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Changes in fishing behaviour of two fleets under fully documented catch quota management: Same rules, different outcomes

A.T.M. van Helmond *, C. Chen, B.K. Trapman, M. Kraan, J.J. Poos

Wageningen IMARES, Institute for Marine Resources and Ecosystem Studies, PO Box 68, 1970 AB IJmuiden, The Netherlands

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ABSTRACT

A Dutch pilot study of fully documented fisheries provided the opportunity to observe actual changes in fishing behaviour under catch quota management (CQM). Interviews with fishers in the pilot study aided in interpreting the results and giving insight in the decision making process and reasoning of fishers. The CQM pilot study entailed a fleet of small and large demersal vessels. For these vessels, all cod catches were counted against quota, including catches of individuals below minimum landings size. To obtain reliable catch data all vessels were equipped with electronic monitoring (EM) systems. These systems recorded videos of all fishing and processing activities on board. In return, fishers received a 30% quota bonus for cod and were compensated with more flexibility on effort regulations. It was hypothesized that vessels in the CQM will (i) increase their landings by 30% according to their quota bonus, (ii) increase the use of gear with large mesh size, and (iii) change effort towards fishing locations with high catch rates of large cod and avoid areas with high catch rates of undersized cod. The results showed that CQM had no effect on fishing behaviour of the small vessels. In contrast, large vessels significantly increased their cod landings (216%) and avoided undersized cod. This difference in response of different fleets suggested that implementation of CQM, for instance in the context of the European Common Fisheries Policy, should consider fleet characteristics. It seemed that larger vessels in this study more easily adapted their behaviour to new management regimes and that the quota bonus opened up new fishing strategies, that were not envisaged during the implementation.

1. Introduction

European fishery management traditionally attempts to control fishing mortality in commercial fisheries by setting annual quotas on landings [23,30]. However, constraining landings may not reduce total catches, and thus fishing mortality, because fishers may optimize the use of their quota by discarding low-valued fish (high-grading), or continue fishing and discard species after quotas have been reached [11,20,34,45]. Apart from the discarding of fish because of quota restrictions on landings, fishers also discard fish as a result of technical regulations and the economics of the fishery, e.g. fish that is caught but that is under the allowed minimum landing size, and fish that has no market value [7]. These aspects are particularly challenging in a mixed fishery context [29,3].

In general, discarding is considered to be a waste of natural resources. Indeed, the fish that does not survive after being discarded does not contribute to the future catch, as it would have if it had remained alive. Additionally, the discarded and unreported catch leads to unaccounted mortality and makes it difficult to appropriately monitor and manage the effects of fishing activities [10,35,47]. Recognizing these problems, the European Union (EU) has agreed to reform the Common Fisheries Policy (CFP) [18]. The reformed CFP includes a phased implementation of the obligation to land all catches [17].

If properly enforced, the obligation to land all catches prohibits discarding of commercial species and should serve as a driver for improved selectivity, and provides more reliable catch data [39,41,8]. Implementing a landing obligation requires that the complete catch is reported and deducted from the available quota. In such a catch quota management (CQM) regime fishers are held accountable for the total amount of fish caught, including the unwanted and unmarketable (previously discarded) part of the catch. Consequently, an incentive is created to change fishing behaviour, because every fish caught is deduced from the quota, including small and low-valued fish [30].

In order to gain insight in the potential effects of the landings obligation prior to its full implementation, the EU established provisions in the quota regulations to conduct pilot studies on fully documented catch-quota management schemes, or "fully

* Corresponding author.
E-mail address: edwin.vanhelmond@wur.nl (A.T.M.v. Helmond).

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documented fisheries". These provisions were established for cod in the North Sea, Skagerrak and Eastern Channel, under the condition that participating vessels use closed circuit television (CCTV) associated to a system of sensors, that record all fishing and processing activities on board. All cod catches are counted against the quota, including catches of individuals below minimum landings size. In order to create incentives for fishers to participate in the pilot studies, Member States are permitted to allow additional catches of participating vessels within an overall limit of 5% above the national cod quota. However, per vessel, additional quota is limited to 30% of the normal quota applicable to the vessel [16]. Within this context, a fully documented catch-quota pilot study for cod in Dutch demersal fisheries is initiated in 2012. The pilot study is a collaboration between the Dutch Ministry of Economic Affairs and the Dutch Federation of Fishermen's Organisations. In addition to the increase of individual cod quota, the Dutch government provides a derogation on national effort control regulations: vessels deploying a CCTV on board are not limited by the available number of days at sea for fisheries with mesh size ≥ 120 mm. The idea behind this derogation is to create extra flexibility for participants to be able to operate in a catch-quota system.

So far, publications on fully documented fisheries (FDF) have been concentrating on the efficacy of catch documentation technology [25,31,37,46,48,49]. The efficacy of catch documentation by video gives promising results, particularly when fish are processed in such a manner that it is easy to detect individual fish in video footage, e.g hook-and-line fisheries [1,49]. However, few studies have investigated changes in fishing behaviour under a fully documented catch-quota management regime and little is known about the effectiveness of the landings obligation in changing fishing behaviour. Kindt-Larsen et al. [25] and Ulrich et al. [48] observe that fishers participating in catch-quota trials reduced discarding of legal sized cod of low value. When asked, the participating fishers confirm that they are more aware of catch compositions than before the start of FDF, and more often change fishing grounds to avoid small cod [25]. Avoiding discarding of small cod can be achieved by fishing with larger mesh sizes and fishing effort reallocation towards fishing grounds with high densities of larger cod [49].

Changes in fishing behaviour in two mixed bottom trawl fleets on catch quota management have been studied in this pilot study. The results are used to indicate whether the changes of behaviour comply with the purpose of the regulation, i.e. avoiding undersized cod. A before-after control-impact (BACI) study of catch and effort data is applied, contrasting vessels within the two fleets with their peers who are not under CQM. In addition, interviews with participating fishers about changes in behaviour under CQM are conducted. It is hypothesized that vessels in the CQM will (i) increase their landings by 30% according to their quota bonus, (ii) increase the use of gear with large mesh size, and (iii) change effort towards fishing locations with high catch rates of large cod and avoid areas with high catch rates of undersized cod.

Improved understanding of fishers behaviour, eventually, allows for a better understanding of fisheries dynamics, which in turn is essential for effective fisheries management [32,38,6]. In the context of the CFP, with the implementation of catch quotas and the obligation to land all catches, this study gives an important insight in what the significant factors are in the decision making process of individual fishers in a mixed bottom-trawl fisheries under such management systems.

2. Methods

2.1. Implementation of CQM in the pilot study

The full documentation of cod catches was done by the participating fishers in the study. Catch weights (kg) per haul were recorded in a logbook for each fishing trip. All catches were landed and subtracted from the quota. Undersized individuals that were landed were not allowed to be sold, and were therefore collected by the control authorities.

In order to attract vessels, a 30% extra individual cod quota was handed out to the participants of the pilot study. This 30% quota increase was based on the total quota (owned and leased) in the previous year. In addition to the increase of individual cod quota, the Dutch government provided a derogation on national effort control regulations: vessels deploying a CCTV on board were not limited by the available number of days at sea for fisheries with mesh size ≥ 120 mm. The idea behind this derogation was to create extra flexibility for participants to be able to operate in a catch-quota system.

To verify if logbooks were filled out correctly, video observations on the catch were obtained with electronic monitoring (EM) systems. A random selection of hauls (ca. 10% of the total number of hauls) was used to compare catch recordings in the logbooks with catch estimates from video analysis, see van Helmond et al. [49].

The EM system consisted of a GPS unit, up to four closed circuit television (cctv) cameras, and sensors for measuring force on the tow cables and net drum rotation. All sensors and cameras were connected to a control box with exchangeable hard drives for data storage [25,28]. The sensors were used to trigger the control box to start video recording during fishing operations. The cameras recorded overhead views of the working deck and catch-handling areas, while fishing, hauling, and processing the catches. Sensor and GPS data were recorded continuously whilst at sea. See also van Helmond et al. [49] for a detailed description of the EM system set up on board of the vessels.

2.2. Study fleet

The pilot study was applied to a bottom-trawl fishery that targets multiple species using various bottom trawl gears (e.g. otter trawl, Scottish seine, or beam trawl), and mesh sizes depending on target species. Within this fishery cod is targeted during short periods of the year, typically <2 months, using a mesh size ≥ 120 mm, or as valuable by-catch in fisheries with mesh size ≤ 100 mm, by a small part of the fleet. Vessels within this fleet were identified based on their possession of individual cod quotas and fishing effort track records. The identification of vessels in the fleet was done by the Dutch Federation of Fishermen's Organisations. In total, 40 vessels were identified as cod fishers and all were contacted by the Dutch Federation of Fishermen's Organisations.

Vessels were divided in two groups based on their engine power, since Dutch demersal fleet vessels with different engine powers exhibit different spatial fishing patterns due to (amongst others) regulations [33,36]: vessels with engine power ≤ 221 kW have access to fishing grounds within the 12 nautical mile zone and within a protected nursery area; the "plaice box" [4]. Vessels with engine power exceeding 221 kW are forbidden in this zone. In the ≤ 221 kW engine power group, 24 vessels were contacted, of which 6 vessels participated in the study (Table 1). These vessels used otter trawls and beams trawls with a wide range of different mesh sizes, from 20 to 130 mm, depending on season and target species. Of the group in the second category (with engine powers between 677 and 1471 kW), 16 vessels were contacted, and

Table 1
Overview of participating vessels per group, including fishing effort per year. Effort is in bold for the years the vessels participated in the pilot study. Underlined vessels code names indicate that the skipper of the vessel is interviewed.

Group	Vessel	Engine power (kW)	Effort (days at sea)				
			2009	2010	2011	2012	2013
Small vessels	V08	221	120	147	**166**	**186**	**185**
	V06	221	78	139	113	**166**	**176**
	V07	221	46	47	41	**63**	**53**
	V09	221	166	179	153	**162**	**180**
	V17	221	–	–	–	**215**	**224**
	V19	221	103	147	89	173	**164**
Large vessels	V16	1052	208	231	**242**	**271**	**221**
	V14	735	220	219	**214**	**187**	**202**
	V15	677	212	214	**185**	**219**	**195**
	V13	1471	–	59	205	**243**	**235**
	V11	734	194	200	193	**192**	**216**
	V18	762	192	202	191	222	**223**

6 vessels decided to join (Table 1). These vessels used Scottish seines with a range of mesh sizes between 80 and 130 mm, depending on season and target species.

2.3. Catch and effort data

The CQM pilot study resulted in high-resolution catch and effort data for the participating vessels through haul-by-haul catch registration in logbooks and the EM system. However, because comparisons between vessels within and outside of the pilot study are required, only data that is available for the entire Dutch fleet can be used. Hence, catch and fishing effort data were collected from two different sources for the vessels: EU logbook data and vessel monitoring system (VMS) data. The EU logbook data contains catch and fishing effort information. Each fishing vessel must provide a logbook to the authorities at the end of each fishing trip in which more than 50 kg of fish is caught. The data comprise: vessel code; engine power; type of fishing gear and mesh size; date and time of departure; harbour of departure; date and time of arrival; harbour of arrival; landings (in weight) by species per geographic area ("ICES rectangle"). The data were obtained as the annual landing and effort for each vessel and year, where year ranges from 2010 to 2013. A "programme" variable was added to the data, indicating whether the vessel participated or not.

The VMS data contains information on the location of fishing vessels at a high temporal (~2 h) and spatial (~200 m) resolution. This information was available for all vessels in the study. The VMS sends GPS information on board of the vessel to land-based stations using satellites. This GPS information includes the position and ground speed of the vessel. High resolution fishing effort (in hours) maps are created from the pings. First, each ping is converted to an estimate of fishing effort in terms of time by calculating the time span between all pairs of subsequent pings, and assigning it to the first ping in each pair. Then, pings that are located in fishing harbours are removed. Finally, all pings with speeds >8 knots are removed as those pings likely indicate steaming activity of the vessels. The final maps of fishing effort are raster representations of the sum of the time associated to the remaining pings [22].

As a first step in the data analysis, differences in cod landings between participating and non-participating vessels in the years prior to the study (2009 and 2010) were analysed using a *t*-test with equal variance on log-transformed landings.

2.4. BACI analyses on landings and gear use

A before-after-control-impact (BACI) analysis was used to investigate the impact of the pilot study. It was hypothesized that after joining the study, the participating vessels changed their annual landing and effort, and their behaviour was different as compared to the non-participating or "control" vessels. To adjust the annual variation in landings and effort, the vessel-year-programme data were re-structured for the pooled BACI analysis: since CQM was employed from an increasing number of vessels in the years 2011–2013, three BACI (year-before vs. year-after) data structure can be extracted: 2010 vs. 2011, 2011 vs. 2012, and 2012 vs. 2013. Each record of the vessel-year-programme was assigned to one of the three BACI structures, or else excluded. In the BACI analysis, the change in fishing behaviour caused by the entrance in the CQM pilot study was investigated (one year before, and one year after). Therefore, a participating vessel was selected either as a control vessel in a BACI structure when it did not enter the CQM pilot study, or as a test vessel in the BACI structure when it entered the study. Afterwards, it was excluded in the analysis in the following BACI year structure. As a result, a participating vessel can be selected either as a control vessel or a test vessel in the three BACI structures, depending on whether the vessel joined the programme in the year-after (Table 2). Not all vessels could be used in the BACI structure because of missing data (Table 2). After re-categorizing the records into the three BACI structures, they were pooled as an entire BACI structure. Analysis on such pooled structure assumes that the difference in change of the fishing behaviour from the participating vessels (as compared to the control vessels) is only caused by the programme, rather than year.

The BACI method was used for testing whether (i) there was a change of the log-transformed cod annual landing from participating vessels compared to non-participating vessels, and (ii) there was a change of the proportion of annual fishing effort using large (≥ 120 mm) mesh size from participating vessels compared to non-participating vessels. Both were tested by comparing the average change of landing or effort (year-before vs. year-after) between control and test vessels, using a two sample *t*-test with equal variance.

Table 2
Selection of vessels and their treatment types for the three BACI structures. "Test"=vessel entering CQM, "control"=vessel not entering in CQM, "NS"=not selected because already in CQM or because of missing data.

Group	Vessels	Number of vessels	BACI		
			2010 versus 2011	2011 versus 2012	2012 versus 2013
Small vessels	v08	1	Test	NS	NS
	v06, v07, v09	3	Control	Test	NS
	v19	1	Control	Control	Test
	group of non participants	13	Control	Control	Control
	v25*	1	Control	Control	NS
	v17, v23, v24, v28, v31**	5	NS	NS	NS
Large vessels	v14, v15, v16	3	Test	NS	NS
	v11, v13	2	Control	Test	NS
	v18	1	Control	Control	Test
	group of non participants	9	Control	Control	Control
	v12	1	NS	NS	NS
Total number of vessels		40			

* Vessel v25 was taken out of service in 2013, and hence could not be selected in BACI 2012–2013.

** Data for vessels v12, v17, v23, v24, v28, v31 were not available in the period 2010–2013.

2.5. Spatial distribution of fishing effort

To analyse shifts in spatial fishing effort distribution, the spatial effort distribution for the study fleet was plotted in gridded maps of the North Sea. In the plots, a distinction was made between (i) vessels that were asked to participate, but never joined the CQM pilot, (ii) participating vessels prior to entering CQM, and (iii) the same vessels under catch quota management.

The plots of spatial effort allocation were compared to the spatial distribution of cod Catch Per Unit Effort (CPUE) from the International Bottom Trawl Survey in quarter 3 (IBTS Q3). The survey in the third quarter was chosen because it co-occurs with the commercial fishing season for cod in the Dutch fishery. The IBTS Q3 survey uses a standardized GOV net with 20 mm mesh size in the codend. Several nations around the North Sea take part in the survey that covers the North Sea and Skagerrak area. Annual survey CPUE per length and ICES rectangle were available through ICES. Spatial distribution of abundance was calculated for the period 2001–2015 for fish sizes under and over 55 cm. The sum of CPUEs over all observed lengths within the size classes were calculated over the period 2005–2015.

2.6. Interviews

In addition to the collection and analysis of catch and effort data, semi-structured interviews were conducted with eight participants; four skippers from small vessels and four skippers of large vessels (Table 1). The interviews were conducted in order to help interpret the results and to provide insight in the decision making process and reasoning of fishers in the study. Each interview lasted for approximately one hour. Interviews were conducted in the period from February 2014 to February 2015. Fishers were visited at their docks, their ships, their homes or their local bar. Sometimes family and co-owners of vessels or companies joined the interview.

Each interview started with questions about the incentives for participating in the study. Then, data was presented on participant's annual landings of cod, effort data per mesh size category and maps of annual cod landings per statistical rectangle. Fishers were asked to comment and elaborate on this information. Annual landing information of cod was presented in the years before and after entering the pilot study. This landings information indicated whether the participant made use of the extra quota and increased cod catches. Effort data was presented as the average number of trips per year per mesh size categories of ≤ 24 (shrimp gear), 79–99, 100–119, and ≥ 120 mm. Participants were asked to elaborate on the number of trips per mesh size category and fishing locations before and after entering the study.

Interviews were audio-recorded and converted in transcripts afterwards. Interview transcripts were analysed for common themes using text mining. Responses were analysed with the software package Atlas.ti [19].

3. Results

3.1. Study fleet

From the 24 small vessels that were contacted prior to the pilot study, the annual cod landings of the 6 small vessels that eventually participated were on average 31 tons higher in the years before the pilot study (2009 and 2010) than those that did decide not participate (Fig. 1). A t-test on the log transformed weights revealed that for the small vessels, this difference was statistically significant ($t=-3.70$, df=40, p-value <0.001). For the 16 large vessels that were contacted prior to the pilot study, there was no statistically significant difference between the 6 vessels that eventually participate and those that decided not to participate ($t=-0.75$, df=27, p-value=0.46).

3.2. BACI

3.2.1. Landings

For small vessels, there was no statistical difference in the average change of annual cod landing between participating and non-participating vessels (p-value=0.53, Fig. 2 and Table 3). For large vessels, the cod landings decreased by $((1-10^{-0.1})*100\%)=20.6\%$ for the control vessels. For the large vessels, the cod landings increased by $((10^{0.5}-1)*100\%)=216\%$. The t-test indicated that for large vessels, the average change of annual landing from the participating large vessels was statistically significantly different than those from the non-participating vessels (p-value <0.01, Fig. 2 and Table 3).

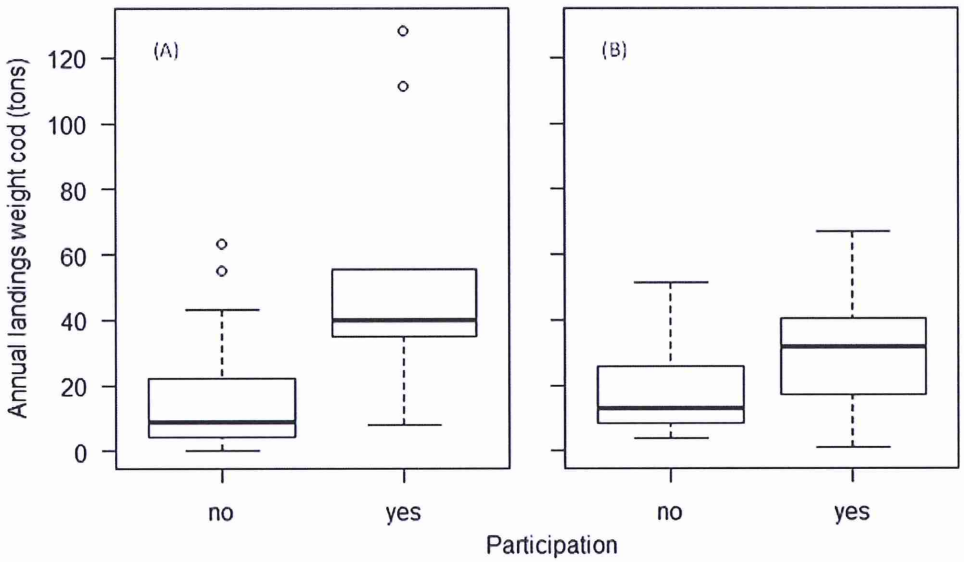

Fig. 1. Box and whiskers plots of annual cod landing (t) in the period before the CQM pilot study (2009 and 2010) for (A) small vessels and (B) large vessels, that eventually decided to join the programme ("yes") or decided not to participate ("no"). Boxes represent Q1 and Q3. Thick drawn lines represent the median. The whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

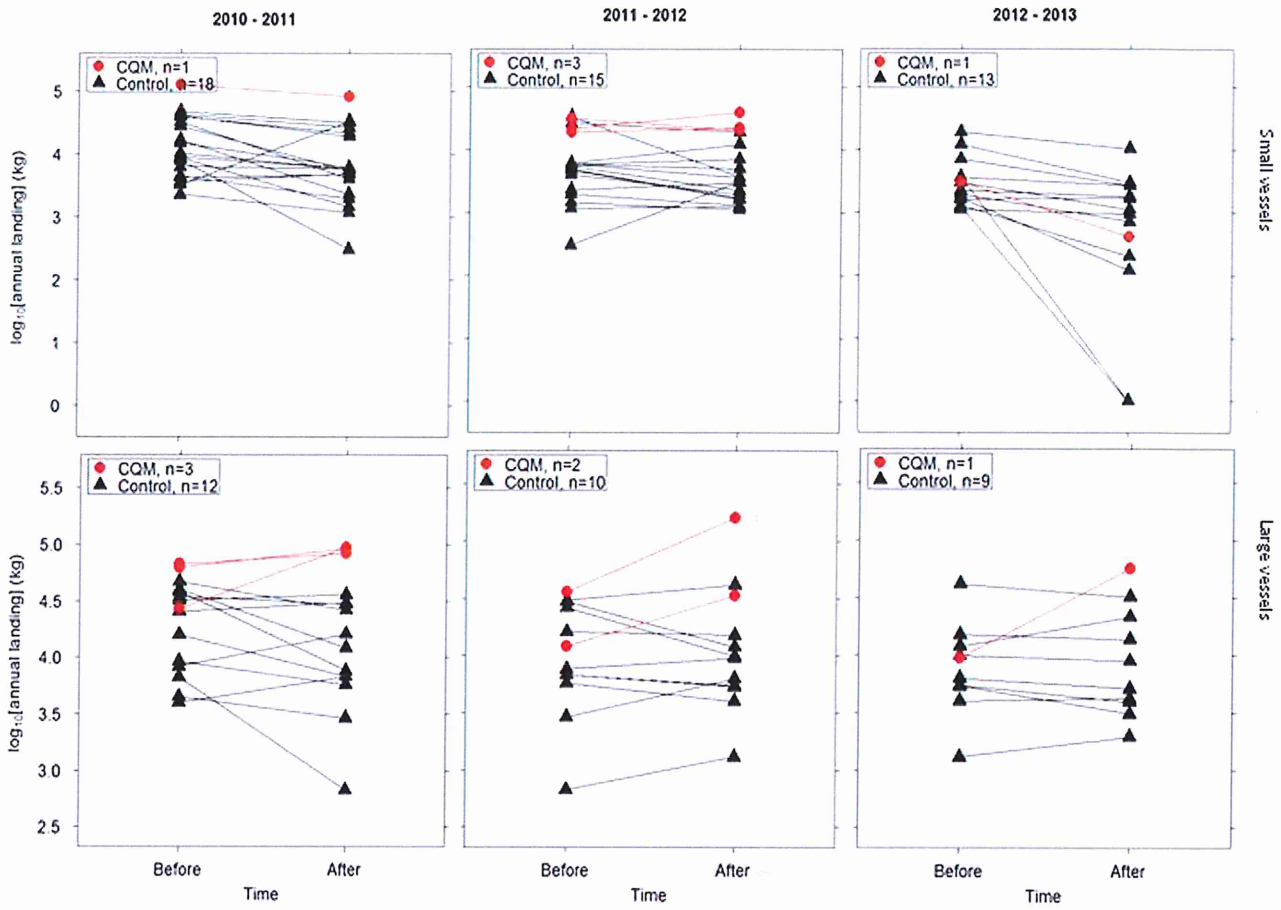

Fig. 2. BACI plots of $\log_{10}$ transformed annual landing (kg) from year 2010–2011, 2011–2012, and 2012–2013, respectively. Top panels represent the small vessels, bottom panels represent large vessels. In each panel, the CQM vessels refer to vessels that switched to CQM in that period. The control vessels refer to vessels that did not participate until that year, being vessels who were offered to join but never participated and vessels starting CQM in later years. A participating vessel is plotted either as a control vessel in panel year when it did not use CQM yet, or in the panel year when it was the first year of CQM. It is excluded in the plots of the subsequent years. For instance, in 2011, three vessels (V14, V15, and V16) started CQM and they are excluded in the plots of 2012 and 2013. This procedure is repeated for vessels V11 and V13, and for vessel V18 who started CQM in 2012 and 2013, respectively.

Table 3
Comparing the change in landing and percentage of effort (in days at sea) with mesh size larger than 120 mm (year before vs. year after) between control and test vessels, using a Welch two sample *t*-test (equal variance).

Variable	Group	Mean change CQM vessels	Mean change control	*t*-Value	df	*p*-Value
Landings ($\log_{10}$[kg])	Small vessels	−0.2	−0.4	0.6	49	0.53
	Large vessels	0.5	−0.1	4.2	35	<0.01
Percentage effort > 120 mm	Small vessels	−3.7	−1.2	−0.7	49	0.48
	Large vessels	8.7	−2.7	2.0	35	0.05

3.2.2. Mesh size

For small vessels, there was no difference in the average change of fishing effort ≥ 120 mm between participating and non-participating vessels (*p*-value=0.48, Fig. 3 and Table 3). For large vessels in the control group, there was a decrease in the use of mesh sizes ≥ 120 mm: the percentage of fishing effort with mesh sizes ≥ 120 mm decreases by 2.7% per year. For large vessels entering the CQM pilot study, there was an increase in the use of mesh sizes ≥ 120 mm: the percentage of fishing effort with mesh sizes ≥ 120 mm increases by 8.7% per year. The *t*-test indicates that for large vessels, the average change of effort using ≥ 120 mm mesh size from the participating large vessels was statistically significantly different than that from the non-participating vessels (*p*-value=0.05, Fig. 3 and Table 3).

3.3. Spatial distribution of fishing effort

The spatial distribution of cod CPUE from the IBTS Q3 survey showed clear spatial variation, with higher CPUEs in the north and north-eastern areas off the Danish coast (Fig. 4). Also, the contribution of large fish (≥ 55 cm) to the CPUE of the survey was higher in those areas compared to the central and southern areas of the North Sea.

For small vessels, the spatial distribution of fishing effort in the North Sea was concentrated in the Dutch coastal zone, and a number of fishing grounds scattered around the southern North Sea (Fig. 5a–c). There were no marked differences between the vessels that were asked but never joined, and those vessels that joined in the years before participating (Fig. 5a vs. b). For those vessels in the CQM pilot study, the fishing effort was largely

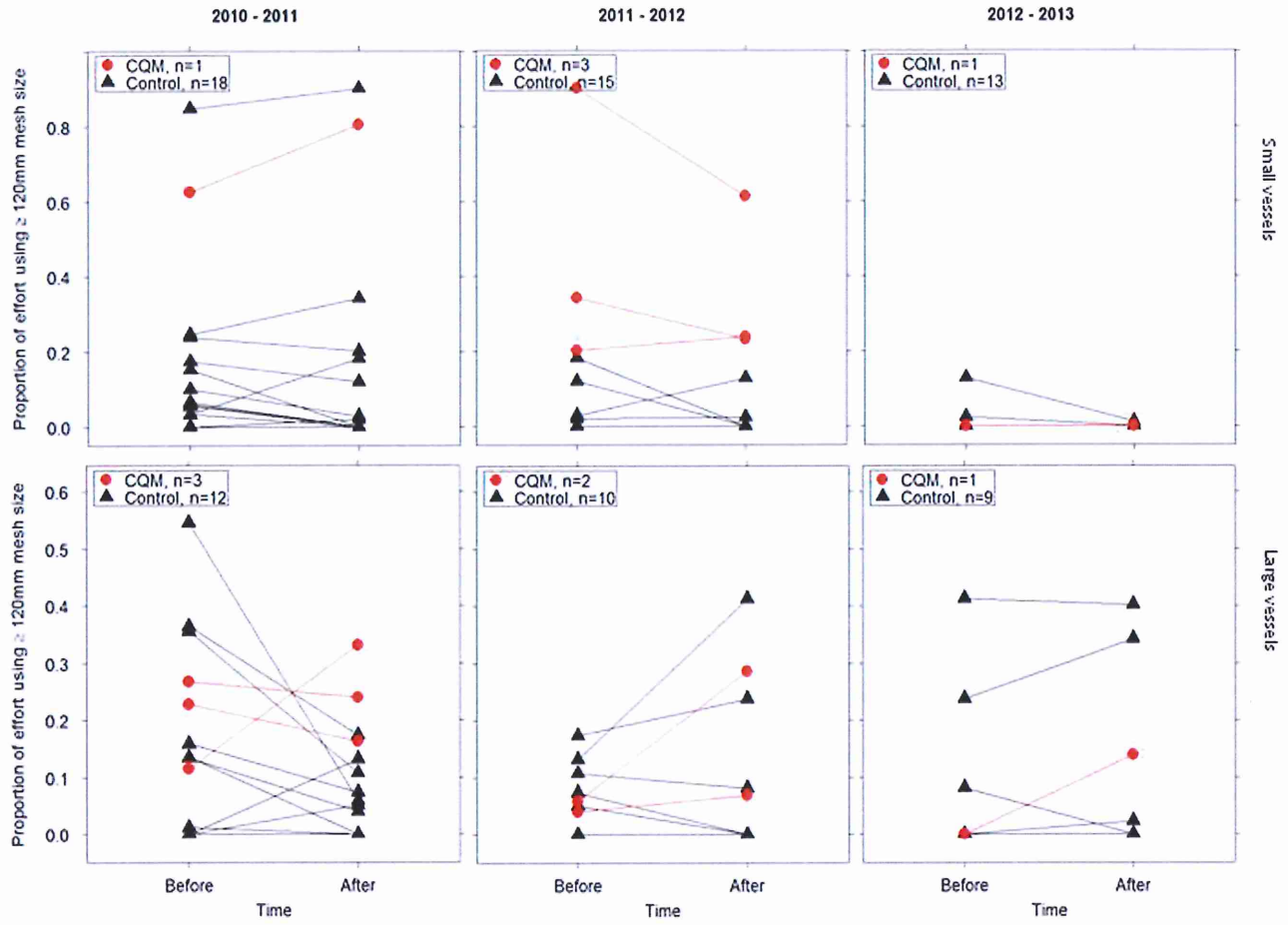

Fig. 3. BACI plots of proportions of annual fishing efforts (days at sea) using ≥ 120 mm mesh size for large vessels from year 2010 versus 2011, 2011 versus 2012, and 2012 versus 2013, respectively. Top panels represent the small vessels, bottom panels represent large vessels.

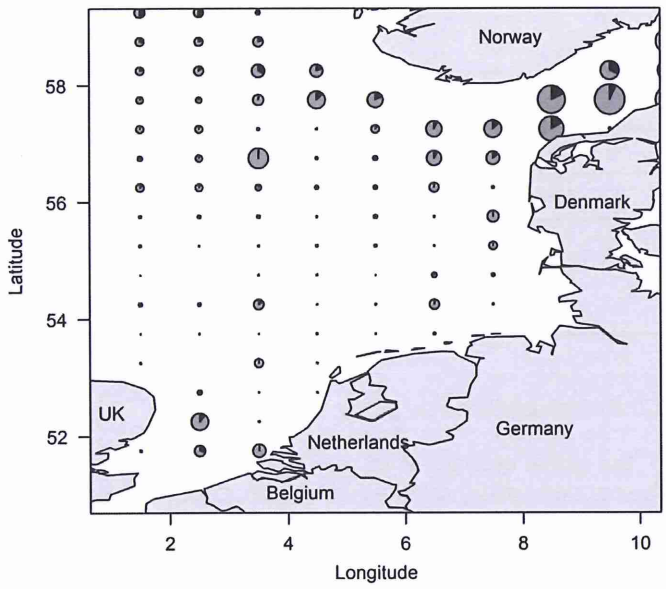

Fig. 4. Spatial distribution of cod CPUE calculated from the annual International Bottom Trawl Survey in quarter 3, in the period 2005–2015. Larger surfaces of the pie charts indicate increasing CPUE. Light grey within the pie charts indicates proportion of CPUE of fish < 55 cm and dark grey indicates proportion of CPUE of fish ≥ 55 cm. (1.5-column).

similar to the vessels and years for which there was no participation, with the exception of the absence of fishing effort of CQM vessels in the Sylt fishing grounds off the south-western coast of Denmark (Fig. 5a and b vs. c), one of the brown shrimp (*Crangon crangon*) fishing grounds. However, there was no marked change in the other brown shrimp fishing grounds off the Dutch and Belgian coasts.

For the large vessels, there were marked differences between the vessels that were asked but never joined, and those vessels that joined in the years before participating (Fig. 5d vs. e). Clearly, the vessels that eventually joined the programme have a more Easterly fishing effort distribution than the vessels that never participated. The fishing effort for those vessels participating in the study showed a clear difference in the years for which the vessels participate (Fig. 5e vs. f): there was a move of fishing effort towards the north and north west coast of Denmark, in an area that the fishers call "The Holmen Grounds". This area was associated with high CPUE of large cod in the IBTS.

3.4. Interviews

3.4.1. Incentives

For the skippers of the small vessels the flexibility on the effort regulation was an important incentive to join the pilot study (Table 4). Three out of four interviewed skippers mentioned this during the interviews. The flexibility on effort regulations was a sufficient incentive to participate and outweighed the presence of the cameras: two skippers of the small vessels mention that they "*have nothing to hide*". Finally, one skipper mentioned that his main motivation was the interaction with scientists that participation would bring.

For the skippers of large vessels the interviews made clear that

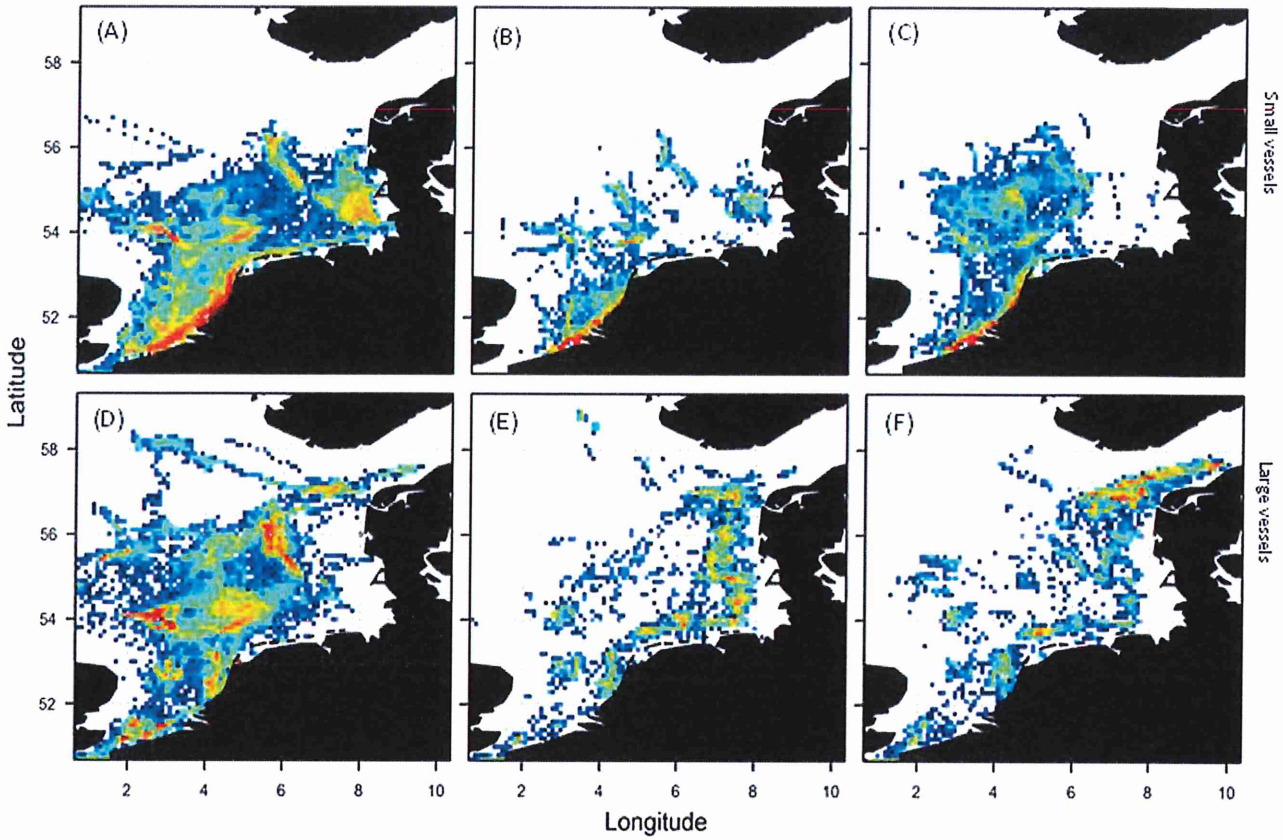

Fig. 5. Spatial effort distribution for the study fleet. Warmer colours indicate increasing fishing effort. Top panels indicate small vessels, bottom panels indicate large vessels. Distribution for vessels that were asked to participate, but never joined the CQM pilot (A and D). Distribution for participating vessels in the years prior to entering the pilot (B and E). Distribution for vessels in CQM during the pilot (C and F). (2-column).

the quota bonus was an important incentive to participate in the pilot study. For example the skipper of v14 mentions: *"The reason is the extra 30% cod that we get. It is as easy as that. To have a camera in your neck the whole day is not something you do for fun"*. One skipper mentioned the increase in transparency of what is happening on board was also an important motivation to join: "*There is always sort of a haze around the fisherman*". In addition, he hoped that the cameras would show that "*...there is really enough cod to be caught...*". In contrast with the motivations given by the skippers of the small vessels, none of the skippers of large vessels mentioned the additional flexibility on the effort regulation as an important motivation to join.

3.4.2. Landings

No significant increase in landings of cod was observed for the small vessels after entering CQM. Three out of four skippers indicated that they observed too little cod on their fishing grounds. The skipper of vessel v07 answers: *"We tried to catch cod, but cod fishery in front of the coast seems to be finished, at least for the last two years"*, while the skipper of v09 mentions *"...no cod in the area this year..."*, and"*...I think cod moved towards northern areas...*".

Two skippers said that they fished on shrimps the whole year because it was a good shrimp year. Going to the fishing grounds off the Danish coast, was not an option for these fishermen, because it was either not profitable given the cod prices, or the risk for bad weather and resulting low catches was too high.

For the large vessels, interviews for two owners suggested that they had started specifically targeting cod after the start of the project on fishing grounds off the Danish coast. The skipper of V16 stated his change in targeting behaviour: *"Back then [before participation] it was not interesting to target cod. We caught cod as bycatch, but we did not have enough quota to specifically target cod"*. One of the fishers (v14) noted however, that his change in fishing grounds was unrelated to project but that it resulted from the need to find new target species when the price of the tub gurnard had decreased (Table 4).

The large variation in the increase in cod landings among the different large vessels could be explained by the difference in attitude towards cod as target species: One of the skippers (v11) that had a small increase explains that they see cod as a bycatch:*"But we really don't go to the north with the intention, let's catch some cod, we do not have enough quota for that. But they are in the bycatch. Last year and this year were good cod years. I see it getting better"*. On the other side of the spectrum there were vessels for which landings have increased by more than the quota bonus of 30%. The skipper of v16 explained that the 30% quota bonus created an incentive to rent additional quota, because the bonus was calculated on the total of owned and rented quota in the previous year (Table 4).

3.4.3. Mesh size

The analysis of catch and effort data did not find an increase in the use of large mesh sizes for small vessels. Effort control regulations of the Common Fisheries Policy [15], permits only one gear of one mesh category per fishing trip. Skippers of the small vessels did not use large mesh sizes as they did not target cod. Species that they were targeting instead required smaller mesh. Two of the four interviewed skipper of small vessels indicated that they target shrimp which are caught using small mesh sizes.

The large vessels traditionally fished with 80 mm in winter and with at least 100 mm in summer. The two skippers specifically targeting cod both do as expected: they fish with larger mesh

Table 4
Summary of interviews.

Group	Vessel	Interview	Motivation	Feedback from interview		
				Landings	**Mesh size**	**Fishing grounds**
Small vessels	V06	Skipper	More flexibility on the effort regulation. Also quota bonus and more transparency. Skipper: "*I have nothing to hide.*"	Constant cod landings overall, no difference before and after participation. Targeted other species. Skipper: " *But 2012 was of course a fantastic shrimp year. Look, if the shrimps are 4 or 5 euros, then yes, I would be crazy to go for cod if I can earn more if I go for shrimps*". Also, "*..there was no cod, due to high water temperatures..*".	Did not change mesh size. Skipper targeted Brown shrimp *Crangon crangon*, with mesh 20–24 mm in 2012.	Skipper: "...we always fish on the same grounds, just under the coast line...". He avoids places with smaller cod. Based on experience he knows which places to avoid.
	V07	Skippers (father and son).	Quota bonus and more flexibility on the effort regulation.	Did not increase landings. Skipper 1: "*We tried to catch cod, but cod fishery in front of the coast seems to be finished, at least for the last two years*".	Skippers explained, they used 80 mm mesh to target other species then cod. Skippers feel limited in their gear/mesh choice due to technical measures cod recovery plan. Difficult to estimate what they will catch before leaving harbour.	No shift in fishing grounds. Skippers explain it is to problematic to fish that far north, due to the weather conditions. Skipper 2: "*We can't go that far, it is out of our range*".
	V09	Skipper	Quota bonus and more flexibility on the effort regulation. Skipper: "*we have nothing to hide*"	Did not increase landings. Skipper: "...*no cod in the area this year...*","*...I think cod moved towards northern areas...*", "*Not profitable to target cod with 120 mm last year*". "*Fifteen years ago, we caught lots of cod just in front of the Dutch coast*".	Skipper explained, he used 80 mm mesh to target other species then cod. Skipper: "*Not profitable to target cod with 120 mm...*". Skipper feels limited in his gear/mesh choice due to catch composition regulations (technical measures cod recovery plan).	No shift in fishing grounds. Skipper: "*Not profitable for us to fish that far north*". "*...we are too dependent on good weather conditions to travel to distant fishing grounds..*"
	V19	Skipper	Interaction with scientists in order to be part of what is going on.	Did not increase landings. The quota bonus was not a motivation. Cod was a bycatch, skipper did not target cod specifically. Skipper:"*There is no cod near the coast last few years. If the cod is in the area, I go for it. It need to be close to shore to make enough profit*".	Skipper explained they fished for shrimp after he joined the pilot study. Fishers use 20–24 mm in cod end to catch Brown shrimp, *Crangon crangon*. Skipper: "*Made enough profit with shrimp fishery. Rather stay near the coast to target shrimp, then going off shore to catch something else*".	No shift in fishing grounds. Did not move north to richer cod grounds. Skipper: "*Not enough quota available to make it profitable to travel that far*".

Table 4 (*continued*)

Group	Vessel	Interview	Motivation	Feedback from interview		
				Landings	**Mesh size**	**Fishing grounds**
Large vessels	V16	Skipper, his brother (deckhand), and his father (previous skipper of this vessel).	Quota bonus.	Increased landings. Start targeting cod, after participating in the pilot study. Before cod was valuable bycatch. Start to rent more quota. Fisher: "*We see more cod*". " *The rent for cod quota is very high. If you get 30% extra quota over your rented cod quota, the rent prices goes down in total. If we would not have gotten those 30% extra it would not have been profitable to rent*".	Increased mesh size to target cod in North sea. Skipper: "*We started fishing with larger mesh sizes in order to let the small ones swim*". Brother:" *It is purely to let the small ones escape*".	Changed fishing grounds. Start targeting more cod and moved to richer cod ground based on experience. Father: *"In the north in front of the Danish coast are richer cod grounds*". Father explains that, based on his experience they moved to that area. Start avoiding smaller cod. Father: "*Cod at the Cleaver bank. is really small*". Skipper:"*....we have to record the undersized, which is not attractive. That is why we shift from the Cleaver bank to Denmark*".
	V14	Skipper	Quota bonus. Skipper: "*When the opportunity was there, we immediately joined the pilot study*".	Increased landings. Start targeting cod. Did rent extra quota. Previous target species was Tub gurnard, *Chelidonichthys lucerna*, the price dropped at the time the pilot study was initiated.	Increased mesh size, from 100 mm to 120 mm or more (up to 135 mm) to target cod in North sea. Before, 100 mm was used regularly to target Tub gurnard.	Changed fishing activity to more Northern grounds (Denmark). Skipper avoided the "Cleaver bank", since cod is smaller in this area.
	V11	Skipper	Quota bonus.	Did not increase landings in general. Cod is bycatch.	Did not change mesh size, targets mainly gurnards and plaice with 110. Skipper:"*If we catch more cod we have to increase mesh to 120 mm* [technical measures cod recovery plan]".	Did not specifically change area to target cod. However, when prices of main target species drop, e.g. gurnards, they move northwards, but not specifically for cod. Skipper: "*..we not only move north for cod, we don't have enough quota for that...*".
	V18	Skipper (cousin of V11 skipper).	Increase the transparency of what is happening on board. In addition, the quota bonus provides extra flexibility to land the cod.	Did not increase landings in general. Cod is bycatch. Although, the extra quota did trigger additional cod landings in 2013. However, this was not the case in 2014.	Did not change mesh size, targets mainly gurnards and plaice with 110 and 120 mm.	Did not specifically change area to target cod. However, explains, that they caught more and larger cod together with commercially interesting species North in front of Danish coast. Skipper also explains that cod on the "Cleaver bank" area is smaller.

sizes, 130 mm and 135 mm, to avoid catching undersized cod. One of these skippers (of v16) explains: *"We have started fishing with larger mesh sizes in order to let the small ones swim"*. The other two large vessels fish with 110 mm and 120 mainly to target larger, more expensive plaice, red gurnard and dab. One of the skippers explains he changed to larger mesh sizes when he catches a lot of cod in order to comply with the regulations about catch composition (see [14,26]). With a lower mesh size a lower percentage of cod could be held on board.

3.4.4. Spatial distribution

For the small vessel skippers going north towards fishing grounds with high densities of larger cod was not profitable or too risky as the vessels were too small to cope with possible bad weather (e.g. V07, V09 in Table 4). Another skipper mentioned that even with the quota bonus he did not have enough quota for cod to make fishing in the these distant areas profitable (V19 in Table 4).

The two large vessels targeting cod confirmed that they fish off the Danish coast for large cod. They both mentioned the possibility to catch small cod at the Cleaver bank. One of the skippers said that it is not attractive to fish for cod at the Cleaver bank as he had to report catches of undersized cod, and hence they shifted their practice to the coast in front of Denmark. As a result of the change in fishing grounds both vessels regularly landed their cod in Denmark (V14 and V16 in Table 4).

The two large vessels with less cod quota did also go more north. One said that he went looking for large gurnards, dab and plaice as the price for regular gurnard was low. The skipper of the other vessel (V11) said that the project did make a difference for him as it created the flexibility to go further north: *'[Historically] we caught 2-3-4-5 thousand kilos of gurnard a week, for which we got on average 3-4 euro. So we made a good landings value with the bycatch. But then more Scottish seiners came – first we were only four – and we are now with approximately 25 of those ships that target gurnard. So the gurnards have no value anymore, and it is no longer worth it. […] So then we went North and then you have cod as bycatch, which is really good. There is a lot of cod here. Right now you often catch 1000 kg of cod, and big ones, not small ones.'*

4. Discussion

Several studies have hypothesized that catch-quotas and discard bans potentially create strong incentives to change fishing behaviour for more selective fishing practices [2,44,9]. Those studies use models to forecast vessel fishing behaviour based on the premise that fishers optimize a utility function. Simplifying assumptions have to be made when defining a utility function and net revenues are often used as proxies for the actual utility function of the fisher. Another simplifying assumption is that fishers with similar gears and vessels respond similarly to changes in management systems. Indeed, economic performance variables provide useful information about fisher preferences in resource use [13,40,50,51]. However, tradition, culture, knowledge, experience, vessel constraints, regulation, enforcement, and information sharing are also important elements in the rationale of fisher behaviour [27,32,51,6]. Rather than relying on model predictions on the potential outcome of catch quota management, this pilot study allows observing actual fishing behaviour under CQM. Additionally, the interviews help to interpret the results and give insight in the decision making process and reasoning of fishers in the study.

It was hypothesized that all participating fishers would attempt to increase their annual cod landings, given their 30% increase in cod quotas. However, for the small vessels no significant increase in annual cod landings was observed in the BACI analysis: catches were either equal or lower after joining the study in comparison with previous year. In interviews, fishers explained that there was no cod on their fishing grounds (Dutch and Belgian coast). Two fishers described the year, in which they switched to CQM, as a good year for catching brown shrimp and that targeting shrimp close to shore is more profitable than fishing for cod. Possibly, all fishers would have switched to shrimping. However, not all vessels are fitted with the specialized equipment and gear that is necessary for the fishery on brown shrimp [5]. The large vessels, on the other hand, did increase their annual cod landings, on average by 216%. The reason that landings have increased considerably more than 30% was that the large vessels rented additional quota. A substantial increase in quota renting is an unforeseen side effect of the pilot study. Participants receive the 30% bonus on their total quota share of the previous year, including additional rented quota. Hence, there is an indirect discount on renting cod quota, when you consider the 30% bonus for next year. Fishers confirmed this concept in the interviews. This unintended consequence of the pilot study might have triggered participating fishers to focus more on cod as they would have normally done and possibly overstated the effect of the catch quota regime in this study. Two fishers of the 'large vessel group' did not increase their cod landings under the CQM regimes. They consider cod as a valuable bycatch product when targeting other species.

It was hypothesized that vessels participating in the pilot study would increase their use of large mesh sized gear and change fishing grounds. For the fleet of small vessels, there was no significant increase in effort with mesh size ≥ 120 mm compared to the control group. Also, small vessels did not change their fishing effort towards areas with large cod. For the fleet of large vessels, there was a significant increase in fishing effort with mesh size ≥ 120 mm, and change in fishing grounds to avoid undersized cod. These are indications that the participants change their fishing behaviour in compliance with the purpose of CQM, i.e. maximize individual quota and change fishing behaviour to avoid catching undersized cod. Part of the change in mesh size may also be explained by technical measures in the cod recovery plan [26]. This plan dictates catch limits for cod in the total catch: max. 20% cod bycatch with 80 mm mesh and max. 5% cod bycatch with 100–119 mm mesh. Catches taken by demersal towed gears of mesh size equal to or greater than 120 mm are exempt from conditions relating to percentages of target and non-target species [14]. Fishers targeting plaice and gurnard with 110 mm mesh have to increase mesh size to 120 mm to comply with the regulations, when the catch consist of more than 5% of cod. Because all cod catches are registered, discarding cod to get the desired catch compositions, i.e. high grading, is not an option. Similar behaviour is observed in the study of fully documented fishery in Denmark [25]. Meanwhile, fishers that specifically targeted cod adjusted their mesh size in order to avoid undersized cod and more frequently fished on Northern fishing grounds (Danish coast). Those fishers confirmed that they avoided areas with smaller cod, such as the Cleaver bank. Other large vessels, that did not increase their cod landings, did not increase their mesh size or change fishing locations.

Compared to the larger vessels in the pilot study, the small vessels are more constrained by physical vessel characteristics (e.g. size, engine power) and the existing regulations. Effort control regulations of the Common Fisheries Policy [15] permits only one gear or one mesh category per fishing trip. When cod is not abundant, it is not profitable to go out with 120 mm mesh. As a result, fishers of small vessels prefer to use 80 mm mesh size gears, instead of exploring cod fishing grounds with large mesh. The latter holds the risk of not finding cod and having to return home empty handed. However, when they unexpectedly start

catching cod with small mesh, the cod recovery plan dictates catch limits for cod in the total catch (max. 20% cod bycatch with 80 mm mesh and max. 5% cod bycatch with 100–119 mm mesh). Fishers of small vessels find it difficult to foresee cod catches before leaving the harbour. The complexity of regulations and technical measures has an effect on their fishing behaviour, as the skipper of v07 explains: "*Actually you are occupied with this* [the right catch composition] *every week, having the right percentages*". CQM possibly complicates their situation, since discarding of cod is not an option with video monitoring on board.

The derogation on the effort regulation was emphasized as an important motivator for the small vessels to participate in the pilot study. Not being limited by a lack of available sea-days provides them with the opportunity to fish with large mesh, ≥ 120 mm, and target cod at the end of the year. This would otherwise be impossible, since the scarcely available sea-days in this fleet segment (bottom trawlers with mesh size ≥ 120 mm) are normally finished before the end of the year, as a result of the fishery on cod by large vessels earlier in the year on more distant fishing grounds in the North. Skipper v09: "*We had to participate… Because there is no other way… Last year* [2011] *we still had cod quota available, but couldn't go for it, because there were no sea-days available. But, colleagues with camera's on board were allowed to go out and fish cod*". The pilot study created an opportunity for the traditional cod fishery of the smaller vessels in the coastal areas at the end of the year. This fishery now struggles with effort control that has been developed with a focus on larger scale fishing operations; an example of unfit fisheries management for small scale fisheries [12].

The methodology of the study relies on a BACI [21] approach. Ideally, the control and impacted part of the population are exactly the same. In this case, the population is created through the network of industry representatives, who are of the opinion that all contacted vessels are eligible and likely to participate. The fishers in the pilot study are offered a bonus of 30% cod quota and increased flexibility in effort regulations under the conditions that all cod catches, including discards, is counted against their quota. Rational choice theory (e.g. [42,43]) predicts that fishers with cod discard rates above 30%, and no options to reduce cod discards, will most likely not participate under the proposed conditions. Meanwhile, fishers with low cod discards rates, large cod quotas, and the possibility to reduce the catches of small cod, most likely, will participate in the 'burdensome' CQM project with camera's on board, because they gain most from adopting the CQM rules [30]. Indeed, small vessels joining the programme had larger cod catches on average prior to the pilot study than those vessels not joining (Fig. 1). For large vessels no statistically significant difference in cod catches was found prior to the programme. However, differences in the spatial distribution of fishing effort were found between participating and non-participating large vessels in the period prior to the study (Fig. 5d and e). Hence, although the populations of control and impacted vessels are very similar, there are always individual differences among the skippers of the vessels that are considered potential candidates by the fisheries organizations. Those differences most likely play a role in accepting to join the CQM pilot study. It is expected that almost all fisheries pilot studies, where participation is voluntary, suffer from selection bias. Hence, control and impacted populations may differ.

5. Conclusion

To summarize, changes in fishing behaviour are observed. For the large vessels, participants in the CQM increased their landings to use their quota bonus, increased the use of large mesh-sized gear, and changed effort towards fishing locations with high catch rates of large cod and avoid areas with juvenile cod. These observations are in line with the hypotheses. However, the increase in landings was on average much larger than 30%, because fishers found ways to use the quota bonus to their advantage and increase their landings beyond the envisaged 30%, e.g. by borrowing quota on the market. The observations for population of small vessels are not in line with the hypotheses. First of all, the incentives for joining the pilot study were generally related to having increased flexibility in effort regulations rather than the quota bonus. Also, no increase in cod catches was observed in the year that vessels entered the pilot. Likewise, no change in mesh size was observed, nor a clear change in fishing grounds. Interviews with fishers suggest that the small vessels do not change mesh size nor explore richer cod fishing grounds because they are hindered by technical regulations and constrained by the limitations of their vessels, e.g. size, engine power. Within their options, the small vessels changed to alternative options such as shrimp fishing.

To conclude, the results show that (i) the incentives created in the CQM pilot study had very different effects on two different fleets. The fleet of large vessels changed fishing behaviour while under CQM, while the fleet of small vessels did not. Within fleets different effects for different individuals were observed. The different effects of CQM, for fleets and individual fishers, should be taken into account by fisheries managers when implementing CQM regimes. It seems that the larger vessels had more flexibility in adapting their behaviour to new management regimes. Meanwhile, these large vessels managed to use the pilot rules to their maximum advantage, with the quota bonus opening up new fishing strategies, that were not envisaged during the implementation.

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