Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data

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High resolution estimates of trawling effort are needed to underpin studies of trawling impacts on species, habitats, and ecosystem processes, and to monitor responses to area closure and other management actions. Satellite-based vessel monitoring systems (VMS) were designed for fishery control and enforcement, but they provide potentially valuable source information on spatial and temporal patterns of trawling activity at multiple scales. Based on an analysis of VMS data for UK beam trawlers in the North Sea, a method is described for identifying trawling activity and estimating fishing intensity based on the minimum and maximum potential spatial extent of trawling effort from VMS data. The optimal method for identifying trawling and steaming behaviour combined speed and directionality rules and correctly identified trawling and steaming in 99% and 95% of cases, respectively. Using speed- and directionality-filtered VMS data, trawling effort can be reported as area impacted per unit time per unit area at a range of grid scales from 1 km to 100 km (10 000 km^2). Trawling effort is accurately represented at a grid cell resolution of 3 km or less.

Keywords: beam trawling, fishing effects, fishing effort, North Sea, vessel monitoring system.

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Introduction

High resolution data on the spatial and temporal distribution of trawling effort are needed to support studies of the impacts of trawling on species, habitats, and ecosystem processes (Collie *et al.*, 2000; Kaiser *et al.*, 2002) and to help monitor fleet responses to management actions, including marine protected areas (Rijnsdorp *et al.*, 2001; Dinmore *et al.*, 2003; Murawski *et al.*, 2005). Historically, high resolution data were only available from studies of small groups of vessels tracked using position loggers (Rijnsdorp *et al.*, 1998) or from vessel positions recorded by fishery enforcement aircraft (Jennings *et al.*, 2000). Such data represented subsets of a particular fleet or a small proportion of a fleet's fishing grounds. Although the data helped to improve our understanding of the behaviour of fishing vessels (Rijnsdorp *et al.*, 2000) and trawling impact studies (Piet *et al.*, 2000), they were not suitable for large-scale, fishery- or ecosystem-level impact assessments.

At large scales, trawling effort data are usually reported in areas of 100s or 100 000s of square kilometres, such as ICES statistical rectangles (Rauck, 1985). Effort reported at such large scales can provide a misleading picture of the small-scale spatial distribution of effort: areas trawled frequently will be aggregated with untrawled areas. Indeed, trawling effort is only randomly distributed at scales of $\leq$1 nautical mile^2 (Rijnsdorp *et al.*, 1998). The implications of patchy effort distributions are considerable. For example, when assessing the ecological impacts of trawling, the first pass of a trawl on a previously unimpacted seabed has greater relative impacts on biomass and production than repeated passes on a previously impacted seabed (Duplisea *et al.*, 2002). Therefore, analyses at finer scales that take account of the patchiness of trawling and the presence of unimpacted areas show that trawling impacts are smaller than when they are calculated with large-scale (e.g. ICES rectangle) estimates of mean trawling intensity (Duplisea *et al.*, 2002; Dinmore *et al.*, 2003).

In 1998, the European Commission (EC) introduced legislation to monitor European fishing vessels for control and enforcement purposes using a satellite-based vessel monitoring system (VMS) (EC, 1997). From 1 January 2000, all vessels >24 m long were required to transmit their position at intervals of 2 h or less, and by 1 January 2005, the legislation had been extended to include all vessels >15 m (EC, 2003). As VMS data provide a near continuous record of vessel position, they are potentially valuable source information on spatial and temporal patterns of fishing activity at multiple scales. At present, VMS data do not indicate whether a vessel is fishing when its position is reported. Therefore, the use of VMS data to estimate fishing effort depends on accurate differentiation between fishing and non-fishing activity. Vessel speeds are commonly used to determine when trawling is in progress, with 8 knots considered to represent the upper limit of trawling speed for North Sea beam trawlers (Polet *et al.*, 1998; Rijnsdorp *et al.*, 1998; Dinmore *et al.*, 2003). Vessels may, however, also steam at 8 knots or less when slowing down on approach to port, between hauling and shooting the gear, when in close proximity to other boats, or during adverse weather (Rijnsdorp *et al.*, 1998; Dann *et al.*, 2002). Speed alone is therefore unlikely to be a suitable criterion for identifying trawling activity. Moreover, between 2000 and 2005, speed data are not available for all vessels fitted with VMS, because mandatory reporting of speed information only came into force in 2006 (EC, 2003).

An alternative way of identifying when vessels are trawling is to examine the spatial relationships between successive position records (Deng *et al.*, 2005). Analyses of relationships between position records have long been used to distinguish between animal foraging and feeding behaviour using tracking data (Bell, 1991; Zollner and Lima, 1999; Austin *et al.*, 2004; Morales *et al.*, 2004). Foraging behaviour is often typified by long steps and strong directional movements, whereas feeding behaviour is characterized by short steps, frequent turns, and large turning angles. Relatively distinct behavioural patterns may also be exhibited by trawler skippers, such that directional movements may vary when trawling and steaming. If so, rules based on movement patterns could be used, in combination with speed rules, to improve the precision of trawling effort estimates from high resolution VMS data.

To assess relationships between trawling and biological or physical processes, trawling effort is most usefully expressed as the area impacted by trawling per unit area per unit time (Duplisea *et al.*, 2002). When analysing VMS data, this requires that trawl tracks be reconstructed from successive vessel positions and that the area (length $\times$ breadth) of the track crossing the spatial unit of analysis is known. However, vessels do not necessarily travel in straight lines between successive positions (Deng *et al.*, 2005), and this has to be taken into account when attempting to reconstruct vessel tracks.

As VMS vessel speeds were not routinely transmitted prior to January 2006, speed has to be estimated on the basis of straight-line distances between successive positions. For vessels not trawling in a straight line, calculated speeds are therefore underestimated with subsequent effects on the accuracy with which non-trawling positions are separated from trawling positions using speed rules. Wrongly assuming straight-line tracks would also reduce the likelihood of detecting trawled areas of the seabed, leading to underestimates of the spatial extent of trawling. To assess the effects of deviation from a straight-line track, the limits of possible deviation need to be quantified. The maximum distance of deviation can be assumed to be an ellipse surrounding any two successive positions. The ellipse encompasses all possible vessel tracks, regardless of direction of travel, between the two positions, based on the vessel's maximum speed. Methods for describing such ellipses have been developed by Pfoser and Jensen (1999).

Here, we describe a robust method for identifying and reporting trawling effort and for quantifying the minimum and maximum spatial extent of trawling effort from 2-hourly VMS data. To achieve this, we first evaluated the use of speed and directionality rules, individually and in combination, for identifying fishing activity by UK beam trawlers operating in the North Sea. Speed and directionality rules were then used to define trawling behaviour and to discriminate trawling from non-trawling positions in the VMS database. Quantitative spatial estimates of fishing effort could then be made at both small and large scales in terms of area impacted by trawling per unit area per unit time.

Methods

Data

The UK VMS database records the geographic position, date, time, and identification number of UK fishing vessels in all areas, along with the same information for other EC vessels fishing within or transiting UK waters. Here, we analyse UK beam trawling data in the North Sea, and within this region almost all beam trawling is in ICES divisions IVb and IVc (Figure 1a). VMS data for UK-registered beam trawlers from June 2000 to December 2003 inclusive were used in the analyses, because VMS coverage of the trawling fleet remained relatively constant for the period. Although transmission of vessel speed was not mandatory then, 65% of UK beam trawlers provided speed information (recorded as an integer) voluntarily. Vessel course was estimated from the relative positions of successive positions every 2 h. During a 7-month period from November 2000 to May 2001, nine UK beam trawlers reported their position at an increased frequency of 15 min (Dann *et al.*, 2002). These more frequent position reports were used in two ways: first, to validate the rules for assessing trawling behaviour developed from the 2-h data on position; second, to support development of a "best" estimate of the spatial extent of trawling.

Between 2000 and 2003, discard observers on board UK beam trawlers fitted with VMS recorded the time and position of 332 individual trawls during 10 fishing trips. Position reports for 2-h VMS data were linked to fishing trips to identify VMS records that corresponded with observed trawling events. Relationships between vessel speeds and directional movements from the VMS database and known trawling could then be established. Steaming events from the observer reports were determined as the time of leaving port to the time when the first trawl was shot away, the time between hauling and shooting subsequent trawls, and the time between hauling the last trawl and returning to port.

Trawling and steaming behaviour rules

To develop rules to discriminate fishing from steaming positions, the VMS data associated with the 10 discard observer trips were split randomly into two data sets of five trips, one providing data from which to estimate parameters (186 hauls), the other being retained for parameter evaluation (146 hauls). From the

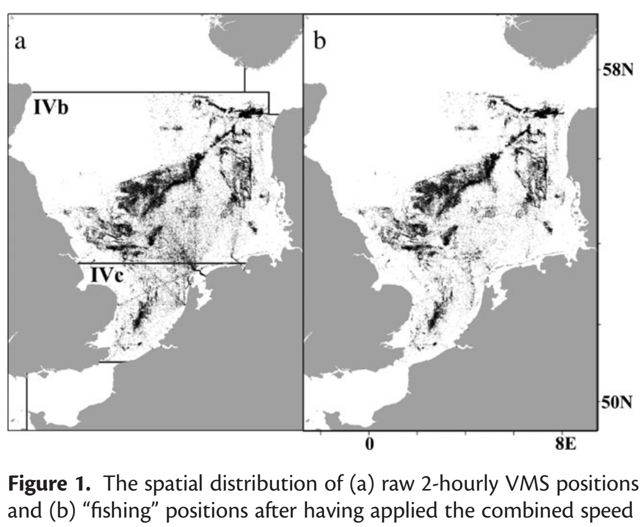


Figure 1. The spatial distribution of (a) raw 2-hourly VMS positions and (b) "fishing" positions after having applied the combined speed and directionality trawling behaviour rule.

parameter-estimation data set, two behaviour rules were developed to differentiate between trawling and steaming: one based on vessel speed, the other based on directionality of movement. Speed rules were developed by identifying lower and upper trawling speed limits from speed frequency distributions. Directionality of movement rules were defined by the mean deviation angle (MDA) and the length of the mean vector of movement (MVL) along the vessel track. The MVL calculation returns an index of deviation in vessel movement and was used to determine upper and lower confidence intervals for MDA, following the methods described by Batschelet (1981).

Directionality of movement metrics were calculated for moving windows encompassing successive position records. Track characteristics within the moving windows were then used to estimate MDA and MVL for a single position. To determine optimum moving window configurations, MDA and MVL were estimated from moving windows of various size ranging from 4 to 8 successive positions. Once the optimum moving window was established, the point within the window at which fishing activity was most accurately predicted was determined. MDA and MVL were calculated by implementing trigonometric functions defined by Batschelet (1981) in ArcGIS 9 (®Environmental Systems Research Institute). Four directionality-based methods for separating steaming and trawling were tested: (i) identifying steaming positions within the full range of MDA and MVL, then assuming the remaining positions to be trawling; (ii) identifying trawling from the full range of MDA and MVL, and assuming the remaining positions to be steaming; (iii) identifying steaming positions within the 95% confidence range of MDA and MVL, then assuming the remaining positions to be trawling; (iv) identifying trawling from the 95% confidence range of MDA and MVL, and assuming the remaining positions to be steaming. Once the optimum directionality metric was determined, a combination of both the speed rule and directionality were tested.

Spatial estimates of trawling effort

To estimate trawling effort at a regional scale, trawling positions identified from the behavioural rules were used to calculate swept area within regular spatial units of predefined size (grid cells) using data from 2003. A consequence of positions being reported at 2-h intervals is that uncertainty about the true vessel position will increase during the first hour following a position report, then decreases gradually until the next position report. Measures of trawling effort based on the assumption that vessels travel in straight lines between two successive positions will therefore be underestimated, with the degree of underestimation being related directly to the extent of deviation from a straight line. To account for this uncertainty, the degree of deviation was expressed in three ways: the minimum deviation, the maximum deviation, and a "best" estimate of deviation from a straight line. Estimates of deviation were used to estimate the spatial extent and intensity of trawling as described subsequently. All three estimates were calculated with data from 2003, and it was assumed that all UK beam trawlers towed two beam trawls, each with a beam width of 12 m (Dinmore *et al.*, 2003).

(i) Minimum extent swept area was calculated by assuming that all beam trawlers towed their gear in a straight line between reported positions. For each grid cell, swept area (km^2) was first calculated on a tow-by-tow basis, then summed over all tows to estimate total swept area per grid cell.

(ii) To estimate the maximum spatial extent requires more explicit consideration of possible vessel movements between reported positions. Assuming a constant maximum trawling speed, there is a maximum distance ($d_{\max}$) a vessel could potentially deviate from a straight line drawn between two consecutive known positions separated by distance d (Figure 2). This limit of possible movement can be described by an ellipse (Pfoser and Jensen, 1999). As speed information in the VMS database was incomplete, and its reliability unknown, we attributed an estimate of maximum trawling speed to all trawling positions identified using the behaviour rules, and used these to construct the corresponding maximum extent ellipses. The ellipses were created in ArcGIS 9 by plotting positions along the ellipse boundary at x, y coordinate locations (Figure 2), where x and y were calculated from:

$$\begin{aligned} x &= \bar{x} + a\cos\theta\cos\psi - b\sin\theta\sin\psi, \\ y &= \bar{y} + a\sin\theta\cos\psi + b\cos\theta\sin\psi, \end{aligned} \tag{1}$$

where

$$a = \frac{d_{\max}}{2}, \tag{2}$$

$$b = \sqrt{\frac{d_{\max}^2 - d^2}{4}}, \tag{3}$$

and where ψ is the angle increasing from 0° to 360°, $\bar{x}$ and $\bar{y}$ are coordinates for the centre of the ellipse, and θ is the angle of the ellipse from the horizontal. Each ellipse was subsequently gridded (with grid resolution varied to meet the requirements of the analysis), and the value of the maximum distance trawled ($d_{\max}$) was uniformly distributed among all grids cells within the ellipse. The values of the distances trawled per grid cell were then summed over all grid cells to estimate the total swept area per grid cell (km^2).

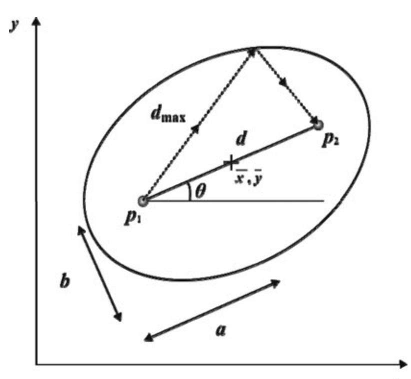


Figure 2. Schematic of the ellipse used to estimate the spatial extent of trawling activity between successive 2-hourly VMS position reports based on the maximum and "best" estimate of deviation from a straight line track. $d_{\max}$ is the maximum distance a vessel could have travelled between consecutive positions p_1 and p_2, a and b are parameters estimated from distance d between p_1 and p_2, $\bar{x}$ *and* $\bar{y}$ are coordinates for the centre of the ellipse, and θ is the angle of the ellipse from the horizontal (Pfoser and Jensen, 1999).

(iii) A more realistic estimate (hereafter termed "best estimate") of the extent of trawling impact will lie between the mimimum extent swept area (i) and the maximum swept area (ii). We derived a more realistic estimate by adjusting for vessel speed using a three-step approach that accounted for variation in the availability of speed records. First, ellipses were generated on the basis of the mean transmitted speed between two consecutive positions. Second, if no speed data were available, we assumed a speed that would create an ellipse including 99% of track deviation. To calculate this, vessel positions at 2-h intervals were extracted from the 15-min VMS data set and a series of ellipses generated using Equation (1) by varying the assumed maximum trawling speed from 3 to 7 knots. In this instance, 99% of track deviation represented the speed at which 99% of the remaining intermediate 15-min VMS positions were encompassed by the associated ellipses. Third, if the assumed speed meant that a vessel could not reach its known position after 2 h, a straight line was used to describe the track between the successive positions.

Sensitivity test for grid resolution

Trawling effort is most usefully summarized and reported in relation to a predefined grid size. To identify grid sizes that captured the patchiness of trawling effort and could be used to summarize trawling effort over large areas, we tested the effects of varying grid size on estimates of the area impacted by trawling and recorded the maximum effort. Using the "best estimate" method, we calculated the total trawled area of seabed within ICES divisions IVb and IVc and expressed this as a proportion of the total trawled area summarized by grid cells of 1 km to 100 km resolution (= 1–10 000 km^2). In calculating total trawled area based on grid cells, the entire area of any grid cell in which any trawling was recorded contributed to the calculation. This approach indicated how well the total spatial extent of trawling in the North Sea was estimated at different grid cell resolutions.

Results

Trawling and steaming behaviour rules

Speed frequency distributions demonstrated that vessels were trawling at speeds of 2–8 knots (Figure 3), so a 2–8 knot speed window was adopted to identify vessels that were trawling. The speed rule alone correctly identified 99% of trawling and 94.3% of steaming activity in the evaluation data set (Table 1).

For the directionality of movement rules, MDA and MVL were largely unaffected by changing the moving window from 4 to 8 successive positions, so the smallest window of four consecutive points was used. Trawling activity was also predicted most reliably at the first position in the moving window, so results were always attributed to this position.

The general patterns of track deviation during trawling showed that vessel movements were highly variable, with vessels sometimes turning through 180°. In contrast, steaming proceeded in relatively straight lines (Table 2). The distributions of MDA were tested for randomness (Rayleigh Test) (Batschelet, 1981); neither trawling nor steaming were random. Both MDA for steaming and trawling were orientated towards the mean deviation (V Test) (Batschelet, 1981). MVL for trawling was relatively low, indicating that trawling activity was rarely along a continuously straight

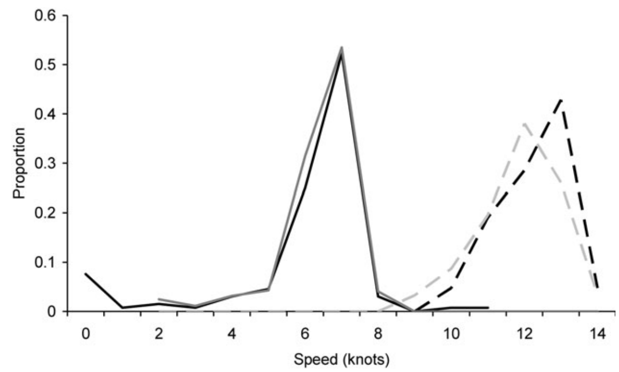


Figure 3. Frequency distribution of steaming and trawling speeds from 2-hourly VMS data linked to trips with observers onboard. Solid line, fishing; dashed line, steaming; grey line, parameter-estimation data set; black line, evaluation data set. Speeds were recorded in the VMS database as integer values.

track. For steaming vessels, however, MVL was close to the maximum of one, consistent with straight-line movement.

As with the speed rule, the directionality-based methods successfully distinguished trawling from steaming, although less so for steaming, which only achieved 46% accuracy. The best method used the full range of MDA and MVL and successfully predicted trawling in 100% of the evalution data set (Table 1). The direction rules were less successful when identifying steaming, the best method achieving 46% accuracy. Use of a directionality rule alone would therefore lead to an overestimation of trawling activity.

The combined speed and directionality rule was based on the assumption that high speeds (>8 knots) were steaming activity and that all other speeds were trawling. The directionality rule was then applied to the entire data set to distinguish trawling from steaming. Combining speed and directionality resulted in a marginally better overall rule, trawling and steaming being identified successfully in 99% and 95% of cases, respectively (Table 1). Having applied the combined speed and directionality rule, the number of VMS locations clearly associated with steaming were reduced substantially, although some still remained among those identified as fishing (Figure 1b).

Spatial estimates of trawling effort

Spatial estimates of trawling effort based on the minimum and maximum possible deviation from a straight line were similar in terms of the overall pattern of spatial distribution, but noticeably different in relation to estimates of trawling effort, with maximum trawling effort predicted to be higher when based on estimates of the maximum possible deviation (Figure 4). For the "best" spatial estimates of fishing effort, a speed of 6.4 knots was applied to the 2-hourly records without a transmitted speed, because this speed generated ellipses that, on average, encompassed 99% of track deviation shown by the 15-min VMS records. The strongly negative relationship between the proportion of 15-min positions not covered by the constructed ellipses and vessel speed shows that the higher speeds closely approximated the true extent of deviation (Figure 5).

Sensitivity test for grid resolution

Tests of the effects of varying grid size on the estimation of the total spatial extent of trawling in 2003 showed that the use of large

Table 1. Proportion of evaluation records predicted to be associated with steaming or fishing for the speed rule, direction rule, and combined speed and direction rules.

Observed	Predicted					
	Speed rule		Direction rule		Combined rule	
	Fishing (%)	Steaming (%)	Fishing (%)	Steaming (%)	Fishing (%)	Steaming (%)
Fishing	99	1	100	0	99	1
Steaming	6	94	54	46	5	95

grid cells did not accurately represent the true spatial extent of trawling as defined by the "best" estimate method (Figure 6). At grid cell sizes of approximately 10 km and smaller, the error in calculated extent dropped markedly (Figure 6), suggesting that cells of that size are appropriate for describing the footprint of trawling in this fishery. The failure of large cell sizes accurately to represent the spatial footprint and heterogeneity of beam trawling effort in 2003 is clearly demonstrated in Figure 7. The maximum fishing effort recorded in any grid cell was inversely related to grid cell size. Grids with a resolution of 10 km or smaller were essential to capture the true patchiness of trawling effort. Even when grid cell size was <10 km, a small amount of additional patchiness was still described by further reductions in grid cell size (Figure 7).

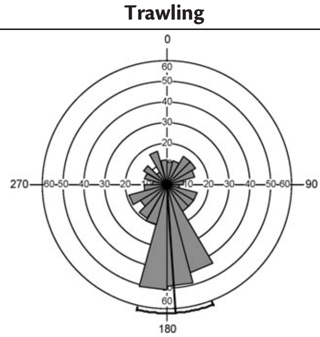
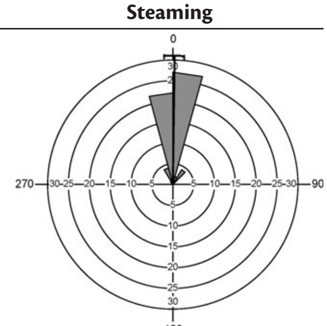
Discussion

Data filtered with both speed and direction rules, processed with the "best" estimate method and summarized in 3-km grid cells, provided an accurate representation of the spatial distribution of trawling effort by the UK North Sea beam trawl fleet in 2003. The adoption of a consistent method for analysing VMS data will help to ensure that calculations of trawling effort are repeatable and comparable among studies. We recommend a reporting scale of 3 km as a compromise between the perfect description of all patchiness, the level of information on true trawling tracks provided by 2-hourly positional data, and the need to select grid cell sizes that can sensibly be applied at very large spatial scales. Based on previous experience of assessing trawling impacts, trawling effort data summarized on a 3-km grid would support most studies of trawling impacts (Jennings *et al.*, 2001; Duplisea *et al.*, 2002; Kaiser *et al.*, 2002). Notwithstanding, data filtered with both speed and direction rules and processed with the "best" estimate method can readily be summarized at different grid cell scales, as required.

The speed rule (i.e. 2–8 knots taken to reflect trawling activity) provides a simple method for identifying trawling activity in the North Sea beam trawl fishery, but a speed rule alone is not recommended to support accurate quantification of trawling effort. The primary reason is the absence of speed records for 17% of the VMS positions. The speed rule also fails to detect times when beam trawlers steam at speeds <8 knots, relying on the assumption that the transmitted speeds are accurate and relatively constant between successive position reports. When speed records are absent, the direction rule can identify those vessels in transit to and from port, but more importantly, those vessels steaming slowly between fishing grounds and close to port.

Whereas the speed rule underestimated steaming, the use of deviation angle or mean vector length independently tended to overestimate steaming. By combining the directionality methods, prediction accuracy increased, although there remained some inaccurate predictions for fast-moving vessels. Using the highest speeds to identify steaming was, therefore, a logical step towards developing the optimum method. However, the optimum method still overestimated steaming. This may arise if the seabed allows vessels to trawl in straight lines for extended periods, or when vessels are trawling along closed area boundaries such as the Plaice Box (Pastoors *et al.*, 2000).

Table 2. Summary statistics for the mean deviation angle (MDA) and the length of the mean vector of movement (MVL) for vessels observed trawling and steaming.

Statistic	Trawling	Steaming
Angles of deviation		
MDA (and full range)	176° (0–360°)	1° (321–39°)
99% CI of deviations (±)	159–193°	356–5°
95% CI of deviations (±)	163–189°	357–4°
MVL (and full range)	0.29 (0.01–1.00)	0.97 (0.94–1.00)

The ranges of values encountered are given in parenthesis. Both MDA and MVL are calculated from 2-hourly VMS data linked to 5 trips with observers on board UK North Sea beam trawlers. The compass rose diagrams illustrate the differences between the angle of movement for trawling and steaming.

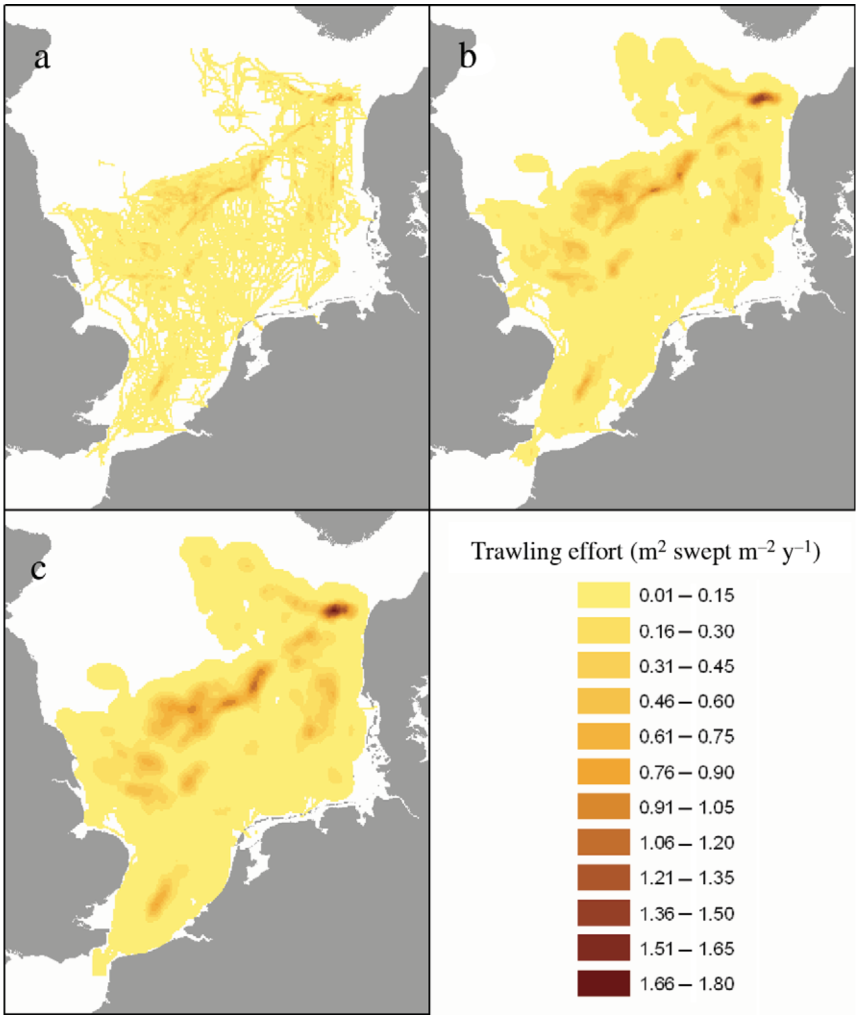


Figure 4. Distribution of UK beam trawling effort in the North Sea during 2003 based on (a) minimum estimate, (b) "best" estimate, and (c) maximum estimate of track deviation from a straight line. Trawling effort is summarized in 3 km (i.e. 9-km^2 resolution) grid cells.

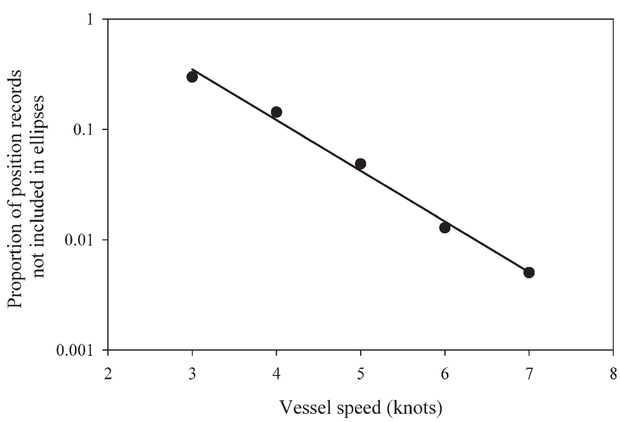


Figure 5. Proportion of intermediate 15-min VMS positions not encompassed by the ellipses constructed from varying vessel speeds from 3 to 8 knots when applied to 2-hourly VMS data.

To assess the value of estimates of trawling effort from VMS data, it is important to consider how well the reconstructed tracks reflect true vessel movement. Of the 534 hauls recorded by observers, the mean tow duration for beam trawlers in the North Sea was 2 h 15 min, and 22% of hauls were 2 h or less. In most cases, trawls were therefore represented by a single VMS record, and in some cases a haul would fall entirely between VMS records, so would not have been represented at all. The current frequency of VMS position reporting is, therefore, lower than required to represent trawl tracks from UK beam trawlers adequately. Nevertheless, the characteristics of trawling directionality developed from the 2-hourly VMS data correspond well with our current understanding of trawling behaviour. Most notably, the description of trawlers frequently turning through 180° is consistent with observations of trawlers returning to a trawl line to catch fish that have been attracted to organisms that were killed or damaged during previous tows, perhaps leading to increased catch rates in a repeated tow (Kaiser and Spencer, 1994; Rijnsdorp *et al.*, 2000). In addition, the speed frequency distributions for 2-h and 15-min interval data (not shown) were similar, suggesting that 2-h data will generally provide an adequate representation of vessel movement. Locations of trawling will always be more difficult to predict as the frequency of position fixes decreases. Both Deng *et al.* (2005) and we here demonstrate that trawlers are unlikely to be trawling in straight lines between recorded positions, so uncertainty as to the true location of tracks will increase as the

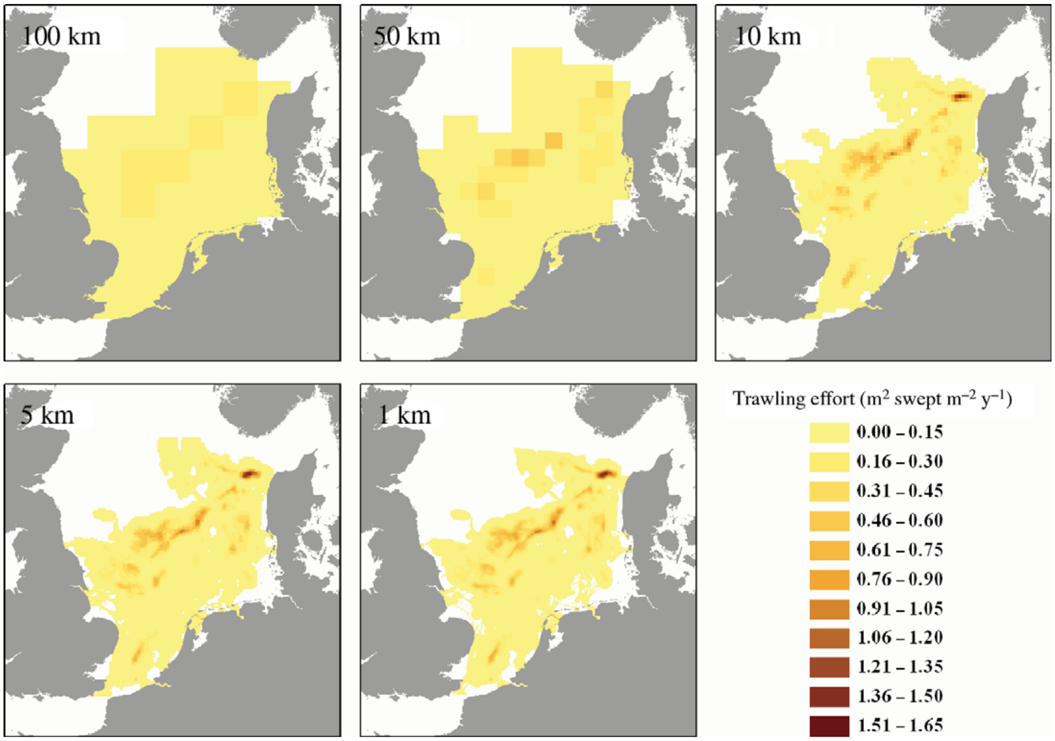


Figure 6. The effect of changes in grid cell size on the representation of UK beam trawling effort in the North Sea in 2003. Trawling effort is summarized in 3-km grid cells and darker colours represent the areas of greatest trawling effort.

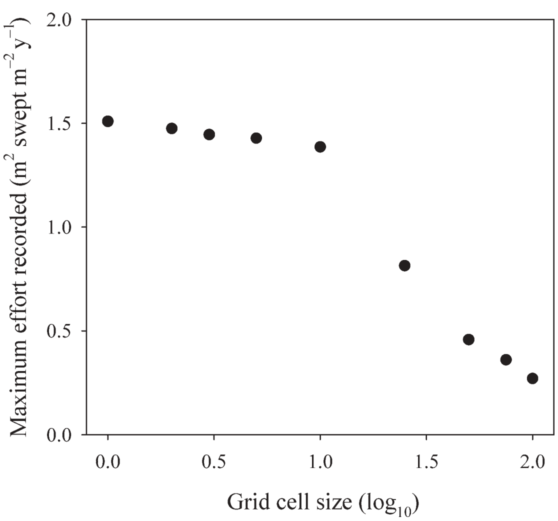


Figure 7. Maximum estimated fishing effort as a function of grid cell resolution for North Sea beam trawling effort in 2003.

frequency of position reporting decreases. With low-frequency position reports, straight-line interpolation will underestimate swept area and provide a biased measure of small-scale effort distribution. To some extent, this bias depends on the extent of habitat suitable for trawling and the typical length of tows. In the UK North Sea beam trawl fishery, vessels tow over large areas for periods that generally exceed the polling interval.

Our approach was developed and applied to the UK beam trawl fleet in the North Sea, but it can also be developed and applied to other fleets in other areas. We worked with UK beam trawlers because their gears have significant impacts on seabed biota and habitats and because they account for a large proportion of the total trawling effort in the North Sea (Jennings *et al.*, 1999). Nevertheless, for a complete picture of trawling effort in the North Sea, it is necessary to compile international VMS data for all fleets. Although the VMS was designed for fishery control and enforcement, it is important to work towards international agreement on access to and collation of these data to ensure that scientists have access to comprehensive long-term and high-resolution data that can be used to estimate relatively unbiased spatial descriptions of trawling effort.

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