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*Published in:*

ICES Journal of Marine Science

*Link to article, DOI:*

[10.1093/icesjms/fsv028](https://doi.org/10.1093/icesjms/fsv028)

*Publication date:*

2015

*Document Version*

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*

Ulrich, C., Olesen, H. J., Bergsson, H., Egekvist, J., Håkansson, K. B., Dalskov, J., ... Storr-Paulsen, M. (2015). Discarding of cod in the Danish Fully Documented Fisheries trials. *ICES Journal of Marine Science*, 72(6), 1848-1860. DOI: 10.1093/icesjms/fsv028

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## Discarding of cod in the Danish Fully Documented Fisheries trials

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Ulrich, C., Olesen, H. J., Bergsson, H., Egekvist, J., Håkansson, K. B., Dalskov, J., Kindt-Larsen, L., and Storr-Paulsen, M. Discarding of cod in the Danish Fully Documented Fisheries trials. – ICES Journal of Marine Science, doi: 10.1093/icesjms/fsv028.

Received 31 December 2013; revised 30 January 2015; accepted 4 February 2015.

Denmark was the first nation in Europe to promote the use of Fully Documented Fisheries (FDF) through Remote Electronic Monitoring (REM) and CCTV camera systems, with pilot schemes in place since 2008. In theory, such a scheme could supplement and even potentially replace expensive control and monitoring programmes; and when associated with a catch quota management (CQM) system, incentivize positive changes in fishing patterns in a results-based management approach. New data flows are, however, required to ensure the practical implementation of such a scheme. This paper reviews the quality of the FDF data collected during 2008–2014 and their potential in strengthening information on cod discards. The analyses demonstrate the improved reporting of discards in logbooks and overall discard reductions, but they also show that some uncertainties around the absolute estimates of discard quantities have remained. Regular validation of weight estimation methods and close collaboration between scientific monitoring and control are important to support the use of reported discards as a reliable source of information. We discuss the potential of electronic monitoring in the context of the EU landing obligation.

**Keywords:** catch quota management, data collection, discard, electronic monitoring, Fully Documented Fisheries, landing obligation, North Sea cod.

### Introduction

Around the end of the 20th century, European fisheries were trapped in a vicious circle where low Total Allowable Catches (TACs) for cod led to over quota catches being discarded or landed on the black market. As a result of these catches being poorly monitored and quantified, they undermined the quality and reliability of the stock assessment, leading in turn to even lower TAC advice the following year (Ulrich *et al.*, 2011; Kraak *et al.*, 2013). This situation of poor control and monitoring of cod catches has raised political awareness, and from 2006, a variety of initiatives were launched to overcome this, including changes in control, management, and scientific advice.

One of the earliest initiatives to support officially an alternative results-based approach to the management of cod fisheries was launched by Denmark in November 2007. The Danish government put forward new objectives that were intended to ensure better management, rewarding good practices, and relying less on detailed and prescriptive technical rules (Regeringen, 2007). In 2008, the Danish

Minister of Fisheries presented a comprehensive proposal to the EU Council of Ministers, stating that all catches and not only landings should be counted in the quota (Ministry of Food, Agriculture and Fisheries, 2009). This was meant to break the circle and restore the basis for reliable assessment and management of the depleted stocks, with a specific focus on cod. A requirement for entering into such a catch quota management (CQM) scheme is that the entire catch is reported and documented; this is what is known as Fully Documented Fisheries (FDF).

FDF requires accurate catch documentation that can also be verified for compliance purposes. Therefore, the National Institute of Aquatic Resources (DTU Aqua) started investigating the possibilities for alternative catch monitoring and took the first steps towards full documentation by electronic observation in late 2007. Remote Electronic Monitoring (REM) had been implemented in Canada since the early 2000s (McElderry *et al.*, 2003) and trialled in many fisheries around the world (cf. the reviews of published and unpublished reports by Mangi *et al.*, 2013, and Wallace *et al.*, 2013).

A feasibility study (J. Dalskov, unpubl. report) was then conducted in Denmark in 2008 to understand the technicalities of the REM technology developed by Archipelago Marine Research Ltd (Victoria, BC, Canada). Subsequently, a full pilot project combining CQM principles with REM-based full documentation was initiated for the period May 2008 to September 2009 (Dalskov and Kindt-Larsen 2009; Kindt-Larsen *et al.*, 2011). Building on the encouraging results of the feasibility study, the paradigm shift towards CQM and FDF gained rapid political support at the regional level and was endorsed by a Joint Statement signed in October 2009 by fishing authorities in Denmark, UK, and Germany who agreed to explore the scope for a voluntary and incentive-driven management scheme (Ministry of Food, Agriculture and Fisheries, 2009). This translated almost immediately into basic changes in the annual TACs and quota regulation for cod. In early 2010, the European Union officially made provisions for a CQM scheme for the quotas of cod in the North Sea, Skagerrak, and Eastern Channel (EU, 2010), stating that: “Member States may allow vessels participating in initiatives regarding fully documented fisheries to make additional catches within an overall limit of an additional 5% of the quota allocated to that Member State, provided that:

- the vessel makes use of closed circuit television cameras (CCTV), associated to a system of sensors, that record all fishing and processing activities on board the vessel,
- all catches of cod with that vessel are counted against the quota, including those fish below the minimum landing size,
- the additional catches are limited to 30% of the normal catch limit applicable to such a vessel”

In 2011, the additional limit was raised to 12% of the quota allocated to the Member State and has stayed at that level since. In December 2014, EU and Norway agreed that 2015 would be the final year of this additional cod quota scheme, since the situation in 2016 will depend on the implementation processes for the EU Common Fisheries Policy landings obligation (EU, 2013).

Since 2010, DTU Aqua and the Danish Directorate of Fisheries (now The Danish AgriFish Agency) have implemented FDF trials annually (Dalskov *et al.*, 2011, 2012), which have been fully financed by the Ministry of Food, Agriculture and Fisheries and the European Fisheries Fund. The basic principle of the trials is that participating fishers must record their cod catches (landings + discards) on a haul by haul basis. A number of other European nations has also developed their own FDF trials in recent years. In 2012, FDF fisheries represented a small proportion of the total fishery in the North Sea and Skagerrak (ICES Subdivisions IV and IIIaN) (5.6% of total effort), but they represented a large proportion of the cod catches (36%, STECF, 2013a). Most of the FDF fisheries occurred in the main cod gear (otter trawls/seines of  $\geq 120$  mm mesh size, TR1), where they represented almost 30% of the effort and 45% of the cod catches. Among the countries fishing in the area, the FDF share was largest for Denmark, where it represented up to 48% of TR1 effort and 58% of TR1 cod catches.

The FDF trials which have been carried out in European fisheries have been developed at national level; therefore, there are some differences among the trials. FDF trials have been conducted either together with the prohibition of discarding all cod, including cod under the minimum landing size (Scottish Government, 2011; Marine Management Organisation, 2013; Needle *et al.*, 2015), or without [Danish and Dutch (van Helmond *et al.*, 2015) trials,

where all cod is accounted on the quota but discarding of undersize cod is still allowed]. This nuance underlines that the various concepts of CQM, FDF, and REM are different, although these acronyms are sometimes erroneously used in replacement of each other. To summarize, a discard ban implies a CQM, but conversely a CQM does not necessarily require a discard ban (since a CQM means only that all catch are recorded and accounted for in the quota, not necessarily that they have to be landed). Similarly, CQM requires full documentation of catches, but conversely, FDF does not necessarily require a CQM (since FDF can also be used for monitoring purposes only without a catch quota, as is, for example, trialled for bycatch of harbour porpoises; Kindt-Larsen *et al.*, 2012). Ultimately, REM with CCTV cameras is only one possible way for controlling the accuracy of FDF; however, other FDF ways are possible, including observers, self-sampling, reference fleets, and at-sea control (Mangi *et al.*, 2013; STECF, 2013b).

For the Danish trials, Kindt-Larsen *et al.* (2011) documented that the REM technology was working satisfactorily and could deliver extensive and unbiased control of at-sea activities and initiated some scientific analysis of the data collected during the earliest trial in 2008/2009. Since then, the functioning of the trials has been monitored (Dalskov *et al.*, 2011, 2012), but the accuracy and the potential scientific value of the data routinely collected has not been assessed in depth. Therefore, this work aimed to collate and assess the data collected during the FDF trials and to infer scientific observations from these data. The analyses were articulated around two specific questions: (i) can FDF data be trusted? and (ii) can FDF data help inform about actual catches? Our hypothesis is that if fishers' own discards estimates in logbooks could be shown to be trustworthy, that would represent major progress since the data would come from a direct and cost-effective source. We further envision that if some random discards samples are regularly brought to land by the fishers (an approach currently being trialled in Danish gillnet fisheries), then a larger sampling coverage could be achieved. This would then provide additional data on length and weight distributions using a cheaper and safer method than onboard sampling. Thus, there is a real potential for cost-effective results-based management, if self-sampling estimates are reliable. This approach to FDF is an alternative use of REM that we are keen to explore further, in parallel to the more intuitive approach of using video data for sampling and monitoring as developed in, for example, Scotland (Needle *et al.*, 2015).

## Material and methods

### Description of the trials

This paper deals only with the catches of cod in the North Sea and Skagerrak, as the Danish CQM trials in other waters have been more limited in their scope and coverage (including monitoring of cetaceans bycatches in gillnet fisheries; Kindt-Larsen *et al.*, 2012). Distinction is made between the North Sea and Skagerrak, as discarding patterns and codend mesh-size regulations differ (mesh size  $\geq 120$  mm in the North Sea, 90–119 mm in Skagerrak until 1 January 2013,  $\geq 120$  mm or selective panels from 2013).

### Participation

Since the first trial, participation has been incentivised by an additional cod quota, but the conditions for this and the number of participating vessels have changed over time. The first trial was fully launched in September 2008 and vessels' cod quota in the North Sea, Skagerrak, and Kattegat was doubled as an incentive to

**Table 1.** Summary of the FDF trials.

Vessel		Number of trips 08–14				Camera views			
Code	Type	First Year	Last Year	Before FDF	During FDF	Number of trips	Nbr hauls (EU)	Nbr hauls (NO)	Nbr trips (NO only)
A	Trawler	2010	–	79	170	141	66	190	113
B	Trawler	2010	–	173	168	138	45	180	121
C	Trawler	2010	2013	103	116	95	74	78	76
D	Trawler	2011	–	156	368	159	165	0	0
E	Gillnetter	2012	–	346	235	17	17	0	0
F	Gillnetter	2012	2013	497	183	45	45	0	0
G	Trawler	2011	2014	318	352	188	299	0	0
H	Trawler	2011	–	126	188	159	34	310	148
I	Trawler	2010	–	127	184	147	34	247	133
J	Trawler	2011	–	140	196	159	25	238	143
K	Trawler	2010	–	160	570	201	204	3	5
L	Trawler	2010	–	49	220	179	169	149	112
M	Trawler	2011	–	149	184	154	48	216	136
N	Seiner	2011	2012	109	70	48	51	0	0
O	Seiner	2011	–	36	72	69	33	87	53
P	Seiner	2011	–	56	63	78	78	63	39
Q	Trawler	2011	2012	144	41	43	11	91	42
R	Seiner	2011	–	37	97	81	44	132	54
S	Seiner	2011	2012	111	49	49	9	61	46
T	Gillnetter	2012	2014	60	137	62	19	24	53
U	Trawler	2010	–	107	289	224	130	220	174
V	Trawler	2010	–	63	193	123	57	128	90
X	Gillnetter	2011	–	216	25	31	31	0	0

Vessel code and type (in 2014), start and end years in the trials (“–” means that the vessel was still active in the trial in late 2014), total number of trips reporting cod catches in North Sea and Skagerrak between 2008 and December 2014 (both before and after entering the FDF trials), and number of camera views by the AgriFish Agency (number of full trips viewed, number of individual hauls in EU and Norwegian waters, and number of trips in Norwegian waters, i.e. when leaving Norwegian waters after a suite of hauls).

participate. Six vessels participated (one gillnetter, one Danish seiner, four trawlers). In 2010, the trial was reconducted, but under less favourable conditions. The quota premium was set to 75% of the estimated discards (using the percentage of the total catch discarded by the fishery in the previous year) but capped to a maximum of 30% increase in the vessel’s landing quota according to the EU (2010) regulation. A fixed set of requirements and rules for participation was fully established in February 2010, in collaboration with the Danish Fishermen Association (Dalskov *et al.*, 2011). Seven trawlers participated, but only two vessels from the first trial chose to continue under this reduced premium in 2010. The 2011 and 2012 trials were extensions of the 2010 trial to new vessels (Dalskov *et al.*, 2012). Most vessels joining after 2010 have stayed in the scheme. New participants were integrated as long as there was some quota available, but the trial is currently closed for new entrants. Three vessels stepped out of the trials voluntarily, and three others stepped out because the vessel stopped fishing for other reasons.

One vessel from the trial operated mainly in the Baltic Sea and was removed from the dataset. In total, data are available from 23 vessels (coded A to X) (Table 1).

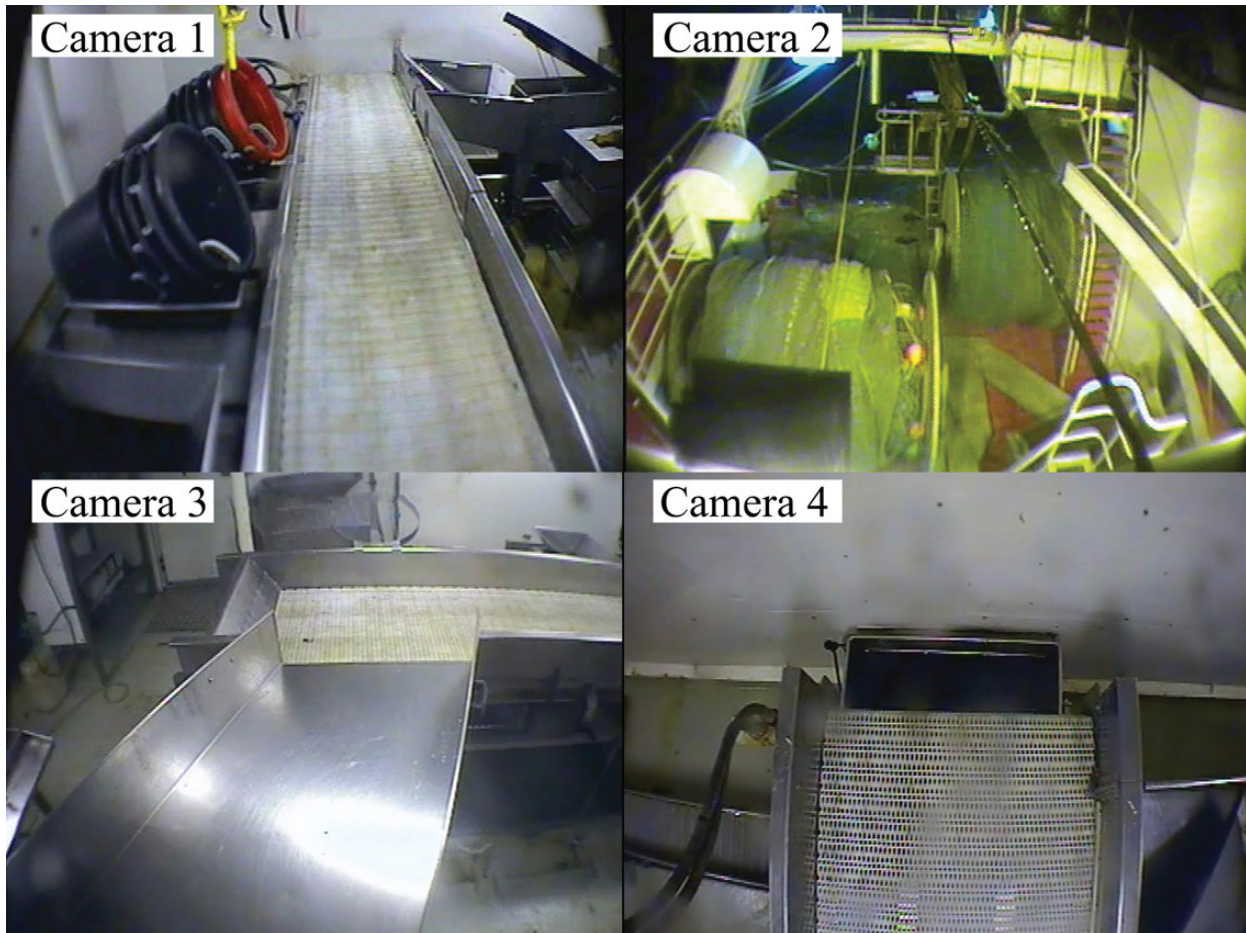
### Technology and data flow

All trials have been performed using the Archipelago Marine Research Ltd technology (<http://www.archipelago.ca/fisheries/electronic-monitoring/>). No substantial changes in the technological set up have been implemented since the first trial in 2008. The system consists of a GPS (Global Positioning System), a hydraulic pressure sensor, a photoelectric drum rotation (winch) sensor, and up to 8 closed circuit cameras (CCTV; of resolution 480 × 720 pixels and

adjustable frame from one to five pictures per second) providing an overhead view of the aft deck and closer views of the fish handling and discard chute areas (Figure 1). Further details on the technology can be found on Archipelago’s website.

The sensors and cameras are connected to a control box located in the wheelhouse, which monitors sensor status and activates image recording. This control box is a computer with data storage capability for up to 30 d of vessel fishing activity (500 GB) and is set to collect and store sensor data (GPS, hydraulic pressure, and drum rotation) every 10 s. REM sensor data and image recording is recorded continuously while the REM system is powered, which in principle should occur constantly during the entire fishing trip (port to port). No image recording takes place in port. When the capacity is full, the REM hard drives from the vessels are collected by staff from the Danish AgriFish Agency for data storage and interpretation. The analyses of both sensor and video data are performed using the EM Interpret (EMI) computer software developed by Archipelago Marine Research Ltd.

The participating skippers must report additional information in their logbooks, beyond the usual requirements. This includes, for each individual fishing operation, the recording of date, time and position of gear shooting, time and position of gear hauling, total catch in weight (usually visually estimated by the skipper), weight of retained part of the catch by species, cod discard weight, and total discard weight for other species. According to the protocol, fishers must collect cod discards in standardized baskets and hold them in front of the cameras for a few seconds before discarding. This procedure was not always well complied with at the beginning, but has become increasingly applied by the crew over time. Landings and discards have to be uploaded sequentially in two consecutive



**Figure 1.** Example of CCTV providing an overhead view of the aft deck and closer views of the fish handling and discard chute areas for one vessel.

e-log transmissions. Discard information is then reported separately in logbooks as a negative landing value.

The Danish AgriFish Agency reviews video footage from ~10% of the hauls carried out by each vessel. The protocol of selection of hauls to be reviewed has evolved over time and is at present semi-random, including systematically a review of at least one haul within the last five hauls of the trip (when highgrading is more suspected to occur). At least 10% of the viewed hauls are cross-checked by more than one viewer. Viewers estimate cod discards by counting the number of baskets, using a standard weight of 22–25 kg for full baskets. When some individual cod are observed in the discard chute and not put in a basket, they are length measured on the screen (measurement of the number of pixels calibrated on the vessel's bandwidth) and given an approximate weight ( $=0.000009 \times \text{Length}^{3.0366}$  for cod between 38 and 115 cm—relation fitted from Danish commercial samples in 2009, 2328 fish measured), which is added to the total discard weight. These length–weight parameters were checked for consistency with Fishbase estimates (<http://www.fishbase.org>, Reference #94,462) and with Danish commercial samples for the North Sea in 2013 (2770 fish), and they gave similar results (<5% difference in estimated weight per length across the three estimates). The total cod weight estimated by viewers is then compared with the discards estimates reported in the logbooks. Additional targeted control can be performed if irregularities are detected.

Video files are stored on the Agency's server for a period of 3 months before being deleted. DTU Aqua is in charge of the technological support to ensure the installation and functioning of the camera systems. DTU Aqua has also access to logbooks information and upon request can receive copies of the REM data (EMI files with sensor information) and of the discard estimates as reported by the Agency. Video files can also be consulted from the Agency's building before their deletion. In practice, it is certain that this division of work has limited the amount of interactions and scientific collaborations between both institutes, resulting in little strategic inclusion of REM into DTU Aqua's standard data collection programmes.

#### Data issues

Scrutinizing the FDF data available to DTU Aqua during the present study evidenced a number of issues and pitfalls in the data that are summarized here.

First, the earliest trial in 2008/2009 was rather exploratory and focused primarily on onboard technology. Unfortunately, the hard-copies of individual haul data collected during this initial trial and summarized by *Kindt-Larsen et al. (2011)* have not been electronically archived, making it impossible to pool together a full time-series since 2008. Electronic logbooks (e-log) were first introduced in 2010, greatly facilitating the reporting of haul-by-haul information during the subsequent trials. Therefore, the FDF data (both video

footage control and logbooks declarations) are only available from April 2010 (Table 1).

Second, a major challenge in analysing the data comes from the fact that the Danish cod fisheries occur to a large extent in Norwegian waters where discarding is prohibited, which causes major difficulties when handling and reporting discards. Danish vessels fishing in Norwegian waters must retain fish below the minimum reference size (MLS) on board while in Norwegian waters and discard them once back EU waters. Therefore, fish from several hauls can be discarded at once. Consequently, control is performed at the haul level in EU waters and at the trip level in Norwegian waters. Some individual hauls are, however, also monitored in Norwegian waters to verify for the absence of discarding and are thus double counted in the overall estimate for the Norwegian waters. The dataset had therefore to be analysed for the two waters separately. Often, both EU and Norwegian waters are visited during a single trip, rendering it also difficult to accurately estimate the percentage of the catch which is discarded.

Third, it was realized that the Danish e-log system could induce some mismatch in the haul-by-haul discard information controlled by the Agrifish Agency. The e-log system does not yet register haul ID (although this feature may become compulsory soon). To register haul-by-haul information, FDF vessels are required to transmit information after each haul (landings and discards separately). But if discards are not systematically reported for every single haul (typically if no discards occur), the number of lines reported for landings and discards differ, and discard information can potentially be allocated to a different haul when the data are compiled. This is in principle checked by the Agency using haul time information, and hauls without discards estimates are treated as if the fisher reported zero discards (especially as those are mainly observed in Norwegian waters). Nevertheless, a slight uncertainty remains whether the historical hauls viewed by the Danish Agrifish Agency are rigorously the same as those reported by the fishers. The actual extent of this issue on historical data cannot be easily verified and quantified, but this feature is now being corrected for the incoming data.

Fourth, matching hauls with DTU Aqua discard sampling database was usually not possible because of this absence of a standard haul identifier, so the comparison with observers' data could only be done at trip level.

## Data analyses

### Availability and accuracy of cod discard estimates

Reporting of discards in logbooks for all species above 50 kg has been in principle compulsory for all EU vessels since 2011, but largely has not been enforced. Reporting cod discards (including quantities below 50 kg) is one of the strongest requirements for participating in the FDF trials. Reported cod discards in logbooks were thus compared for those vessels participating in the FDF and those not, to see whether FDF contributes to increased compliance to this obligation. It can be argued that this is not a sufficient evidence, since non-FDF vessels may simply catch less cod than FDF vessels; however, observers' data show that non-FDF fisheries still discard substantial amounts of cod (see also Table 4). Therefore, some discard amount should in principle be expected to be reported by the other vessels.

Second, the accuracy of discard estimates was investigated using three sources of information: those documented in logbooks (covering all FDF trips—referred to as “fishers' estimates”), Agrifish

Agency video estimates (covering around 10% of trips/hauls—referred to as “viewers' estimates”), and those collected by DTU Aqua's observers (which can be randomly present onboard on the basis of the national sampling programme from the EU Data Collection Framework—referred to as “observers' estimates”). Analysing these data simultaneously can help judge their validity and highlight potential strengths and weaknesses. The desired outcome would be to observe no differences in the discard estimates across the different data sources, which would support the option that fishers' estimates can subsequently be used as a reliable source of information when estimating discards (providing that the other sources are accurate as well).

The data provided by the Agency contains discards estimates for a subset of hauls viewed on cameras (“fishers' vs. viewers'”). In all, 4105 hauls including paired fishers' vs. viewers' estimates of cod discards were available for the period April 2010 to November 2014 (1688 in European waters, 2417 in Norwegian waters). Additionally, data for 1538 trips when leaving Norwegian waters (potentially including several hauls) were available. In this analysis, we concentrated only on discard estimates in absolute value (kg per haul or trip) to quantify the accuracy of the metric that will subsequently be used to compute discards ratios for stock assessment. Due to the data issues mentioned above, hauls were also aggregated by trip (same logbook nr, same landings date, but excluding the individual hauls controlled in Norwegian waters to avoid double counting) across both EU and Norwegian waters, leading to 2590 paired whole trip estimates (Tables 1 and 2).

Notably, serious infringements occurred for two vessels (C and L), with systematic underreporting of large quantities of discards over a 3-month period around the end of a quota year (late 2010–early 2011); those irregularities were spotted by the AgriFish Agency, who subsequently increased the monitoring of these vessels beyond the standard 10% control. After the vessels were confronted, their discard reporting became more consistent with those observed by the Agency. The Agrifish Agency deducted the amount of cod estimated by the viewers from the two vessels' quota in that period.

A second dataset gathered all trips where an observer was onboard a FDF vessel and matched the corresponding fishers' estimate (directly from logbook) and, when available, the viewers' estimates (from the previous dataset) with the observers' estimate. Data from a total of 51 trips were available for 2012 and 2013, of which 27 reported discards in either fisher's or observer's estimates (Table 3). Two trips (nr. 8 and nr. 31) had extreme discrepancies. Thirteen of those trips also had a viewer's estimate available. Simple linear relationships were fitted to describe the consistency between those three sources of information.

### Cod discard ratios and size distribution

The primary use of discard sampling is to provide total discard estimates by métier, to be included in stock assessment and management advice (e.g. ICES, 2013, STECF 2013a). A decision must thus be made on which source of information to use for providing estimates for FDF fisheries. The impact of the uncertainty in trip-by-trip discard estimates from the previous analyses was investigated by comparing the overall figures for discards (by weight and percentages) for the various métiers (both FDF and non-FDF), raised from the various sources of data. Fishers' estimates for FDF métiers were used as a total absolute value (the sum of discards in logbooks). The raising of discards from observers' data was done

**Table 2.** Number of paired discard estimates per water (European or Norwegian), observations type (haul by haul or trip by trip) and year, characterizing the discrepancies between fishers', and viewers' cod discard estimates.

Water	Year	fisher&viewer>0	fisher&viewer = 0	fisher = 0	viewer = 0	Total
EU (haul)	2010	2	39	12	13	66
	2011	88	243	162	47	540
	2012	41	211	167	32	451
	2013	43	193	116	23	375
	2014	5	157	83	11	256
NO (haul)	2010	0	167	8	14	189
	2011	34	477	137	93	741
	2012	25	417	140	66	648
	2013	16	400	79	61	556
	2014	8	220	33	22	283
NO (trip)	2010	14	41	28	34	117
	2011	225	90	19	91	425
	2012	228	113	19	63	423
	2013	182	115	13	96	406
	2014	100	38	5	24	167
whole trip	2010	17	66	39	44	166
	2011	278	237	93	110	718
	2012	274	231	140	83	728
	2013	218	245	107	112	682
	2014	108	107	53	28	296

“fisher&viewer>0”, both the fisher and the viewer have reported discards; “fisher&viewer = 0”, both the fisher and the viewer have reported zero discards; “fisher = 0”, the fisher has reported zero discard but the viewer has reported discards; “viewer = 0”, the viewer has reported zero discard but the fisher has reported discards.

following the standard procedure defined in ICES (2007):

$$\begin{aligned} \text{Discard Rate}_{\text{Time, Area, Metier, Species}} &= \frac{\sum^{\text{Weight}} \text{of discard}_{\text{Trip, Haul, Time, Area, Metier, Species}}}{\sum^{\text{Weight}} \text{of landing}_{\text{Trip, Haul, Time, Area, Metier}}} \\ &= \text{Landings (tonne)}_{\text{Time, Area, Metier}} \\ &\quad \times \text{Discard Rate}_{\text{Time, Area, Metier, Species}} \end{aligned}$$

Different trips aggregation levels were tested, pooling, or separating FDF trips from the other sampled trips from the same métier.

This comparison of the percentages discarded by FDF vs. non-FDF vessels was supplemented by comparing the length composition of cod in the catches (from commercial categories) for the FDF vessels before and after they entered the trials, thus updating the initial findings by Kindt-Larsen *et al.* (2011).

## Results

### Availability and accuracy of cod discards estimates

Vessels participating in FDF represent only few per cent of the total number of vessels reporting cod landings (4–5% in Skagerrak, 6–9% in the North Sea). However, the percentage of total cod landing by FDF vessels is considerably higher (around 20% in Skagerrak and 40% in North Sea, Figure 2), indicating that the vessels entering the FDF trials were targeting cod. There is a striking contrast regarding compliance to the obligation to report discards in logbooks. All FDF vessels have reported discards in logbooks, and they have been almost the only ones to do so. They represented 90–100% of discard reports in number of vessels and close to 100% in tonnage. For vessels participating in FDF, the percentage of cod catch weight reported to be discarded has fluctuated

around 1.5–3% in Skagerrak and between 0.5 and 1.5% in the North Sea. FDF vessels have also reported discards for other species. These are usually unsorted (total discards other than cod, around 50 t by year in average for all FDF vessels), although some specific discard records of herring, hake, Norway pout, haddock, and grey gurnard have been observed in logbooks.

Many hauls were assessed to occur without discarding of cod (Table 2). In European waters, both fishers and viewers agreed on no discards occurring in 50% of the hauls (and 70% in Norwegian waters). When leaving Norwegian waters (aggregation of several hauls), no discards were reported by either sources in 26% of the trips.

The direction and magnitude of the discrepancies for each paired estimate were investigated in more details, characterizing whether the viewer reported discards but not the fisher (“fisher = 0”), whether the fisher reported discards but not the viewer (“viewer = 0”), or whether both did report discards but with different quantities (“fisher&viewer>0”) (Table 2). For all areas and years, fishers reported <40 kg of cod discarded in half of the paired estimates, and <100 kg in 85% of those. Discrepancies between fishers and viewers were generally small, with half of them being within ± 5 kg (Figure 3). The consistency increased over time, with major deviations observed in 2010 and 2011 (illustrating the magnitude of the two observed 3-month infringement periods). From 2012 to 2014, almost 90% of the differences lay within the range of ± 50 kg. When removing the two 3-month periods of discard under-reporting from the two vessels, the difference between fishers and viewers were not significant ( $p > 0.05$  with paired two-sample Wilcoxon test, 95% confidence interval between [−1,3] with 100 000 bootstrap replicates).

Second, the accuracy of the basketting estimation method used by both fishers and viewers was investigated by comparing with observers' estimates for the same trips when available (Table 3, Figure 4). Some occurrences where no cod were discarded were confirmed by observers (24 trips, mainly for gillnets). For those other trips where discarding did take place, fishers' estimates were

**Table 3.** Percentage of cod catches discarded by trip (in kg) for the FDF trips with observers onboard in 2012 and 2013.

Trip	Year	Area	Gear	Raising Factor	Observers' estimates	Fishers' estimates	Viewers' estimates
1	2012	North Sea	Danish Seine	1.5	3.7	0	
2	2012	North Sea	Danish Seine	2.89	0.1	0	0.1
3	2012	North Sea	Danish Seine	1.75	0.9	0	0
4	2012	North Sea	Danish Seine	2.33		0	
5	2012	North Sea	Danish Seine	3		0	
6	2012	North Sea	Gillnet	1	0.3	0.4	
7	2012	North Sea	Otter Trawl	2.57			
8	2012	North Sea	Otter Trawl	2.33	13.6	0	
9	2012	North Sea	Otter Trawl	2.33	0.5	0	
10	2012	North Sea	Otter Trawl	2.5	11	4.9	4.2
11	2012	North Sea	Otter Trawl	2.5	11.9	4.4	6.1
12	2012	North Sea	Otter Trawl	2.33	9.4	2.1	0
13	2012	Skagerrak	Gillnet	1	0	0	
14	2012	Skagerrak	Gillnet	1	0	0	
15	2012	Skagerrak	Gillnet	1	0	0	
16	2012	Skagerrak	Gillnet	1	0	0	
17	2012	Skagerrak	Gillnet	1	0	0	
18	2012	Skagerrak	Gillnet	1	0.4	0	
19	2012	Skagerrak	Gillnet	1	0	0	
20	2012	Skagerrak	Gillnet	1	0	0	
21	2012	Skagerrak	Gillnet	1	0	0	
22	2012	Skagerrak	Gillnet	1	0	0	
23	2012	Skagerrak	Gillnet	1	0	0	
24	2012	Skagerrak	Gillnet	1	0	0	
25	2012	Skagerrak	Gillnet	1	0.4	0	
26	2012	Skagerrak	Otter Trawl	2	4.9	4.1	
27	2013	North Sea	Danish Seine	2.6	0.1	0	0
28	2013	North Sea	Danish Seine	2.33	0	0	
29	2013	North Sea	Danish Seine	2.25	3	0	0
30	2013	North Sea	Gillnet	1.5	0.5	0.3	0.7
31	2013	North Sea	Otter Trawl	1.89	21.1	0.5	
32	2013	North Sea	Otter Trawl	1.8	1.8	2.7	2.5
33	2013	North Sea	Otter Trawl	1.83	1.7	1.7	1.3
34	2013	North Sea	Otter Trawl	2	0	1.8	
35	2013	North Sea	Otter Trawl	2	2.8	1.7	2.2
36	2013	North Sea	Otter Trawl	1.67	7	4.6	
37	2013	North Sea	Otter Trawl	2.6	1.1	0.2	
38	2013	North Sea	Otter Trawl	2.86	3.9	1	
39	2013	North Sea	Otter Trawl	2.67	0.1	0	0
40	2013	Skagerrak	Gillnet	1	0.1	0	
41	2013	Skagerrak	Gillnet	1	0	0	
42	2013	Skagerrak	Gillnet	1	0	0	
43	2013	Skagerrak	Gillnet	1	0.8	0	
44	2013	Skagerrak	Gillnet	1	0	0	
45	2013	Skagerrak	Gillnet	1			
46	2013	Skagerrak	Gillnet	1	0	0	
47	2013	Skagerrak	Gillnet	1			
48	2013	Skagerrak	Gillnet	1	0.2	0	
49	2013	Skagerrak	Gillnet	1	0	0	
50	2013	Skagerrak	Gillnet	1	0	0	
51	2013	Skagerrak	Otter Trawl	2	3.3	2.3	

The raising factor is the coefficient for raising the number of hauls observed to the entire trip.

significantly lower ( $p < 0.005$ ) than observers' estimates (around half of the value on average). When viewers' estimates were also available for the same trips (13 trips), those estimates were slightly lower than the fishers' (85%), but not significantly different ( $p = 0.86$ ).

#### Percentages of cod discarded and size distribution

The implications of these differences in weight estimation were investigated by raising cod discards (percentages and weights)

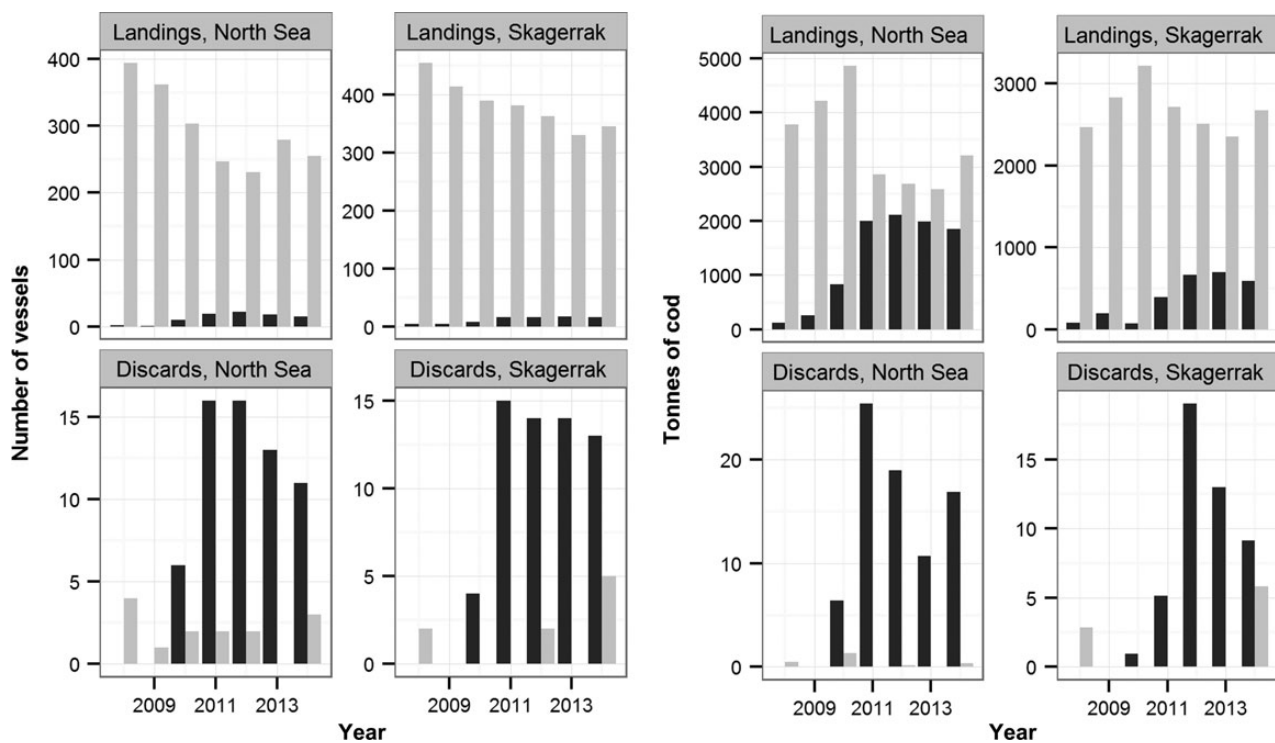
from 2012 and 2013 for the main trawl fisheries in North Sea and Skagerrak (Table 4). Obviously, discard estimates were quite sensitive to the method used. However, two main findings emerged: first, the census sums of discards written in logbooks in the FDF fisheries were lower than the estimates coming from observers' trips, as could be expected from the previous observations (e.g. 1 vs. 4% in the North Sea, 3 vs. 8% in the Skagerrak in 2012). It cannot be fully determined whether this was due to an underestimation from the vessel side or an overestimation from the observer side, as both



**Table 4.** Total cod landings and discards (in tonnes) and corresponding discards ratio (%) by area and métier (FDF vs. non-FDF) using different estimation methods.

Area	Métier	Discard estimation method	Year	Number of observed trips	Landings (t)	Discard (t)	Discards ratio (%)
North Sea	OTB $\geq$ 120 mm non-FDF	Raising from non-FDF observers trips	2012	4	704	182	21
			2013	4	672	187	22
North Sea	OTB $\geq$ 120 mm non-FDF	Raising from both FDF and non-FDF observers trips	2012	10	704	96	12
			2013	13	672	106	14
North Sea	OTB $\geq$ 120 mm FDF	Raising from FDF observers trips	2012	6	1557	66	4
			2013	9	1620	123	7
North Sea	OTB $\geq$ 120 mm FDF	Sum of estimates from logbooks	2012	Census	1557	15	1
			2013	Census	1620	9	1
North Sea	OTB $\geq$ 120 mm FDF	Raising from both FDF and non-FDF observers trips	2012	10	1557	111	7
			2013	13	1620	121	7
Skagerrak	OTB 90–119 mm non-FDF	Raising from non-FDF observers trips	2012	35	1235	1431	54
			2013	33	1154	747	39
Skagerrak	OTB 90–119 mm non-FDF	Raising from both FDF and non-FDF observers trips	2012	36	1235	1418	53
			2013	34	1154	713	38
Skagerrak	OTB 90–119 mm FDF	Sum of estimates from logbooks	2012	Census	366	10	3
			2013	Census	336	7	2
Skagerrak	OTB 90–119 mm FDF	Raising from non-FDF observers trips	2012	1	366	30	8
			2013	1	336	47	12
Skagerrak	OTB 90–119 mm FDF	Raising from both FDF and non-FDF observers trips	2012	36	366	155	30
			2013	34	336	116	22

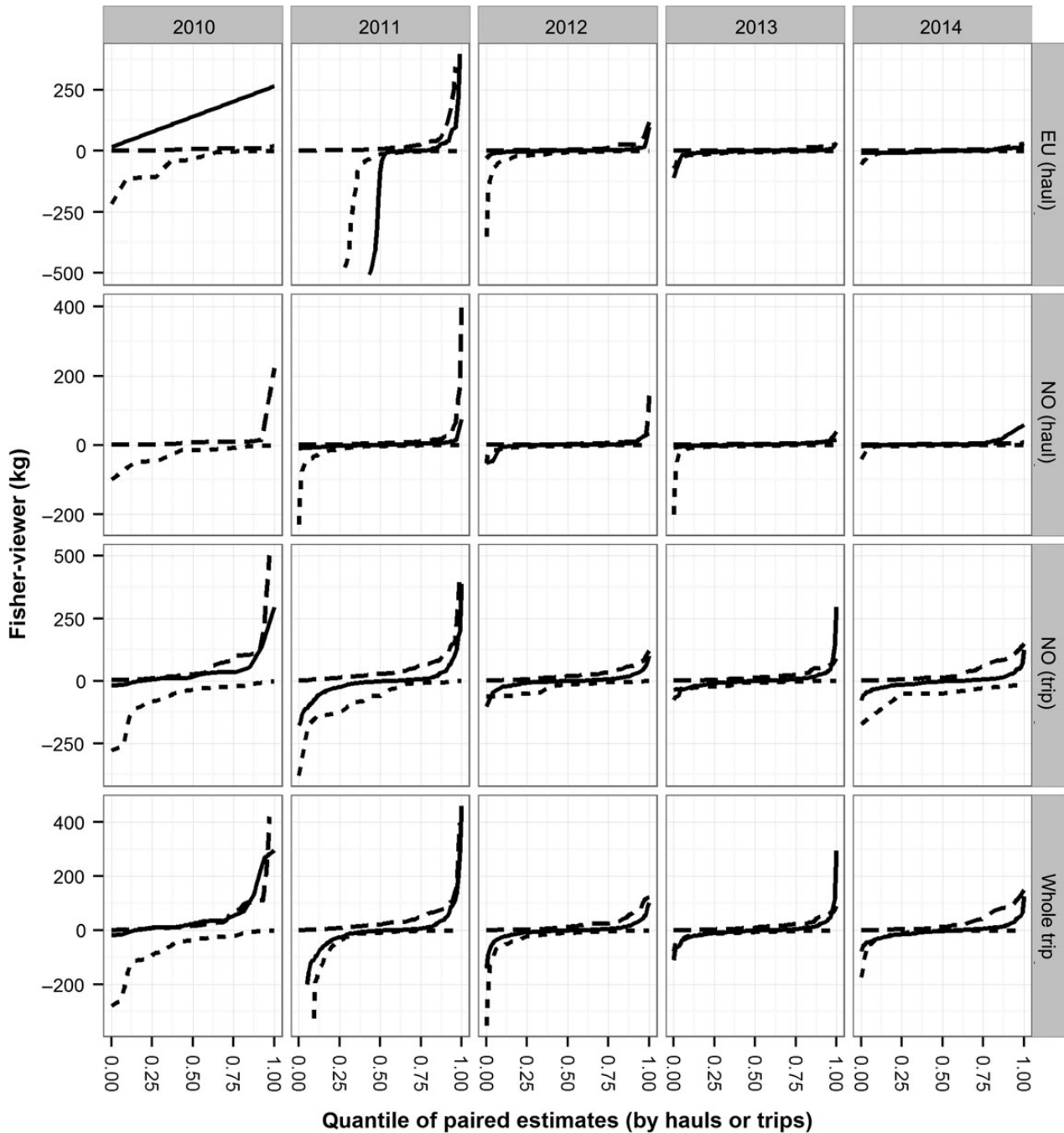
The first lines within each category (in grey) highlight the method that was used for providing discard estimates to, for example, ICES and STECF.

**Figure 2.** Coverage in cod information available in logbooks regarding number of vessels (four left panels) and tonnage (four right panels) for FDF vessels (black) vs. non FDF vessels (grey), by year (2008–2014, x-axis), area (horizontal panels), and catch type (landings in top line panels, discards in bottom line panels).

estimates bear some uncertainties. Second, while FDF discard levels were still uncertain, they were nevertheless much lower than the levels observed in the corresponding non-FDF fisheries (e.g. 21% in the North Sea, 54% in the Skagerrak in 2012). FDF has induced significant discards reduction, so we can expect that the overall impact of the

uncertainty around discard estimates for these fisheries on stock assessment outcomes and on management decisions has also reduced.

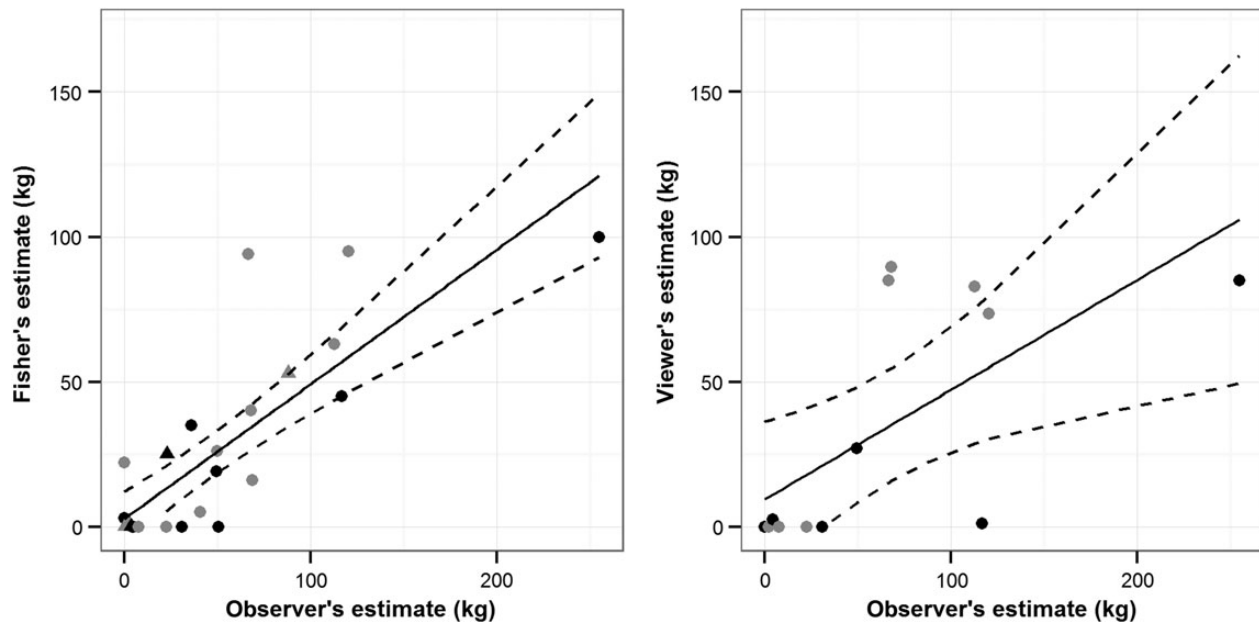
This pattern was corroborated by observing how FDF trials affected cod size composition. The average size composition of cod landings by market category for the period 2008–2014 was



**Figure 3.** Absolute differences in cod discard estimates (in kg) between fishers and viewers per quantile of paired observations (hauls or trips), water (European or Norwegian), year, and type of discrepancy: Plain line: “fisher & viewer > 0”: both the fisher and the viewer have reported discards; Dotted line: “fisher = 0”: the fisher has reported zero discard but the viewer has reported discards; Dashed line: “viewer = 0”: the viewer has reported zero discard but the fisher has reported discards. Plotted capped at (−500 kg), some large negative outliers in 2011 are not displayed.

plotted for all vessels before and after entering the FDF trials (Figure 5). An overall significant increase ( $p < 0.05$  in analysis of variance) in the mean market category by trip (weighted by tonnage in each category) was observed for many vessels after entering the FDF trials, especially for vessels fishing with demersal trawls and seines. FDF landings comprised significantly larger proportions of smaller cod [categories 4 (1 to 2 kg fish<sup>-1</sup>) and 5 (0.3 to 1 kg fish<sup>-1</sup>)] than before entering the trial.

Since most FDF vessels entered the trials in late 2010–early 2011, we compared these results with the average changes in cod market category for all other non-FDF vessels in the same gears and areas, for the period 2008–2010 vs. 2011–2013 (Figure 5). Although the means in both periods were significantly different across the much larger number of observations, the overall size distribution did not suggest a radical change in the size composition of the landings of the other vessels that could have indicated a change in the cod



**Figure 4.** Paired cod discard estimates by FDF trip with observers onboard. Left: fishers' estimate vs. observers' estimate (trips 8 and 31 omitted). Right: viewer's estimate vs. observer's estimate. Black = 2012. Grey = 2013. Circle: North Sea. Triangle: Skagerrak.

population towards younger year classes. Also, the stock assessment for North Sea cod has not indicated any large year class since 2008 (ICES, 2013). It is therefore likely that the small cod landed within the FDFs used to be discarded before participants joined the trials. This is consistent with the findings from the previous analysis. More in-depth analyses on the individual changes in fishing patterns following the FDF introduction are ongoing, but they lie beyond the scope of the present study.

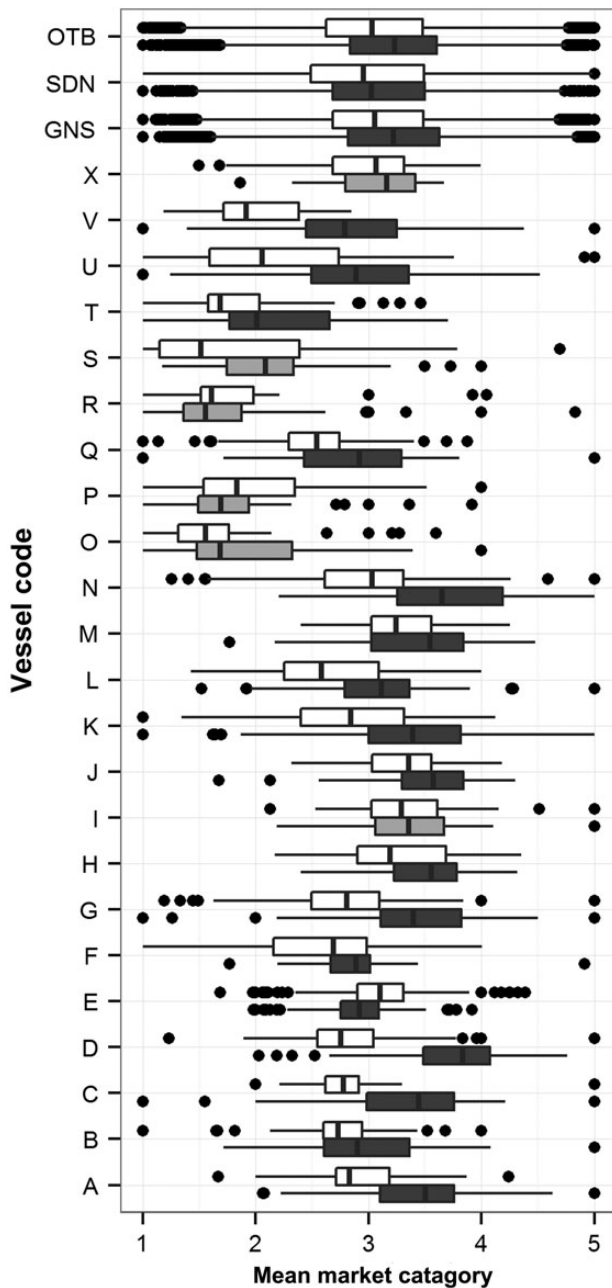
## Discussion

The results obtained herein provide new insights into what the Danish FDF trials have actually meant for catch monitoring programmes and for the participating vessels. The Danish FDF trials aimed to test the feasibility of implementing results-based management through CQM, with REM being only the chosen monitoring tool, and not the ultimate purpose of the trials. Trials have been run entirely on a voluntary basis, rewarding participation with additional cod quota. Our general perception is that using REM as a control and documentation tool for obtaining accurate reporting of discards in logbooks has great potential as a cost-effective and wide-covering monitoring programme. However, we also found that some adjustments would be needed to ensure full effectiveness.

Regarding the first aspect, the results presented can be considered as a positive and successful demonstration of the concept, having (i) reduced discards without additional technical rules, (ii) improved compliance to registering all catches in logbooks, and (iii) enhanced controllability of the TAC management system. This supports the use of logbooks as a potentially reliable source of information on discard weight for FDF vessels. In comparison, this source is completely useless for other non-FDF vessels under the current low level of enforcement of this requirement. The control agency has full video access to all fishing operations, and while it is obvious that not all hauls can be examined in details, there is nevertheless a clear possibility to carry out more targeted controls if necessary. This potential is likely to create a deterrent effect on logbook

misreporting, as control can occur any time after the trip has been completed. We have two cases where a simple phone call mentioning that some mismatch between logbooks and video footage were being observed was enough to raise awareness and return to trustable reporting.

Regarding the second aspect, our work has, however, raised a number of points that would need some further attention. More emphasis should now be given to the full validation of the accuracy of the data collected. The discard weights estimated by the different methods and sources (fishers, viewers, and observers) were different, although some improvements have been observed over time. For the few trips where observers were onboard FDF vessels, the fishers' estimates were around half of the observers' estimates, and viewers' estimates were around 85% of fishers' estimates. We investigated the reasons for this discrepancy and asked observers and viewers for their respective protocols. Observers' estimates depend on the number of hauls sampled, the size of samples and subsamples, and their weighing method. Observers may also use the basketting method, but we realized that different average basket weights were routinely used by different measurers, with the observers using a full basket weight of 30 kg (against 22–25 kg used by fishers and viewers). As both monitoring schemes are conducted independently from each other and led by different institutes, this difference had never been noticed until this present analysis, but its impact may be important. This raises some questions on the overall validity of the basketting method, which should be reconsidered. The actual weight of each basket can fluctuate around the mean value, and discard baskets may not be weighed by the crew as often as landings boxes are. Also, viewers have acknowledged that if the camera vision is reduced because of mist or dirt, the identification of species in the basket can be difficult and some might be omitted or wrongly allocated. Additionally, one should keep in mind that counting discards against the quota maintains an incentive to underreporting if not properly controlled. It is therefore of utmost importance to maintain the accuracy of the discards estimation protocol through



**Figure 5.** Average cod market category by trip (market category number weighted by the percentage weight of that category to the total trip's landings), plotted against vessel ID [gillnet (GNS), trawl (OTB), and Danish seine (SDN) trips in North Sea and Skagerrak only]. Categories from 1 (largest cod, 7 kg/fish and above) to 5 (smallest cod, 0.3 to 1 kg/fish). White, non-FDF trips; grey, FDF trips. Additionally is shown the average cod market category by trip for non-FDF vessels in the same gears and areas between 2008 and 2010 (white) and between 2011 and 2013 (grey). Dark grey colour indicates that the two distributions are significantly different ( $p < 0.05$ ), while pale grey indicates that they are not.

regular control of weight estimates, both with fishers and with viewers. Some training had taken place at the early stages of the first trial, but a protocol for regular validation has clearly been missing. Historical records cannot be improved, but better attention is now already being paid to this issue.

Despite these uncertainties, we observed that percentages discarded in FDFs were lower than in the equivalent fisheries without full documentation. Pragmatically, this means that the impact of the estimation uncertainty on, e.g. stock assessment and management is actually much smaller, because the extent of the issue has been considerably reduced. Small cod are now landed in larger quantities, with the additional quota providing the necessary economic buffer to reduce the need to highgrade. Nevertheless, DTU Aqua made use of logbooks data for providing discards data to ICES and STECF for the Skagerrak FDF fisheries, because of too few observers' trips available in this fishery. These data might have to be re-estimated upwards in the light of the findings of this study.

These analyses provide a timely insight on a controversial topic. [Mangi et al. \(2013\)](#) reviewed the strengths and weaknesses of alternative approaches to FDF. Often, the move to REM systems has been motivated by the idea of replacing onboard observers for scientific sampling. While this can be sometimes challenging ([Wallace et al. 2013](#)), major progress is being achieved. In Scotland, a full monitoring programme estimating discards rates for six commercial species is being implemented ([Needle et al., 2015](#)). Automatic image recognition software is being developed to detect bycatch ([Kindt-Larsen et al., 2012](#)) and infer catch composition and length distribution from video footages ([Marine Management Organisation, 2013](#)). Newer and cheaper REM systems are available (e.g. another Danish trial launched in 2014 makes use of the REM technology developed by AnchorLab A/S, <http://www.anchorlab.dk/>). REM is proving to be an adequate tool, being considerably more cost-effective than observers if good coverage is required ([Kindt-Larsen et al., 2012](#); [Dinsdale, 2013](#)), especially after some years when the initial installation costs have been covered ([McElderry, 2014](#)). Its sustained use in European fisheries is nevertheless uncertain, both because the applicability of REM is more difficult for large fleets of small vessels, and because of the ethical questions that the system raises. [Mangi et al. \(2013\)](#) stated that fishers would potentially prefer using other methods such as reference fleets or self-sampling. On the contrary, some enquiries conducted by the Scottish authorities revealed a high degree of satisfaction from the fishers voluntarily involved in the trials ([Scottish Government, 2012](#)). In Denmark, gillnetters have been voluntarily entering FDF trials without any financial reward ([Kindt-Larsen et al., 2012](#)), being only motivated by the will to demonstrate that they have limited bycatches of harbour porpoise. Obviously, entering an FDF needs to make sense for the skipper to join. In such a voluntary trial, it is therefore difficult to disentangle incentives arising from the quota uplift from those arising from the FDF. In particular, it is interesting that four out of six vessels from the initial trial, who received a 100% quota premium did not continue when the premium reduced to 30%, while most of the vessels that joined after 2009 have remained in the trials since then. Also, one may think that the voluntary vessels are those already most likely to comply and keenest to collaborate with scientists. It is thus difficult to infer how FDF would work if it would become compulsory for all vessels, without a quota premium. Nevertheless, experiences in Canada and USA demonstrated that larger discard reductions had actually been achieved after that FDF became mandatory compared with the initial years when the system was voluntary ([McElderry, 2014](#)), because the system became more strictly enforced and included all vessels, also the less cooperative ones.

In Denmark, the REM system has not been developed as a possible replacement of scientific observers, but as a compliance tool oriented towards improved recording of logbook data. There is

thus scope for further scientific use of the data collected. The proper integration of FDF into the global national sampling scheme is not straightforward and requires specific focus. In retrospect, we realize that the status of the Danish FDF system has remained unclear, being considered a scientific trial but with national and EU-wide management implications. In such a case, it is important to clarify the distribution of responsibilities between the scientific and control institutions to ensure adequate quality proofing and use of the data (including, for example, storage and access to data, legal obligation to delete videos, choice of hauls to be monitored, estimation methods, coupling of FDF data with e-log information, etc.). Also, the daily follow-up and feedback process with the participating vessels must be carefully planned. Except for the two main cases reported above, limited action has been taken when discrepancies have been observed. Skippers have had concerns whether their data were of any use. Ultimately, the specific issue of Danish cod fisheries taking mainly place in Norwegian waters where different rules apply has been an additional factor of complexity and uncertainty. We have also observed the pros and cons of the basketting system, and the challenges for accurately estimating discards weight. In the Scottish trials, no basketting system is used, since skippers are not required to perform self-reporting. Discards are monitored on the band. The absence of cod discards is controlled, and at the same time, videos can be used to sample other species (Needle *et al.*, 2015). Interestingly, a more recent FDF trial run in the Netherlands (van Helmond *et al.*, 2015) combined self-reporting and discards estimated on the band rather than with baskets. Large discrepancies between the two estimates were observed, and difficulties to monitor from the video were reported. Basketting imposes additional burden to the crew, requiring sorting and manipulation of heavy charges. However, without basketting it is likely more difficult for the crew to visually estimate discard weight. Obviously, different options for FDF are possible, with different manners to make use of video data. It is therefore important to clarify the purposes and the protocols of the trials with the skippers to reach the desired balance between data quality and feasibility of the handling onboard.

This study has raised our awareness on such issues, which must now be addressed. Ways to improve the use of the REM system for further scientific purposes are now being explored. As a next step before full video-based monitoring and automatic recognition software, the combination of REM with self-sampling is to be trialled. In addition to reporting discards and using REM for the full documentation of the fisheries as presented here, fishers will be asked to bring to land the entire discarded portion of an entire haul following a statistical sampling scheme. The discards will be subsequently sorted out and measured at shore. If properly validated and controlled, this simple system would present a number of advantages, including (i) full census of discard data through 100% trip coverage in log-books reporting, (ii) less dependence on species recognition when observing footage, and (iii) biological sampling of discards at shore integrated at limited additional costs into the usual landings sampling programme. This alternative use of REM systems could thus represent a pragmatic and cost-effective approach combining control and monitoring purposes into one single programme, reaching a much larger coverage with the same financial resources. Nevertheless, it is evident that such a system requires a comprehensive and cohesive initial commitment of the industry, managers, and scientists before reaching these benefits, to ensure efficient and useful data flows.

In conclusion, the impression of these trials is positive, despite the technical and institutional challenges. The judicious combination of

CQM with full catch documentation where the burden of proof relies on the industry is a promising driver of change. Such a combination can create a decisive shift from a top-down control and command to a bottom-up results-based management system providing better monitoring, more accurate management and less waste. In the context of the incoming landing obligation in Europe, we observed from, for example, the UK trials that REM was even more suitable as a control tool when no discards are allowed. It is more difficult to monitor and control discards that need to be quantified and reported, rather than controlling that no discards take place (assuming that there are no blind spots). The next challenge is to consider the feasibility of the system when discarding of several species must be monitored closely. Mixed-fisheries REM trials have been in place for some time in the UK and are now also starting in Denmark. Some FDF vessels are already reporting discards for other species than cod. It appears possible, although not always practical, to extend the basketting system to a limited number of commercial species, knowing that the actual number of baskets that can be handled differs across vessels and fisheries. A more comprehensive use of the video data following the Scottish model is also promising. Based on our experience, we thus support the sustained use of REM to help implement and enforce the landing obligation policy.

## Acknowledgements

The Danish Ministry of Food, Agriculture and Fisheries and the European Fisheries Fund have funded the FDF trials since 2008. This support is gratefully acknowledged. The first author for this work was also financed by the EU FP7 projects SOCIOEC (grant agreement no 289192) and MYFISH (grant agreement no 289257). This publication reflects the views only of the authors, and neither the European Union nor Danish Ministry of Food, Agriculture and Fisheries cannot be held responsible for any use which may be made of the information contained therein. The authors are very grateful to the two referees and to the colleagues that have greatly helped improve this work and to all skippers who participated in the trials.

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Handling editor: Finbarr (Barry) O'Neill