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European Fisheries Fund: Investment in sustainable fisheries

Using electronic monitoring to record catches of Sole (*Solea solea*) in a bottom trawl fishery.

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Keywords: electronic monitoring, landing obligation, bottom trawl fisheries, sole (*Solea solea*).

Abstract

Electronic monitoring (EM) is often presented as a solution to fully document catches for commercial fisheries. EM includes video monitoring to record catches on board fishing vessels. A large part of the flat fish stocks in Northern Europe are fished with bottom trawl gears. These fisheries catch a mix of demersal species with a substantial volume of by-catch. Identifying small fish on video in large volumes of catch is challenging. In the context of full documentation of catches under the EU landing obligation, the accuracy of EM is tested for sole, *Solea solea*, on board of bottom trawlers. Logbook records were compared with video observations for catches to test efficacy of EM for different size classes. In addition catches of small sole, individuals <24 cm, were compared while using a protocol where vessel crews put individual fish in front of the cameras. Comparisons were based on: i) systematic differences (paired t-test), ii) linear correlation (Pearson's r), and iii) absolute agreement (ICC) between video observations and logbooks records. Result suggest that EM for small individuals in mixed fisheries is not as effective as it is for large individuals. To be effective for small fish, methods are required to enhance video review. The protocol where crew puts individual fish in front of the cameras substantially improves EM for the complete catch. However, given the large number of quota species under the landing obligation, implementing the protocol comes with a cost for the fishing industry: the extra time needed to conduct a simple protocol would exceed 12 hours per fishing trip.

Introduction

A phased implementation of the policy to fully report and land all catches is part of the reform of the European Common Fisheries Policy (Holden, 1994; EU, 2013). The obligation to land all catches will be in place for all European fisheries by January 2019. For several species in demersal fisheries, including sole (*Solea solea*) in the North Sea, the implementation started in January 2016.

Implementing the landing obligation involves that the complete catch (landings and discards) of species under quota regulations need to be reported and deducted from the available quota. Reliable methods to accurately monitor catches on board commercial fishing vessels are a crucial element of the implementation of the landing obligation. Without accurate methods for monitoring all catches, sustainability of fisheries may be hampered as unobserved catches cause fishing mortality to exceed limits set by quotas.

Electronic monitoring (EM) is often presented as one of the solutions to fully document catches in the context of the implementation of the landing obligation (Kindt-Larsen *et al.* 2011; Mangi *et al*., 2013; Msomphora and Aanesen, 2015). 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 100% coverage of a vessel's fishing activity and the monitoring of all catches using video technology (Ames *et al*., 2007; Stanley *et al*., 2009, 2011; Kindt-Larsen *et al*., 2011).

However, when catch volumes are large and specimens of fish are small and similar looking estimating species specific catches on video can be challenging (Ruiz *et al*., 2015; van Helmond *et al*., 2015). This is the case in the bottom trawl fishery (Catchpole *et al*., 2008, Ulleweit *et al*., 2010), where it will be difficult to observe relatively small specimen, like undersized sole, through video review. A substantial part of the flat fish stocks in Northern Europe are fished with bottom trawlers or gears with comparable volumes of by-catch (Catchpole *et al*., 2008; Uhlmann *et al*., 2014).

At the end of 2014, a pilot study was initiated in as a collaboration between the Dutch Ministry of Economic Affairs and the Dutch National Federation of Fishermen's Organisations (van Helmond *et al.*, 2016). Within the context of the landing obligation, the aim of the pilot study was to evaluate the efficacy of EM to record sole catches in the Dutch bottom trawl fishery. Two commercial fishing vessels were equipped with EM systems for a period of 10 months. The hypothesis is that with the current catch processing routines on board of bottom trawlers, it is not possible to accurately detect catches of sole with video monitoring. To test the hypothesis we compared direct observations registered in logbooks by crew members with video observations for sole catches in weight and numbers. In addition, the improvement in accuracy of video observations by having a simple protocol to display the catch is explored. Such protocols of displaying the catch in front of EM cameras potentially improve accuracy of video observations considerably but impose an extra burden on the fishers (Ulrich, *et al.*, 2015). In this study we analyse two aspects of video observations: i) systematic differences, ii) linear correlation between video observations and logbooks, and iii) absolute agreement between video observations and logbooks of crew members. As such, this study gives an insight in the possibilities of using EM on board bottom trawlers within the context of monitoring the landing obligation.

Methods

Data collection

During 2015 two pulse trawlers were equipped with EM systems. Pulse trawling is a variant of bottom trawling, that makes use of an electrical pulsating field, as an alternative to tickler chains attached to a beam. The electrical field stimulates flatfish out of the sea bed (De Haan *et al.*, 2016). Pulse trawling is used to a growing extent in the Dutch flatfish beam trawl fleet, and considered as a promising alternative to conventional chain beam trawling (van Marlen *et al.*, 2014; Batsleer *et al.*, 2016). Both vessels participated in the pilot study on a voluntary basis. Monitoring started in January 2015. One vessel participated for 35 weeks, the other vessel participated for 42 weeks. The vessels were fitted with EM systems consisting of GPS, six digital cameras (closed circuit television), 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). Sensor and GPS data were recorded continuously while at sea. Video recording was done only during fishing operations. The cameras recorded overhead views of the working deck and catch-handling areas, while fishing, hauling, and processing the catches (Figure x). The EM system and the video analysis software were developed by Archipelago Marine Research Ltd. Deploying EM on board was compensated with “scientific quota”, this is national quota that is made available to compensate for potential revenue losses for vessels that participate in research projects.

The total catch of sole, above and below the minimum landings size (MLS) of 24cm was registered per haul, in both weight and numbers, by crew members in logbooks. Electronic scales were used to estimate catch weights on board the vessels. Crew members were asked to count the individuals below MLS and to keep them separate during the sorting process.

In the first step of video review, footage was observed during the usual catch sorting process, when fishers did not change their routines on board. Counts of sole, under and above minimum landing size, were made from footage of unsorted catch from cameras above the sorting conveyer belt. In the second step of video review, crew members executed an additional protocol: all individuals below MLS were displayed on the sorting belt in front of the cameras after the catch was processed (Figure 1). Counts were recorded from footage of this second step.

Figure 1. Video still from fish according to protocol.

Comparing logbooks with video registrations

A selection of hauls was used for further analysis. This selection was made in a stepwise procedure (see also van Helmond *et al*., 2015). In a first step, all hauls with video recordings were matched to on board observations from those hauls. In a second step, image quality was evaluated for each fishing day in those trips. In the third and final step, hauls were randomly selected for comparison from the days with sufficient image quality.

Visual inspection of the statistical distribution of catches suggested that these are log-normally distributed. To correct for this in statistical tests that assume normality, a common logarithm transformation was applied to all catch data. The agreement between the paired logbook vs. video estimates were explored for three aspects: systematic differences, linear correlation, and absolute agreement. A paired t-test was applied to compare the average difference between the two sources, with the hypothesis that the average difference is zero. A p-value smaller than the 0.05 significance level implies a systematic difference. The linear correlation was calculated by the Pearson correlation coefficient (Pearson's r). Additionally, an intra-class correlation coefficient (ICC) was computed (Shrout and Fleiss, 1979). In our case, the absolute agreement ICC(2,1) was selected, computed as the ratio of variability between catches (subjects) to the total variability including catches, counter and error variability, thus ranging from 0 to 1 (Shrout and Fleiss, 1979). A higher value of ICC indicates a higher agreement between the two sources. In ICC, the data are centred and scaled using a pooled mean and standard deviation, whereas in the Pearson's r, each variable is centred and scaled by its own mean and standard deviation. Therefore, ICC provides a more natural way of quantifying agreement between 2 or more resources (Shrout and Fleiss, 1979).

The agreement of catch estimates from video observations were tested in three different comparisons: 1) logbook records vs. video observations (≥24cm, weight), 2) logbook records vs. video observations (<24cm, weight & number), and 3) logbook records vs. protocol video observations (<24cm, number). The first comparison was only done in weights because catch above ≥24cm was only recorded in weights on board. Agreement in the second comparison was tested for both numbers and weights. Agreement in the third comparison was tested for numbers only. Differences in agreement between comparison 1 and 2 indicate that individual fish size affect accuracy of video monitoring. Differences in agreement between comparison 2 and 3 indicate that using a protocol to display catch in front of the cameras affect accuracy of video monitoring.

To be able to compare catch weights on board with video observations, the catch estimates in numbers of the video reviewer were converted to weights using a length-weight relationship $W = aL^b$, where W is the weight in grams and L is the length in cm. Parameter values a and b were taken from Coull *et al.* (1989), with a being 0.0036 and b being 3.3133. Lengths of undersized sole caught by beam trawling are, in general, distributed between 17 and 24 cm (Ulleweit *et al.*, 2010). However, identifying length categories in such detail was not possible with the used camera set up. Therefore, fixed lengths were assumed for sole below and above MLS. For individuals below MLS (< 24 cm) the length was set on 21.1 cm, the average length of discarded sole on beam trawlers in the North Sea (van Helmond & van Overzee, 2010). For sole above MLS (≥ 24 cm), the length was set on 28.5 cm, the average length of landed sole on beam trawlers in the North Sea (van Helmond & van Overzee, 2010). The accuracy of this conversion from numbers to weights with fixed lengths was tested in a cross-check with logbook records: numbers in logbooks were converted to weights and compared with the weights recorded. The agreement between the recorded weight and converted weight were explored for systematic differences, linear correlation, and absolute agreement.

The plots and ICC estimation were conducted using R version 3.2.0 with packages “lattice” and “psych”, respectively (R Core Team, 2015).

Review of extra costs to conduct protocol.

The duration of the different phases of catch processing were analysed using video data. The phase that were distinguished were sorting, gutting, and conducting the protocol. For 31 hauls the mean and standard deviation of the duration of the sorting and gutting phases were estimated. In addition, the mean and standard deviation of the extra time needed to conduct the protocol for improved video review was estimated for 13 hauls.

Results

Data collection

During the pilot study the two vessels together completed 73 trips. Due to technical failure or missing video data of 15 trips, (21 % of the total) were not sufficient for further analysis. For 3 trips (4% of total) there were no logbook data available on haul level. From the remaining trips, 45 hauls were randomly selected for comparison of logbook records and video data. From these 45 haul, the fishers counted the fish < 24 cm 39 times. In addition, they used the protocol 17 times to display catches in front of the cameras.

Systematic differences, correlation, and agreement

Table 1**.** Results of paired t-test, Pearson's r, and ICC (2,1) –agreement for the logbook-video comparisions.

Comparison	**1** (n=45) logbook vs. video (≥24cm, weight (kg))	**2A** (n=45) logbook vs. video (<24cm, weight (kg))	**2B** (n=39) logbook vs. video(<24cm, number)	**3** (n=17) logbook vs. protocol (number <24cm)
Paired t-test (mean difference and p-value)	Δ=0.05 p=0.13	Δ=0.38* p<0.01	Δ=0.34* p<0.01	Δ=0.02 p=0.31
Pearson's r (95% CI)	0.65 (0.45, 0.80)	0.35 (0.06, 0.59)	0.54 (0.26, 0.73)	0.98 (0.95, 0.99)
Agreement ICC(2,1) (95% CI)	0.64 (0.43, 0.78)	0.20 (0.00, 0.47)	0.34 (0.00, 0.64)	0.98 (0.95, 0.99)

* refers to the result with an outlier excluded.

In total, there were 45 samples available for the comparisons of logbook records vs. video observations of sole ≥24cm based on weights. The paired t-test for this comparison suggested no systematic difference in the means of the samples (comparison 1, Table 1). Moreover, this comparison had a Pearson's r value of 0.65 (with 95% CI 0.45-0.80) and ICC(2,1) of 0.64. This suggests a moderate agreement between the logbook records and the video observations for soles ≥ 24 cm (Figure 1).

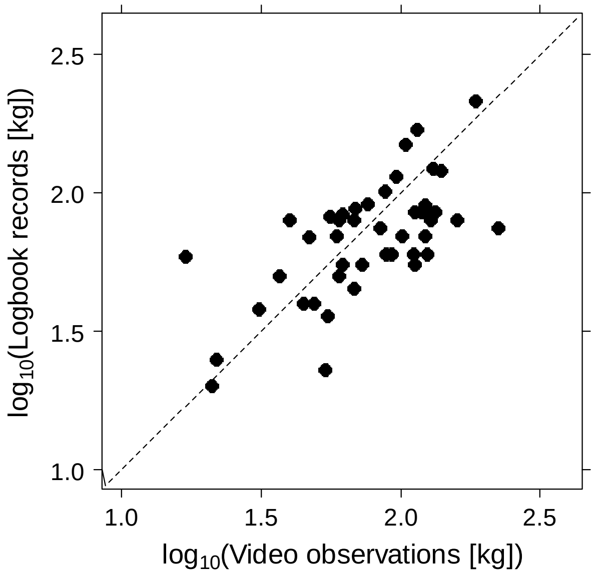

Figure 2. Scatterplot of video observations versus logbook records for sole ≥24cm based on weights (kg).

The results of comparison for logbook records and video observations of sole <24cm was done in terms of weight and numbers (comparison 2A & 2B, Table 1). For both comparisons, there was a significant difference in the means of the two methods: when comparing weights, the average weight is ($10^{0.38}$ =) 2.4 times higher in the logbooks records than it is in the video observations. When comparing numbers, the average number is ($10^{0.34}$ =) 2.2 times higher in the logbooks records than it is in the video observations. The comparisons for the fish < 24 cm had lower Pearson's r values (of 0.35 and 0.54, for the comparison based on weight, numbers, respectively) than the comparison for fish ≥ 24 cm. The ICC(2,1) agreements were also low, being 0.20 for the comparison based on weights, and 0.34 for the comparison based on numbers. The data thus suggest a weak to moderate linear trend that is, however, not on the diagonal, as can be seen from Figure 3.

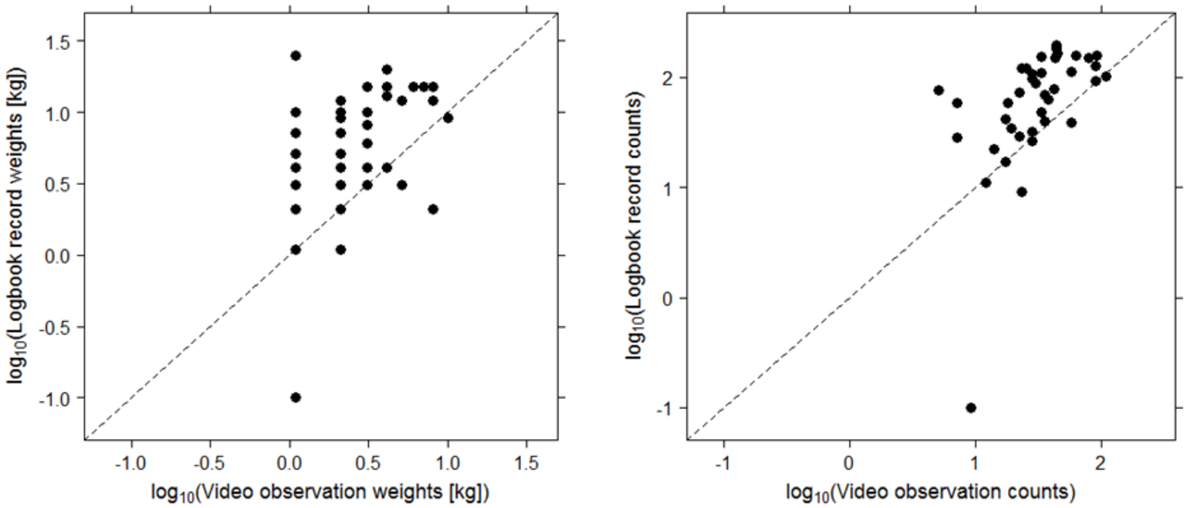

Figure 3. Scatterplot of video observations versus logbook records for sole < 24cm based on (a) weights (kg) and (b) numbers.

When using the protocol to improve the video review, the comparison for logbook records and video observations of sole <24cm improved substantially. There no significant difference between the means of logbook records and video observations. Meanwhile, there is a high agreement in the observations, with Pearson's r =0.98 and the ICC(2,1) = 0.98.

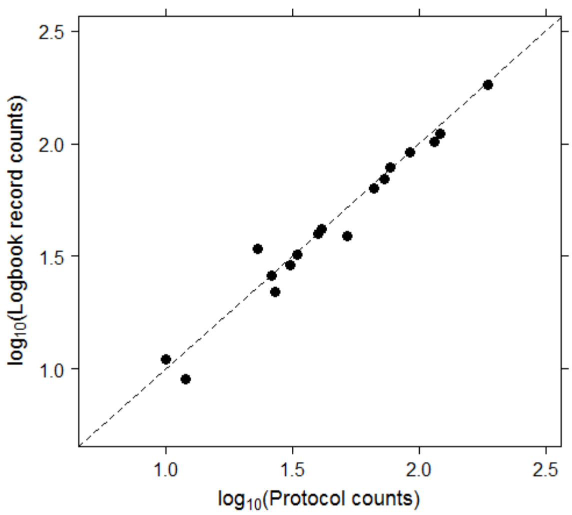

Figure 4. Comparison between logbook records and video observations using a protocol to diplay the cath of sole < 24 cm.

Accuracy of number-weight conversion

A cross-check with logbook weight records and weights converted from logbook number records indicates that the conversion from number to weights in a length-weight relationship using fixed lengths, 21.1cm for sole <24 cm and 28.5cm for sole >= 24 cm, provided reliable weight estimates. The difference in mean weight is not significant (p =0.42). The estimated weight exhibit high agreement with the actual recorded weights in the logbooks for sole below MLS, Pearson *r*= 0.96 and ICC (2,1)= 0.96 (Figure 5).

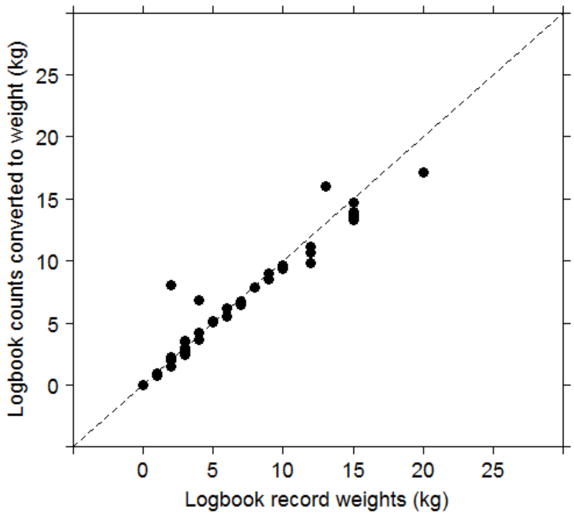

Figure 5. Scatterplot of logbook records in weight (kg) and estimated weights converted from recorded numbers in logbooks using a length-weight relationship with a fixed length for sole < 24 cm.

Implementation of the protocol

For 31 hauls the duration of the different phases of the catch processing routines on board a vessel were estimated. The complete catch processing routine was divided in two phases: the sorting phase and the gutting phase. During the sorting phase the catch is transported on a running conveyer belt, and four crew members sort out the marketable fish from the unmarketable fish, putting marketable fish aside. The average time needed to complete this phase is 20.4 ± 5.5 minutes. During the gutting phase the intestines and other internal parts are removed to prevent disintegrating when the fish is stored on ice for the remaining part of the fishing trip. On average four crew members needed 10.8 ± 4.8 minutes for this processing phase. For 13 hauls the crew conducted the protocol to improve video review (Figure 1). The average time needed for the protocol was 2.9 ± 1.1 minutes.

Discussion

Video review of the standard catch processing routines on board bottom trawlers significantly underestimates the number of sole < 24cm present in the catch. The average estimated weight based on video review is 2.4 times lower than recorded in logbooks by crew. When comparing numbers, the average difference is smaller but still significant, 2.2 times lower for video review compared to records in logbooks (Table 1). This suggests that EM is unfit to detect small fish species in mixed catches of bottom trawlers. However, the implementation of a simple protocol substantially improves the efficacy of video monitoring: using the protocol, there is no difference between the means of logbook records and video observations, and a high agreement between logbooks and video for sole < 24cm (Table 1, Figure 4).

For sole ≥ 24cm no significant systematic difference was found for logbook records and video observations (Table 1). Also, the agreement between video review and on board observations is considerably higher for sole ≥ 24cm than for sole < 24cm (Table 1, Figure 2,3). This result is in line with findings of Ruiz *et al.* (2015), who concluded that it is difficult to identify small fish as bycatch in purse-seiners using EM. The consistent under estimation of sole < 24cm in weights and numbers (Figure 2) indicates that part of the catch is not identified during video review. Lager individuals are easier to spot on video during the sorting process on board.

In the analyses, weights for video observations were infered from counts. To do so, fixed lengths were used for retained and discarded fish, because it was impossible to classify length in more detail. Fish weight for retained and discarded fish were subsequently calculated using a length-weight relationship. The comparison of converted weights fom recorded numbers in the logbooks with the actual logbook recorded weights suggests that the lenght-weight conversion used to convert counted numbers from video to weights did not cause bias in our results.

EM is seen as a promising option in monitoring catches under the forthcoming landing obligation in the European Union (Kindt-Larsen *et al.*, 2011; Mangi *et al.*, 2013). However, this is mostly the case for fisheries where it is easy to detect individual fish, e.g. hook and line (McElderry, *et al.*, 2003; Ames *et al.* 2007; Stanley *et al.*, 2009, 2011) or where EM focusses on a single species that is easy to detect with video review, like cod, *Gadus morhua*, (Kindt-Larsen *et al.*, 2011; Ulrich *et al.*, 2015). However, the efficiency of EM may be limited for fisheries catching small individuals with large volumes of by-catch (Ruiz *et al.* 2015; van Helmond *et al.* 2015). Nevertheless, this study suggests that when EM is used in combination with strict protocols that allows for better recording of individual fish, there can be a considerable improvement in the efficiency of video review. Hence, this combination could be a successful formula to control the landing obligation for fisheries with less favourable conditions for video inspection, e.g. fisheries for small species with large volumes of mixed catches, like bottom trawling.

The implementation of a protocol to aid in video observations of small fish proved to be a considerable improvement of the video review process. However, even the smallest change of the routines on board impose a burden for the crew. It is therefore important to clarify the purpose of the protocols with the skippers to reach the desired balance of data quality and feasibility of handling on board (Ulrich *et al.*, 2015; Hold *et al.*, 2015). This process of discussing the balance between data quality and feasibility of protocols on board is especially important In the context of the landings obligation (Salomon *et al.* 2014; Borges 2015) that may change fishing practices drastically.

The average time needed to conduct the protocol was 3 minutes. During an average trip a beam trawler sets it net 40-50 times (Poos *et al.* 2013). Hence, the total estimated time to conduct the protocol is 2 hours – 2 hours and 30 minutes for a single species. However, within the context of the EU landing obligation for a mixed bottom trawl fishery, multiple species will fall under the obligation to record and land all catches: these trawlers catch a number of quota species, including plaice, sole, turbot, brill, dab, and European flounder (Gillis *et al.* 2008), and the time to conduct the protocol would exceed 12 hours per fishing trip. Of course, automated image recognition and computer vision are promising solutions to improve video monitoring and, eventually, the need for protocols to show the catch may become redundant (Zion *et al.*, 2000. White *et al.*, 2006; Needle *et al.*, 2015, Griffin *et al.*, 2016). However, these technologies are still under developement and the conditions to monitor catches on board of commercial fishing vessels are challenging.

Conclusion

The implementation of the landing obligation is currently ongoing, finding a way to ensure that all cathes are recorded is of great importance. EM is ineffecient in recording catches of sole <24cm during the current catch processing routines on board. The implementation of a simple protocol of having the crew put individual fish in front of the camera improves video observations and substantially increased the ability of EM to record all catches of sole < 24cm. However, using a protocol to show the catch is a burden for the crew and comes with a cost for the fishing industry.

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