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Final Report on Catch Quota Management and choke species – 2014

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Final Report on

Catch Quota Management and choke species – 2014

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Denmark and The EU invest in sustainable fishing.

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Ministry of Food, Agriculture and Fisheries

The European Fisheries Fund

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Introduction

In the former Common Fisheries Policy (CFP of 2002) of the European Union (EU), catches in the commercial fisheries were limited by the Total Allowable Catch (TAC) (Council of the European Union 2002; EU Commission 2009). TAC is defined as the quantity of catches that can be landed from stocks under quota each year. The European Council sets the TACs each year for individual stocks of fish or shellfish within the Member States of the EU. Since TACs are managed and controlled by the landed catches, any unreported catch not taken ashore will not be accounted for (Dalskov *et al.* 2012). Unwanted catches not taken ashore are thrown back into the sea during handling of the catch onboard commercial fishing vessels, a practice referred to as discarding (Jennings, Kaiser & Reynolds 2001a; Uhlmann *et al.* 2013).

In 2008 the Danish Government proposed that commercial fishing vessels of the EU should account for the total removal of fish from the stock instead of merely accounting for the TAC. This would shift quotas from being based on landings to be based on catches, also known as Catch Quota Management (CQM) (Dalskov, Håkansson & Olesen 2011). The European Council and the European Commission followed up on this proposal by issuing a Joint Statement in October 2009 which recommended trials and development on CQM together with full accountability, also referred to as Fully Documented Fisheries (FDF) (Dalskov & Kindt-Larsen 2009; Dalskov *et al.* 2011; Ulrich *et al.* 2013). Measures to achieve FDF include:

- Onboard observers
- Reference fleet
- Self-sampling
- At-sea control
- Remote Electronic Monitoring (REM) (Ulrich *et al.* 2015)

In 2010, the European Council made further provisions for conducting CQM with REM in COUNCIL REGULATION (EU) No 219/2010 of 15 March 2010 by 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 or to an amount which is justified as being capable of ensuring that there will be no increase in the fishing mortality of the cod stock,*
- *where a Member State detects that a vessel participating in the initiative is not complying with the above conditions, the Member State shall withdraw the additional catches granted to that vessel and exclude it from any further participation in this initiative."* (Council of the European Union 2010).

In December 2009, Danish national regulations for the establishment of a CQM project were issued and rules for participation in the project were finalized in February 2010. The first REM systems were installed on vessels in April and May 2010 (Dalskov *et al.* 2011). The REM system chosen for the trial were provided by the Canadian company Archipelago Marine Research Ltd. (Archipelago). Archipelago have provided REM systems for full documentation in an array of fisheries for several years (McElderry, Schrader & Illingworth 2003; Marine Management Organisation 2013a; b, 2014; Archipelago Marine Research Ltd. 2015).

The need for FDF has been further emphasized by the recent developments in the fisheries policy of the EU. The European Commission issued a Green Paper in 2009 which focused on the shortcomings of the CFP of 2002 (EU Commission 2009; Salomon, Markus & Dross 2014). The CFP of 2013 is meant to mitigate the shortcomings of the former CFP of 2002, amongst other incentives, by introducing the Landing Obligation (LO) which will change the management of European fisheries from being based on landings to be managed on actual catches (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014). Two consequences of a LO will be examined on this report:

1. In order to verify compliance with the LO, fisheries need to be fully documented by one or more of the previously mentioned management tools (Ulrich *et al.* 2015[1]). This report will assess the use of a REM system to fully document fisheries in the project conducted from 2010 to 2014 by DTU Aqua and the Danish AgriFish Agency, referred to as the CQM trial henceforth.
2. Mixed fisheries risk depleting the TAC for certain species of fish faster than for other species. These species – generally termed as “choke species” – risk stopping fishing activities for remaining TACs due to the risk of unintentionally catching more of the choke species, which would be illegal to land when the TAC for that species is depleted and which under a LO cannot be discarded (Hatcher 2013; Sigurðardóttir *et al.* 2015). This report will assess the risk for certain fish species to become choke species under a LO for mixed demersal fishing in the North Sea and Skagerrak.

[1] Appendix 5; peer reviewed article using data from the CQM trials

Brief Overview of the Common Fisheries Policy of 2013

The CFP of 2013 is in line with overall principles of managing all commercial fishing activities conducted by EU fishing vessels at EU level and delegating enforcement and control to Member States (Salomon *et al.* 2014). Article 1 in the CFP of 2013 states that the CFP applies to all waters covered by the Treaty of the European Union, including vessels under a third country flag operating in these waters. Additionally, all fishing vessels under flag of a Member State of the EU are covered by the CFP whether or not the vessel operates in EU waters (European Parliament and Council of the European Union 2013). The main management instrument of the CFP is the setting of TACs, which has to be set in order to achieve an exploitation rate at the maximum sustainable yield (F_{MSY}) by 2015. If this target seriously endanger the social and economic sustainability of the fisheries, the timeframe for achievement of F_{MSY} can be extended to 2020 (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014). In Article 9 multiannual plans based on scientific, technical and economic advice are stressed as effective tools to achieve the target on F_{MSY} (European Parliament and Council of the European Union 2013). The Landing Obligation (LO) is specified in Article 15. The gradual introduction of the LO began 1 January 2015 and all vessels and waters covered by the CFP are subject to the LO by 1 January 2019 (European Parliament and Council of the European Union 2013). All species with a TAC will be covered by the LO making it illegal to discard these species. Exemptions for the LO are:

- Species not under a TAC. Article 15 do allow for Member States to submit a Joint Recommendation for expanding the LO to other species otherwise not covered.
- Species prohibited from fishing.
- Species which, according to scientific advice, have a high survival rate after discarding.
- Catches falling under the *de minimis* exemptions. The *de minimis* exemptions apply if there is scientific advice stating that increased selectivity for the given fishery is very difficult to achieve. Discard ratios of 7% in 2015 and 2016, 6% in 2017 and 2018 and 5% from 2019 are acceptable for fisheries that are covered by the *de minimis* exemptions (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014).

No specific requirements are stated in Article 15, in order to ensure compliance with the LO, although it is specified that Member States shall ensure documentation of all fishing trips. Methods to ensure this documentation are listed as observers, CCTV and (literally) "others" (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014). Article 15 allow Member States the possibility to derogate from their annual quota by 10% on a year-to-year basis in order to ensure flexibility (additional landings from one year will then be deducted from the given Member State's TAC in the following year) and to derogate from the obligation to count catches against quota if the Member State has no quota on the species. The last exemption only apply if the species in question is a non-target species that is assessed to be within safe biological limits in that area (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014).

Specifics for the restriction on fisheries in order to ensure Member State compliance with obligations under the Habitat Directive 92/43/EEC, the Birds Directive 2009/147/EU and the Marine Strategy Framework Directive 2008/56/EC are given in Article 11 of the CFP. In short, Member States can restrict fishing activities for own nationals. If restrictions to ensure conservations obligations affect other Member States' fisheries, a recommendation together with scientific information can be

presented to the European Commission which can then adopt the conservation measure if deemed justified (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014). Adjustment of the fleet capacity in the EU and the possible implementation of Individual Transferable Quotas (ITQs) are specified in Article 22 and Article 21. Article 21 on ITQs do not go in to any specifics but merely states that:
"Member States may establish a system of transferable fishing concessions. Member States having such a system shall establish and maintain a register of transferable fishing concessions." (Article 21, European Parliament and Council of the European Union 2013).

Article 22 states that Member States shall ensure measures to adjust their fishing capacity over time and ensure that their fishing capacity do not exceed the limits set in Annex II of the CFP by 1 January 2014. Member States are obliged to send a report on fishing capacity compared to TACs to the European Commission on a yearly basis. If it is evident from such a report that fishing capacity exceeds the TAC, the Member State must produce an action plan to adjust the fishing capacity. Finally, any lowering in fishing capacity by removal of fishing vessels with public funds must remain at the new lower level. In other words, no replacement of the terminated vessel is allowed to take place (European Parliament and Council of the European Union 2013; Salomon *et al.* 2014). In Article 7 of the CFP a number of measures for sustainable exploitation of the marine resources are listed (European Parliament and Council of the European Union 2013). For the full list of measures, please see Appendix 4.

Description of the Project

Objectives

The project aims at assessing Catch Quota Management (CQM) in combination with full catch documentation by Remote Electronic Monitoring (REM) and Closed Circuit Television (CCTV) as a management tool.
Furthermore the project aims at assessing the risk for certain species to act as choke species under a Landing Obligation (LO) for mixed demersal fishing in the North Sea and Skagerrak.

Participating Vessels

RI 427 Mette Helene 	Homeport: Hvide Sande Vessel type: Trawl Building year: 2009 Length over all: 26.50 m BT: 243 Entered project: 2010 Ended project:2014
HM 127 Karen Nielsen 	Homeport: Hanstholm Vessel type: Trawl Building year: 2002 Length over all: 29.95 m BT: 274 Entered project:2011 Ended project:2014
RI 468 Juli-Ane 	Homeport: Hvide Sande Vessel type: Trawl Building year: 2000 Length over all: 23.95 m BT: 209.8 Entered project:2010 Ended project:2014
FN 226 Andrea Klitbo	Homeport: Østerby Havn Vessel type: Trawl

	Building year: 1986 Length over all: 35.40 m BT: 314 Entered project:2010 Ended project:2014
HM 555 Kingfisher 	Homeport: Hanstholm Vessel type: Trawl Building year: 2007 Length over all: 31.25 m BT: 467 Entered project:2010 Ended project:2014
HM 128 Borkumrif 	Homeport: Hanstholm Vessel type: Trawl Building year: 2001 Length over all: 27.75 m BT: 295 Entered project:2011 Ended project:2014
HG 306 Tobis 	Homeport: Hirtshals Vessel type: Trawl Building year: 2009 Length over all: 39.95 m BT: Entered project:2010 Ended project:2014

HM 228 Pondus 	Homeport: Hanstholm Vessel type: Trawl Building year: 1982 Length over all: 27.95 m BT: 230 Entered project:2011 Ended project:2014
HM 635 Karbak 	Homeport: Hanstholm Vessel type: Trawl Building year: 1999 Length over all: 28.30 m BT: 397 Entered project:2011 Ended project:2014
HM 423 Fru Middelboe 	Homeport: Hanstholm Vessel type: Trawl Building year: 1983 Length over all: 20.35 m BT: 86,1 Entered project:2011 Ended project:2014
HG 352 Polaris 	Homeport: Hirtshals Vessel type: Trawl Building year: 2003 Length over all: 23.50 m BT: 173.3 Entered project:2011 Ended project:2014

L 447 Jane Kynde 	Homeport: Thyborøn Vessel type: Danish seine Building year: 1969 Length over all: 20.26 m BT: 56.4 Entered project:2011 Ended project:2014
L 423 Karen Margrethe 	Homeport: Thyborøn Vessel type: Danish seine Building year: 1960 Length over all: 18.90 m BT: 53.6 Entered project:2011 Ended project:2014
L 620 Austria 	Homeport: Thyborøn Vessel type: Danish seine Building year: 1959 Length over all: 18.30 m BT: 58.5 Entered project:2011 Ended project:2014
T 247 Sandy 	Homeport: Hanstholm Vessel type: Gillnet Building year: 1988 Length over all: 11.00 m BT: 10.1 Entered project:2011 Ended project:2014

HG 5 Skovsmose	Homeport: Hirtshals
	Vessel type: Gillnet Building year: 1988 Length over all: 11.99 m BT: 7.7 Entered project:2012 Ended project:2014

Note that the number of participating vessels was 5 in 2010, compared to 15 from 2012 and 16 from 2012 and on. Additionally video recording began during April and May for vessels entering the project in 2010.

Technical Setup

In all, 16 vessels operating in the North Sea and Skagerrak participated in the project until 2014. Of these 11 were demersal trawlers, three were Danish seiners and two were gillnetters. From these 16 vessels, 5356 video sequences were audited by video inspectors from 2010 to 2014.

All five vessels participating in 2010 were demersal trawlers, in 2011 11 of the participating vessels were demersal trawlers, three were Danish seiners and one was a gillnetter, making the total number of participating vessels 15. In 2012 the last vessel (a gillnetter) joined, bringing the total number of participating vessels to 16.

The system used for video based REM in the trial was developed by Archipelago Marine Research Ltd., Victoria, BC, Canada. The system has been used in different fisheries in a number of areas (McElderry *et al.* 2003; Marine Management Organisation 2013a; b, 2014; Archipelago Marine Research Ltd. 2015) The system had previously been chosen by DTU Aqua in pilot projects carried out from 2008 to 2010, where its reliability had been tested (Dalskov & Kindt-Larsen 2009; Dalskov *et al.* 2011).

The REM system consists of hydraulic pressure transducers, GPS, photoelectric drum rotation sensors and four television cameras (CCTV). Cameras were placed at locations on the vessel were they provided an overhead view of the stern and aft deck as well as views of the catch handling areas. Depending on the individual vessels the placing of the three cameras for view of catch handling areas differed, since camera placing had to be balanced between optimal view of catch handling and practical issues such as space and minimum interference with fishing crew operations. At least one camera was always situated to view specifically for the discard chute in order to give optimal video data for identification and quantification of discards. A control box consisting of a computer to monitor sensor status and activate image recording was located in the wheelhouse. Here it received input from cameras and sensors and stored the data onto a hard drive. Figure 1 depicts a sketch of the REM system onboard participating vessels.

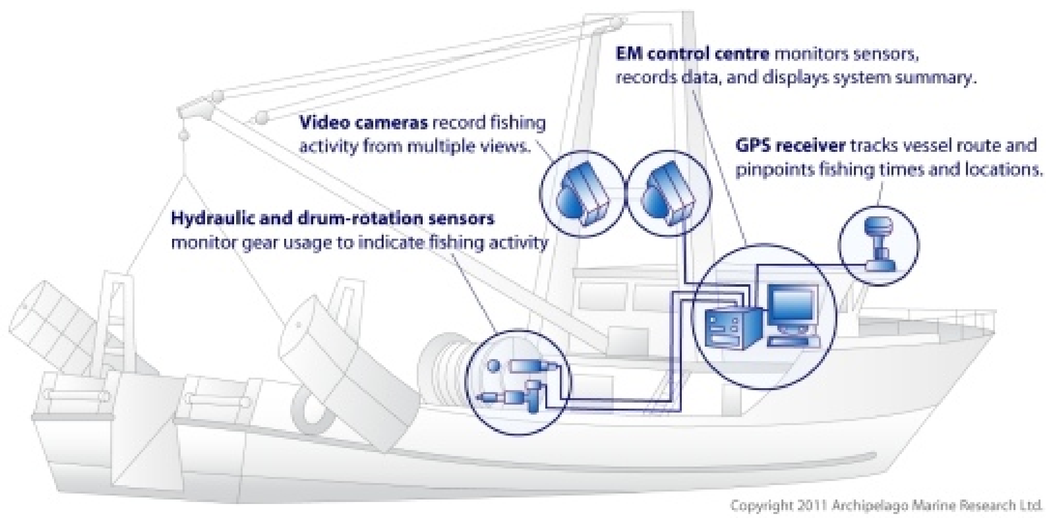


Figure 1. Schematic of the REM system provided by Archipelago Marine Research Ltd.

Conditions for Participation in the CQM Trial

Vessels participating in the trial were obliged to have the REM system with CCTV described above installed onboard, as well as reporting all catches and discards of cod in the electronic logbook on a haul to haul basis. All catches of fish, under TAC and above the minimum landing size (MLS), had to be landed, whereas catches of fish below the MLS could be discarded. Discard of catches had to be done at sites where the CCTV could record the discards adequately. If a vessel depleted its TAC on a species it had to either cease fishing or lease or buy additional quota from another vessel. The setting and hauling of gear had to be registered in the electronic logbook on a haul to haul basis. All participating vessels, including those with a length below 12 meters, had to carry a VMS system. System breakdowns or other malfunctions, be it of the REM system, the electronic logbook or the VMS system, had to be reported immediately to the Danish AgriFish Agency. A daily functionality test of the REM system should be carried out and camera lenses should be cleaned whenever necessary. Any blocking of camera view was prohibited and adequate free capacity on the onboard hard drives had to be ensured before commencement of a fishing trip (Dalskov *et al.* 2012).

Data Handling and Analyses

Hard drives containing video and sensor data were collected on participating vessels when in port, by staff from the Danish AgriFish Agency. Hard drives were sent to the Danish AgriFish office in Copenhagen where video and sensor data was transferred and stored on a server. All sensor data was analyzed to determine all transits, gear settings and gear retrievals conducted by vessels. The analysis was used to infer start and end of each fishing trip and fishing event conducted by the given vessel. Two types of analyses were conducted depending on whether or not the given vessel had fishing events in Norwegian waters. Due to the Norwegian ban on discards, all unwanted catches must be stored onboard. Since discarding was legal in EU waters during the trial, vessels operating in Norwegian waters could discard unwanted catches from Norwegian waters upon entry into EU waters. In order to account for these discards it was necessary to analyze all transits from Norwegian waters back into EU waters. The two types of analyses were:

- Catch processing – Ten percent of fishing hauls were selected for further analysis of the video recordings, whereby discards were estimated for the specific fishing event on a haul by haul basis.
- Compliance with Norwegian discard regulations – Each fishing trip with one or more fishing events taking place in Norwegian waters were audited to account for any unwanted catches stored onboard the vessel that were discarded upon vessel returning to EU waters.

Activities and discards were compared with the recordings in the electronic logbook. All interpretation of sensor and video data were done using the computer software developed by Archipelago Marine Research Ltd.

Results of the analyses of sensor and video data were stored for further analyses by DTU Aqua. In addition to the above mentioned data collection, a supplementary trial was performed in the first six months of 2015 to elaborate further on choke species (henceforth termed the Choke Species trial). The camera systems and software used in the Choke Species trial were developed and provided by the Danish company Anchor Lab K/S (www.anchorlab.dk). As in the CQM trial, camera placements in the Choke Species trial were done to give optimal view of the catch handling and processing areas. The system provided by Anchor Lab K/S could support up to 6 cameras. Recording was activated when the vessel left port and the recorded data was stored in a local control box onboard the vessel. Upon return to port from the fishing trip, the recorded data was sent via 3G network to a server at DTU Aqua.

Audit of the recorded data was done with the software Black Box Analyzer, provided by Anchor Lab K/S. After identification of hauls and catch processing's, video inspectors estimated the discarded amount of fish. Participating vessels were obliged to sort discards into baskets and each basket had to contain only one species. Video inspectors estimated the discarded amount of each species by estimation of the number of baskets and based on how full the individual baskets were. Since the weight of a full basket was known for the species, the weight of the discards could be inferred from the number of discarded baskets. Three vessels (all demersal trawlers) from the CQM trial were participants the Choke Species trial. Results from the Choke Species trial presented in this report are based on data from these three vessels. This corresponds to 321 catches.

Result of the Trials

Video Sequence Errors

During the trial from 2010 to 2014, a total number of 5356 video sequences from the participating vessels were audited by viewers. 661 of these video sequences were reported to have an error, corresponding to 12.3% of the total audited video.

Audited video sequences can be divided between video sequences of catch processing's and video sequences to assure compliance with regulations for discards in Norwegian waters. For video sequences of catch processing's, a total of 3832 video sequences were audited and 516 of these were reported to have an error, corresponding to 13.5% of the video sequences. For video sequences on compliance with Norwegian discard regulations, a total of 1524 video sequences were audited and 145 of these were reported to have an error, corresponding to 9.5% of the video sequences (see Appendix 1 for a full list of reported video sequence errors).

The four major types of errors reported by video inspectors were:

- Blurry video recording, which potentially affected estimates made by video inspector.
- Dirt on camera, which potentially affected estimates made by video inspector.
- Water droplets on camera, which potentially affected estimates made by video inspector.
- Video lost.

These four error types account for 68.2 % of reported errors. Except for the error type "Video lost", assessment is still possible for video sequences with these errors, although estimates may be influenced by the degraded picture quality.

Overall the error types occurring can be divided into three categories:

- Error affects the discard estimate making the viewed estimate less reliable.
- Error makes video inspector unable to estimate discards.
- Error does not affect discard estimate.

Table 1 summarizes the number of errors for these three categories and the percentage of the total video sequence errors that each error category represents.

Table 1. Number of video sequence errors and percentage of total video sequence errors for the three overall error categories

Error effect	Number of errors	Percentage of total errors
Affects discard estimate	457	69.1
Unable to assess discards	203	30.7
Discard estimate unaffected by error	1	0.2

Average numbers of video sequences with errors per vessel from 2010 to 2014 for both video sequences of catch processing's and video sequences to assure compliance with Norwegian discard regulations are presented in table 2. Note that the number of participating vessels was five in 2010, compared to 15 from 2011 and 16 from 2012 and on. Additionally, video recording began during April and May for vessels entering the project in 2010.

Table 2. Average number of video sequence errors per vessels per year.

Type of video sequence	Year	Average number of video sequence errors per vessel
Catch processing	2010	8.3
Catch processing	2011	13.0
Catch processing	2012	7.0
Catch processing	2013	8.4
Catch processing	2014	2.6
Discard from Norwegian waters	2010	6.8
Discard from Norwegian waters	2011	3.8
Discard from Norwegian waters	2012	2.6
Discard from Norwegian waters	2013	2.3
Discard from Norwegian waters	2014	0.6

The average number of video sequence errors per vessel changed during the project period. Figure 2 present the number of video sequence errors per vessel with a trend line for the change in video sequence errors for catch processing's.

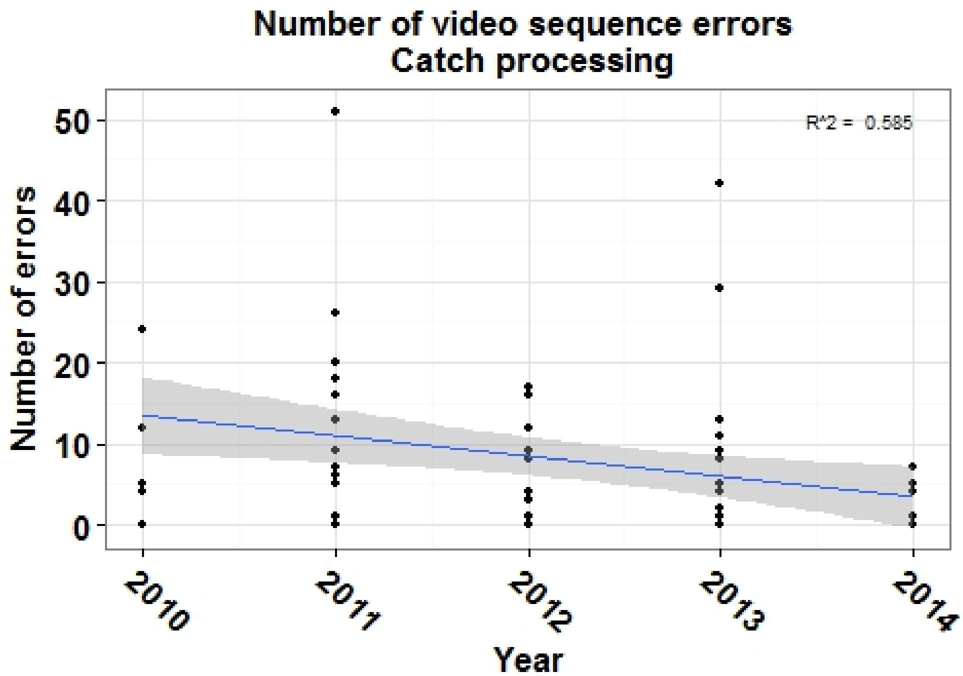


Figure 2. Number of video sequences with errors per vessel from 2010 to 2014 with trend line (blue) for number of errors and standard deviation (grey). Each dot represents the total number of errors for a specific vessel the given year. Residual standard error: 7.282 on 51 degrees of freedom. F-statistic: 4.5 on 16 and 51 DF, p-value: $2.0*10^{-5}$

Figure 3 present the number of video sequence errors per vessel with a trend line for the change in video sequence errors for discards from Norwegian waters.

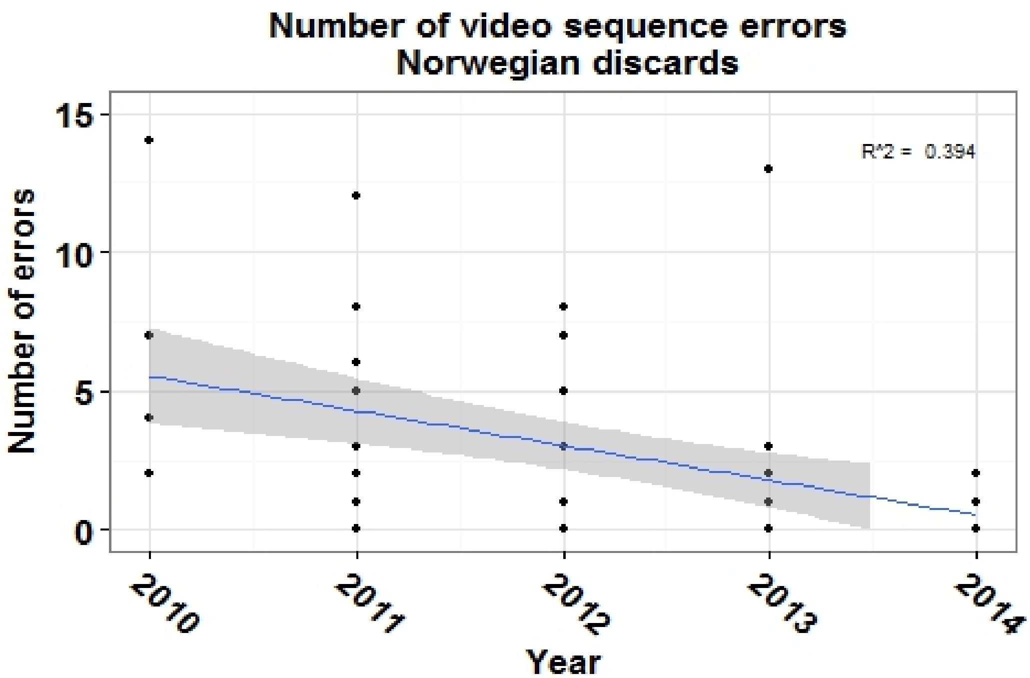


Figure 3. Number of video sequences with errors per vessel from 2010 to 2014 with a trend line (blue) for the number of errors and standard deviation (grey). Each dot represent the total number of errors for a specific vessel the given year. Residual standard error: 3.075 on 40 degrees of freedom. F-statistic: 2.2 on 13 and 40 DF, p-value: $3.0*10^{-2}$

For both video sequences of catch processing's and discards from Norwegian waters, the trend lines indicate that the number of video sequences with errors decline from the onset of the project to the end of the project.

During the timeframe of the project five video inspectors left the project and seven video inspectors entered the project. The change in video inspector staff was generally gradual with no major change in staff from one year to another. One video inspector audited video footage throughout the entire project period from 2010 to 2014.

Discard Estimates

Video Inspector Estimates and Self-Reported Estimates from Electronic Logbook

A comparison between total estimated discards of cod during catch processing's made by video inspectors and reported in the electronic logbook can be seen in figure 4.

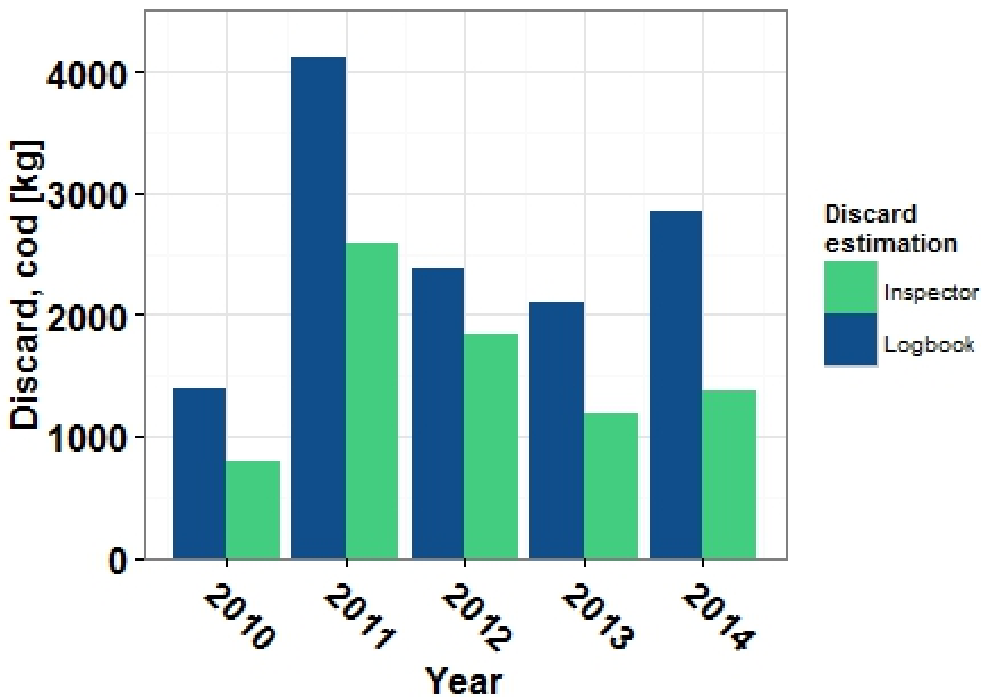


Figure 4. Total discard estimates of cod for all participating vessels in the North Sea and Skagerrak by video audit and logbook, catch processing's. n = 3680 catch processing's.

Estimation of cod discards reported in the electronic logbook is as a whole larger than the summed estimation of cod discards made by video inspectors for each year. Note that the increase in total mass of discarded cod from 2010 to 2011 mainly is a result of the increase in vessels participating in the project from 2010 (five vessels) to 2011 (15 vessels).

The amount of discarded cod varies greatly between individual hauls. Figure 5 shows the estimate of discarded cod for video inspectors compared to the amount reported in the electronic logbook for all catch processing's of all vessels during all years of the project.

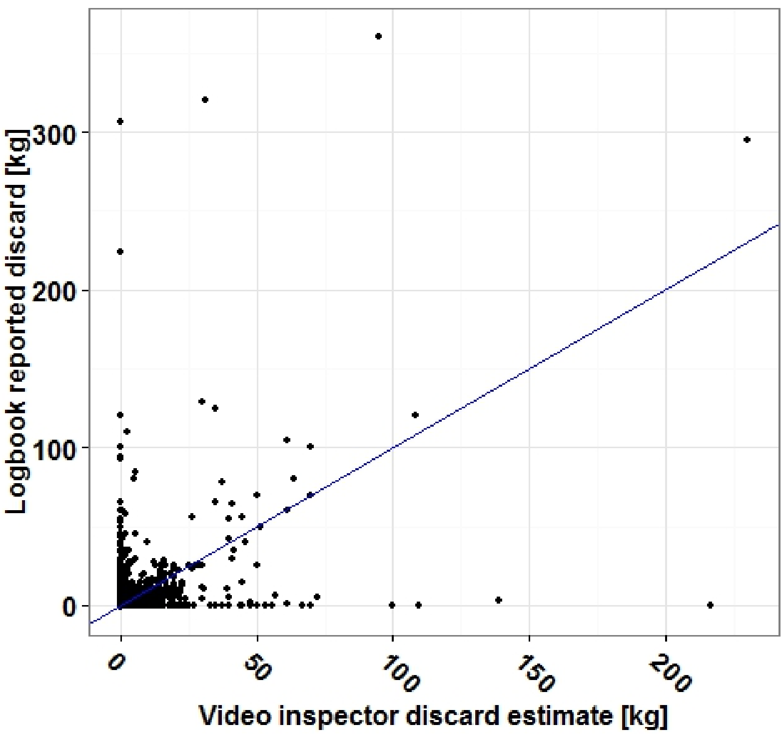


Figure 5. Video inspector and reported estimate of cod discard for all catch processing's of all vessels, 2010-2014. Blue line represent the 1 to 1 ratio. n = 3680 catch processing's.

The bulk of reported cod discards are less than 50 kg per haul but estimates by video audit of more than 200 kg occur and amounts above 300 kg have been reported in the electronic logbook. From the figure it can also be seen, that hauls were video inspectors report discards of cod, despite zero discards reported in the electronic logbook occur on a number of occasions. The reverse, were fishermen report discards of cod in the electronic logbook but video inspectors do not see any cod discards also occur on a number of occasions. Table 3 summarize the average difference and standard deviation between reported discards of cod in the electronic logbook and the estimated discards of cod made by video inspectors for all catch processing's during all years and individual years. An average above zero corresponds to a higher average in the electronic logbook than estimated by video inspector and vice versa. For the difference between estimated cod discard made by video inspectors and reported in the electronic logbook on a haul by haul and year to year basis, please go to Appendix 2.

Table 3. Average estimate of cod discards, average difference and standard deviation between reported discards of cod in the electronic logbook and the estimated discards of cod made by video inspectors for all catch processing's, 2010-2014.

Year	Number of catch processing's audited	Average discard of cod per haul, estimated by video inspector in kg	Average discard of cod per haul, reported in the electronic logbook in kg	Average difference between video inspector and electronic logbook in kg	Standard deviation in kg, difference between video inspector and electronic logbook
All years	3680	2.1	3.5	1.4	13.5
2010	241	3.3	5.8	2.4	34.1
2011	906	2.9	4.5	1.7	12.7
2012	841	2.2	2.8	0.7	8.1
2013	781	1.5	2.7	1.2	11.8
2014	911	1.5	3.1	1.6	9.4

The above discard estimations of cod do not cover the unwanted catches stored onboard in Norwegian waters and discarded upon return to EU waters. A comparison between total discards of cod that were discarded upon return to EU waters, estimated by video inspectors and reported in the electronic logbook, can be seen in figure 6.

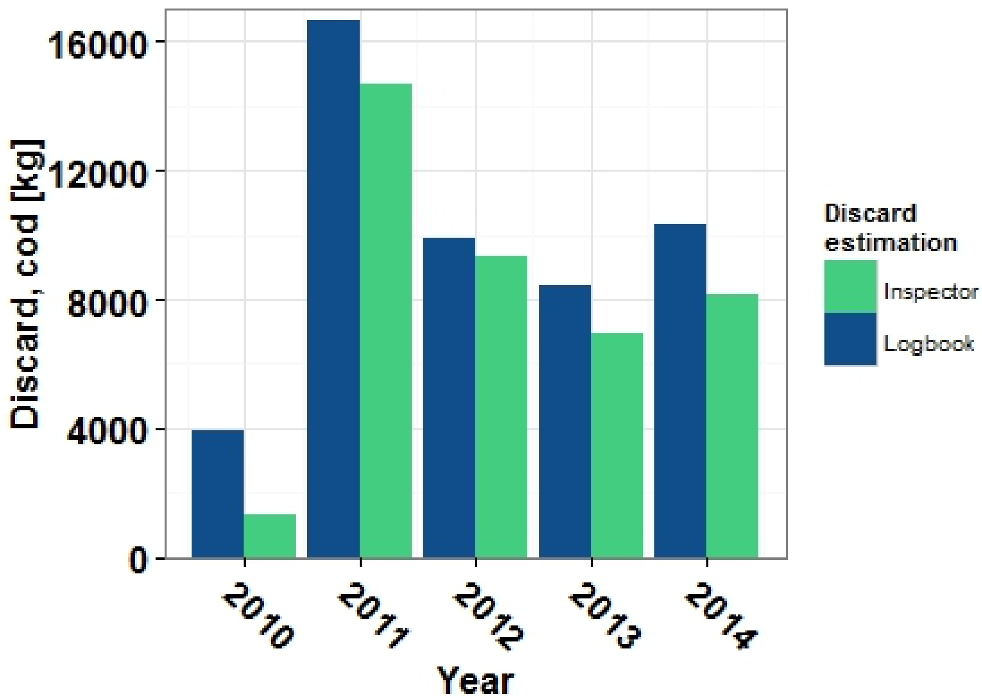


Figure 6. Total discard estimates of cod for all participating vessels by video audit and logbook, compliance with Norwegian regulations on discards. n = 1455 fishing trip ends.

Estimation of cod discards reported in the logbook is as a whole larger than the summed estimation of cod discards made by video inspectors for each year. Note that the increase in total mass of discarded cod from 2010 to 2011 mainly is a result of the increase in vessels participating in the project from 2010 (five vessels) to 2011 (15 vessels). Since estimation of unwanted catches stored onboard in Norwegian waters and discarded upon return to EU waters had to be done on a trip by trip basis, it is not possible to calculate the average discards per haul for two reasons:

A. Video inspectors could see catches being stored. However it was not possible to see whether or not a specific load of fish were to be discarded upon return to EU waters or were to be landed, since the storage for both were often the same.
B. Unwanted catches discarded upon return to EU waters had to be reported in the electronic logbook as a total sum at the time of return to EU waters. Otherwise Norwegian at-sea fisheries inspectors might believe that the fish had been discarded at the time entered into the electronic logbook and that the vessel therefore had violated the Norwegian discard ban.

The amount of discarded cod varies greatly between individual fishing trips. Figure 7 shows the estimate of discarded cod after return to EU waters done by video audit compared to the amount reported in the electronic logbook for all fishing trips of all vessels fishing in Norwegian waters during all years of the project.

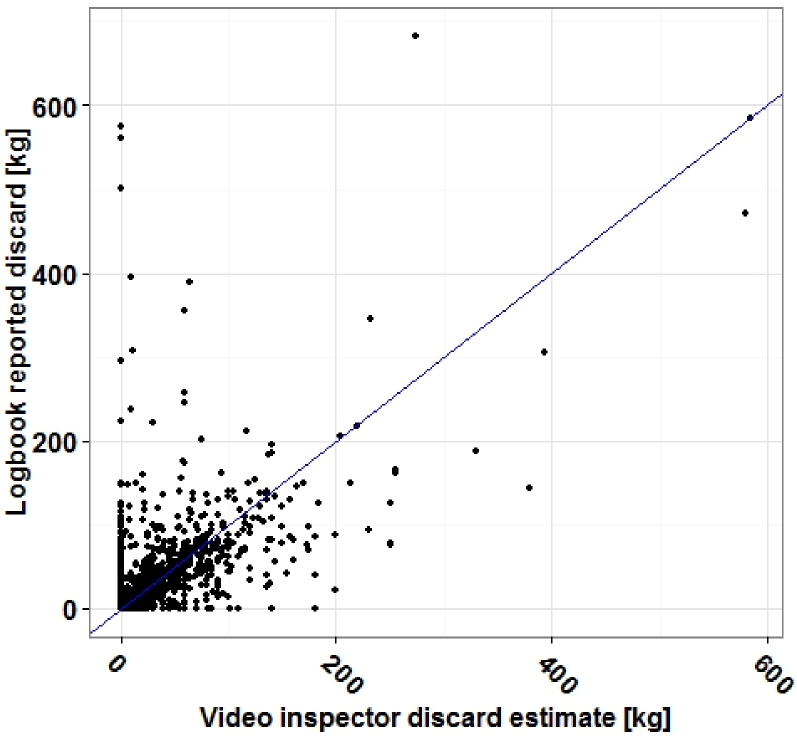


Figure 7. Video inspector and reported estimate of cod discard for all fishing trips in Norwegian waters after return to EU waters for all vessels, 2010-2014. Blue line represents the 1 to 1 ratio. n = 1455 trip ends

The bulk of reported cod discards are less than 100 kg per haul but estimates by video audit of more than 500 kg occur and amounts above 600 kg have been reported in the electronic logbook. From the figure it can also be seen, that hauls were video inspectors report discards of cod, despite zero discards reported in the electronic logbook occur on a number of occasions. The reverse, were fishermen report discards of cod in the electronic logbook but video inspectors do not see any cod discards also occur on a number of occasions. Table 4 summarize the average difference and standard deviation between reported discards of cod in the electronic logbook and the estimated discards of cod made by video inspectors for all fishing trips after return to EU waters during all years and individual years. An average above zero corresponds to a higher average in the electronic logbook than estimated by video inspector and vice versa. For the difference between estimated cod discard after return to EU waters, made by video inspectors and reported in the electronic logbook on a trip by trip and year to year basis, please go to Appendix 3.

Table 4. Average estimate of cod discards, average difference and standard deviation between reported discards of cod in the electronic logbook and the estimated discards of cod made by video inspectors for all fishing trips after return to EU waters, 2010-2014.

Year	Number of trip ends audited	Average discard of cod per trip, estimated by video inspector in kg	Average discard of cod per trip, reported in the electronic logbook in kg	Average difference between video inspector and electronic logbook in kg	Standard deviation in kg, difference between video inspector and electronic logbook
All years	1455	27.8	33.8	6.0	48.4
2010	87	15.4	44.6	29.2	104.1
2011	352	41.7	47.4	5.6	68.3
2012	349	26.8	28.4	1.6	24.1
2013	344	20.2	24.5	4.3	28.7
2014	323	25.2	32.1	6.8	30.4

Although the target species for this project was cod, video inspectors also made estimation on the discard of other species. This estimation was made as a whole, meaning that all other species seen discarded were grouped as one entity. Other species therefore cover a whole range of species, from those close to cod in appearance (gadoid species like whiting or haddock) to completely different species (like plaice, dogfish or rays). A comparison between total estimated discards of other species than cod made by video inspectors and reported in the electronic logbook can be seen in figure 8.

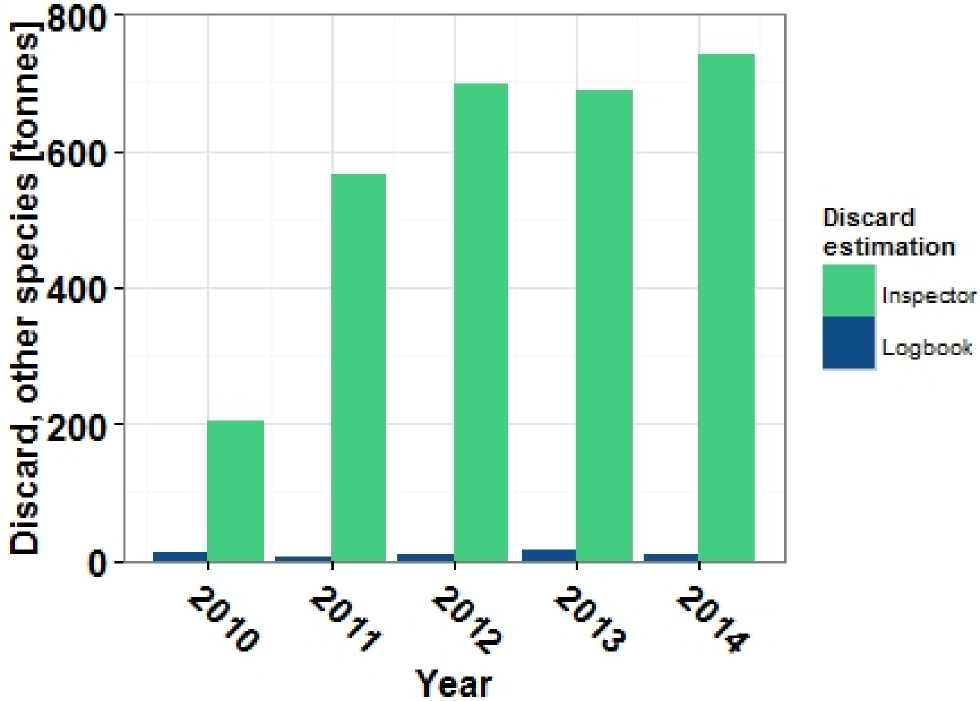


Figure 8. Total discard estimates of other species than cod for all participating vessels North Sea and Skagerrak by video audit and logbook, catch processing's. Note that y-axis unit is in tonnes. n = 3548 catch processing's.

Estimation of discards of other species than cod is markedly higher for video inspectors than reported in the electronic logbook.

Discard Ratio

The discarded amounts presented above should be considered together with the catches. Due to the Norwegian regulations on discards it is not possible to accurately connect the specific discards to specific catches via the electronic logbook. The following figures are therefore based solely on the estimated discards of cod and reported catches of cod in the EU waters of the North Sea and Skagerrak.

An overview of the average discard ratios of cod made by video inspectors and reported in the electronic logbook can be seen in figure 9.

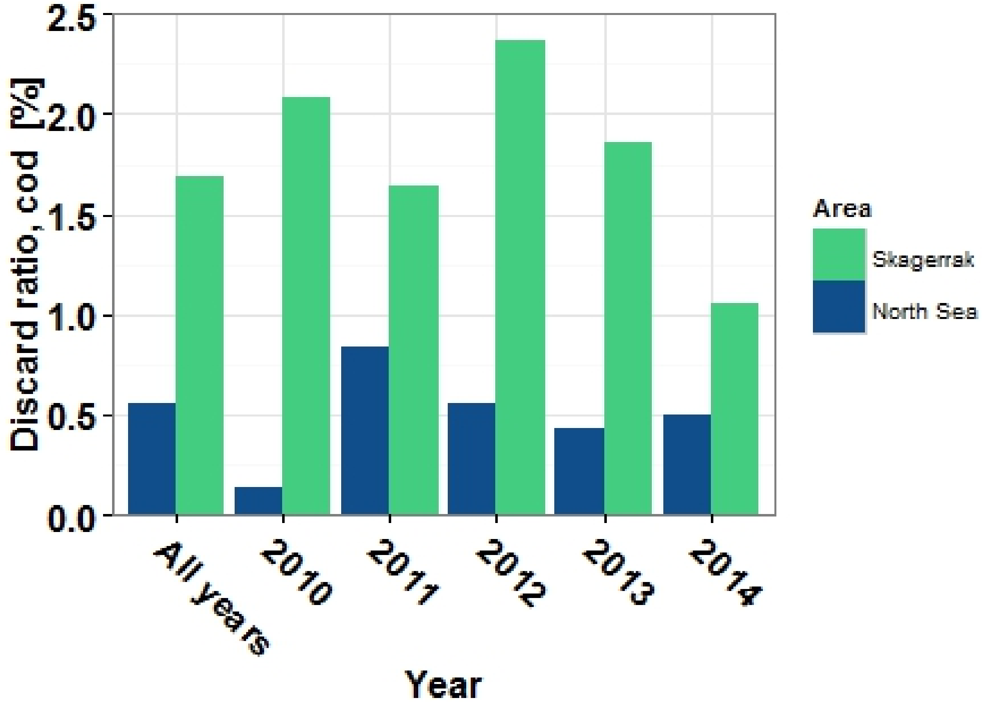


Figure 9. Average discard ratio of cod per year for Skagerrak and the North Sea, all vessels fishing in the respective area. All years represent the total average from 2010 to 2014. $n_{North\ Sea}$ = 512 catch processing's, $n_{Skagerrak}$ = 594 catch processing's.

The average discard ratio of cod is larger for Skagerrak than the North Sea throughout all years. The largest average discard ratio of cod occurred in Skagerrak in 2012 at 2.4%. The lowest discard ratio occurred in the North Sea in 2010 at 0.1%. Figure 9 is for all vessels participating in the project, when fishing in the EU areas of the North Sea and Skagerrak. The discard ratio solely for participating demersal trawlers can be seen in figure 10.

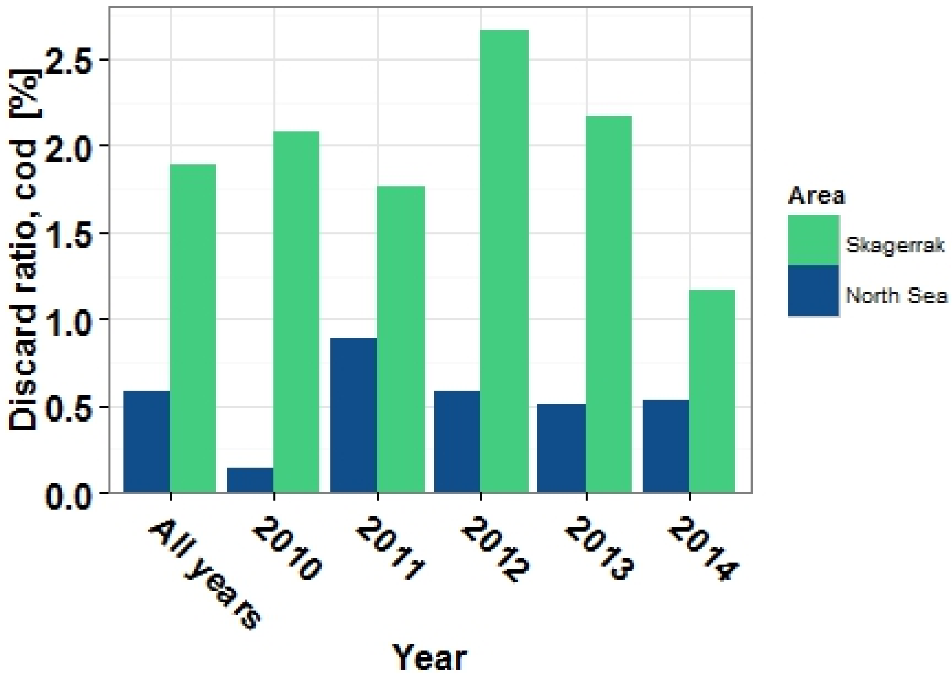


Figure 10. Average discard ratio of cod per year for Skagerrak and the North Sea, demersal trawlers fishing in the respective area. All years represent the total average from 2010 to 2014. $n_{North\ Sea}$ = 414 catch processing's, $n_{Skagerrak}$ = 561 catch processing's.

Average discard ratios for demersal trawlers are almost the same as for all vessels, albeit slightly larger. There are several reasons for this. Firstly, demersal trawlers constitute 11 vessels out of a total of 16 participating vessels and in 2010 all five participating vessels were demersal trawlers. Secondly, participating demersal trawlers by far have the greatest number of hauls in the EU waters of the North Sea and Skagerrak compared to participating Danish seiners and gillnetters. This is evident from table 5 were number of hauls in the EU part of the North Sea and Skagerrak is summed for demersal trawlers, Danish seiners and gillnetters, together with the respective average discard ratio of cod.

Table 5. Number of hauls in the EU areas of the North Sea and Skagerrak for demersal trawlers, Danish seiners and gillnetters

Gear type	Number of hauls in the EU part of the North Sea, 2010-2014	Number of hauls in the EU part of Skagerrak, 2010-2014	Average discard ratio of cod, North Sea	Average discard ratio of cod, Skagerrak
Demersal trawlers	414	561	0.6 %	1.9 %
Danish seiners	84	3	0.1 %	0 %
Gillnetters	28	30	0.2 %	0 %

A comparison between the discard ratio of cod estimated by video audit and by onboard observers for demersal trawlers in the North Sea is presented in figure 11. Only data from the North Sea is shown, due to low quantities of onboard observer data from Skagerrak.

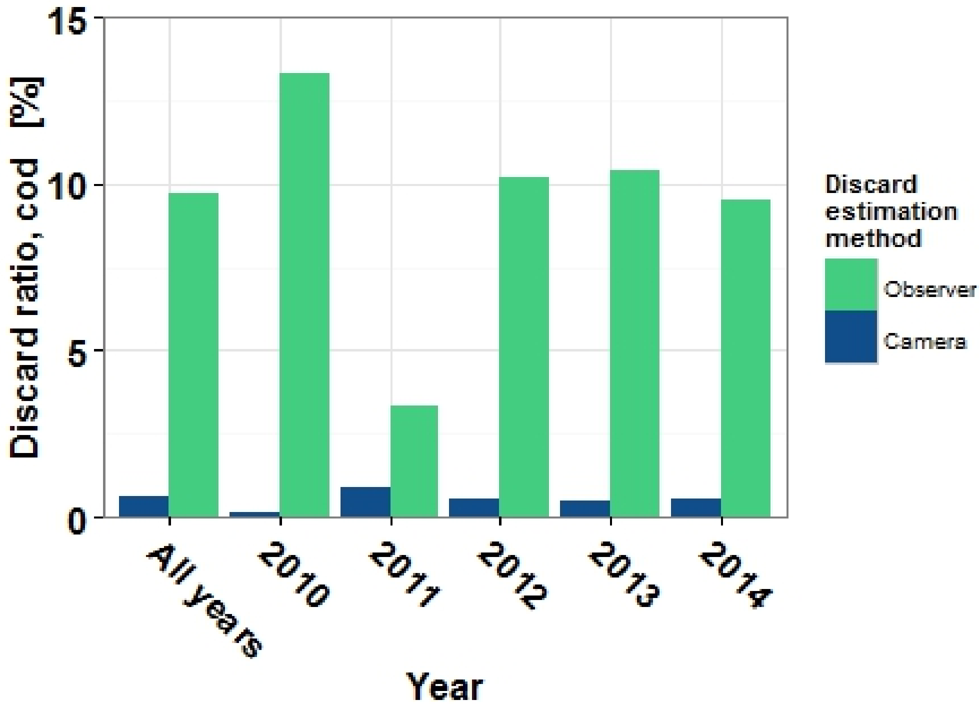


Figure 11. Discard ratio for cod per year in the North Sea estimated by REM system with CCTV and onboard observer. All years represent the total average from 2010 to 2014. n_{camera} = 414, $n_{observer}$ = 1175.

The total discard ratios are higher for estimations done by onboard observers than for estimations done by video audit for all years, both individually and as a total. Since the above numbers are based on all onboard observations in the North Sea, the discard ratios estimated by onboard observers cover both vessels participating in the CQM trial and non-participating vessels. To explore the discrepancy further, figure 12 show a comparison between the discard ratio of cod estimated by video audit and by onboard observers, solely for demersal trawlers in the North Sea, which have onboard observers while simultaneously having REM with CCTV onboard.

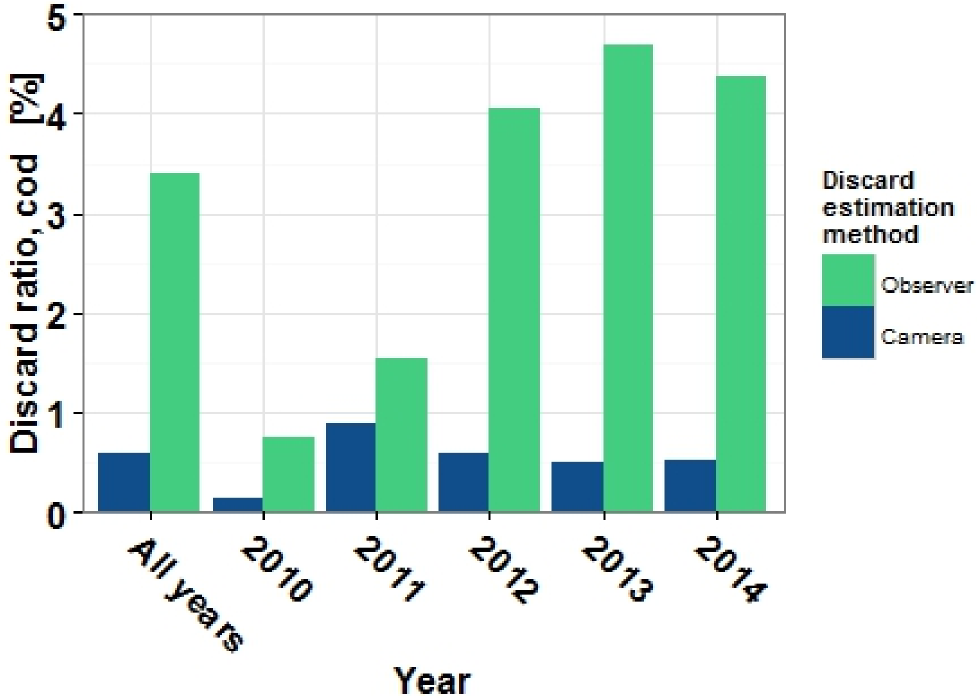


Figure 12. Discard ratio for cod per year in the North Sea estimated by REM system with CCTV and onboard observer. All years represent the total average from 2010 to 2014. n_{camera} = 414, $n_{observer}$ = 575.

The total estimated discard ratios calculated from onboard observer data are lower when solely looking at data from demersal trawlers participating in the CQM trial. The discard ratios calculated from onboard observer data are still higher compared to discard ratios calculated on the basis of video audit estimation, especially from 2012 and forth.

Figure 13 depicts the discard ratios of cod, calculated solely from observer data for demersal trawlers in the North Sea participating in the CQM trial and demersal trawlers not participating in the CQM trial.

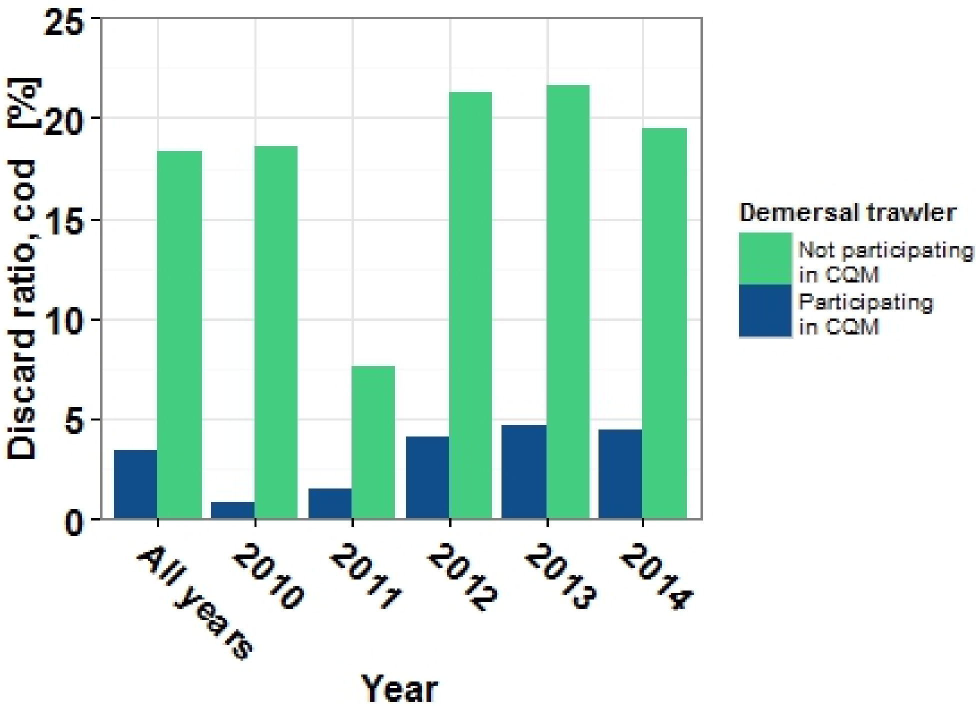


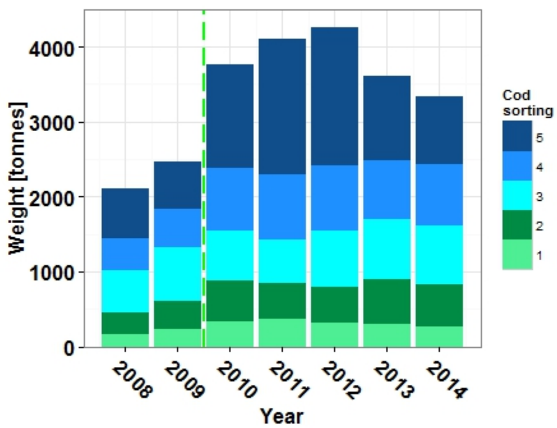
Figure 13 Discard ratio for cod per year in the North Sea estimated by onboard observer for demersal trawlers participating in the CQM trial and demersal trawlers not participating. All years represent the total average from 2010 to 2014.
$n_{\text{Participating in FDF}}$ = 575, $n_{\text{Not participating in FDF}}$ = 601.

There is a clear difference through all years in the discard ratios of cod based on observer data between demersal trawlers participating and demersal trawlers not participating in the CQM trial.

Landings

Cod

A comparison between total landed catches of cod for participating vessels and all Danish vessels, minus vessels participating in the project, can be seen in figure 14.



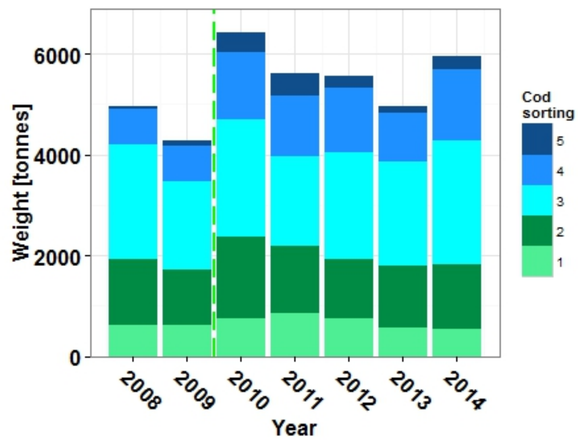


Figure 14. Total landings of cod for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

The total Danish landings of cod from the North Sea and Skagerrak, the vessels participating in the trial contribute with, are quite significant throughout all years, especially after 2010 where the increase in quota given for participation in the trial began to add to the landings for these vessels. Landings of sorting class 5 seem larger for participating vessels than for the rest of the Danish vessels operating in the North Sea and Skagerrak. Figure 15 shows the percent vise composition of landed catches of cod in sorting classes for participating vessels and all Danish vessels, minus vessels participating in the project.

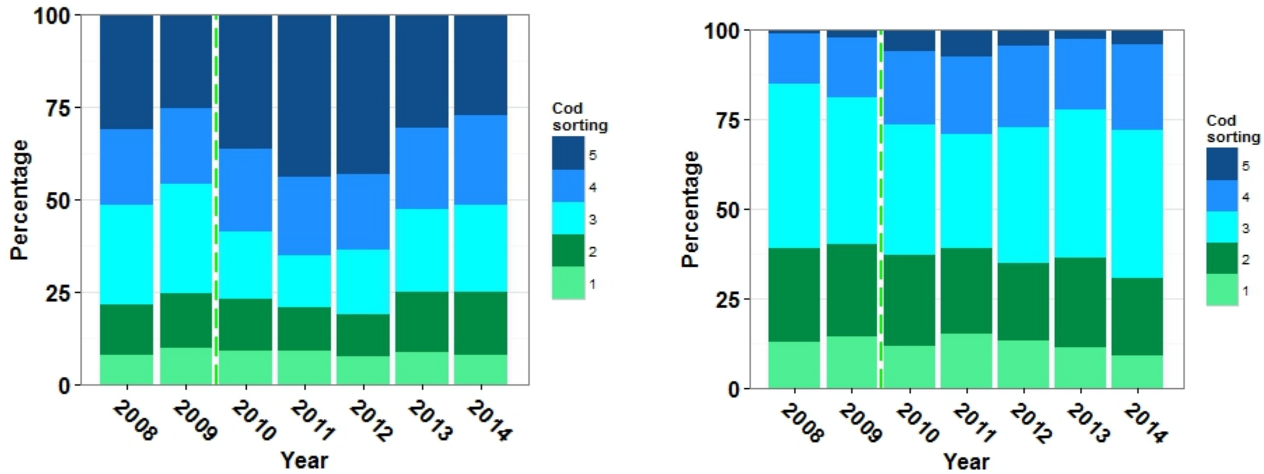


Figure 15. Landed cod sorting composition in percent for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of project.

The percent that each sorting class of cod comprised in the total catches are quite different between vessels participating in the CQM trials compared to the rest of Danish vessels fishing in the North Sea and Skagerrak for all year. Table 6 summarize the average percentage of sorting class 5 in landings of cod for all vessels participating in the trial and for the rest of the Danish vessels operating in the North Sea and Skagerrak.

Year	Average percentage of catch, sorting class 5, participating vessels	Average percentage of catch, sorting class 5, all Danish non-participating vessels
2008	31.3 %	1.1 %
2009	25.4 %	2.4 %
2010	36.7 %	6.0 %
2011	44.0 %	7.7 %
2012	43.2 %	4.6 %
2013	30.9 %	2.7 %
2014	27.3 %	4.4 %

Table 6 Average percentage of sorting class 5 in landings of cod, 2008-2014.

Haddock

A comparison between total landed catches of haddock for participating vessels and all Danish vessels, minus vessels participating in the project, can be seen in figure 16. Figure 17 shows the percent vise composition of landed catches of haddock in sorting classes for participating vessels and all Danish vessels, minus vessels participating in the project.

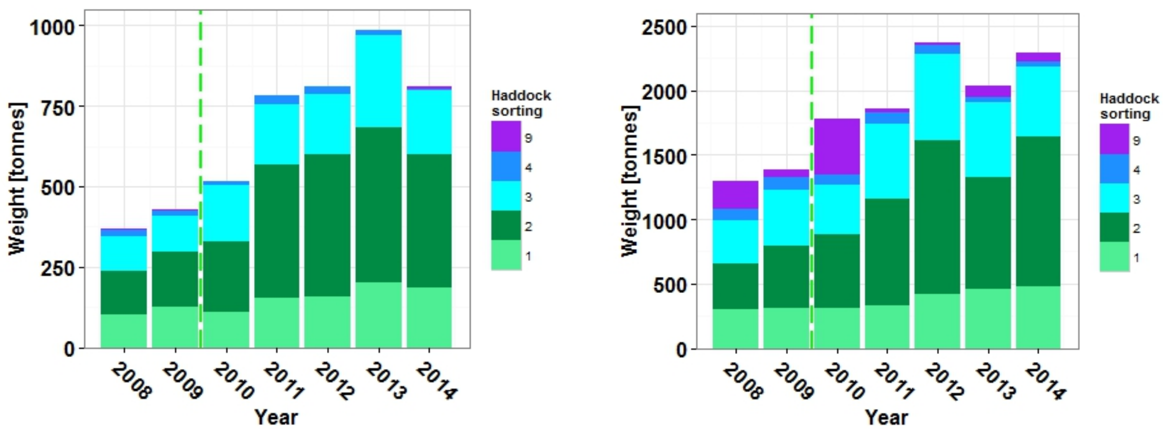


Figure 16. Total landings of haddock for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

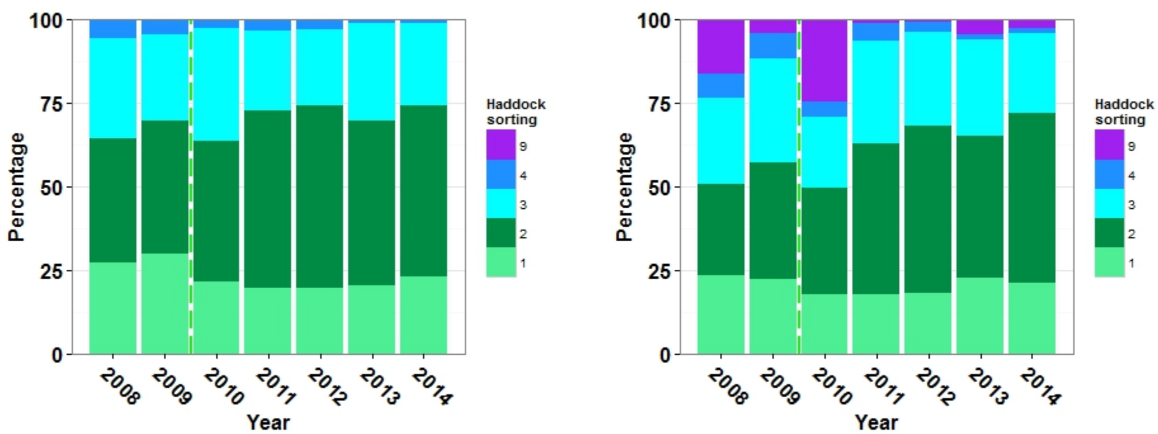


Figure 17. Landed haddock sorting composition in percent for all participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

Whiting

A comparison between total landed catches of whiting for participating vessels and all Danish vessels, minus vessels participating in the project, can be seen in figure 18. Figure 19 shows the percent vise composition of landed catches of whiting in sorting classes for participating vessels and all Danish vessels, minus vessels participating in the project.

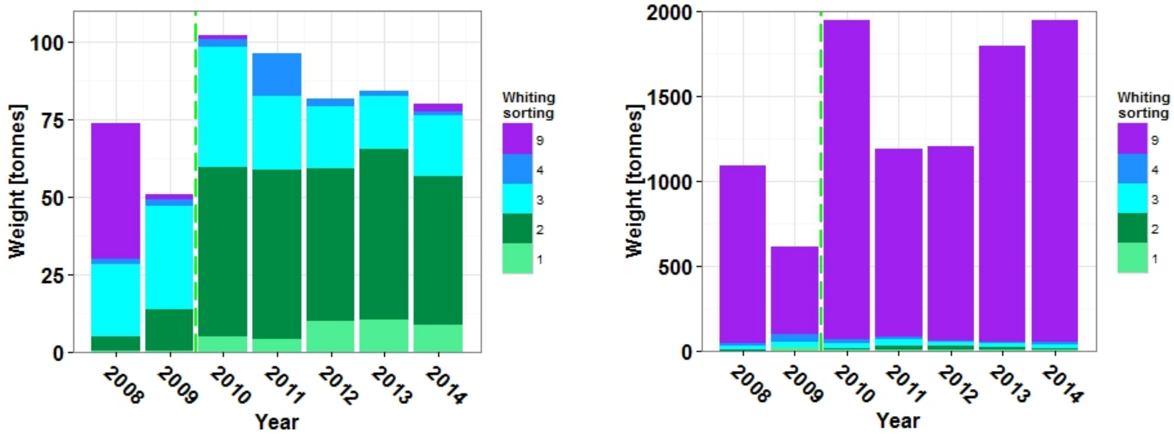


Figure 18. Total landings of whiting for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

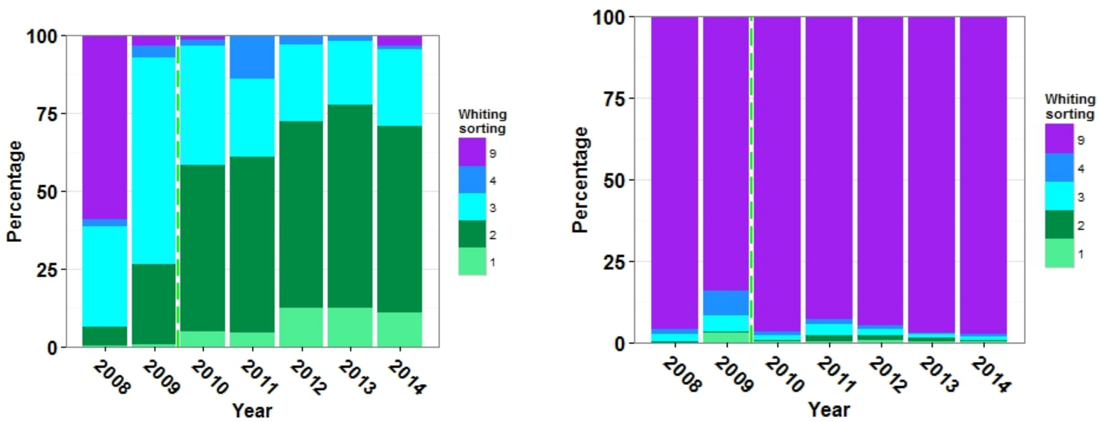


Figure 19. Landed whiting sorting composition in percent for all participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

Saithe

A comparison between total landed catches of saithe for participating vessels and all Danish vessels, minus vessels participating in the project, can be seen in figure 20. Figure 21 shows the percent vise composition of landed catches of saithe in sorting classes for participating vessels and all Danish vessels, minus vessels participating in the project.

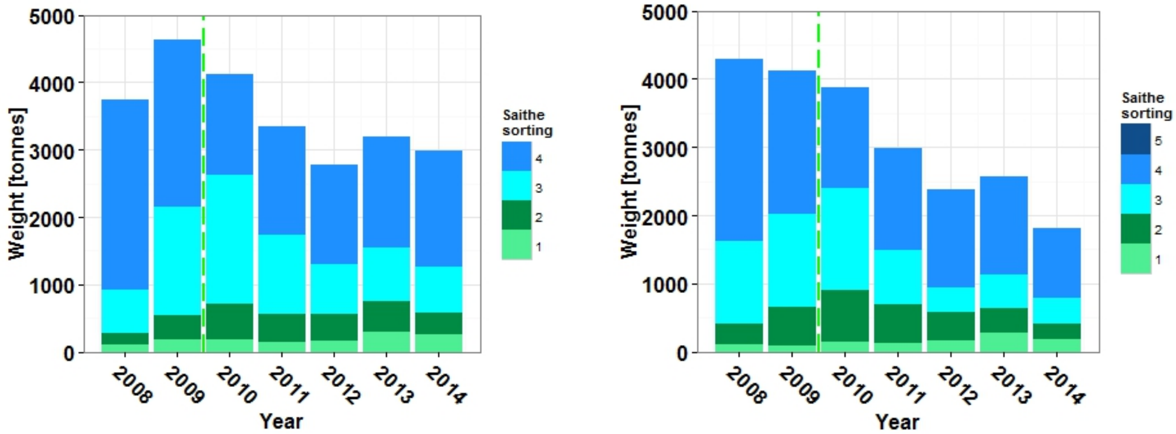


Figure 20. Total landings of saithe for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial. In 2010 and 2011 a minute amount of sorting class 5 was landed, which is why this sorting class is in the legend for non-participating vessels and not in the legend for participating vessels.

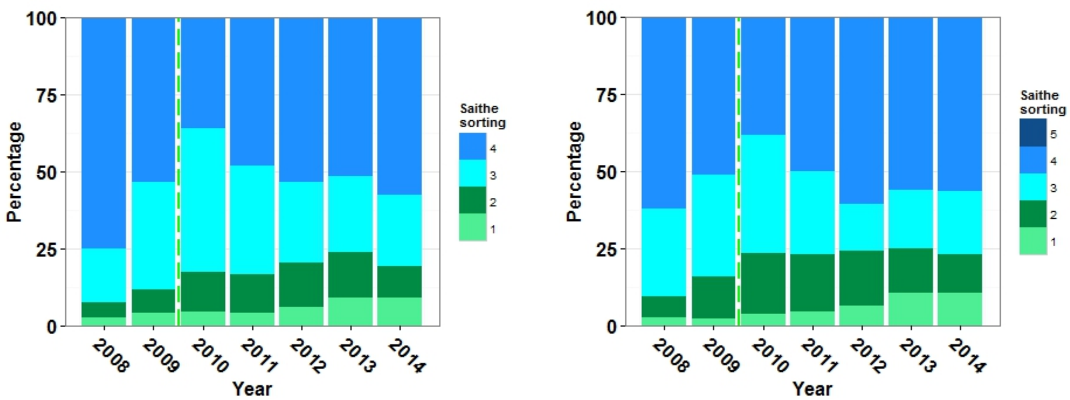


Figure 21. Landed saithe sorting composition in percent for all participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial. In 2010 and 2011 a minute amount of sorting class 5 was landed, which is why this sorting class is in the legend for non-participating vessels and not in the legend for participating vessels.

Hake

A comparison between total landed catches of hake for participating vessels and all Danish vessels, minus vessels participating in the project, can be seen in figure 22. Figure 23 shows the percent vise composition of landed catches of hake in sorting classes for participating vessels and all Danish vessels, minus vessels participating in the project.

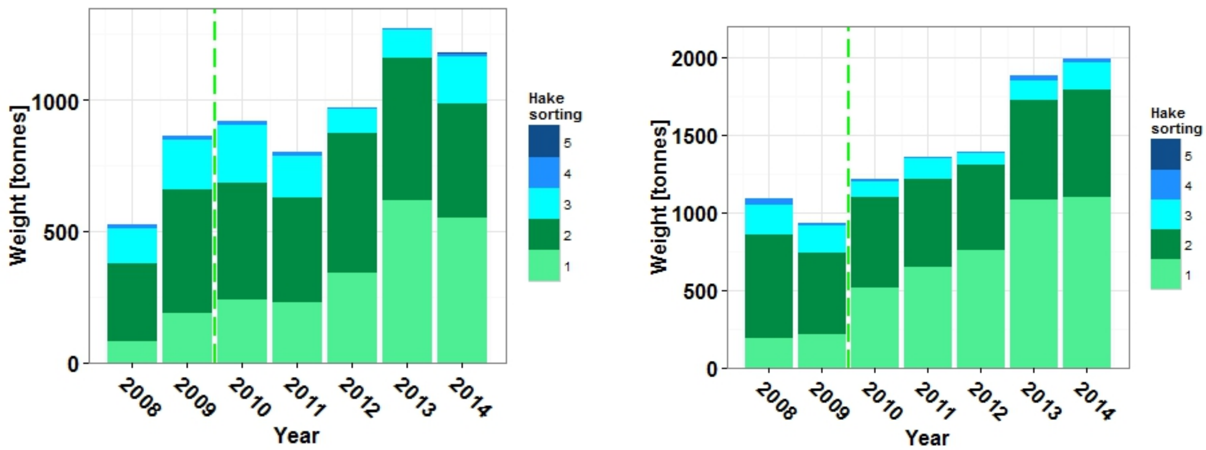


Figure 22. Total landings of hake for participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

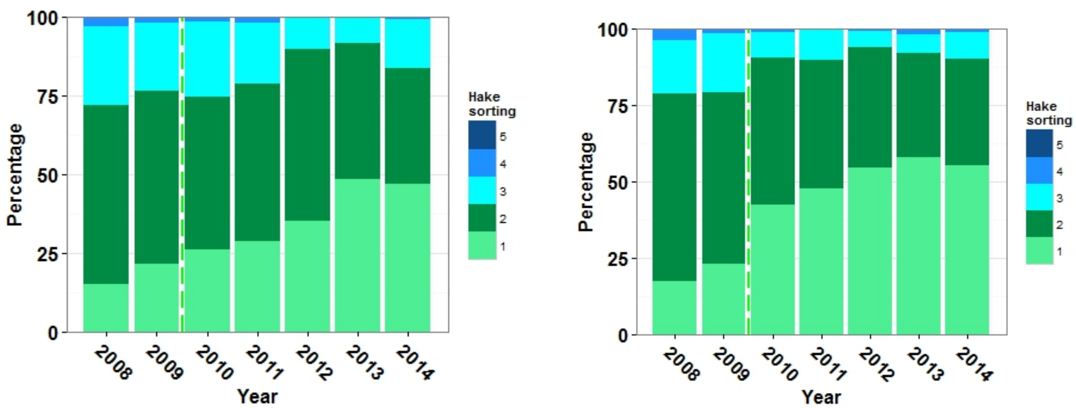


Figure 23. Landed hake sorting composition in percent for all participating vessels (left) and all Danish non-participating vessels (right), North Sea and Skagerrak. Green vertical line indicates onset of the CQM trial.

Choke Species trial

Data on landings, discards and discard ratios from the Choke Species trial from 17 December 2014 to 12 June 2015 for the three vessels participating in the CQM and Choke Species trials are presented below. Total landings of whiting, hake, haddock, saithe and cod from 17 December 2014 to 12 June 2015, for the three vessels participating in the CQM and in the Choke Species trial, are presented in figure 24.

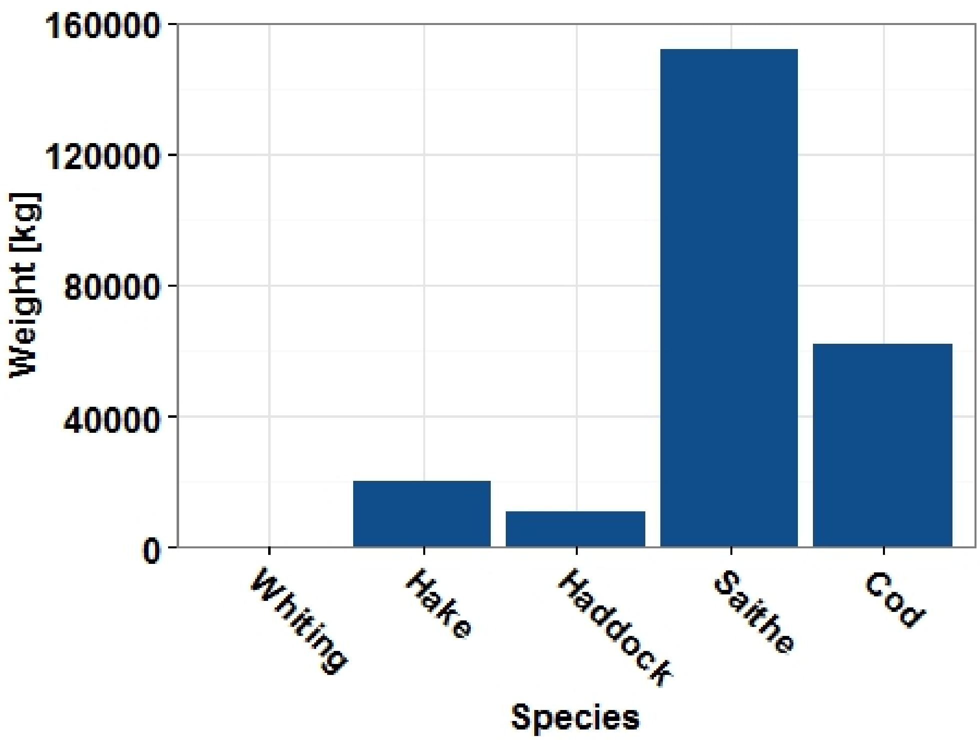


Figure 24. Landings of whiting, hake, haddock, saithe and cod for the three vessels participating in the Choke Species and CQM trials from 17 December 2014 to 12 June 2015. n = 321 catch processing's.

Saithe – by far – constitute the major proportion of landings, followed by cod, then hake and finally haddock. No landings of whiting were reported.

The total discards of whiting, hake, haddock, saithe and cod from 17 December 2014 to 12 June 2015 for the three vessels participating in the CQM and Choke Species trials are presented in figure 25.

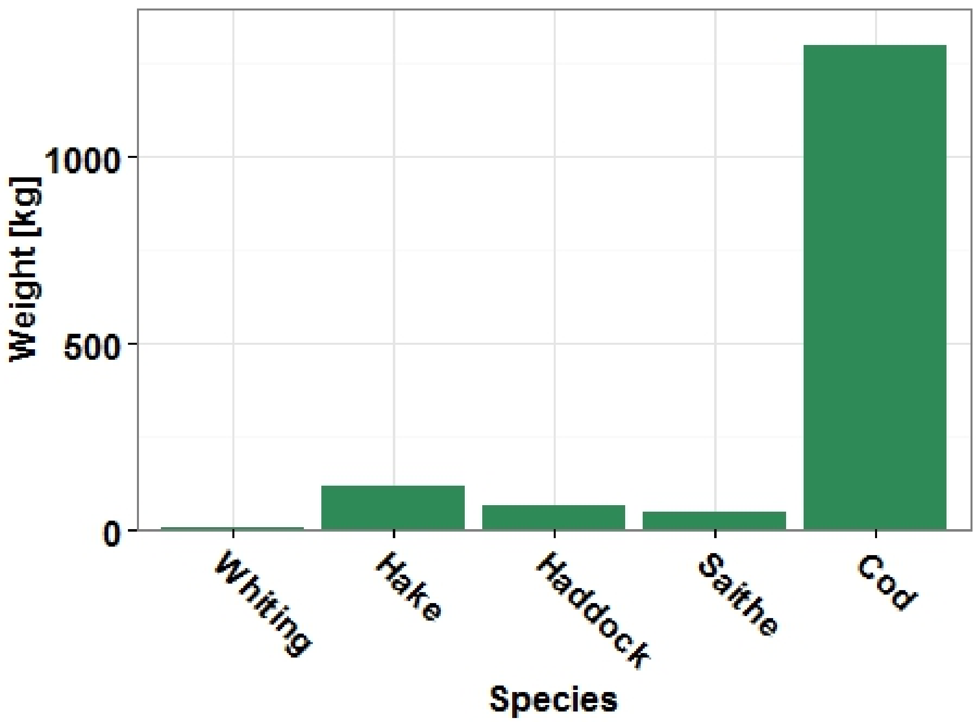


Figure 25. Discard of whiting, hake, haddock, saithe and cod for the three vessels participating in the Choke Species and CQM trials from 17 December 2014 to 12 June 2015. Discard estimated by video inspectors of the Choke Species trial.
n = 321 catch processing's.

Cod – by far – constitute the major proportion of discards (1298 kg), hake is the second most discarded species (118 kg), then haddock (66 kg), saithe (45 kg) and finally a minute amount of whiting (10 kg).

The discard ratio of whiting, hake, haddock, saithe and cod from 17 December 2014 to 12 June 2015 for the three vessels participating in the CQM and Choke Species trial are presented in figure 26.

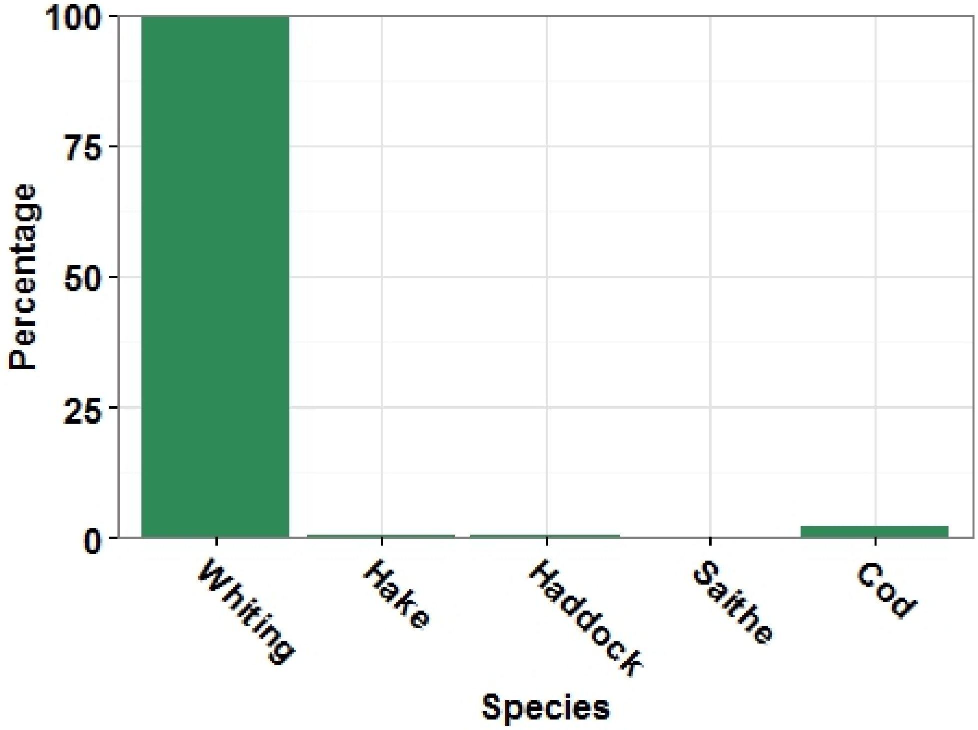


Figure 26. Discard ratio of whiting, hake, haddock, saithe and cod for the three vessels participating in the Choke Species and CQM trial from 17 December 2014 to 12 June 2015. Discard estimated by video inspectors of the Choke Species trial.
n = 321 catch processing's.

The discard ratios per species are as follows:

- 100 % for whiting
- 2.0 % for cod
- 0.6 % for haddock
- 0.6 % for hake
- 0.1 % for saithe

Discussion

General Challenges Regarding the Landing Obligation

Introduction of a LO – or rather a ban on discarding – have many merits, such as potentially ending the malpractice of high-grading (high-grading is the practice of discarding legal catches in the hope that larger and more valuable specimens of the same species will be caught later) (Gullestad *et al.* 2015; Sardà *et al.* 2015), creating a greater incentive for developing and using selective gear (Sigurðardóttir *et al.* 2015) as well as reducing what seems as a great waste of natural resources, at least from an ethical point of view. However, there are also possible negative effects. A biological issue is that discards act as a food source for different species, ranging from seabirds such as gulls, to benthic invertebrates such as crabs. Since the practice of discarding have been going on for many years the impact on these species, and on the ecosystem when this "free" food source is removed, could be significant (Sardà *et al.* 2015). From the fishermen's view there are a number of practical issues that threaten the economic sustainability of the fisheries.

When all catches (except for the exemptions mentioned in the section "Brief Overview of the Common Fisheries Policy of 2013") has to be stored onboard, storage rooms are likely to be filled faster, meaning that the vessel has to return to port sooner. Since less valuable species under TAC and damaged specimens have to be landed too, the average value of catches are likely to decrease. The cost of fishing will however not be affected by the LO and the earnings made by the fishermen per trip is therefore likely to decrease (Sardà *et al.* 2015; Sigurðardóttir *et al.* 2015).

As mentioned in the introduction, especially mixed fisheries risk having a choke species that effectively end the fisheries, before the TACs for other species have been caught (Hatcher 2013; Sigurðardóttir *et al.* 2015). The issue with choke species can potentially be mitigated with transferrable fishing rights which the CFP of 2013 allow Member States to introduce. With transferrable fishing rights a fisherman, who has caught his TAC of a species can buy additional quota from another fisher who still have quota left for this particular species, allowing the first fisher to continue fishing (Salomon & Holm-Müller 2013; Salomon *et al.* 2014). It should be mentioned that although transferrable fishing rights may mitigate the effects of choke species for the individual fishermen, there is still a risk that certain species can act as choke species on a more general level, since the transferrable fishing rights only counter choke species if someone still have quota left for the species in question. The concession of transferable fishing rights in order to counter the effect of choke species also risk leading to quota speculation. Some owners of TACs might hold on to their share of the TAC for a choke species, in order to drive up the price when the TAC of this species begin to be depleted in the mixed fisheries, leading to prices on some TACs to be heavily influenced by speculation. Such speculations can have a negative effect on the economic sustainability of the fisheries in question (Hatcher 2013). Other measures to mitigate potential choke species include optimization of the TAC for the species to, allow for some discards of the choke species and to optimize selectivity (European Parliament and Council of the European Union 2013; Hatcher 2013; Rochet, Catchpole & Cadrin 2014; Sigurðardóttir *et al.* 2015). Increased optimization of specific TACs and selectivity might be possible to do on a level that is substantial enough to avoid certain species to become choke species. However, time will tell whether or not the effect of these measures can mitigate all potential choke species. If not the last resort is to allow for some discards to take place in accordance with the *de minimis* exemptions. It is quite likely that fisheries managers will need to address the challenges, regarding choke species under a LO and the measures to mitigate this, in a holistic manner and combine measures to tailor solutions for the specific fishery.

Finally, in order to verify that the LO is complied with, it is necessary to have control measures that cover activities at sea. The cost of fisheries control is therefore higher if the fisheries management want to ensure that the LO is complied with. The benefit with such an enhanced control is that data on catches will be better, which can generate a better stock assessment and knowledge on the marine environment (Sardà *et al.* 2015; Sigurðardóttir *et al.* 2015).

General Challenges Regarding the Use of REM with CCTV as a Control Measure

One way of enhancing fisheries control is to ensure compliance with the LO by use of REM with CCTV (Ulrich *et al.* 2015). REM is reliable, can be fitted onto most vessels and is cost-effective compared to other full documentation measures, such as onboard observers (Dalskov & Kindt-Larsen 2009; Hatcher 2013; Ulrich *et al.* 2015). However, the usage of CCTV is controversial since fishermen may be uncomfortable with being monitored at all times. This is not surprising, since the vessel for many acts both as a working area and as a private area (Eliasen 2015; Sigurðardóttir *et al.* 2015). Additionally it will be a substantial task to equip all European fishing vessels with REM, especially in fisheries dominated by smaller vessels, like the Mediterranean, where the fitting of the REM equipment can become a problem due to space limitation or challenges regarding suitable places to mount the cameras and get proper view of the vessel (Damalas 2015). In line with this, is the issue of auditing all the video data from such a large volume of fishing vessels (Sigurðardóttir *et al.* 2015). It should however be remembered, that although all fishing trips and all hauls are recorded, it is not necessarily required that all the data is audited, since random samples of the data can be taken for audit, just like at-sea control is not done for all the fishing activities of all fishing vessels. In this manner, REM can be used to collect random samples of the fishing activities and further inquiries on the actions of the individual vessels can be performed, if reason for suspicion arises when auditing the data samples.

Video Quality

The reliability of the REM system used in this project has been assessed by the DTU Aqua and the Danish AgriFish Agency in prior trials. The conclusion of these trials were that the system is reliable (Dalskov & Kindt-Larsen 2009; Dalskov *et al.* 2011, 2012).

The results presented in figure 1 and figure 2 under results of the trials for video sequence errors furthermore suggest, that the errors occurring on video footage decline as users become more experienced with the equipment. It is not possible from the data to specify what underlying reasons account for this trend. Possible reasons include:

- Increased awareness and habit adaptations for fishermen on the importance of assuring cleaning procedures for the cameras onboard the given vessel.
- Increased video inspector experience, allowing video inspectors to make assessments despite less than optimal video quality.
- Decreasing occurrence of errors due to better handling of equipment in general.
- Change in video inspectors' willingness to report errors.

The change in video inspector staff over the project period suggests that the effect of increased video inspector experience should be affected by this. However since the replacements were gradual and no abrupt change in staff occurred it is also possible that more experienced video inspectors can have mitigated this effect.

Deviation in Discard Estimates Between Video Inspectors and the Electronic Logbook

As a total, the estimation of cod discards is greater in the electronic logbook than by video audit for both catch processing's and discards from Norwegian waters during all years of the trial. This suggests that fishermen as a whole were keen on asserting a proper estimation on their discards, although underestimation of discards from the video inspectors also may explain this pattern. It should be noted though, that the discards of cod are very small compared to the actual catches. The average deviation on the estimated discard of cod for the individual hauls is no more than a couple of kilograms and the average deviation on the estimated discard of cod on a trip basis is less than ten kilograms, except in 2010, which is also the first year of the trial. These are rather small numbers compared to the catch that a vessel can take in of cod in a single haul. Looking at the difference between estimation by video audit and reported in the electronic logbook for the individual hauls and trips, it can be seen that rather large differences occur between the estimations. Particular peculiar are the incidents were fishermen have reported zero or close to zero discards in the electronic logbook and video inspectors do report discards and the opposite, where video inspectors report zero or close to zero discards of cod although fishermen report discards in the electronic logbook. There are a number of explanations that may account for these incidents:

- Incidentals discard of cod by accident or simply because the fish have been overlooked on the discard line (note that the amount of discards as a general are small compared to catches).
- Discards taking place outside of camera view or at completely different times, than the catch processing's or trip back to homeport from Norwegian waters.

- Accurate species identification not possible due to one of the video sequence errors that affect the estimation done by video audit. In these cases the policy throughout the trial was "if in doubt, leave it out", meaning that video inspectors would not report discards of cod unless they were confident that the given discard actually was cod.
- Discrepancy in the reported discards in the electronic logbook due to inaccurate or wrongful reporting. This could lead to a situation where the reported discards in the electronic logbook were not from the haul audited by video inspectors, creating a mismatch in the dataset.

Although these deviations are a nuisance, it is reassuring that the average discard estimates are as close to each other between the video audit and the electronic logbook as is the case. When comparing the discard estimations of other species than cod, the situation is the opposite of that for the discard estimations of cod. For other species than cod, hardly any discards are reported in the electronic logbook compared to the amounts reported by video inspectors. This suggests that since the target species for the trial was cod, the participating fishermen have not directed any particular attention to the actual discards of other species, as well as the general circumstance that fishermen were not obliged to enter discards of other species as rigorously as for cod. For other discards than cod, fishermen were not obliged to report discards in the electronic logbook if the discarded amount were less than 50 kg (Hansen 2012). Participating fishermen are therefore likely to have merely accounted for discarded amounts of cod below 50 kg and in general not have reported discards of other species, unless the amount was above 50 kg.

Discard Ratios

The discard ratio of cod is rather small for the participating vessels, when estimated by video audit, both as a whole, as well as for demersal trawlers only. In fact, the discard ratios for every year are below the *de minimis* exemption of 5 % that the CFP allow for in selected fisheries. As can be seen in Table 5, it is by far the demersal trawlers that contribute the most to the discards of cod in the North Sea and Skagerrak for the participating vessels. The low discard ratio of cod is recurring in the data from the Choke Species trial. Additionally, the discard ratios of hake, haddock and saithe are also very low. The opposite is the case when considering whiting. For this species, the discard ratio is 100% for the vessels participating in both the CQM and the Choke Species trial. Whiting is one of a number of species, including hake and cod, that have been put forward as a potential choke species under a LO (Quirijns *et al.* 2014). The discard ratios calculated on the basis of estimations by video inspectors are lower than that of onboard observer estimations. The difference is less markedly when comparing observer data based solely on demersal trawlers participating in the CQM trial. This suggest that a rather large degree of the difference in discard estimations on cod could be due to larger discard ratios for vessels not participating in the CQM trial. There is however, persistence in higher estimation on the discard ratios for cod on the basis of data from onboard observers compared to data based on video audit, when solely comparing data collected on demersal trawlers participating in the CQM trial. Reasons for this could be, but are not limited to:

- Discards taking place outside of camera view or at completely different times than the catch processing's.

- Accurate species identification not possible due to one of the video sequence errors that affect the estimation done by video audit. In these cases the policy throughout the trial was "if in doubt, leave it out", meaning that video inspectors would not report discards of cod unless they were confident that the given discard actually was cod.
- Change in fishing pattern and behavior for fishermen when having observers onboard compared to when solely participating in the CQM trial.

It is not possible to infer from the data why there seems to be a systematic deviation between onboard observers and video audit estimations of cod discards. The possible explanations given above may very well not be the actual underlying reasons. Further studies on this subject could be done to explore this apparent uncertainty, e.g. by a scientific study on how discard estimations are done by onboard observers compared to how discard estimations are done by video audit and on whether there is disagreement between observer estimation and video audit estimation on hauls with zero discards. If the disagreement between data from onboard observers and data from video audit is negligible when zero discards are reported, the disagreement between these two management tools will be less substantial when the LO is fully introduced. Further exploration on this subject is beyond the scope of this report. What the comparison between discard ratios calculated from onboard observer data and video audit do reveal is, that there is a lower estimated discard ratio from observer data when comparing between demersal trawlers in the CQM trial with REM and CCTV onboard and demersal trawlers without REM and CCTV onboard. It is possible that the large and systematic difference between onboard observers discard estimates and video audit discard estimates, when comparison is done for all demersal trawlers with observers in the North Sea, at least to some degree is due to a lower discard ratio when vessels have REM systems with CCTV onboard. However since the demersal trawlers with REM and CCTV also participate in CQM trial, whereas demersal trawlers without REM and CCTV do not participate in CQM trial, some of the difference in observer estimates of discards may also be due to different fishing patterns, e.g. by non-participating vessels targeting other species like Norway lobster and thereby catching cod mainly as a bycatch, rather than actually targeting cod.

Landings – Cod

The vessels participating in the trial contribute significantly to the total Danish landings of cod from the North Sea and Skagerrak throughout all years. At the same time, these vessels have a higher percentage of sorting class 5, compared to the rest of the Danish vessels in the North Sea and Skagerrak from 2008 to 2014. This could be due to the high contribution of demersal trawlers in the participating vessels, whereas the landings of the remaining Danish vessels are more influenced by landings done by vessels like gillnetter's, were catches of small sized cod is less frequent, due to the more selective nature of this gear type (Jennings, Kaiser & Reynolds 2001b).

Although there is an increase in the percentage of sorting class 5 for participating vessels from 2009 to 2011, there is also an increase in the percentage of sorting class 5 for the remainder of the Danish vessels. It is therefore not possible to discern, whether this increase in sorting class 5 for participating vessels is due to the onset of the trial in 2010 or whether this increase merely reflects a larger proportion of the cod stock in the North Sea and Skagerrak being of sorting class 5 for these years. Furthermore, the decrease in the percentage of sorting class 5 from 2012 to 2014 for participating vessels also coincide with a decrease of this percentage for the remaining Danish vessels. Possible reasons for this decrease could otherwise have been better selectivity performed by participating vessels but again it is not possible to say since the changes, to some extend also occur for the rest of the Danish vessels.

Landings – Haddock

The landings of haddock from the North Sea and Skagerrak done by participating vessels are around half of the amount landed by the rest of the Danish vessels operating in the North Sea and Skagerrak. The changes in landings from year to year, both in total landings and in percentage of sorting classes appear rather similar for both vessels participating in the trial and the rest of the Danish vessels. What springs to mind is that the participating vessels have an increase in the total landings of haddock from 2012 to 2013, whereas the rest of the Danish vessels have a decrease between these years and that the Danish vessels not participating in the trial have a rather substantial amount of unsorted haddock landings in 2008 and 2010.

Landings – Whiting

Landings of whiting from the North Sea and Skagerrak are more than an order of ten lower for vessels participating in the CQM trial, compared to the rest of the Danish vessels. There seems to be a change in the percentage of sorting classes for vessels participating in the CQM trial, where sorting class 2 begin to contribute more to the landings after the onset of the trial. This cannot be compared to any changes in the landings of the rest of the Danish vessels, since the landings from these vessels are completely dominated by unsorted landings throughout the years, making any comparison on sorting class impossible. This is particular unfortunate, considering the speculations on the risk of whiting being a choke species under a LO (Quirijns *et al.* 2014).

Landings – Saithe

Landings of saithe from the North Sea and Skagerrak is very similar for participating vessels and the rest of the Danish vessels, both for total landings in tonnes and the percentages of sorting classes. This reflects that vessels participating in the trial contribute with roughly half of the total Danish landings of saithe from the North Sea and Skagerrak and that there seems to be no change in sorting composition due to the presence of CCTV.

Landings – Hake

The landings in tonnes of hake from the North Sea and Skagerrak are not as similar between vessels participating in the CQM trial and the rest of the Danish vessels as they are for saithe, although the vessels participating in the trial still account for a great proportion of the Danish landings of hake from these areas. The changes in the percentage of sorting classes in the landings are very similar between the vessels participating in the CQM trial and the rest of the Danish vessels. This strongly suggest that the landings of hake were unaffected by the presence of CCTV.

Choke Species

Two species spring to mind regarding choke species when looking at the data from the Choke Species trial: Cod and whiting.

For cod the discarded amounts in kilograms are large compared to the other species (whiting, hake, haddock, saithe). Although the actual discard ratios of cod have been rather low (at no point larger than 2.7 % for both the CQM and the Choke Species trial) the discard ratio has to be seen together with the large amounts caught and landed. This mean, that under a LO, vessels with a seemingly low discard of cod, when only looking at the discard ratio, can have their storage filled with unwanted catches of cod. This can force the vessel to return to port sooner in order to land these catches.

For whiting the opposite issue seems to be the case. Catches and landings of whiting are very small for the participating vessels, especially when comparing to the landed amounts of the other species (cod, haddock, hake and saithe). However, the data from the Choke Species trial suggest that the discard ratio of whiting is very large. Whiting therefore risk acting as a choke species since the whiting, which would have been discarded prior to the LO, will count against the quota of the vessel under the LO. This risk depleting the vessels TAC on whiting much faster than prior to the LO, forcing the given vessel to stop fishing, since the vessel otherwise risk catching whiting in addition to the target species, e.g. cod. These catches would be illegal to land, due to the vessels depletion of its TAC on whiting, but due to the LO it is also illegal to discard the unwanted catch of whiting.

For haddock, hake and saithe the discarded amounts in kilogram and the discard ratios are rather small. The risks of these species acting as choke species therefore seem rather small. However it should be noted that the data set is limited and that the extrapolation of the findings unto the entire Danish mixed fishery would be hazardous. In order to mitigate the possible negative effects of one or more choke species it is vital that the fisheries management tailor measures to counter this possible effect of the LO. Such measures could be to optimize the TAC for the species, allow for transferable fishing concessions to take place, allow for some discards of the choke species and to optimize selectivity (European Parliament and Council of the European Union 2013; Hatcher 2013; Rochet *et al.* 2014; Sigurðardóttir *et al.* 2015). The specific needed measures will likely depend on the individual fishery, both in terms of area and type of fishing.

Conclusion

CQM with FDF from REM systems

REM systems with CCTV should be viewed as tangible and effective tools in the management of the commercial fishery. The systems have tested effective in a number of trials, and there seems to be an increase in the effectiveness of the system with increased experience. There is however some discrepancy between estimates of discards done by video audit compared to that of onboard observers. Further studies are needed to clarify the underlying reasons for this and on whether this discrepancy is of significance when the LO is fully introduced. Nevertheless, it seems likely that the presence of REM with CCTV increase the awareness of discards and adaption of fishing patterns on the hand of fishermen, at least when the system is applied together with CQM. With the current development within the fisheries policy of the EU, REM systems with CCTV offer a possibility to introduce FDF and ensure compliance with the LO.

Choke Species

Two potential choke species were identified for the Danish mixed fisheries in the North Sea and Skagerrak: Cod and whiting. This should not be seen as a finite list but merely as the identification of two species, where the fisheries management and commercial fishery need to plan ahead in order to mitigate the potential negative effect that these species risk incurring unto the fishing industry when the LO is fully applicable.

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Appendix 1

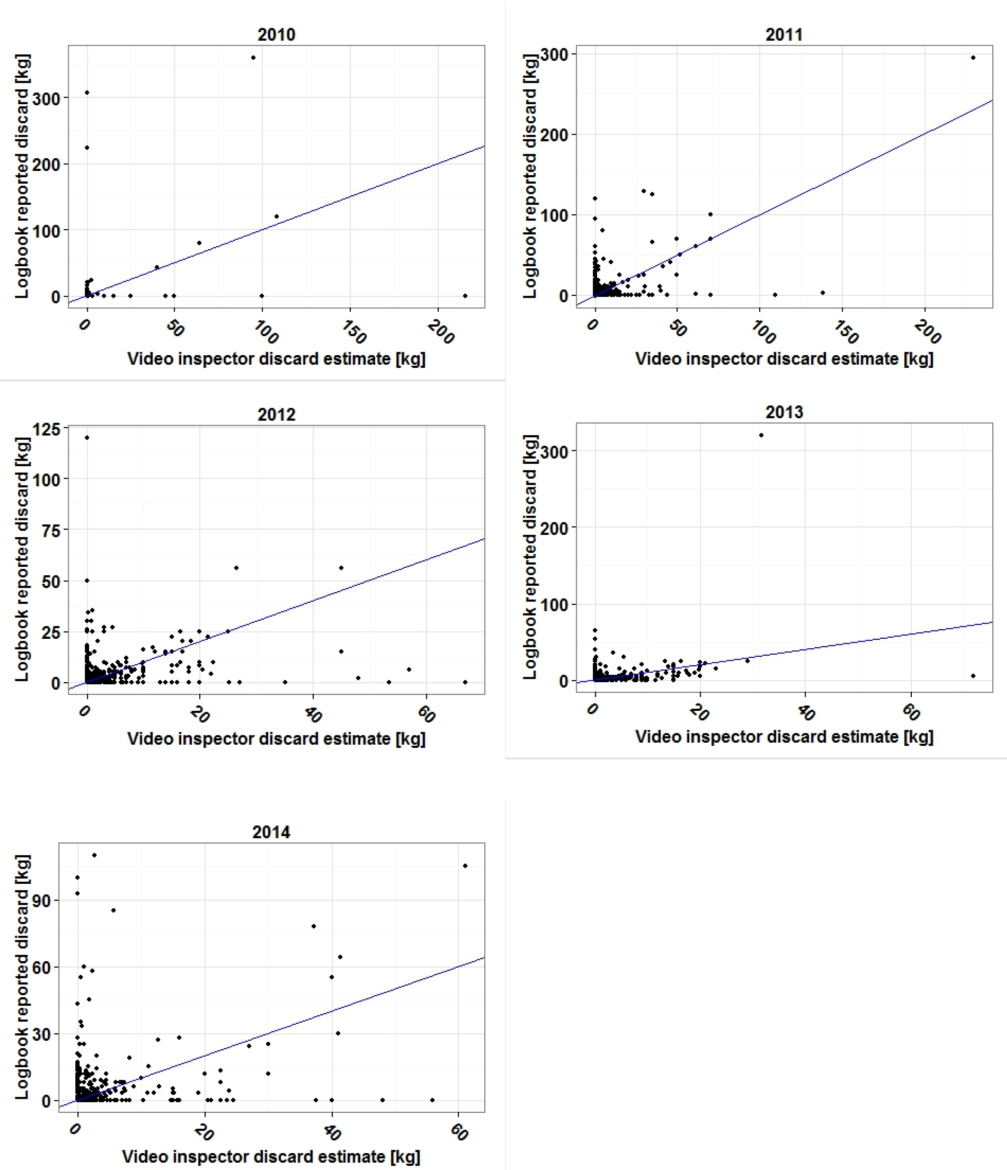
List of all video sequence errors reported by video inspectors during video audit from 2010 to 2014.

Error type	Number of errors	Percentage of total errors
Blurry picture, affects	96	14.5
Blurry picture, unable to assess	4	0.6
Blurry picture, unable to identify and count	6	0.9
Dirty camera, affects	141	21.3
Dirty camera, unable to assess	12	1.8
Discard at the stern, unable to identify	1	0.2
Discard camera covered, unable to identify discard	9	1.4
Discard camera down, unable to assess	1	0.2
Discard hard to identify	1	0.2
Discard hard to identify, affects	26	3.9
Discard hard to identify, due to camera angle	2	0.3
Discard hard to identify, due to handling method	1	0.2
Discard hard to identify, mixed	16	2.4
Discard hard to identify, mixed in baskets	10	1.5
Fisherman blocks camera view, affects	14	2.1
Fisherman blocks camera view, unable to assess	10	1.5
Light reflection, affects	3	0.5
Lights are off at discard line, affects	4	0.6
One camera down, affects	5	0.8
One camera down, assessment unaffected	1	0.2
Two camera down, affects	10	1.5
Video gap, affects	22	3.3
Video gap, other haul audited	2	0.3
Video gap, unable to assess	2	0.3
Video gaps, unable to identify	1	0.2
Video lost	109	16.5
Viewer unable to identify	8	1.2
Viewer unable to identify due to angle	1	0.2
Viewer unable to identify due to camera angle	2	0.3
Viewer unable to identify, due to camera angle	7	1.1
Viewer unable to identify, mixed in baskets	21	3.2
Viewer unable to identify, mixed in baskets due to broken discard line	1	0.2
Water droplets on camera, affects	105	15.9
Water droplets on camera, unable to assess	7	1.1

Appendix 2

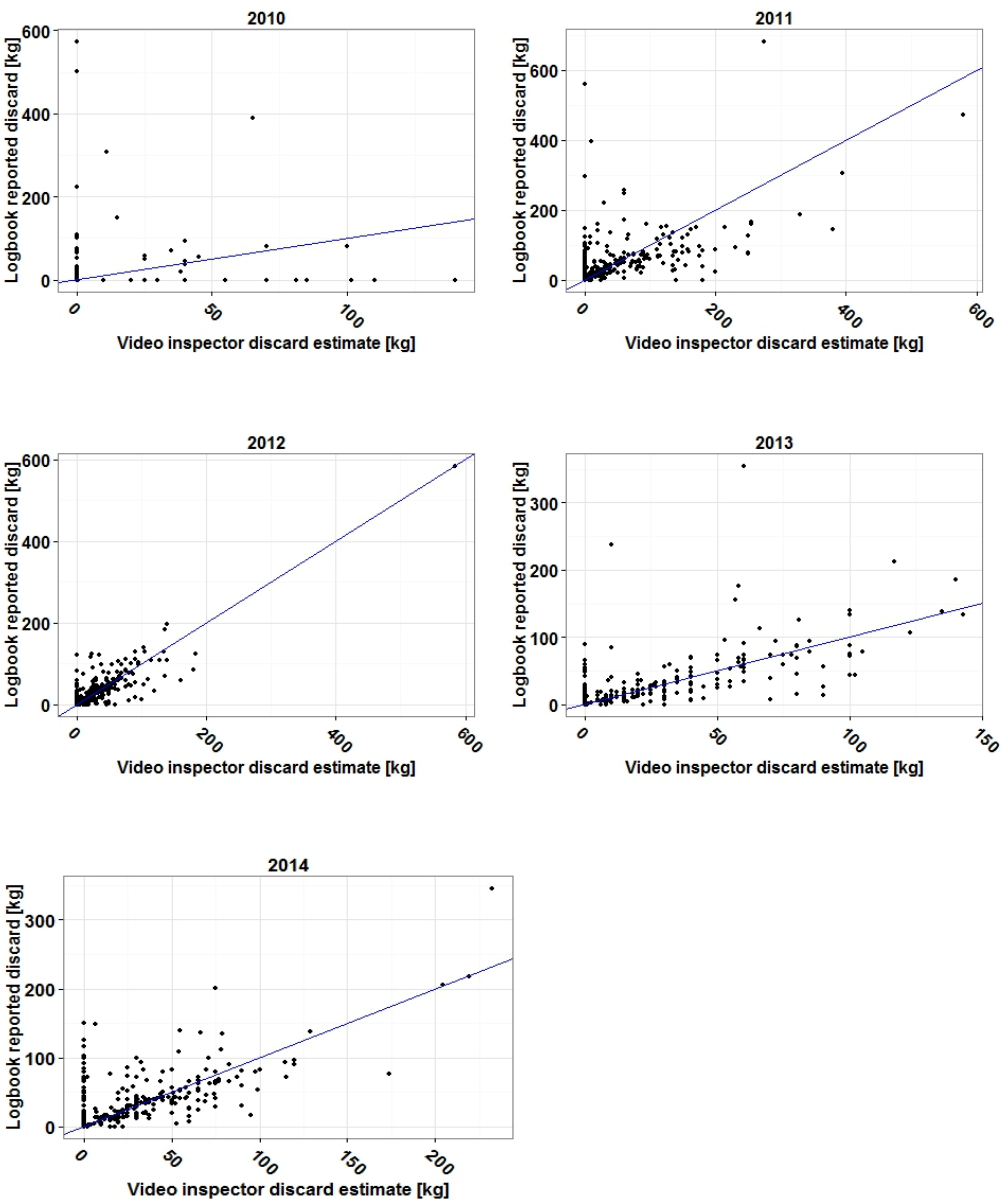
Video inspector estimates and reported estimates in logbook of cod discard per haul for catch processing's in 2010, 2011, 2012, 2013 and 2014. The blue line represents a 1 to 1 ratio.

n_{2010} = 241, n_{2011} = 906, n_{2012} = 841, n_{2013} = 781, n_{2014} = 911.



Appendix 3

Video inspector estimates and reported estimates in logbook per trip for cod discards upon return to EU waters from Norwegian waters in 2010, 2011, 2012, 2013 and 2014. The blue line represents a 1 to 1 ratio. $n_{2010} = 87$, $n_{2011} = 352$, $n_{2012} = 349$, $n_{2013} = 344$, $n_{2014} = 323$.



Appendix 4

List of measures for sustainable exploitation of the marine resources in Article 7 of the CFP of 2013

Quote from the CFP of 2013 (European Parliament and Council of the European Union 2013):

"Article 7

Types of conservation measures

1. Measures for the conservation and sustainable exploitation of marine biological resources may include, inter alia, the following:

(a) multiannual plans under Articles 9 and 10;

(b) targets for the conservation and sustainable exploitation of stocks and related measures to minimise the impact of fishing on the marine environment;

(c) measures to adapt the fishing capacity of fishing vessels to available fishing opportunities;

(d) incentives, including those of an economic nature, such as fishing opportunities, to promote fishing methods that contribute to more selective fishing, to the avoidance and reduction, as far as possible, of unwanted catches, and to fishing with low impact on the marine ecosystem and fishery resources;

(e) measures on the fixing and allocation of fishing opportunities;

(f) measures to achieve the objectives of Article 15;

(g) minimum conservation reference sizes;

(h) pilot projects on alternative types of fishing management techniques and on gears that increase selectivity or that minimise the negative impact of fishing activities on the marine environment;

(i) measures necessary for compliance with obligations under Union environmental legislation adopted pursuant to Article 11;

(j) technical measures as referred to in paragraph 2.

2. Technical measures may include, inter alia, the following:

(a) characteristics of fishing gears and rules concerning their use;

(b) specifications on the construction of fishing gear, including:

(i) modifications or additional devices to improve selectivity or to minimise the negative impact on the ecosystem;

(ii) modifications or additional devices to reduce the incidental capture of endangered, threatened and protected species, as well as to reduce other unwanted catches;

(c) limitations or prohibitions on the use of certain fishing gears, and on fishing activities, in certain areas or periods;

(d) requirements for fishing vessels to cease operating in a defined area for a defined minimum period in order to protect temporary aggregations of endangered species, spawning fish, fish below minimum conservation reference size, and other vulnerable marine resources;

(e) specific measures to minimise the negative impact of fishing activities on marine biodiversity and marine ecosystems, including measures to avoid and reduce, as far as possible, unwanted catches."

Appendix 5

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Original Article

Discarding of cod in the Danish Fully Documented Fisheries trials

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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 ≥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 ≥120 mm in the North Sea, 90–119 mm in Skagerrak until 1 January 2013, ≥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

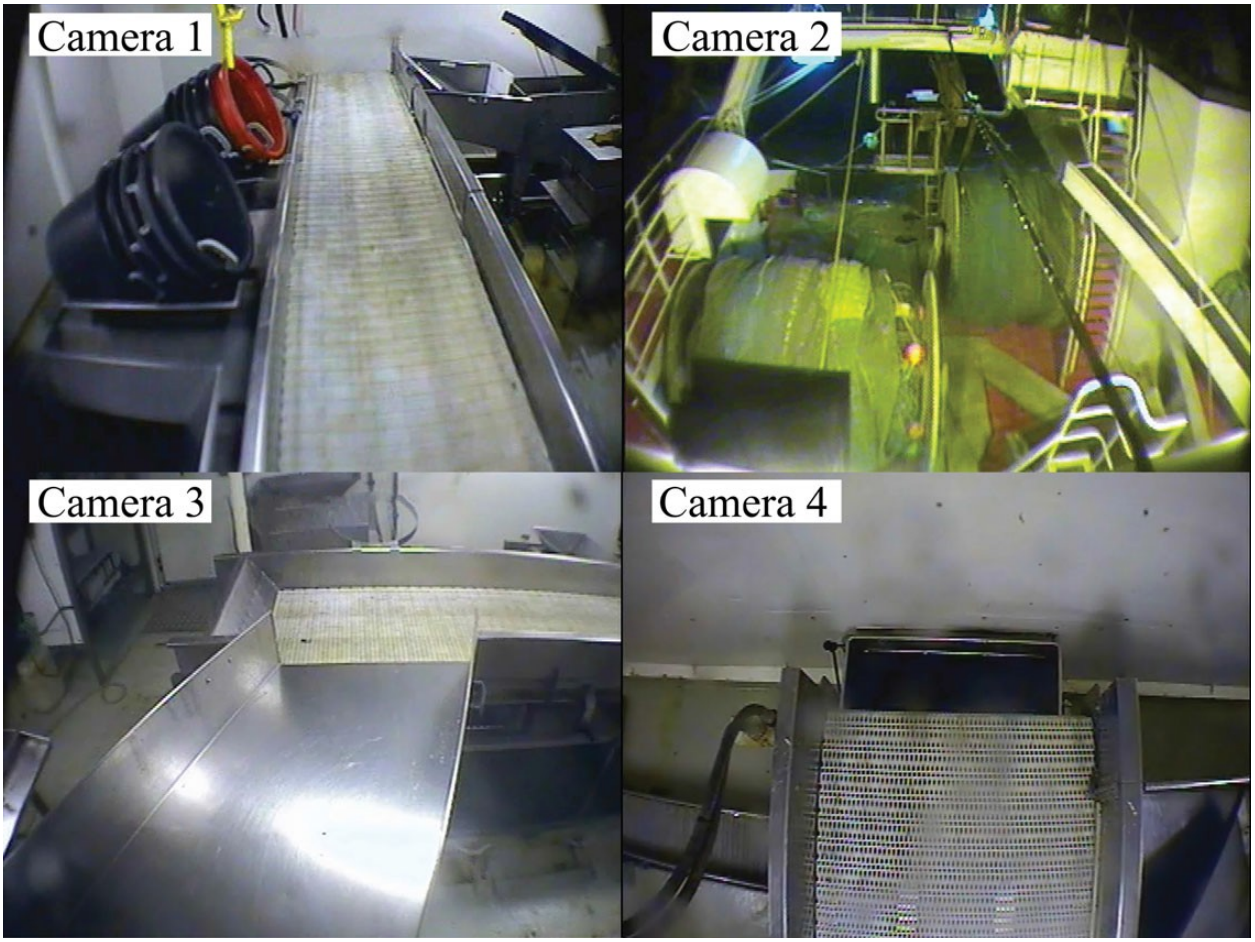

Figure 1. Example of CCTV providing an overhead view of the aft deck and closer views of the fish handling and discard chute areas for one vessel.

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 (¼0.000009× 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. DTUAqua 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 DTUAqua 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 Norwegianwatersto 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 threesources 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 fi rs' 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 5 0	fisher 5 0	viewer 5 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 ¼ 0", both the fisher and the viewer have reported zero discards; "fisher ¼ 0", the fisher has reported zero discard but the viewer has reported discards; "viewer ¼ 0", the viewer has reported zero discard but the fisher has reported discards.

following the standard procedure defined in ICES (2007):

$$\text{Discard Rate}_{\text{Time, Area, Metier, Species}} = \frac{\sum \text{Weight of discard}_{\text{Trip, Haul, Time, Area, Metier, Species}}}{\sum \text{Weight of landing}_{\text{Trip, Haul, Time, Area, Metier}}}$$

$$\text{Discard (tonne)}_{\text{Time, Area, Metier, Species}} = \text{Landings (tonne)}_{\text{Time, Area, Metier}} \times \text{Discard Rate}_{\text{Time, Area, Metier, Species}}$$

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 ¼ 0"), whether the fisher reported discards but not the viewer ("viewer ¼ 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 significative (p . 0.05 with paired two-sample Wilcoxon test, 95% confidence interval between [21,3] 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 ≥ 120 mm non-FDF	Raising from non-FDF observers trips	2012	4	704	182	21
			2013	4	672	187	22
North Sea	OTB ≥ 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 ≥ 120 mm FDF	Raising from FDF observers trips	2012	6	1557	66	4
			2013	9	1620	123	7
North Sea	OTB ≥ 120 mm FDF	Sum of estimates from logbooks	2012	Census	1557	15	1
			2013	Census	1620	9	1
North Sea	OTB ≥ 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.

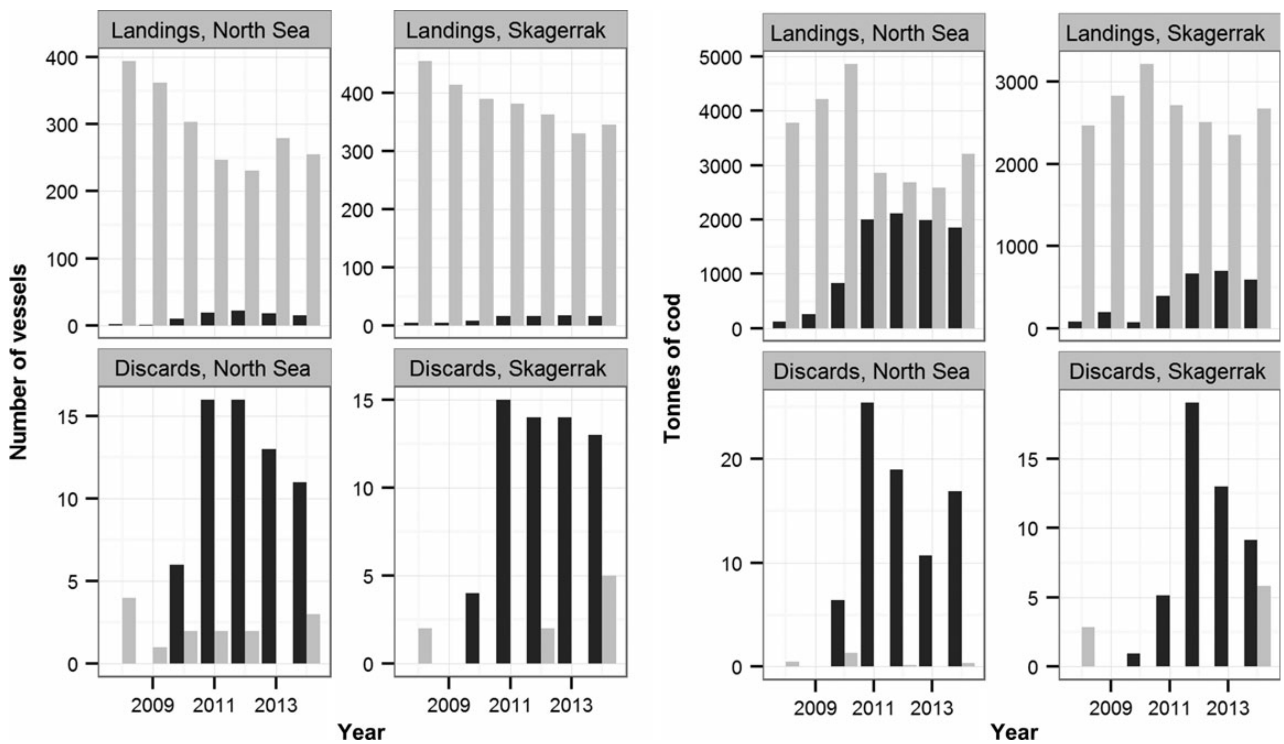

Figure 2. Coverage in cod information available in logbooks regarding number of vessels (four left panels) and tonnage (four right panels) for FDF vessels (black) vs. non FDF vessels (grey), by year (2008–2014, *x*-axis), area (horizontal panels), and catch type (landings in top line panels, discards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

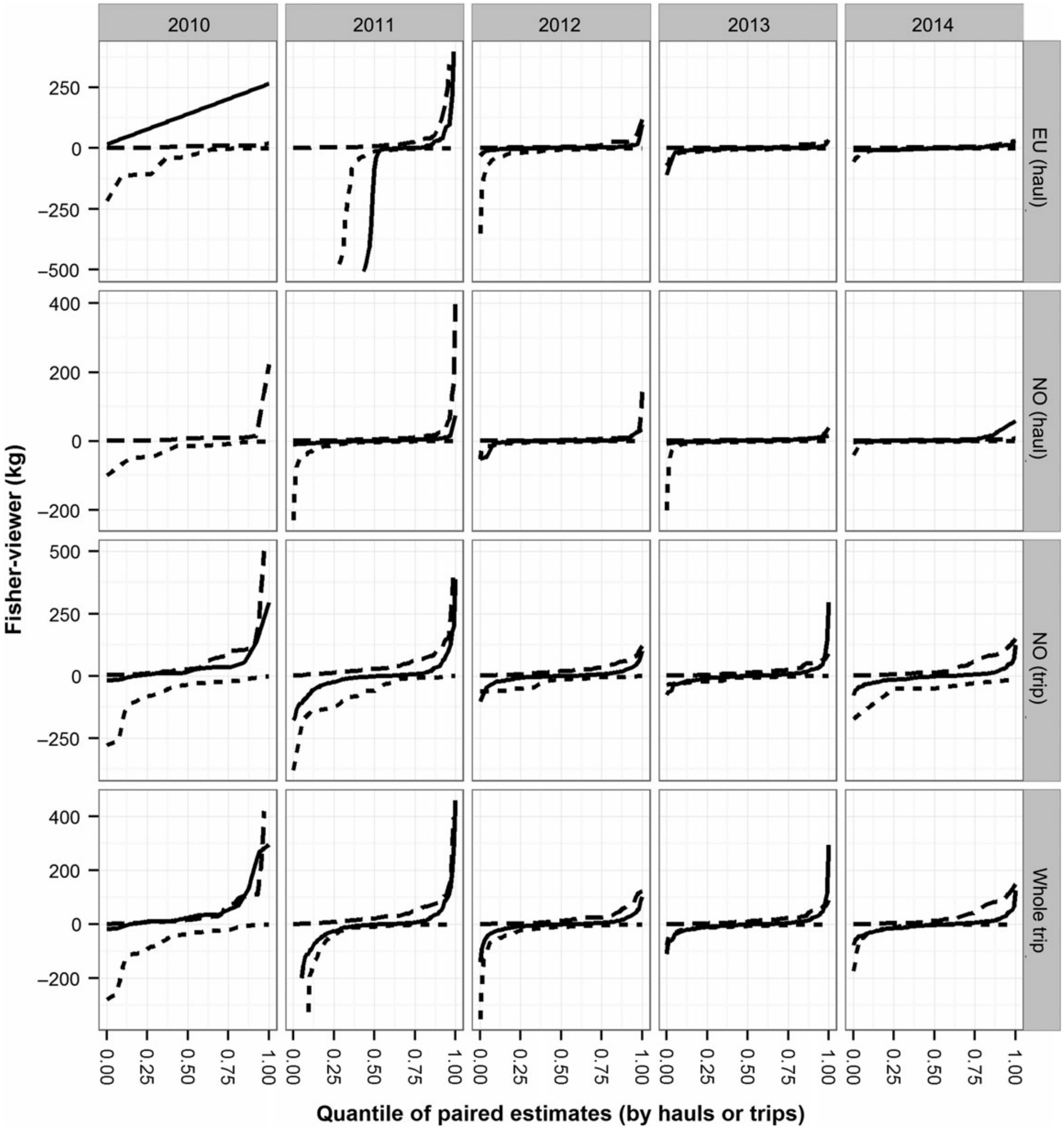

Figure 3. Absolute differences in cod discard estimates (in kg) between fishers and viewers per quantile of paired observations (hauls or trips), water (European or Norwegian), year, and type of discrepancy: Plain line: "fisher&viewer.0": both the fisher and the viewer have reported discards; Dotted line: "fisher ¼ 0": the fisher has reported zero discard but the viewer has reported discards; Dashed line: "viewer ¼ 0": the viewer has reported zero discard but the fisher has reported discards. Plotted capped at (2500 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[21]) and 5 (0.3 to 1 kg fish[21])] 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

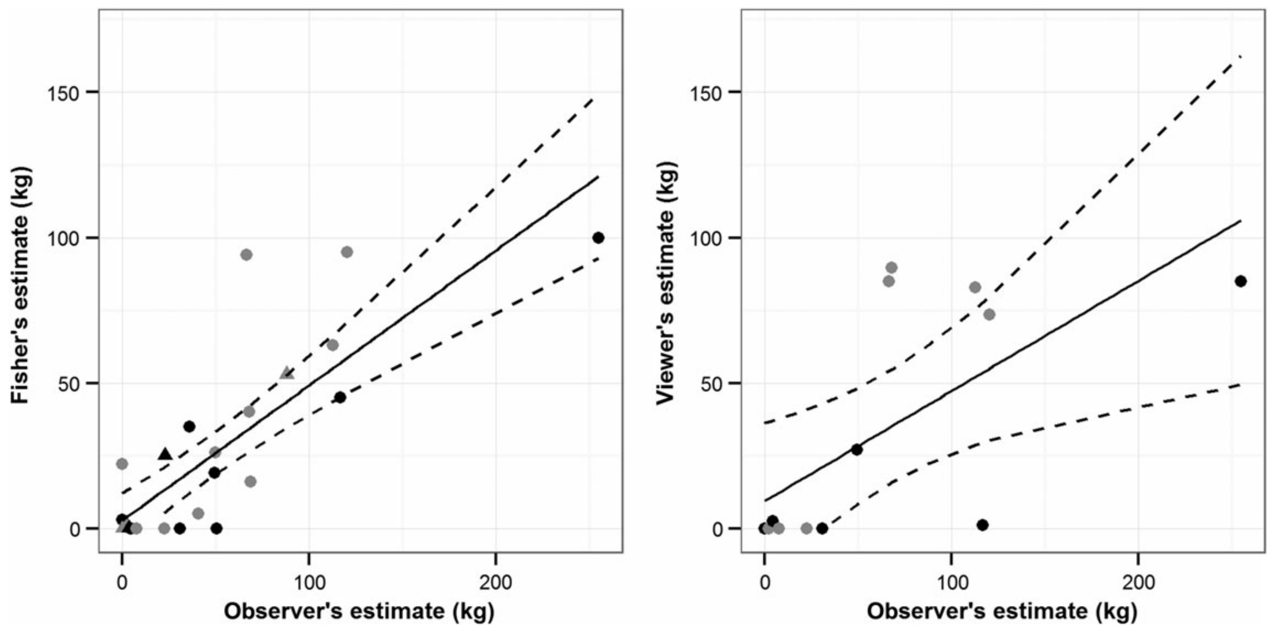

Figure 4. Paired cod discard estimates by FDF trip with observers onboard. Left: fishers' estimate vs. observers' estimate (trips 8 and 31 omitted). Right: viewer's estimate vs. observer's estimate. Black ¼ 2012. Grey ¼ 2013. Circle: North Sea. Triangle: Skagerrak.

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 wherea simple phone call mentioning thatsome 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 pointsthat 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

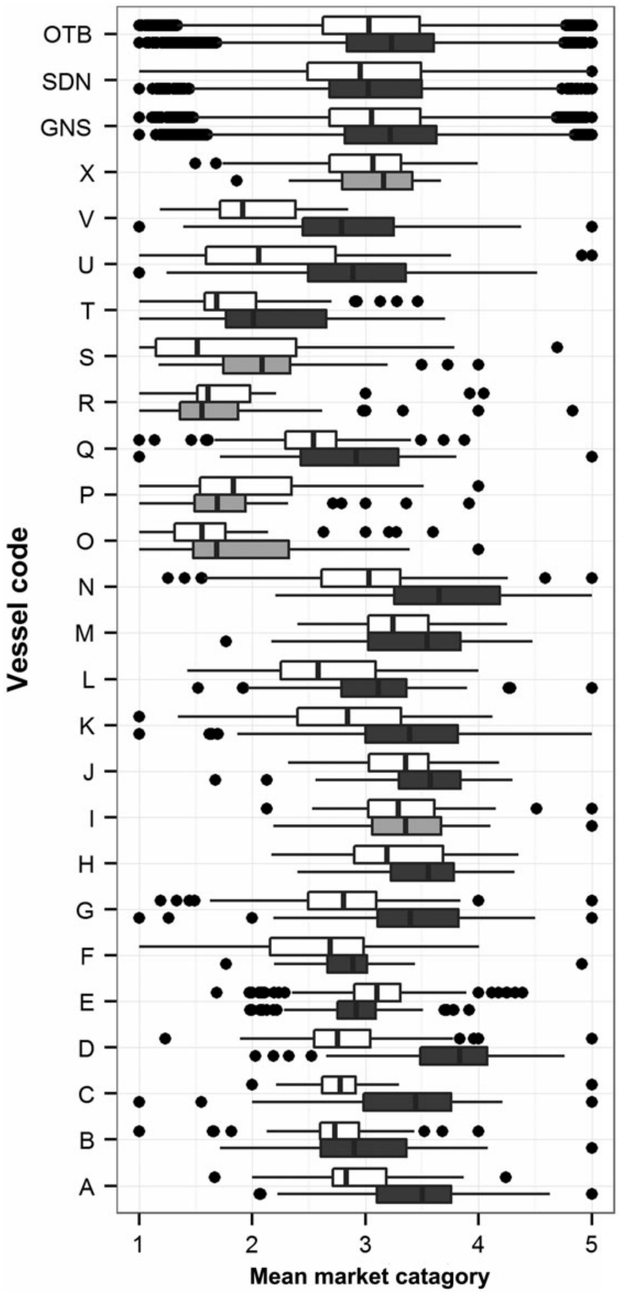

Figure 5. Average cod market category by trip (market category number weighted by the percentage weight of that category to the total trip's landings), plotted against vessel ID [gillnet (GNS), trawl (OTB), and Danish seine (SDN) trips in North Sea and Skagerrak only]. Categories from 1 (largest cod, 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 istherefore 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 thatthe 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 logbooks 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.

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