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# Can trawling effort be identified from satellite-based VMS data?

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Data from satellite-based vessel monitoring systems (VMS) can, in principle, be used to measure fishing effort with a high spatiotemporal resolution. However, it can be difficult to separate between fishing activity and other activities (like steaming). The vessels' speed (at a given time) may give an indication of whether fishing activity occurs or not. In this work VMS data from two factory trawlers in the Norwegian Reference fleet are merged with detailed logbook information. The average speed between consecutive VMS observation was estimated (using time difference and distance) and grouped according to type of activity (from the logbook records). About 70-80 % of the VMS observations below 5 knots represented trawling, but speed alone could not be used to determine with high degree of accuracy whether the vessels were trawling or not.

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## Introduction

Many countries now use satellite-based Vessel Monitoring Systems (VMS) for surveillance of national fishing fleets and foreign vessels operating in national waters to ensure that current fisheries legislation is complied with (Drouin 2001). VMS regularly monitor the location (at least) of individual vessels, and the data are stored in such a way that the vessels' former movement can be tracked. The principal users of this information are surveillance and enforcement personnel, but fisheries scientists are now also beginning to get access to VMS data (Deng et al. 2005; Murawski 2005). From a scientific point of view, these highly resolved fleet data are very valuable and open up a number of new possible approaches in analyses of fishing fleet dynamics. One such possibility is to obtain measures of fishing effort (Murawski et al. 2005). Traditionally, effort data have been collected from logbooks, which may be recorded in many different ways (if recorded at all). Logbook data are also subject to errors and misreporting since usually recorded by skippers. VMS data are independent from logbooks and skippers and true measures can therefore be obtained of the vessels' time spent at different fishing grounds. However, unless integrated with other information, it is difficult to know from VMS data alone whether the vessels are/were fishing or not. For stock assessment purposes (CPUE, fishing mortality) time spent at sea or the fishing grounds may be sufficient effort measures, but it is sometimes beneficial to know the amount of direct fishing activity (e.g. hours trawled). Other situations where it is advantageous to classify VMS-data into type of activity include analyses of fishing effort around MPAs (Murawski et al. 2005), in vulnerable marine habitats (Fosså et al. 2002) and adjacent to petroleum pipelines.

A simple possible indicator of a vessel's type of activity at a given time is the speed; low speed may indicate fishing activity while high speed may indicate steaming. In it's simplest form, VMS data comprise position and time, which have been recorded regularly for each vessel. The average speed between following VMS records can then be estimated using the time difference and distance between these. In this work, VMS data are merged with detailed logbooks from two factory trawlers in the Norwegian Reference fleet in order to explore the distribution of estimated speed by type of activity. The purpose is to evaluate the appropriateness of speed (estimated on the basis of distance and time difference only) as an indicator of a vessel's type of activity.

## Material and methods

### VMS data

Since 1 July 2000, all Norwegian fishing vessels longer than 24 m have been monitored with a satellite-based vessel monitoring system (ARGOS/INMARSAT-C) operated by the Norwegian Directorate of Fisheries. The information recorded from each vessel is time (minute resolution), position, heading and speed, and the Directorate receives this information approximately every 60 minutes. The Institute of Marine Research (IMR) has access to VMS data from the Norwegian reference fleet (described below) from 2000 onwards. The recorded (instantaneous) speed has low resolution and many missing observations, and is therefore not considered reliable.

**Logbook data**
IMR has a contracted cooperation with a number of commercial fishing vessels called the Reference fleet. The Reference fleet vessels regularly send information electronically to IMR including detailed logbooks from their fishing operations. In this work, logbooks from two factory trawlers who have been members of the Reference fleet since 2001 are used. The electronic information from each trawl haul includes start time and stop time recorded with minute resolution.

**Analyses**
The principle methodology was to merge VMS data and logbook data by minute. The VMS records (or satellite tracks) that represented trawling were then known. Only data (both VMS and logbook) from 2002 onwards were used to avoid many of the errors in the first year after the introduction of both the VMS and Reference fleet system. Since the objective in this work was to explore speed as a possible indicator of trawling, the variable of interest from the VMS data is the speed in the interval between consecutive VMS records. This speed was found (in knots) using the estimated distance (nautical miles) and time difference (hours) between following VMS records: Assuming a linear movement the average speed = distance/ Δtime. Since VMS data now were treated as time intervals (with belong speed), and the start/stop times of each trawl haul were given as discrete points of time, some of the intervals contain both trawling and other activity. Thus, VMS intervals could be divided into three groups (a) trawling, (b) other activity and (c) both trawling and other activity (see Fig. 1).

It is prohibited (for large trawlers) to trawl close to the Norwegian coast, and trawling must occur outside the so-called “6 nm border line” (measured from the coast line). VMS records close to the coast were therefore not relevant for the analyses (especially since the speed can be low in sheltered waters) and were therefore removed (Fig. 2). In addition, VMS intervals with unrealistic high speed (>20 knots), distance (>70 nm) or time difference (>300 min) were removed.

The predicted duration of individual trawl hauls was estimated by summarizing the time differences of the VMS intervals classified as trawling and adding the average of the two intervals classified as both trawling and other activity (i.e. the two intervals containing start and stop time, respectively). The relationship between predicted and observed haul duration was explored.

## Results

The distributions of speed are bimodal (Fig. 3), and trawling activity dominates around the lower peaks (centered around 4 knots) while other activity dominates around the upper (centered around 11-12 knots). The probability of trawling (i.e. the proportion of the observations in each speed interval that represent “trawling” or “both”) drops below 0.5 around 6 knots for Vessel 1 and slightly above 5 knots for Vessel 2 (Fig. 4). Below 6 knots Vessel 1 has a probability of trawling of around 0.75 and the corresponding probability for Vessel 2 is around 0.7. Note that a significant amount of trawling activity is recorded above 6 knots (Fig. 3 and 4).

The correlation between predicted and observed haul duration is strong and significant ($p < 0.01$) for both vessels. However, the slopes of the fitted models are significantly different from 1 ($p < 0.01$) and the intercepts are significantly different from zero ($p < 0.01$): for both vessels the recorded haul durations are slightly higher than the predicted for low durations and slightly lower for long durations.

## Discussion

The results from this study show that speed alone could not be used to determine with a high degree of accuracy whether the two vessels were trawling or not. However, most of the observations around the lower peak in the bimodal speed distributions are dominated by trawling activity. A simple approximation is therefore to choose a speed between the two peaks, or near the right edge of the lower peak, as the threshold, and assume that all observation below this threshold represent fishing activity. However, the centre of the two peaks varies between vessels and fisheries so it may be sensible to use vessel-specific or fishery-specific thresholds. In addition, if it is known that fishing does not occur in certain areas (like in the present work) removing observations from these areas will increase the accuracy of this simple classification method.

Murawski et al. (2005) used 3.5 knots as a threshold to indicate when trawling was occurring and eliminated data above this value. This threshold was based on observer data. Compared to the present study, 3.5 knots seems to be a too low threshold. However, my results apply for two large factory trawlers and their towing speeds are probably not representative for all groundfish trawlers. Moreover, it is not clear to me whether the speed in the VMS data analyzed by Murawski et al. (2005) is based on time and distance (like in the present study) or whether it is the “instantaneous” vessel speed recorded when the vessel transmits the information. These two measures are conceptually different and may lead to different thresholds/conclusions. Other, and perhaps more sophisticated classification methods for VMS-data other than only using a speed threshold may be developed in the future. For example, multivariate statistical theory on discrimination and classification is probably appropriate for the type of problem explored (see e.g. Johnson and Wichern 2002).

A significant amount of trawling activity was recorded at unrealistic high speed intervals (> 6 knots), and these are obvious miss-classifications. Many of these errors are probably caused by wrong indication of start and stop time in the logbooks, leading to the trawl hauls being placed at a wrong time interval (relative to the VMS data). Position and time errors may also occur in the VMS data, for example causing the speed to be over-estimated. However, it is difficult to detect and delete such kind of errors. A certain proportions of the VMS observations below 4 knots classified as other activity is probably caused by errors, but there are several situations were low speed not will be associated with trawling like: (1) waiting during bad weather, (2) fixing of destroyed gear and other technical problems, (3) waiting when hold and deck are filled with fish (the factory’s capacity is often the “bottleneck” when the fishing is good). The simplifying assumption about straight-lined movement between consecutive VMS observation will also sometimes lead to under-estimation of the true speed.

The strong relationship between observed and predicted haul duration indicates that the majority of the trawl hauls were “hit” when logbook and VMS data were merged. Most of the variation around the fitted lines is probably due to the hour resolution in the VMS data and minute resolution in the logbooks. This is also probably the reason why the lines’ intercepts deviate from zero and the slopes deviate from 1. A more interesting scatter plot, which unfortunately not was made here, would be to compare the predicted and observed total hours trawled per e.g. day, week or trip.

The necessity of assigning type of activity to VMS-data if these are used to estimate effective fishing effort for stock assessment purposes (e.g. CPUE versus stock size or effort versus fishing mortality) will depend on the type of fishery. If searching is an important part of the fishery (like in pelagic purse seining) it is sensible to include all time spent at the sea or at the fishing ground in the effort measure (Gulland 1983), regardless of speed. In other cases, the time spent during the actual catching process may be more appropriate (e.g. hours trawled).

## References

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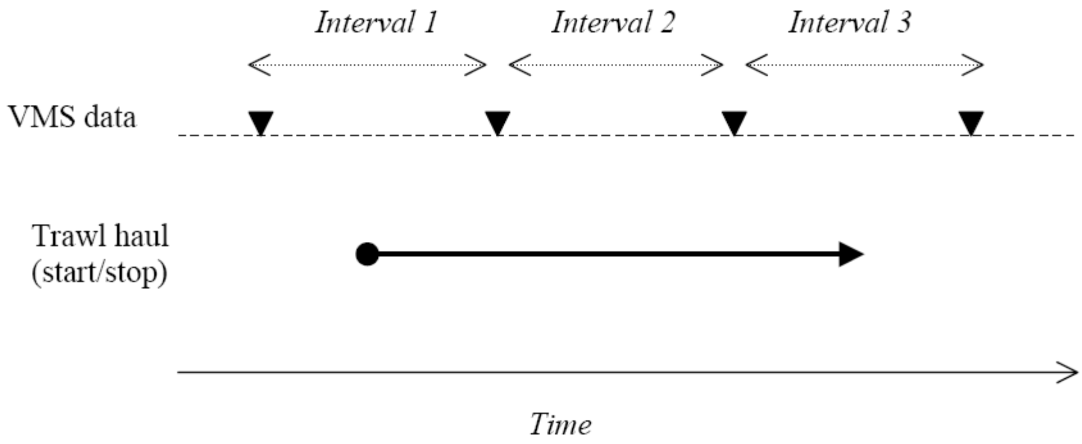


**Figure 1.** Illustration of the “time overlap” between VMS data and logbook data. The VMS observations (▼) contain position and time (approximately every 60 minutes), which makes it possible to estimate the average speed in the intervals between consecutive observations (using estimated distance and time difference). Interval 2 only represent trawling while Interval 1 and 3 also include other activities (like setting, hauling and steaming).

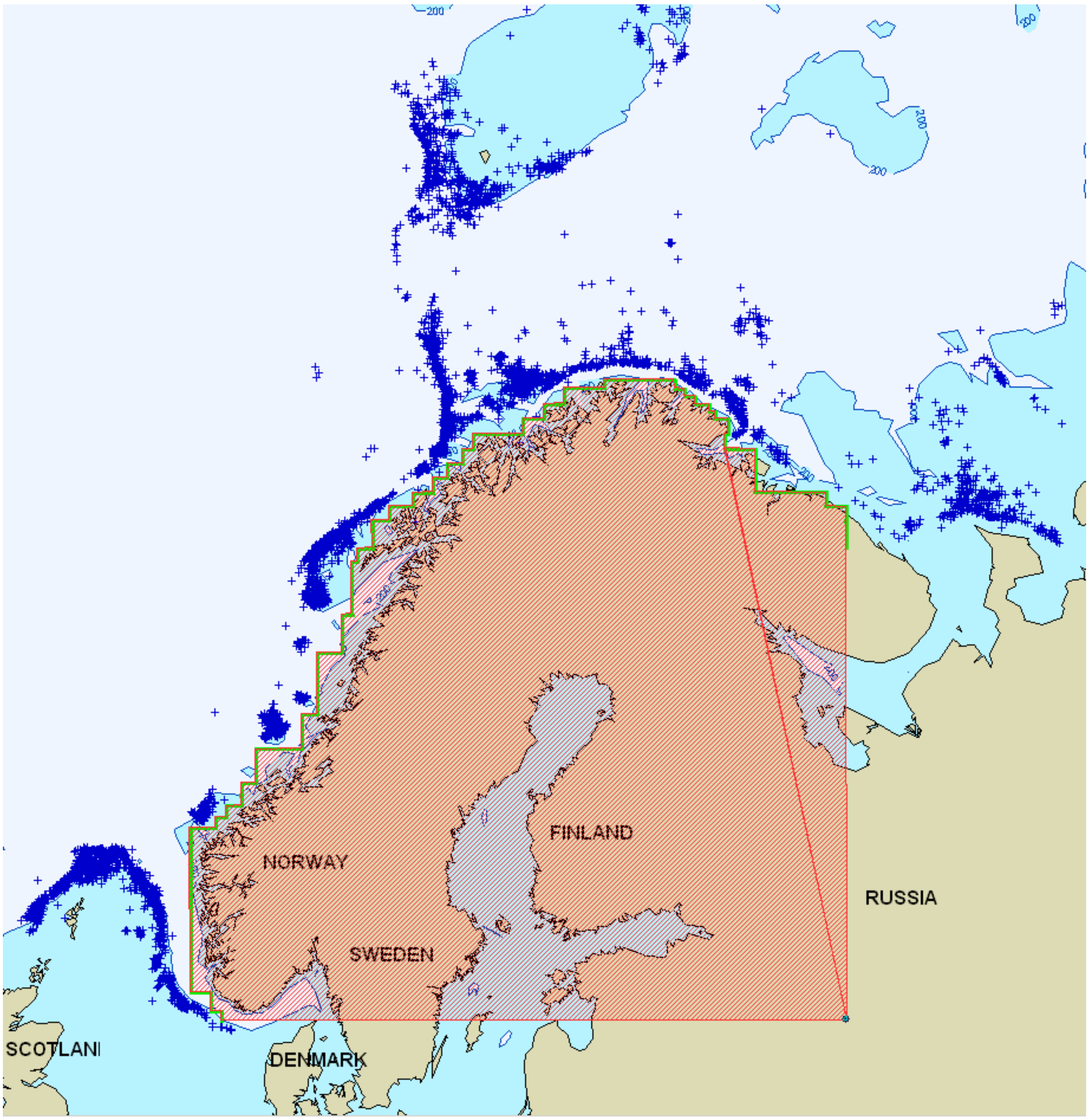


**Figure 2.** Recorded trawl positions from the two trawlers' logbooks in 2002-2005. VMS data inside the shaded polygon (were no fishing activity has been recorded) were removed from the analyses.

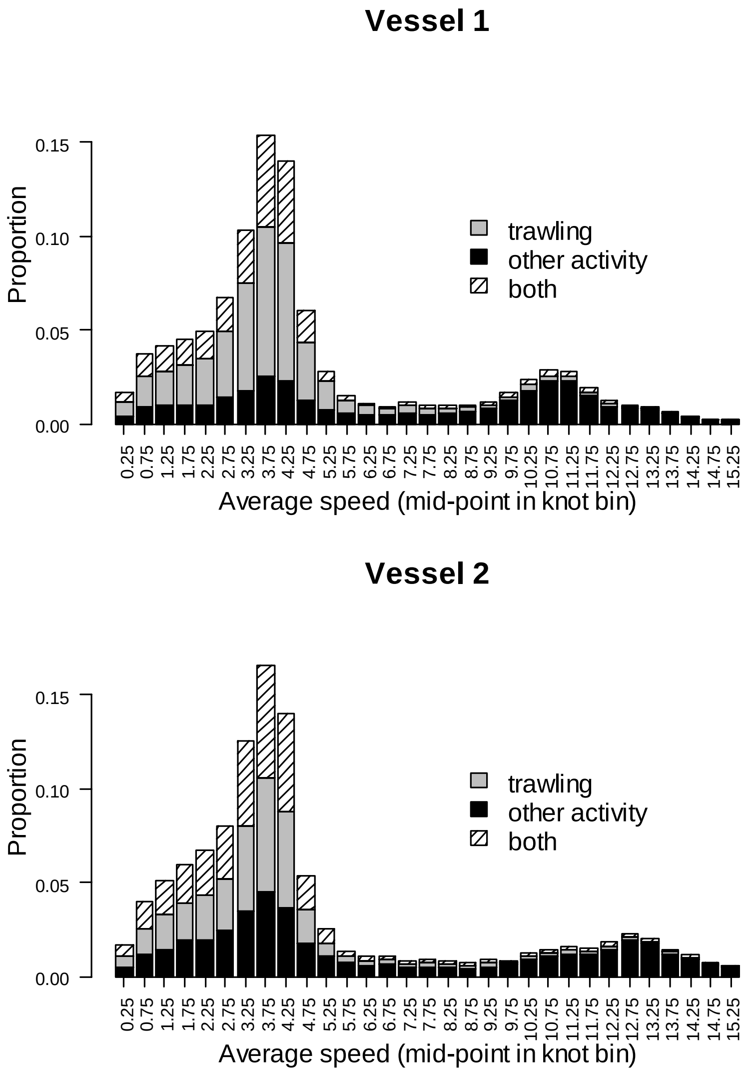


**Figure 3.** Relative distribution of speed between consecutive VMS observations (0.5-knot bins) and assigned activity: *trawling* corresponds to Interval 2 in Fig. 1 and *both* correspond to Interval 1 and 3.

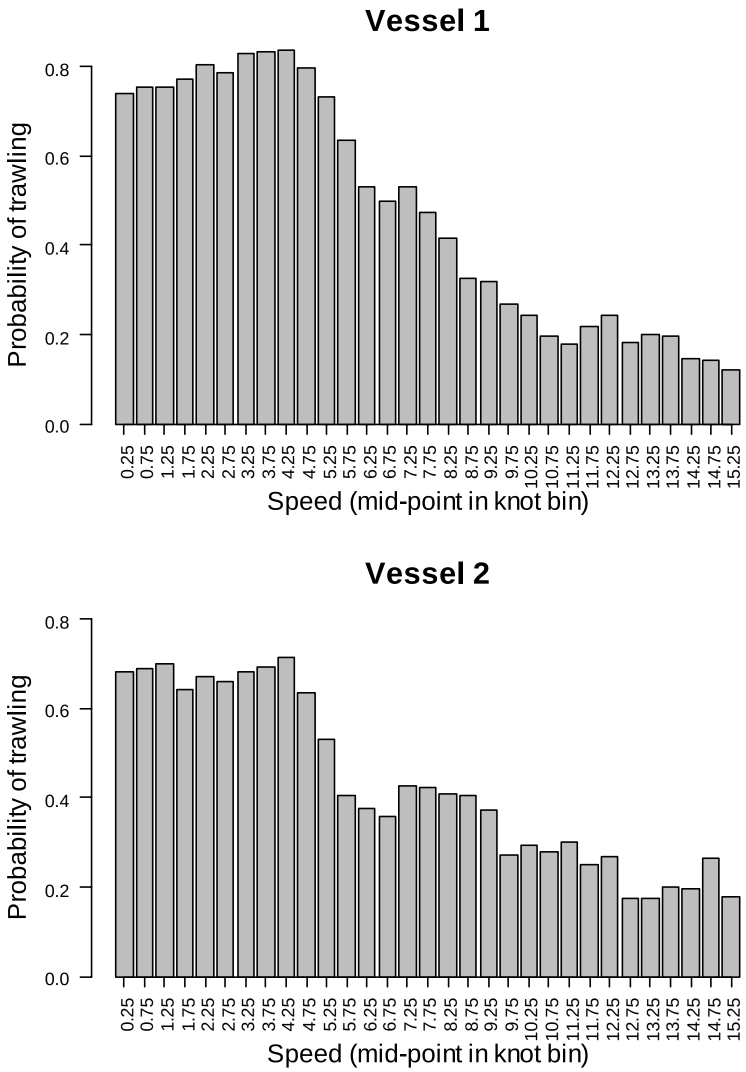


**Figure 4.** Probability that trawling occurs in a given 0.5-knot bin. The probability is the proportion of the observations which is *trawling* or *both*.

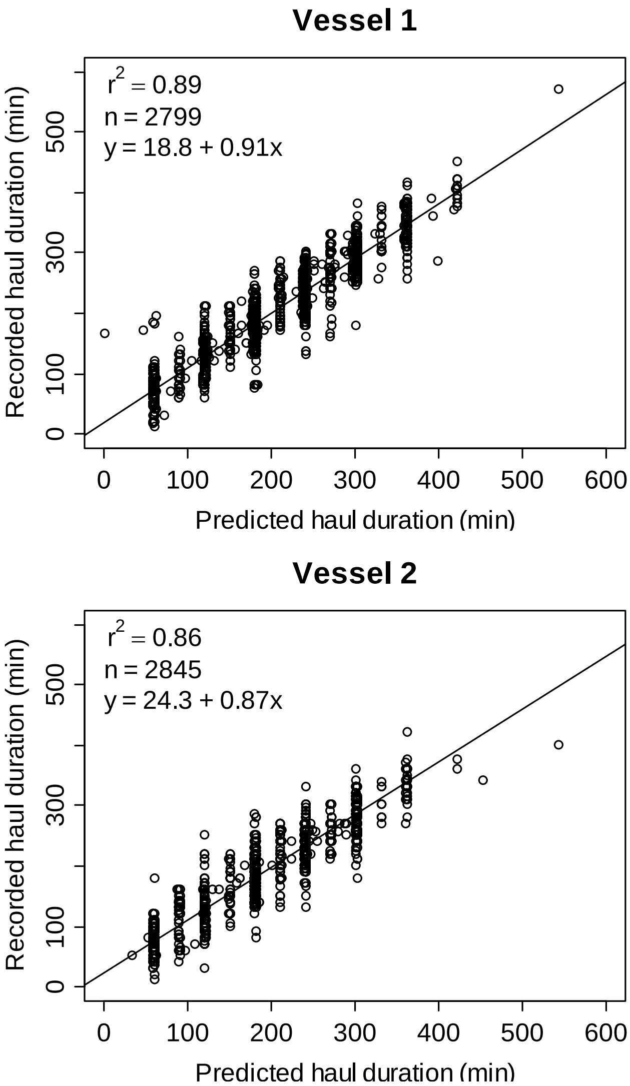


**Figure 5.** Predicted haul duration from VMS data and recorded haul duration from logbooks.