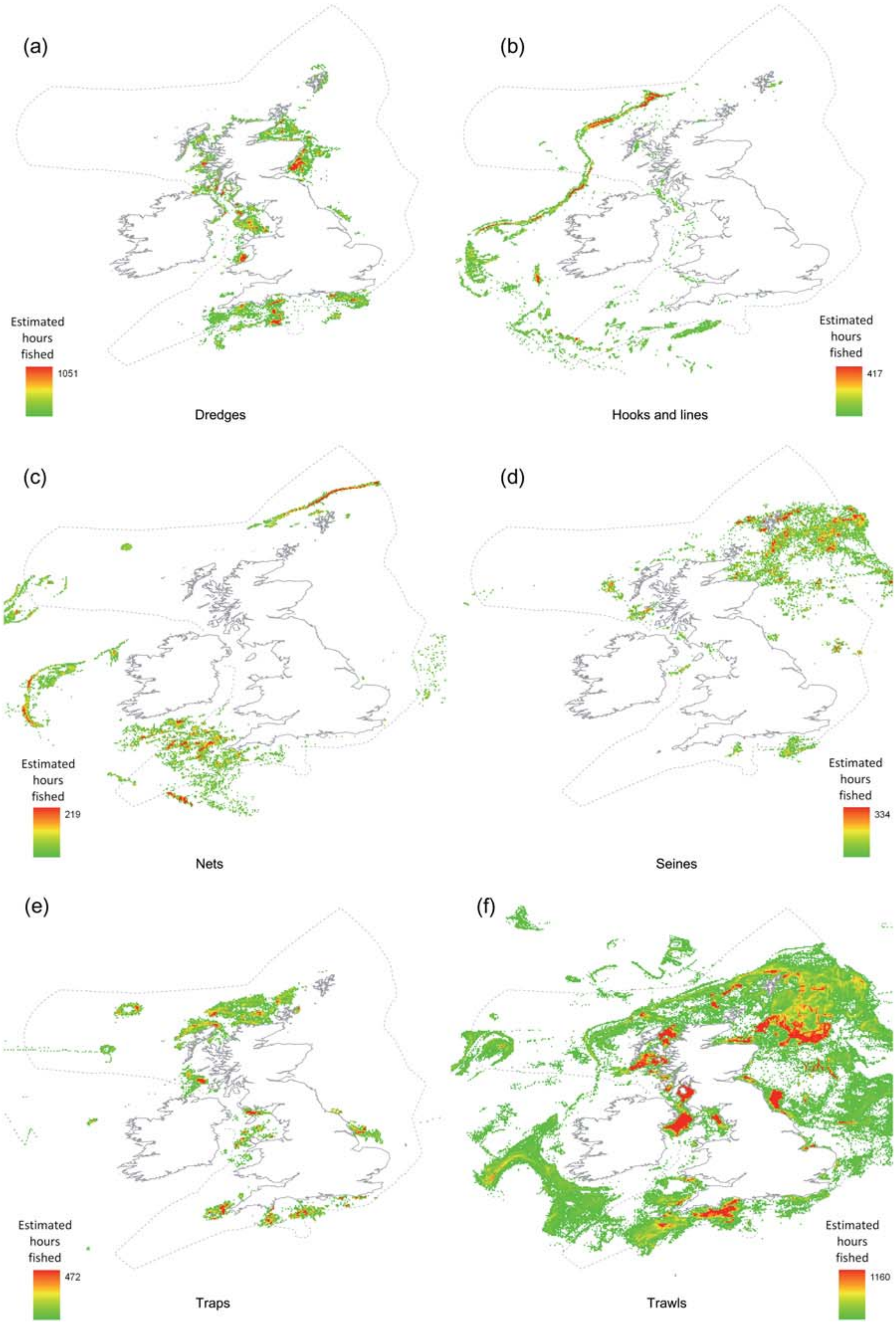

Figure 3. Estimated fishing activity by gear class, UK vessels >15 m in 2007. (a) Dredges, (b) hooks and lines, (c) nets, (d) seines, (e) traps, and (f) trawls.

Table 4. Indices of the relative difference in spatial pattern between pairs of gears for 2007.

Gear class 2007	Dredges	Hooks and lines	Nets	Seines	Traps	Trawls
Dredges	–	0.992	0.987	0.975	0.960	0.935
Hooks and lines	–	–	0.959	0.999	0.995	0.978
Nets	–	–	–	0.999	0.989	0.966
Seines	–	–	–	–	0.983	0.863
Traps	–	–	–	–	–	0.972
Trawls	–	–	–	–	–	–

0, total equality; 1, maximal difference.

analysis and exchange among users. Further, the fishing activities of individual vessels are flagged using the DCR métier classification, so allowing data for many individual vessels to be combined according to a standardized and internationally agreed classification. The six levels of the DCR can, in theory, be used to aggregate and disaggregate associated effort data without gaps or inefficiencies.

The methods used to differentiate fishing and non-fishing activities can be tested with data from the England and Wales discard monitoring programme, but the coverage of fishing activity by that programme is limited and there are always risks of Type I and Type II errors when speed rules are adopted. For national scale studies, we do not believe that a further refinement of the rules based on other factors such as directionality will solve this problem, given the relatively small influence they have on the classification of beam-trawler fishing activity (Mills *et al.*, 2007). Rather, we advocate a straightforward speed-based approach that has broader applicability to other gear groups and fishing areas. This is because the development of relatively simple, standardized methods that could be applied to the majority of fleets across Europe would facilitate greater use of VMS data, and because plausible errors in the speed rule were shown to have a relatively small impact on the calculated distribution and intensity of fishing effort for most gears. The need to combine high-resolution fishing effort data from EU member states is still pressing given that scientists are being asked to advise on the combined pressures and impacts of fisheries and to produce fishing-pressure indicators based on VMS data as part of the DCR (European Commission, 2008a, b). Several initiatives currently employ our standardized method to facilitate the generation of international patterns of fishing activity (South *et al.*, 2009; Le Quesne *et al.*, 2010), and work is under way by the authors to develop software tools that

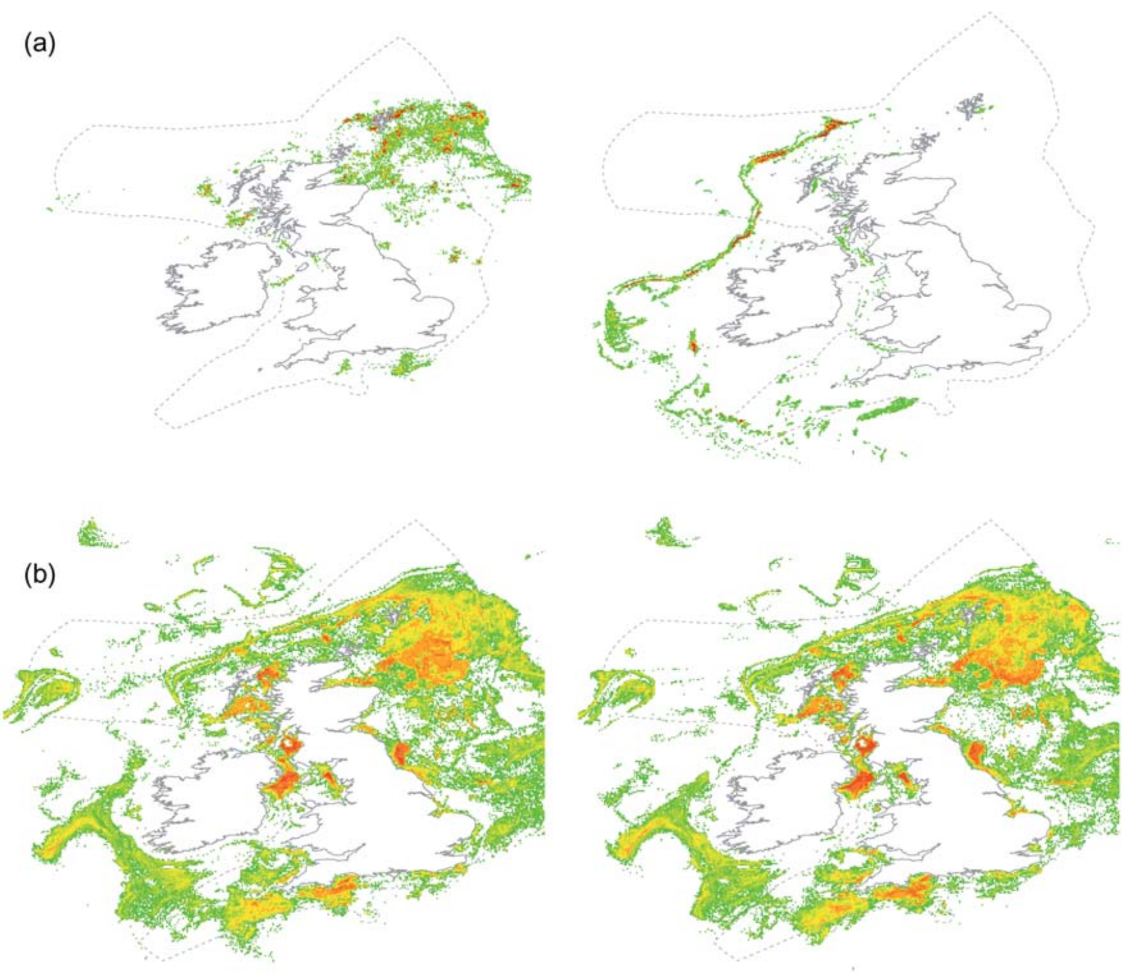

Figure 4. Difference in spatial pattern between (a) gears (seines, left, compared with hooks and lines, right, index value 0.999, for 2007; patterns different), and (b) years (trawls, 2006 left, compared with trawls, 2007 right, index value 0.252; patterns similar).

Table 5. Indices of the relative difference in spatial pattern within gear between 2006 and 2007.

Gear class 2006/2007	Dredges	Hooks and lines	Nets	Seines	Traps	Trawls
Dredges	0.474	–	–	–	–	–
Hooks and lines	–	0.568	–	–	–	–
Nets	–	–	0.553	–	–	–
Seines	–	–	–	0.461	–	–
Traps	–	–	–	–	0.445	–
Trawls	–	–	–	–	–	0.252

0, total equality; 1, maximal difference.

will enable non-specialists to generate reliable and repeatable estimates of fishing activity.

The acceptability of classification errors when using speed rules depends on the intended use of the outputs. Errors are a greater concern when working on small scales of time and space. Although peaks in speed histograms associated with fishing and steaming were apparent for all gear classes, there was also some activity at intermediate speeds that could be associated with either fishing or steaming. Ultimately, a single speed rule of 1–6 knots was applied for all gears because the precise definition of the rule had a limited effect on the distribution of fishing effort, and modifying the rule to suit individual vessels and

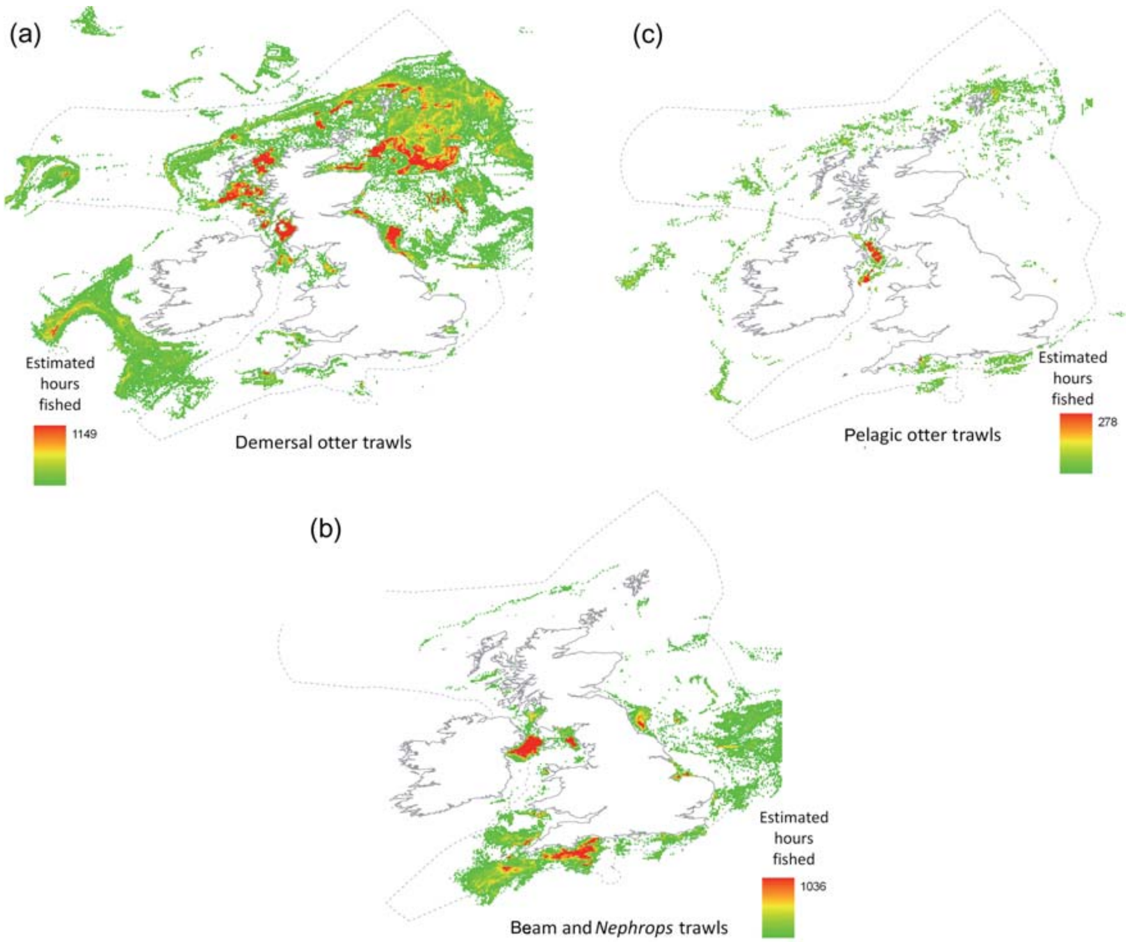

Figure 5. Estimated fishing activity by trawl gear types, UK vessels >15 m in 2007. (a) Demersal otter trawls, (b) beam and *Nephrops* trawls, and (c) pelagic otter trawls.

Table 6. Number of cells and proportion of total cells classified as fished using differing speed rules for 2007 data.

Gear	All speeds	1–8 knots (proportion of total, %)	2–7 knots (proportion of total, %)	1–6 knots (proportion of total, %)	3–6 knots (proportion of total, %)
Dredges	6 414	86	75	70	63
Hooks and lines	4 785	87	69	73	47
Nets	6 809	89	74	70	57
Seines	8 690	83	69	65	55
Traps	5 428	96	88	81	74
Trawls	42 192	86	80	77	73

Table 7. Proportion of fishing activity covered by VMS in UK waters, 2006 and 2007 combined (data from EU logbooks for vessels landing into UK ports).

Gear	Total fishing effort ('000 d)	% activity covered by VMS	Total landings live weight ('000 t)	Percentage of landings (live weight) covered by VMS	Total landings value (million pounds sterling)	Percentage of landings value covered by VMS
Dredges	53	48	86	52	92	63
Hooks and lines	25	17	12	64	21	71
Nets	75	7	17	40	36	42
Seines	8	99	59	100	43	100
Traps	311	4	90	23	177	16
Trawls	323	57	792	94	810	87

regions would make the method less standardized, repeatable, and accessible. For studies of individual vessels, fisheries, and regions, the rule could be modified if more were known about the fishing speeds of the vessels concerned. Realistically, until data indicating whether a vessel is fishing or not fishing are transmitted with VMS records, it is unlikely that any speed or direction rule will identify the activities of vessels without error, particularly for those fishing with static gear. Static fishing gear presents additional challenges because the realized fishing effort depends on the size, type, and soak time of nets or traps, and VMS data provide insight into the vessels' area of operation rather than fishing effort.

For broad-scale data analysis, the use of computationally intensive track-based methods to estimate the paths taken by fishing vessels does not appear to provide more useful estimates of effort distribution than the point summation method we used. In part, this is a consequence of the 2-h polling frequency for most VMS in Europe that provides limited information for reconstructing tracks. For example, when we examined 15-min VMS records that were recorded for ten English beam trawlers from November 2000 to June 2001 (Dann *et al*., 2002) and assumed straight-line fishing tracks between VMS records, we found that the corresponding 2-h records captured just 38% of the length of the fishing track based on the 15-min records (South *et al*., 2009). Further, Deng *et al*. (2005) resampled fine resolution VMS data at a range of intervals and suggested that VMS data based on intervals longer than 30 min did not produce adequate estimates of trawl track position in an Australian prawn fishery. Given that low-frequency records may not allow for effective track construction, point summation methods produce useful high (spatial) resolution effort data if (i) data from many vessels are available and (ii) these data can be accumulated over a relatively long period (e.g. season, year). The use of a point summation method, as adopted here, is computationally less intensive, faster to implement, and more transparent to many users than generating tracks which, when sampling is at 2 h intervals, will often imply a level of precision not appropriate for the data. Track-based methods may be more appropriate when the interval between locations is shorter or when attempting to ascertain the spatial impact of small groups of vessels or larger groups of vessels over short periods. One of the drawbacks of point summation with 2 h intervals is that shorter fishing activities may be missed. However, VMS can be thought of as a sampling approach, and provided data are sufficient, they are likely to produce a good picture of areas visited, with the possible exception of areas used rarely.

In future, the frequency of VMS polling may change, and records of fishing or not fishing may be added to transmissions. Such changes would increase the value of VMS as a source of high-resolution fishing-effort data. However, data collected since the advent of VMS in Europe will still be used for developing time-series of fishing activity, and the methods we have developed could be applied when constructing such time-series. The justification for using VMS even at current intervals is that the resolution and accuracy obtained far exceed that of the ICES rectangle-based data that formerly provided information on spatial and temporal trends in fishing effort (Jennings *et al*., 1999).

We used the estimated time spent fishing as the metric of fishing effort. The next challenge is how best to link logbook data on fish landings and values to the VMS data. This will allow an estimation of the spatial distribution of fish catches. However, that link is not straightforward, landings are usually declared by ICES rectangle and day, and they must then be subdivided between VMS locations. Assumptions must be made about the spatial and/or temporal distribution of fishing activity. One option would be to apportion the reported landings for each rectangle equally between the VMS points falling within that rectangle. Another option would be to apportion the landings for each fishing trip equally between all VMS points contributing to that trip, with no reference to the declared landings rectangle.

One limitation of assessments of fishing activity based on VMS is that they provide limited information on activity close to the coast where most vessels <15 m long operate. These vessels account for a large proportion of hook-and-line, net, and trap effort, but a lesser proportion of total UK landings, owing to their lower catch rates. If a current European proposal (European Commission, 2009) to extend VMS monitoring to all vessels >12 m overall and to all vessels >8 m that use towed gears is implemented, then the description of inshore effort distributions will be improved. Another limitation of our maps is that they do not include foreign vessels, because we could not access full information on the gears used by non-UK vessels. This could be addressed by improved communication and data-sharing with other member states.

Concerns of confidentiality and commercial sensitivity have arisen over the use of raw VMS data as points identify exact vessel positions (Nolan, 2006). The classification and aggregation of VMS data based on the DCR métiers would address these concerns and may facilitate the wider exchange of data in Europe. Linking VMS records and logbooks, to identify fishing gear, would need to be carried out at a national level before any exchange of data and before aggregation. VMS data provide a uniquely valuable description of fishing activity, but restrictions on data access and the absence of standardized methods of analysis hamper data exchange and their use in assessment and planning. We believe, however, that the methods developed and reported here are reliable, repeatable, and accessible and will be a step towards the development of standardized methods to facilitate data exchange and use.

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