ICES Journal of
Marine Science

ICES Journal of Marine Science (2015), 72(4), 1192–1200. doi:10.1093/icesjms/fsu200

Contribution to the Symposium: '*Fishery-Dependent Information*'

Original Article

How effective is electronic monitoring in mixed bottom-trawl fisheries?

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van Helmond, A. T. M., Chen, C., and Poos, J. J. How effective is electronic monitoring in mixed bottom-trawl fisheries? – ICES Journal of Marine Science, 72: 1192–1200.

Received 30 June 2014; revised 17 October 2014; accepted 17 October 2014; advance access publication 11 November 2014.

In the context of the landing obligation under the European Common Fisheries Policy, electronic monitoring (EM) is often presented as one of the solutions to fully document catches. EM includes video monitoring to record the catch handling process on board the vessels. This study evaluated the efficacy of EM for cod (*Gadus morhua*) catches on vessels in a mixed bottom-trawl fishery and tested the hypothesis that cod catches are difficult to detect with video monitoring, specifically in catches with large volumes of bycatch. In 2011, a catch quota pilot study started for cod in the Dutch bottom-trawl fishery in which EM was used as an audit system to review the consistency of reported cod catches. Eleven vessels joined the pilot study on a voluntary basis. Participants received a 30% increase in individual quota for cod and were compensated with extra effort in days at sea. In return, all cod catches were counted against their cod quota. This mixed bottom-trawl fishery differs from fisheries where EM was proven to be a successful method, e.g. hook and line or single-species fisheries with low bycatch volumes. We conclude that distinguishing small numbers of cod in catches of mixed bottom-trawl fisheries is difficult because there is a low correlation between logbook and video data (Pearson $r = 0.17$). We expect similar difficulty in other mixed demersal trawl fisheries with large bycatch volumes, when similar-looking species are targeted. Meanwhile, implementing a landing obligation will pose large challenges for fisheries with large volumes of bycatch. Limitations in the applicability of EM to control one of the most common types of fisheries in Europe will be a burden on the implementation of the European landing obligation. Improved protocols and technical adaptations may reduce some of the limitations encountered in this study.

Keywords: demersal trawl fishery, electronic monitoring, fully documented fishery, participatory research.

Introduction

Fishery management often relies on obtaining accurate estimates of fish abundance and the mortality imposed by fishing. These estimates of fish abundance and fishing mortality are derived from population models that are fit to data, including catches (Beverton and Holt, 1957; Punt *et al.*, 2006; Rijnsdorp *et al.*, 2007). In many fisheries, not all fish caught are being landed and sold; part of the catch may be thrown overboard ("discarded"; Kelleher, 2005). Discarding fish may occur because of market conditions or because of fishery management regulations such as minimum landing sizes or quotas (Catchpole *et al.*, 2005; Rochet and Trenkel, 2005; Poos *et al.*, 2010). The traditional European quota system attempts to manage catches by setting quotas on landings (Holden, 1994). However, constraining landings may not reduce total catches because fishers optimize the use of their quota by discarding low-valued fish (highgrading), or fishing continues after quotas have been reached and all quota species are discarded (Gillis *et al.*, 1995; Daan, 1997; Squires *et al.*, 1998). The alternative to setting quotas on landings is to set quotas on total catches and, therefore, managing the total removal of a particular fish stock. In such a catch-quota regime, fishers are held accountable for the total amount of fish caught, including discards. Consequently, this could create the incentive for fishers to maximize their individual quota and avoid catching undersized fish (Condie *et al.*, 2013, 2014).

Implementing a catch-quota system requires that the complete catch (landings and discards) is reported and deducted from the available quota. A phased implementation of the obligation to fully report all catches (EU, 2013) is planned in the context of the European Common Fisheries Policy (Holden, 1994). For several fisheries on pelagic species, the implementation starts January 2015, and the obligation to fully report all catches will be in place for all European fisheries by January 2019.

Remote electronic monitoring (EM) is often presented as one of the solutions to fully document catches (Mangi *et al.*, 2013). EM systems consist of GPS, cameras, and sensors for measuring force on the tow cables and net drum rotation, all connected to a control box (McElderry *et al.*, 2003). These systems allow full coverage of a vessel's fishing activity and the monitoring of all catches using video technology (McElderry *et al.*, 2003; Ames *et al.*, 2007; Stanley *et al.*, 2009, 2011; Kindt-Larsen *et al.*, 2011). Driven by the successful reduction of discards in catch-quota trials for cod (*Gadus morhua*) in Denmark (Kindt-Larsen *et al.*, 2011) and the Scottish conservation credits scheme (Holmes *et al.*, 2011; Needle *et al.*, 2014), a catch-quota pilot study for cod in Dutch commercial fisheries was started in the Netherlands. This pilot study was initiated in 2012 as a collaboration between the Dutch Ministry of Economic Affairs and the Dutch National Federation of Fishermen's Organisations.

Previous studies on the efficacy of video monitoring concluded that EM is a reliable and accurate method to independently estimate catches on board vessels (McElderry *et al.*, 2003; Ames *et al.* 2007; McElderry, 2008; Stanley *et al.*, 2009, 2011). In all of these studies, catches were processed in such a manner that it was easy to detect individual fish on video footage. Hook and line fishing is a typical example of such a fishery because the catch is brought on deck one individual at a time. The exception is the Danish study on fully documented fisheries by Kindt-Larsen *et al.* (2011), where a seiner and several trawlers were included in the trials. However, the catch weight observations in that study were categorized in large intervals (see Kindt-Larsen *et al.*, 2011), and the difference between video and logbook observations cannot be accurately quantified.

The Dutch pilot study included trawlers and (Scottish) seiners. There are several differences between the Danish and Dutch pilot projects. The Danish pilot was implemented in a fishery that targets cod year-round (Kindt-Larsen *et al.*, 2011). In contrast, the Dutch pilot study is applied to a fishery that targets multiple species using various types of bottom trawl gear, e.g. otter trawl, seine (Scottish), or beam trawl, and frequently using small mesh sizes (80 mm) to target smaller demersal species. Cod is only targeted during a relatively short period of the year, typically <2 months, using a mesh size >120 mm. The Dutch fishery for cod is relatively small and economically less important than the Danish cod fishery, i.e. the Dutch national quota was <10% of the Danish quota in 2013.

The aim of this study is to evaluate the efficacy of remote EM for cod on vessels in a mixed fishery that does not target cod year-round. We use the Dutch demersal trawl fishery as a case study. We test the hypothesis that cod catches are difficult to detect with video monitoring in mixed fisheries. Specifically, we use periods of the year when fishers in the pilot study target flatfish, with large amounts of bycatch of fish and benthic species (Catchpole *et al.*, 2005; Uhlmann *et al.*, 2014). We do this by comparing logbook and video records for two aspects: (i) systematic differences between logbook records and video observations, and (ii) correlation between logbook records and video observations.

In the context of the Common Fisheries Policy and its landing obligation, this study gives important insight in the applicability of EM to fully report or verify reported catches, in this case for cod, in a mixed bottom-trawl fishery. A substantial number of European fisheries are identified as discard-intensive mixed bottom-trawl fisheries (Uhlmann *et al.*, 2014). Considering the scale of the fleet and the level of discarding within these fisheries, reporting and controlling all catches will be a demanding task. Reliable methods to accurately monitor catches on board commercial fishing vessels are an important part of this process.

Methods

Data collection

Vessels in the pilot project participated on a voluntary basis. All vessels with cod quota were contacted by representatives of the national fisheries organization. To create an incentive for participation, participants received a 30% increase in individual quota for cod. In addition to the extra quota allowance, deploying EM on board was compensated with a derogation on national effort control regulations. The vessels using EM on board were allowed to continue fishing after the effort cap of this fleet was reached. All interested fishers were allowed to participate. The resulting study fleet consisted of two groups of vessels participating during 2012–2014. The first group consisted of five vessels, with 221 kW engine power. These vessels used otter trawls or beam trawls, depending on season and target species. The vessels used a wide range of mesh sizes from 20 to 130 mm. The second group consisted of six vessels, with engine powers between 677 and 1471 kW. These vessels used Scottish seines with a range of mesh sizes between 80 and 130 mm, depending on season and target species (Table 1).

For vessels participating in the project, all cod catches, including discards of undersized fish, were counted against their cod quota. Also, vessels were fitted with EM systems consisting of GPS, up to four closed-circuit television (cctv) cameras, and sensors for measuring force on the tow cables and net drum rotation. All sensors and cameras were connected to a control box with exchangeable hard drives for data storage (McElderry *et al.*, 2003; Kindt-Larsen *et al.*, 2011). The sensors were used to trigger the control box to start video recording during fishing operations. The cameras recorded overhead views of the working deck and catch-handling areas, while fishing, hauling, and processing the catches (Figure 1). Sensor and GPS data were recorded continuously while at sea. The EM system and the video analysis software were developed by Archipelago Marine Research Ltd. The installation costs per vessel were ca. 10 000€, and the annual running costs per vessel were ca. 4000€.

In addition to video observations on the catch obtained from the EM system, fishers filled in catch weights (kg) per haul in a logbook.

Table 1. Overview of participating vessels and observed hauls.

Vessel group	Number of vessels	Engine power (kW)	Vessel length (m)	Observed hauls <120 mm	Observed hauls ≥120 mm
Bottom trawl	5	221	20–28	17	39
Scottish seine	6	677–1 471	25–42	42	23

Figure 1. Screenshot of the video images from four cameras on one of the vessels in the pilot study, including the vessels stern with net drums, the catch handling area, and an overview of the deck.

Catch weights of legal sized (>35 cm) and undersized cod (≤35 cm) were distinguished in the logbook. To estimate weight, the larger vessels generally have a scale on board, while the smaller vessels estimate catch by eye.

A selection of the hauls was used for further analysis. This selection was made in a stepwise procedure. First, all trips with video recordings were matched to logbooks from those trips. Not all trips could be matched and analysed. Because of no EM data (due to technical failure or hard disks that were not replaced in time), 35% of the trips could not be used for further analysis, and missing logbooks for ca. 19% of the trips. As a result, only ca. 46% of the trips could be used for further analysis. Next, image quality was evaluated for each fishing day in those trips. For 75% of the fishing days, image quality was sufficient for video analysis, while 25% could not be used because of dirty lenses. From the days with sufficient image quality, ca. 10% of the hauls were randomly selected for analysis.

For the selected hauls, the logbook catch records were compared with catch estimates from video analysis. Based on analysis of video images, the number of cod per haul was counted. These estimates were done for the length categories of <35, 35–46, 46–55, 55–72, 72–88, and >88 cm. Length estimates were done visually by comparing each fish with a colour-coded tape with red and white markings that was used as a length reference in the image (Figure 1). Numbers per length category were converted to weights per category using a length–weight relationship of the form $W = aL^b$, where W is the weight in grammes and L the length in centimetres. Parameter values were taken from Coull *et al.* (1989), with a being 0.020475 and b being 2.8571. For individuals in each length category, the midpoint of the length interval was used, except the smallest and largest categories. For the length category <35 cm, fish were assumed to be 35 cm; likewise for the category >88 cm.

Exploratory data analysis

First, we explored the data using simple statistics. Visual inspection of the statistical distribution of catches suggested that these are log-normal distributed. To correct for this in statistical tests that assume normality, a common logarithm transformation was done on all catch data. Because there were zero catches for both video and logbook observations, we added unity. For the sake of convenience, we used $\log_{10}$ in further explanations in this paper. In the exploratory data analysis, we also analysed the difference in weight between the logbook and video observations as a function of the weight estimated by the video observation. This was done for untransformed and for log-transformed data. Finally, we produced scatter-plots of the estimated catches in weights for the logbooks and video observations by vessel and mesh-size category for visual inspection.

Comparing logbook and video data

The relationship of catches between logbook and video can be explored from two aspects (Figure 2): systematic differences and correlation. With the analyses for systematic differences, we studied whether video overestimates or underestimates catches relative to the logbook. On the other hand, correlation investigates how the estimate from video changes according to the logbook, or whether they follow a linear relationship. In the ideal situation, we would expect no systematic difference and high correlations between logbooks and videos (white points in Figure 2a).

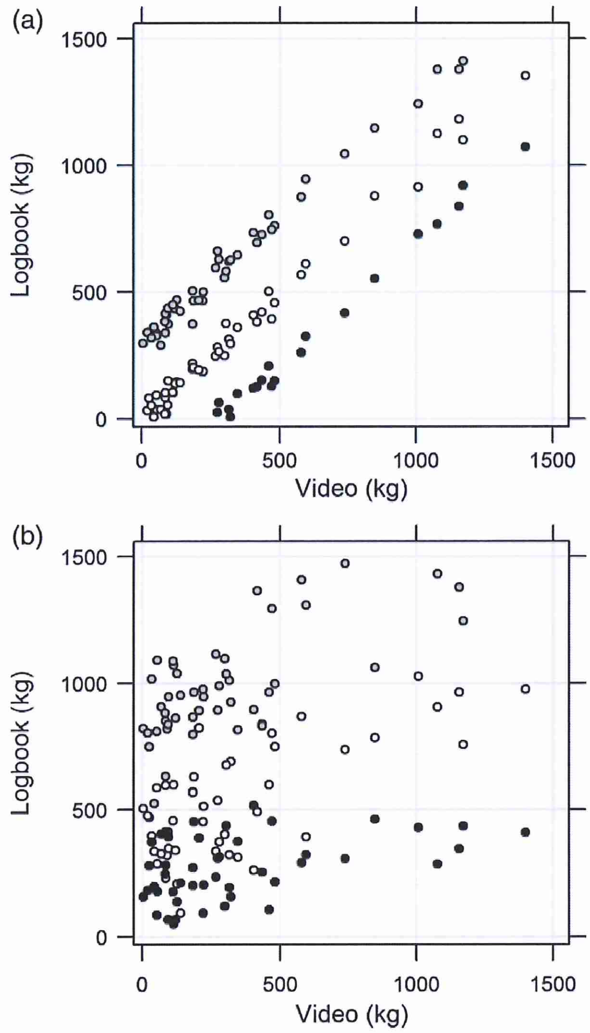

Figure 2. Illustrations of the systematic difference and correlation relationships between catches from video and logbooks. (a) Catches from video and logbooks have high correlation, while the average of logbook is higher (grey), equal (white), or lower (black) than video. (b) Catches from video and logbooks have low correlation, while the average of logbook is higher (grey), equal (white), or lower (black) than video.

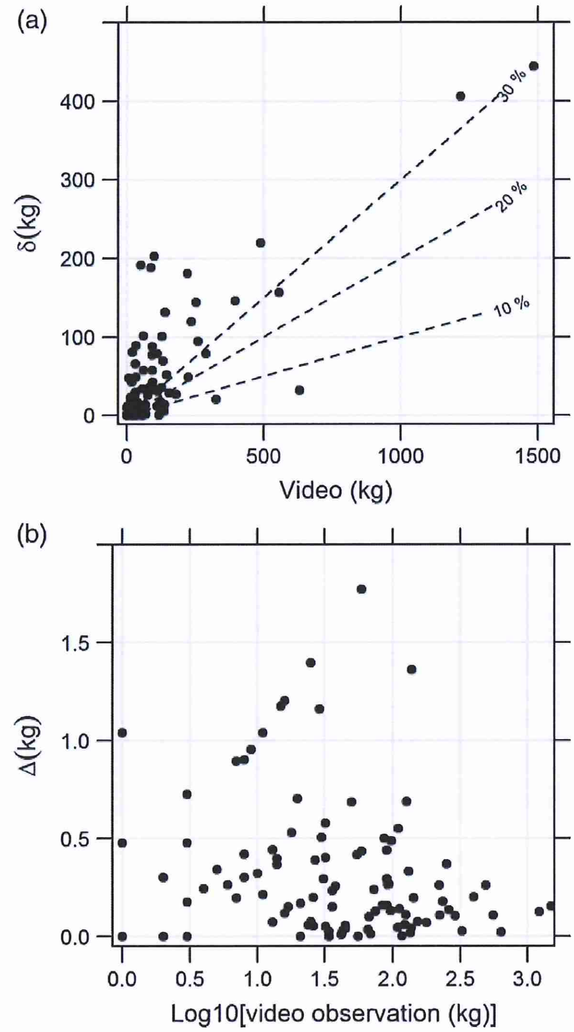

Figure 3. (a) Absolute difference between catch estimation methods δ and catch in video observations before log-transformation. Dashed lines are isolines of δ as a percentage of the estimated catch from video. (b) Difference between $\log_{10}$ transformed catch estimation methods Δ and $\log_{10}$ transformed catch in video observations. Note that unity was added to all log-transformed estimates.

Systematic differences could derive from unintentional errors, possibly as a result of a specific setup flaw of the monitoring system, e.g. the inability to correctly estimate catch from video. Systematic differences could also derive from participants under- (or over-) reporting catches compared with those observed on video. Since the two monitoring methods were tested in matched hauls, a straightforward way to quantitatively analyse the systematic difference is to apply a paired *t*-test on catch records between logbook and video. However, interactions of factors such as vessel or mesh-size category and monitoring method are not considered in a paired *t*-test.

To consider these interactions, we also fitted the log-transformed catch data per haul to the following original full model:

$$\log(\text{catch})_{ij} = V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + V_i \delta m_j + \alpha_i + \varepsilon_{ij}$$
$$\alpha_i \sim N(0, \sigma_\alpha)$$
$$\varepsilon_{ij} \sim N(0, \sigma_s), \qquad (1)$$

where $\log(\text{catch})_{ij}$ refers to the observed catch in the ith haul and jth survey method [either video ($m = 0$ when $j = 1$) or logbook ($m = 1$ when $j = 2$)]. The mesh-size category is defined by s [either $<$120 mm ($s = 0$) or $\geq$120 mm ($s = 1$)]. Vessel is included as a factor variable, where V_i is a dummy vector with length equal to the number of vessels; its kth element is 1, if the observed catch belongs to the kth vessel, and 0 elsewhere. γ and δ are vectors of coefficients (in length equal to the number of vessels), specifying the effect of vessel, and their interaction with survey method, respectively. Coefficients β_1, β_2, and β_3 indicate monitoring method, mesh size category, and their interactions, while α_i indicates the random effect of the matched haul subscripted by i. We then used the Akaike information criterion (AIC) to further simplify the model. All statistical analyses are done using R software (R Core Team, 2014), using the "nlme" package (Pinheiro *et al.*, 2013). In R, the model is implemented as "logCatch ~ vessel × method + mesh × method, random = ~1|haul" using the "lme" method.

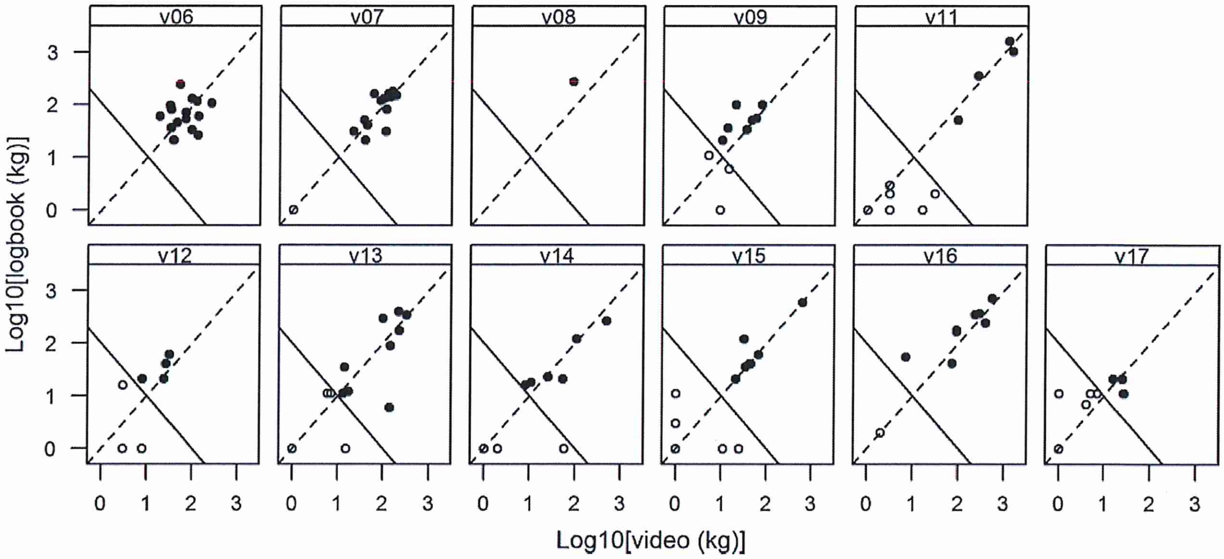

Figure 4. Scatterplot of $\log_{10}$(logbook) vs. $\log_{10}$(video) by vessel. Each panel represents a vessel. The diagonal dashed lines correspond to the ratio of 1. The solid diagonal lines distinguish small catches (in the lower left corners of each panel) from large catches (in the upper right corners). This diagonal line is defined by $\log_{10}(\text{logbook}) + \log_{10}(\text{video}) = 2$.

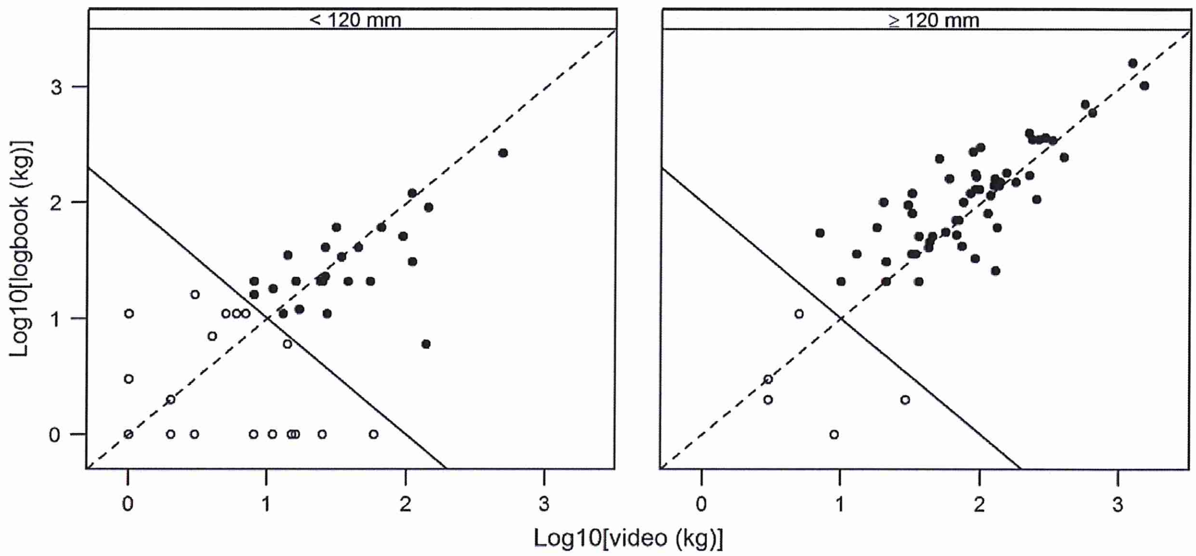

Figure 5. Scatterplot of $\log_{10}$(logbook) vs. $\log_{10}$(video) by mesh-size category. Each panel represents a mesh-size category. The diagonal dashed lines correspond to the ratio of 1. The solid diagonal lines distinguish small catches (in the lower left corners of each panel) from large catches (in the upper right corners). This diagonal line is defined by $\log_{10}(\text{logbook}) + \log_{10}(\text{video}) = 2$.

The significance of the method effect (or whether β_1 is different from zero) indicates whether video yields, on average, a higher (or lower) catch record than logbook. If we are only interested in β_1 and the interaction effects are insignificant, a paired t-test of catch records between video and logbook would suffice.

The correlation between video and logbook catches was calculated by the Pearson correlation coefficient (Pearson's r). Pearson's r specifies the linear dependence between log-transformed video and logbook records, where 1 is a total positive correlation and 0 is no correlation.

Results

Data exploration

During the period 2012–2014, the 11 participating vessels completed 1610 fishing trips, from which 121 hauls were randomly selected for comparison with video data. The estimated catches of cod reported in the logbooks ranged between 0 and 1622 kg, with 25 hauls having cod catches of 0 kg. The estimates of cod catches derived from the videos ranged between 0 and 1484 kg, with 18 hauls having cod catches of 0 kg. The median cod catch estimates for the logbook and video observations were 33 and 31 kg, respectively.

The difference between catch estimates derived from logbook and video observations increased with an increase in the magnitude of catch records (Figure 3a). Isolines in Figure 3a indicate the absolute difference between video and logbook as a percentage of the video estimates. Ca. 65% of the compared observations differ by >30%. Application of a common logarithm transformation corrected for the increase in the difference with an increase in the magnitude of catch records, and results in the difference being

Table 2. Model selection results.

No.	Formulation	Log likelihood	d.f.	AIC
1	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + V_i \delta m_j + \alpha_i + \epsilon_{ij}$	−174.8	26	401.7
2	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + \alpha_i + \epsilon_{ij}$	−180.3	16	392.7
3	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + V_i \delta m_j + \alpha_i + \epsilon_{ij}$	−177.5	25	405.1
4	$V_i\gamma + \beta_1 m_j + V_i \delta m_j + \alpha_i + \epsilon_{ij}$	−199.4	24	446.8
5	$\beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + \alpha_i + \epsilon_{ij}$	−186.9	6	**385.9**
6	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \alpha_i + \epsilon_{ij}$	−182.9	15	395.8
7	$\beta_1 m_j + \beta_2 s_i + \alpha_i + \epsilon_{ij}$	−189.5	5	389.0
8	$V_i\gamma + \beta_2 s_i + \alpha_i + \epsilon_{ij}$	−183.0	14	394.0
9	$V_i\gamma + \beta_1 m_j + \alpha_i + \epsilon_{ij}$	−204.8	14	437.5
10	$\beta_1 m_j + \alpha_i + \epsilon_{ij}$	−222.1	4	452.3
11	$\beta_2 s_i + \alpha_i + \epsilon_{ij}$	−189.6	4	387.3
12	$V_i\gamma + \alpha_i + \epsilon_{ij}$	−204.9	13	435.8

The lowest AIC is in bold.

expressed on a relative scale (Figure 3b). Because $\log_{10}(\text{logbook}) - \log_{10}(\text{video}) = \log_{10}[(\text{logbook})/(\text{video})]$, the difference in the common log domain is equivalent to checking the ratio of catches between logbook and video.

Figure 4 gives the scatterplot between $\log_{10}$(logbook) and $\log_{10}$(video) by vessel. From the systematic difference perspective, if some vessels tend to overestimate the logbook, while others not (or the other way around), this would be an indication of an interaction of vessel and monitoring method. In other words, the effect of monitoring method on the catches differs among vessels. Logbooks from vessel 9, 12, 15, and 17 tend to overestimate the catches in the logbook, while other vessels do not show a difference between logbook and video. Although there seems to be no strong interactions between vessel and monitoring method, we decided to keep vessel monitoring method interaction in the model in analysing the systematic difference. From the correlation perspective, we see a different correlation of the two methods between small and large catches, defined by a solid diagonal line. Catches from both methods seem to be highly correlated in large catches (upper right corners of each panel) and much less correlated in small catches (lower left corners of each panel).

Figure 5 gives the scatterplot between $\log_{10}$(logbook) and $\log_{10}$(video) by mesh size category (<120 vs. ≥120 mm). It seems that hauls made with the larger mesh size (≥120 mm) tend to obtain higher catches of cod than those with smaller mesh size (<120 mm) from both monitoring methods. From the systematic difference perspective, if one mesh-size category tends to overestimate the logbook (or the other way round), while others not, this would be an indication of a mesh-size monitoring-method interaction. In Figure 5, we observe a higher average catch in the videos compared with the logbooks for the small catches, and a lower average catch in the videos compared with the logbooks for the large catches. Therefore, we decided to keep mesh-size monitoring-method interaction in the model in analysing the systematic difference. From the correlation perspective, similar to Figure 4, we observe a different correlation from large catches to small catches. Furthermore, the correlation seems to be different between mesh-size categories. Therefore, we decided to analyse the correlation of the two methods by catch size as well as by mesh-size categories.

Systematic differences and correlation

Initially, model (1) was applied to test the systematic differences between the two monitoring methods, while testing for the effect of vessel and mesh-size category. The model results suggest that the interaction effect of vessel and method, and the interaction effect of mesh-size category and method do not significantly explain the variation in the observations. Model selection based on AIC suggests that 5 is the preferred model (Table 2). That model contains the effect of mesh-size category, the effect of method, and their interaction on the log-transformed catches (Table 3). The mesh-size category was significantly associated with the catch (ANOVA, $p < 0.01$). The monitoring method was not significantly associated with the catch (ANOVA, $p = 0.62$), indicating that there is no overall systematic difference between logbook and video. However, the interaction between mesh-size category and monitoring method was significant (ANOVA, $p = 0.02$) at the significance level of 0.05. The interaction suggests that for the smaller mesh-size category where cod catches are low, the video observations tend to be higher than the logbook records, while the reverse holds for the larger mesh-size category (Figure 6). For the mesh-size category <120 mm, the average cod catch as estimated by the logbooks is 4.8 kg [with 95% confidence intervals (CI) 2.9–7.6 kg], while for the videos, it is 6.6 kg (95% CI 4.1–10.3 kg). For the mesh-size category ≥120 mm, the average cod catch as estimated by the logbooks is 78.9 kg (with 95% CI 53.3–116.8 kg), while for the videos, it is 67.0 kg (95% CI 45.2–99.2 kg).

Table 3. ANOVA table for fixed effects of model 5.

Model term (intercept)	Numerator d.f.	Denominator d.f.	*F*-value	*p*-value
	1	119	574.0893	<0.0001
m_j	1	119	0.2455	0.6212
s_i	1	119	85.1333	<0.0001
$m_j \times s_i$	1	119	5.1682	0.0248

The correlations by mesh size are presented in Table 4. For small catches and small mesh sizes, the Pearson correlation coefficient between logbook and video was low and not significantly different from zero (Pearson's $r = 0.17$ with 95% CI of −0.18 to 0.47). Likewise, the correlation coefficient for small catches with large mesh sizes did not significantly differ from zero. Conversely, the Pearson correlation coefficient for large catches was high and significantly different from zero for both small mesh sizes (Pearson's $r = 0.60$ with 95% CI of 0.25–0.81) and large mesh sizes (Pearson's $r = 0.80$ with 95% CI of 0.69–0.88).

Discussion

This study estimates the systematic difference and correlation between logbook and EM video-estimated cod catches. Importantly,

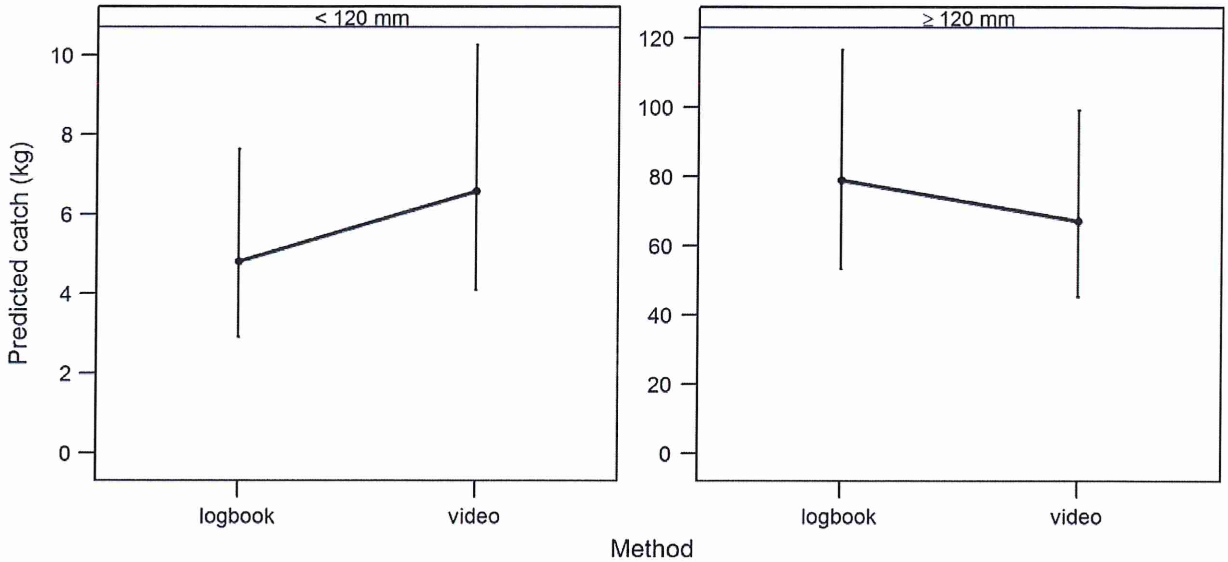

Figure 6. Back-transformed predictions of catch as a function of observation method for the two mesh-size categories, resulting from model 5. Black dots indicate means; arrows indicate 95% CI.

Table 4. The Pearson *r* correlation coefficient for catches by catch size and mesh-size category.

Mesh-size category	Small catches (95% confidence intervals)	Large catches (95% confidence intervals)
<120 mm	0.17 (−0.18 to 0.47)	0.60 (0.25–0.81)
≥120 mm	−0.29 (−0.93 to 0.79)	0.80 (0.69–0.88)

Small catches are defined as $\log_{10}$(logbook) + $\log_{10}$(video) <2, while large catches are defined as $\log_{10}$(logbook) + $\log_{10}$(video) ≥2 (small catch vs. large catch).

the EM system was installed on a heterogeneous group of vessels that fish not only for cod, but also for other demersal species. The mesh size used by the fishing vessels depends on the season and target species. A substantial fraction of the direct comparisons of cod catch weights estimated by logbook and video observations differed by >30%. According to Stanley *et al.* (2011), there is general agreement among managers and industry advisors in a groundfish hook and line fishery in British Columbia, Canada, that such a 30% error does not meet the operational objectives for EM monitoring.

We find that the amount of cod in the catches depends on the mesh size used. In this respect, the mesh size is a proxy for the type of fishery that the vessel is participating in, with mesh sizes ≥120 mm typically being used to target cod. The results from the analyses of systematic differences between the observation methods suggest an effect of the interaction between mesh-size category and the observation method on the estimate of the cod catches. That is to say, for the smaller mesh-size category where cod catches are low, the video observations tend to be higher than the logbook records. The reverse holds for the larger mesh-size category where the video observations tend to be lower than the logbook records. This is in contrast to Stanley *et al.* (2011) who found that logbooks showed a modest tendency to overestimate small catches. The analyses of the correlation between video observations and logbook records suggest that the larger catches are more strongly correlated than the smaller catches. On the log scale used in the analyses, clearly there is more variability for small catches in the observations for both methods.

It must be emphasized to point out that both video and logbook records are estimates. The video estimates require a conversion from the number of fish per species per length category to the total weight of cod in the catch. Three sources of error may be introduced in this procedure. First, species identification may be wrong. In mixed fisheries such as those used in this pilot study, cod is caught together with similar-looking gadoids such as whiting (*Merlangius merlangus*), pollack (*Pollachius pollachius*), and bib (*Trisopterus luscus*). All video reviews were done by the same reviewers with many years of experience as on-board observers in similar fisheries. Nevertheless, species identification was difficult when large concentrations of fish are processed on the conveyer belt. Second, the length estimates are made by visual observation, and individuals may be wrongly classified for length. Third, a length–weight relationship is used with parameters obtained from the literature (Coull *et al.*, 1989) that does not account for seasonal or spatial differences. Logbook records did not require any conversions, but the accuracy of the logbook records relies on the skippers. Our analysis did not find a significant effect of vessel on the difference between logbook and video records. Hence, the "skipper effect" (see Squires and Kirkley, 1999) is probably low.

The limitations of using video estimates in mixed bottom-trawl fisheries could be reduced in several ways. During this study, not all hauls could be analysed. Poor image quality due to murky camera lenses was an important factor; scales, slime, mud, and water drops frequently blurred the view, specifically for the cameras used for species identification close to the conveyor belt, where crew members sort the catch. Stringent protocols to manage and maintain the equipment on board, particularly the camera lenses, would improve image quality and eventually species identification. Possibly an automated warning system, triggered when image quality is insufficient or a substance sticks to the camera lens, would help fishers maintain a clear camera view. Meanwhile, advances in resolution and light sensitivity of digital cameras can improve image quality soon. However, external factors such as lighting (day and night), distance from target, and weather conditions will still affect image quality (Ruiz *et al.*, 2013).

Commonly on European bottom trawlers, the catch is hauled on board and large volumes of catch are immediately placed on the conveyor belt. A method or protocol for managing the volume of catch on the conveyer belt to allow recording of all individual fish would improve the documentation of the catch by video-based monitoring (Hamid *et al.*, 2012; Ruiz *et al.*, 2013). Images of individual fish would ensure that all fish are counted and would facilitate species recognition by video reviewers. Ultimately, the species identification could be made using computer vision (Strachan *et al.*, 1990; Storbeck and Daan, 2001; White *et al.*, 2006). When fish could be recorded individually and move alongside a scale of reference, e.g. measuring board or tape with banded pattern, accuracy of length estimates made by video reviewers can be improved. Alternatively, computer vision would allow fast and accurate length or weight estimations of individual fish (Storbeck and Daan, 2001; White *et al.*, 2006). However, ensuring that individual fish can be recorded by camera would require either changing the conveyor belt system such that high belt velocities can be obtained or that the catch is brought onto the belt at a low pace. While the first option would likely require substantial investments and possible increase in costs, the latter option increases the handling time of the catch. Computer vision generally requires high light intensity and high-contrast images, and would probably also require changes to the camera system or conveyor belt.

Based on the results of this study, we conclude that distinguishing small numbers of cod in catches of small-meshed gears is difficult. We expect similar difficulty in other mixed demersal trawl fisheries with large bycatch volumes where similar looking species are targeted. Still, the results appear encouraging for using EM for control purposes: the system is only inaccurate when the number of cod in the catch is low. Nevertheless, mixed bottom trawling is a common type of fishery in Europe (Uhlmann *et al.*, 2014). In those fisheries, small numbers of cod, or any other target species, will be difficult to distinguish in large volumes of discards for these fisheries. Meanwhile, implementing a landing obligation will pose large challenges for fisheries with large volumes of bycatch. Limitations in the applicability of EM to control one of the most common types of fisheries in Europe will be a burden on the implementation of the European landing obligation.

Acknowledgements

We thank all the participating vessels. We are grateful for their cooperation. Also, we thank our colleagues Bram Couperus, Martien Warmerdam, and Rosemarie Nijman for their effort in analysing video data. We thank Archipelago Marine Research Ltd for their technical support. We thank Geert Aarts, Howard Browman, Cate O'Keefe, and two anonymous reviewers for comments on earlier versions of the paper. Finally, we thank the Dutch Ministry of Economic Affairs and the Dutch National Federation of Fishermen's Organisations for making this pilot study possible.

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Handling editor: Emory Anderson