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Original Article

Reducing discards without reducing profit: free gear choice in a Danish result-based management trial

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The 2013 Common Fisheries Policy introduced a landing obligation on a range of species, bringing more focus on the full accountability of all catches. To investigate the potentials and challenges of these paradigm shifts, a 6-months 'unrestricted gear' trial was performed in Denmark in 2015. Twelve trawlers were challenged to test their own solutions to reduce unwanted bycatch and/or choke species, while maintaining profitable. The participating fishers tested different options depending on their fishery and the type of issues they faced individually, and adjusted their test fishery over time through incremental small steps. Nine vessels reduced discard ratio in the test fishery, one showed no difference between test and control fishery, while two vessels displayed an increase in discard ratio. Catch compositions also differed, with fewer "choke species" occurring in the test fisheries and a more valuable size composition. Ultimately, despite smaller landings in multiple vessels, no vessel showed reduction in value-per-unit-effort (VPUE) and one Baltic vessel significantly increased the VPUE. This trial showed that relaxing technical regulations combined with proper incentives has a potential to provide some flexibility to cope with the landing obligation, where unwanted catches could be reduced to some extent without negative effects on economic viability.

Keywords: bottom-up approach, common fisheries policy, gear development, landing obligation, participatory, technical regulations.

Introduction

One of the key objectives of the 2013 Reform of the European Union (EU) Common Fisheries Policy (CFP) is to phase out the discarding of a number of commercial species in European marine waters between 2015 and 2019 (EU, 2013), through the introduction of an obligation to land all catches (the "landing obligation"). The landing obligation requires that all catches of stocks under catch limits and with a legal minimum conservation reference size (MCRS) are to be recorded and, where applicable, counted against quotas, with provision for some exemptions for protected species, for species with a high survivability and for discards that cannot be easily reduced through selectivity and avoidance measures (*de minimis* exemptions). This means that fishers become accountable for their entire catches of regulated stocks, and not of their landings only. Thus, beyond its primary objective of reducing discard, the landing obligation and the associated TAC uplifts are *de facto* moving the European fisheries management towards a catch quota management (CQM) approach.

Importantly, the landing obligation also impacts another fundamental paradigm of European fisheries management, the technical conservation measures (TCMs). Discards arise from a mismatch between the catching capacity and the landing opportunities, either at individual scale (if vessels are regulated with individual quotas or rations), or at the fleet/national scale This mismatch is itself linked to a broader mismatch between the societal and policy objective of maintaining fishing mortality of stocks within the regulatory frame (e.g. maximum sustainable yield) and the economic and social objective for individual fishers of optimizing the value of their landings. TCMs have thus been implemented incrementally (EU, 1998, 2013) with the aim of mitigating this mismatch by forcing changes in the catch composition (in species and/or in size classes) in the fishing gear (selectivity). The move towards the landing obligation and thus CQM means in theory that fishers would shift from maximizing the value of the part of the catch that can be sold to minimizing the volume of the part of the catch that cannot be sold, which would lead to a better alignment of the individual objective with the societal and policy objective (Nielsen *et al.*, 2015). To achieve this, fishers would in theory select the fishing methods and strategies that maximise their profits within the allowed catch frame. Additionally, under the landing obligation, individuals below the MCRS are not allowed to be sold for direct human consumption (EU, 2013). In theory, that would mean that fishers would be economically incited to avoid catching undersized fish and potential "choke species" and would increase their selectivity. A full and perfect implementation of the landing obligation could therefore also mean that only catch limits are required, which would also represent a shift towards results-based management (RBM) approach (United Nations Development Program – UNDP, 2000).

RBM requires an accurate documentation of catches in order to be operational and controllable. Without full control of the reliability of catches, any deterioration of the quality of catch data because of unreported discarding will negatively affect the accuracy of stock assessments and the ability to maintain fishing mortality within the regulatory frame. Thus, a move towards CQM and RBM approach has potential benefits but bears also important risks. These risks are exacerbated in mixed-fisheries. The introduction of the landing obligation presents several challenges for mixed fisheries, as it implies in principle that fisheries have to stop when the first quota is exhausted, an effect commonly referred to as "the choke species effect", which, potentially, can lead to the under-exploitation of more productive stocks for which quota remains uncaught (Schrope, 2010; Ulrich *et al.*, 2011; Baudron and Fernandes, 2015). This effect, combined with the requirement to land and count catches below MCRS against quotas is expected to negatively impact the economic viability of fisheries in the short term (Batsleer *et al.*, 2013; Condie *et al.*, 2014; Ravensbeck *et al.*, 2015; Russell *et al.*, 2015; Prellezo *et al.*, 2016). This short-term negative economic impact may be further exacerbated if the fishers are prohibited to adapt their current fishing practices and gears owing to stringent technical rules (STECF, 2015). To ensure a smooth transition into the landing obligation with less undesirable economic effects on the fishers, mechanisms are thus needed that remove hindrances to the fishers' ability to avoid unwanted catches. At the time when the ideas behind the project presented in this paper were initially developed (in mid-2013), no progress had been achieved yet to address this issue. The trial presented here was thus set up as an exploration of the potential benefits of relaxing the stringent technical rules in the frame of the landing obligation. Since then, a timely review of the technical rules took indeed place at the European level. The EU Scientific, Technical and Economic Committee for Fisheries (STECF) highlighted that the current TCM regulations were overly detailed and complex, and had little evidence of achieving their stated objective of avoiding catching juveniles and choke species in mixed-fisheries (STECF, 2015). STECF suggested that a shift away from detailed technical rules to catch metrics, such as CPUE-at-age or catchability, would provide more flexibility in fisheries and potentially drive fishers to develop innovative solutions to avoid unwanted catches (STECF, 2015). STECF cautioned, however, that considering the abovementioned risks of imperfect documentation of catches, a limited set of technical rules would still be required to prevent a degradation of the selectivity below an agreed baseline. Following this, a more flexible TCM frame has been proposed in early 2016 (EU, 2016), reflecting this overall shift in the fundamental principles used to manage European fisheries.

This study thus describes the outcomes of an attempt to trigger some changes in selectivity by removing the prevalent technical constraints in a Danish fisheries-science partnership (referred to as MiniDisc project). We analysed the discard ratios from 12 demersal trawlers in Danish waters during a 6-months fully documented "unrestricted gear" trial and contrasted how relaxing technical regulations under a CQM scheme may affect catches. It was anticipated that combining knowledge and knowhow from fishers and commercial fishing gear manufacturers could result in the development of innovative solutions to reduce unwanted catches, thus creating the possibility to reduce discards without jeopardizing economic viability.

Method

The MiniDisc project started in early 2014, but significant time was spent in the first months into spreading the word, identifying the vessels, agreeing on the scope and conditions for participation and obtaining the required permits from the authorities. At that time, there was also a great uncertainty in the fishery whether the freshly voted landing obligation would ever become a reality and whether changes in fishing practices would ever become a necessity. Consequently, the actual trial started in December 2014 and lasted until July 2015, involving 12 Danish demersal trawlers from the North Sea, Skagerrak, and Baltic Sea. The fishers were challenged to reduce their overall discard ratio of seven commercially important species, by modifying or developing new gears and/or changing fishing practice. The species of interest were the most important demersal species for the majority of the Danish demersal trawl fleet that come under the landing obligation between 2015 and 2019: Cod (*Gadus morhua*), Whiting (*Merlangius merlangus*), Saithe (*Pollachius virens*), Plaice (*Pleuronectes platessa*), Haddock (*Melanogrammus aeglefinus*), Hake (*Merluccius merluccius*), and Norway lobster (*Nephrops norvegicus*). To incentivize participation, additional quota (available from the Danish scientific quota pool) was offered to compensate for the additional costs and economic uncertainty linked to developing and testing new gears, and to remove the barriers linked to needing enough quota to cover changes in catch composition and not having to lease. During the trials, discarding was allowed and discards were not counted against quota, except for cod in the Baltic Sea, where the landing obligation entered into force for all vessels on 1 January 2015. The participating skippers were selected by the board of the Danish Fisheries and Producers Organization (DFPO) as being representative of a variety of important fisheries and/or having mentioned preliminary ideas to explore. Six vessels were equipped with twin rigs, and had the ability to use test and control gears simultaneously and to separate catches from the two gears in the tackle box. The other six skippers were instructed to interchange between test and control gears, as a minimum on a weekly basis, less if possible. In practice, most vessels switched gears between fishing trips or every second fishing trip. The participating vessels were equipped for fully documented fisheries, which included remote electronic monitoring (REM) with CCTV and gear sensors, using the technology developed by the Danish company Anchorlab (www.anchorlab.dk). Fishers were required to report landings and discards on a haul by haul basis, through the standard electronic logbook system or the REM software. For each haul, fishers had to separate and sort discards from each trawl into baskets and record the weight of each discarded target species. Discards were verified by video inspection at DTU Aqua. Fishers were required to show baskets containing the discards to the cameras before discarding. Overall, there was a sufficient consistency between fishers' reported catches and discard estimates from video inspectors (Mortensen *et al.*, in press), and the following analysis is therefore only on the basis of fishers declaration.

The purpose and set-up of this approach differed to a large extent from a standard selectivity experiment, where gears are developed scientifically and tested with usually a limited number of hauls performed in a rigorous population-independent trial. Here, our objective was to stimulate innovation and create a sense of ownership over the solutions developed by the fishers. As in a selectivity experiment, we wanted to assess whether the catch and catch composition in terms of species and size of the new solutions were significantly different compared with the standard fishery, but in this study we were primarily focusing on whether this difference would be observable under real conditions of fishing and sampling, rather than on analysing the actual technical properties of well-defined gears. However, the differences estimated in this trial are derived from a mixture of population-dependent and population-independent samples. The catch measures derived from vessels using twin trawls could be assumed to be population-independent, as both test and standard gears fished on the same populations. Catch measures from vessels using single trawls were population-dependent as gears were used randomly on different populations. To reduce the variability arising from such population dependency, the skippers changed gear often and stayed in the same area. Additionally, the trial was planned to be performed over a longer time period, providing substantially more samples than normal selectivity trials.

Another major intrinsic difference between this approach and standard selectivity experiment is that in reality, fishers are likely to experiment with their "free" option continuously, testing various configurations in a trial-and-error approach (Eliasen *et al.*, 2015), whereas the design and set-up of gears tested in standard selectivity experiments is usually fixed during the scientific trial. This feature was acknowledged and even encouraged upfront, to stimulate innovation and exploration. But this set-up creates a major impediment, as it becomes difficult to know all details of what has been tested, when and why. Efforts were made to collect this information through occasional phone contacts with the skippers during the trial, as well as with in-depth interviews at the end of the trial's period (Eliasen *et al.*, 2015). General feedbacks from the skippers were obtained on what they had tested and why, but it became obvious that a detailed timeline of the experimental set-up followed by each fisher could not be established with precision. Table 1 provides an overview of the alternative options as mentioned by the different participants, but this provides only a general idea of the approach followed and does not provide accurate technical details. Ultimately, it was foreseen that if significant discard reductions were observed through the self-sampling data collected here, a next step would be to analyse the technical features of the gears in more details involving also gear technology scientists and gear manufacturers. This next step is currently ongoing, and therefore the causal interpretation of the results presented here is limited; nevertheless, the scope of this trial was primary to assess what may happen under a full RBM approach, where only the output of the fishing operation is recorded, not the means employed to perform it (i.e. the inputs). This would also be the case in a CQM with baseline TCMs as suggested by STECF (2015), where the fishers could flexibly change gears within a given frame to adapt to the changing conditions of their fishery.

As the tested configurations are not known in full details, the solutions tested by the fishers are here thus labelled "test fishery", while standard practices and gears are labelled "control fishery". When gears are specifically in focus (as with twin trawls) the label "test gear" or "control gear" could be used.

The primary measure of performance for the gears was the discard ratio, which here is defined as the proportion discarded of the total catch for a species:

$$\text{Discard ratio} = \frac{\text{Discard}}{\text{Discard} + \text{Landing}}.$$

Additionally, changes in catch composition were included in the evaluation, by estimating and comparing the amounts per species landed per haul of the test fishery.

Initially, data were summarized and inspected for irregularities. Hauls containing incomplete catch registrations or faulty hauls were removed from the dataset (i.e. lacking discard information, gears torn or trash in the catch). Then the analysis of discard ratio was performed at different scales of aggregation. First, the overall achievement of the trial was measured by comparing test vs. control landings and discards per species per haul across all vessels using a Welch *t*-test; discard ratios and all other subsequent ratios were compared using a two-sample test for equality of proportions. Second, the same analysis was performed at the scale of the fishery/area. Vessels belonged to three different fisheries, each targeting a different set of species in a different area: six vessels in mixed demersal fishery in the North Sea (mainly targeting roundfish), three vessels in *Nephrops* fishery in the Skagerrak, and three vessels in cod fishery in the Baltic Sea. To avoid confusion with the "test" vs. "control fishery" wording, these three types of fisheries are hereby referred to using their area label only (North Sea, Skagerrak, Baltic Sea). Landings, discards and discard ratios in test and control fisheries were compared within each area. Finally, landings, discards, and discard ratios of test and control fishery were compared for each individual vessel.

To further explore the landing patterns of the test and control fisheries, landings were analysed for the size composition of each species from each type of gear. Species size distribution (by market category) was obtained from the sale slips. Because landings from the sale slips could not be differentiated into hauls and were thus on a trip level, the size distribution of catches for vessels with twin trawls could not be separated into test vs. control gears in the sale slips. Therefore, only data from vessels that sequentially changed between gears could be used in this analysis (Table 1; six vessels). The proportions by size class of each species were calculated by dividing the amount of each size class landed (S_p) by the total amount landed of that species (T_p). Average proportions of each species in the test and control fishery were compared by a Welch *t*-test. As the fishers were supplied with extra quota and most vessels initiated the trial in the beginning of the year, it was assumed that no vessel exhausted quotas in the trial and that all discard were below MCRS, as previous studies have demonstrated that vessels with REM are not high grading (Kindt-Larsen *et al.*, 2011; Ulrich *et al.*, 2015). Three vessels initiated the

Table 1. Overview of participating vessels, fishing method, type of control and test gear, area fished and the amount of extra quota added.

No.	Fishing method	Control gear	Test gear	Rational for change	Area	Quota addition
1	Twin trawl	Regulatory 120 mm demersal trawl, with 120 mm cod-end	(1) Inserted a 1 300-mm^2 mesh panel in the top of the cod-end of a regulatory 120 mm demersal trawl, with a 120 mm cod-end	Get a better selection in the cod-end by sorting out other fish, craps, and other invertebrates	North Sea	Saithe 32 ton Cod 30 ton
2	Twin trawl	Regulatory 120 mm demersal trawl, with 120 mm cod-end.	(1) Switched to a bacoma cod-end, which was assessed by the fisher to have a negative effect owing to kinking in the rest of the cod-end. (2) Round cod-end with 140 mm mesh size.	Reduce the amount of small fish.	North Sea	Saithe 32 ton Cod 30 ton
3	Single trawl	Regulatory 120 mm demersal trawl, with 120 mm cod-end	(1) Switched to a 140 mm cod-end. Circumference of the cod-end was 85-90 meshes to avoid "pouching" effect	Removes small cod and haddock, along with flatfish	North Sea	Saithe 26 ton Cod 30 ton
4	Twin trawl	Regulatory 125 mm demersal trawl, with 125 mm cod-end	(1) Four sided cod-end, with bottom and sides of 125 mm diamond mesh and top with 180 mm^2 mesh: (a) top with 160 mm^2 mesh (b) top with 140 mm^2 mesh	Would reduce cod landings, including small cod and small plaice	North Sea	Saithe 14 ton Cod 30 ton
5	Single trawl	Regulatory 120 mm demersal trawl, with 120 mm cod-end.	(1) Cod-end with 130 mm diamond mesh.	Less small fish and less discard.	North Sea	Saithe 8 ton Cod 15 ton
6	Single trawl	Regulatory 120 mm demersal trawl, with 120 mm cod-end	(1) Inserted 120 mm^2 mesh panel into the regulatory 120 mm demersal trawl with a 120 mm cod-end, the top panel, just before the cod-end (2) Used a 120 mm topless trawl, with no wings. Opens 1.4–1.5 m vertically	Reduce bycatch	North Sea	Saithe 26 ton Cod 30 ton
7	Twin trawl	Regulatory 90 mm nephrops trawl	(1) Inserted a separator panel and two cod-end. Top cod-end with 150 mm^2 mesh and bottom cod-end with 90 mm^2 mesh	Cleaner catch of nephrops and fewer small fish/undersized fish	Skagerrak	Cod 16.5 ton Nephrops 10 ton
8	Single trawl	Regulatory 90 mm nephrops trawl	(1) Inserted a separator panel and two cod-end. Top cod-end with 90 mm^2 mesh and bottom cod-end with 90 mm^2 mesh	Cleaner catch of nephrops.	Skagerrak	Cod 16.5 ton Nephrops 10 ton
9	Twin trawl	Regulatory 90 mm nephrops trawl	(1) New cod-end in the regulatory 90 mm nephrops trawl, with sides and bottom of 90 mm mesh and top 120 mm mesh (2) Cod-end of 120 mm mesh (3) Cod-end with 105 mm mesh and a section before the cod-end with 105 mm mesh and a 140-mm^2 mesh in the top	Less small fish and less discard	Skagerrak	Cod 16.5 ton Nephrops 10 ton
10	Twin trawl	Regulatory 120 mm demersal trawl	(1) Used a 105 mm diamonds mesh trawl. In the cod-end105 mm T90 mesh was used (2) Used a 105 mm diamond mesh trawl. Last 9.4 meters constricted to 8 meters using straps, to keep mesh open	Catch larger range of sizes to reduce time at sea with a relatively small increase in discards	Baltic Sea	Cod 20 ton
11	Single trawl	Regulatory 120 mm Bacoma trawl	(1) 105 mm diamond mesh trawl: (a) Added steel flounder escape grills (3 pcs.) in the bottom forward part of the cod-end (b) Added straps in the sides to loosen or tighten pull on meshes. Alters mesh form	Less flounders in the cod-end to clog up the selection of cod	Baltic Sea	Cod 20 ton
12	Single trawl	Regulatory 120 mm Bacoma trawl	(1) 110 mm bacoma panel (2) 110 mm bacoma panel with a wider opening, inspired from flotation trawls, to create a balloon effect in the cod-end	Get at steeper selection curve and higher catch rates with relatively less discard.	Baltic Sea	Cod 20 ton

Vessels with multiple test gears are numbered in the order the gears were tested.

trial in December and were supplied with extra quota in this period.

According to Eliasen *et al.* (2015) fishers continuously adjusted and tested their test fishery in small incremental steps. Therefore, data were investigated for temporal differences in discard ratios, in order to assess whether discard reductions had improved over time. Time trends were analysed using generalized additive models, with haul number and fishery as interacting explanatory variables and the discard ratio as dependent variable. As discard ratio is expressed as a proportion, the quasibinomial error distribution was used: *gam*(*discardratio* − *haulnumber* × *fishery, family* = *quasibinomial, data* = *data*). Analysis was carried out across all areas, in the individual fisheries and on each participating vessel.

Results

The trial began on 1 December 2014, where three vessels were fully equipped. In the course of December, the remaining vessels were equipped and by 5 January 2015, all vessels were fully operational. All vessels operated until 1 April after which three vessels stopped and changed to a different fishery (sandeel fishery). Two other vessels stopped on 1 May, as this was the initially planned end date of the trial. Two vessels continued throughout June and a further five until the end of July 2015. Thus, datasets from individual vessels vary as the participation period also varied.

The data covered 781 d of fishing, from 421 fishing trips and 2642 hauls. One twin-trawl haul was counted as two (test and control haul). After data validation, data covering 421 d of fishing, 298 fishing trips and 1497 hauls were usable for analysis, excluding 29% of fishing days and 43% of the hauls in the trial. There were several reasons for so many hauls being removed from the dataset. The primary reason was failure to report correctly, where catches were not or only partially recorded or were not separated between test and control fishery. Other reasons included damaged gears or e.g. large trash pieces in the gears (oil drums, etc.) that prevented video inspection. Additionally, vessels fishing in Norwegian waters in January 2015 could not use the test fisheries, as licenses for carrying out experimental fishing trials in Norwegian waters was not granted until the start of February 2015.

This yielded a total catch of 955 tons of the 7 target species, with a discard of 87 tons of target species. The overall discard ratio across all vessels, fisheries, species (seven target species) and areas was 13% (±41% s.e.). The overall average landing per haul was 654 kg (±25 kg s.e.) in the test fisheries and 622 kg (±25 kg s.e.) kg in the control fisheries. The overall landings per haul were statistically the same in both fisheries (Welch *t*-test, $p = 0.37$, df = 1493). Discards in the test fisheries were on average 52 kg (±5 kg s.e.) per haul, and 65 kg (±6 kg s.e.) per haul in the control fisheries, although this difference was not statistically significant (Welch *t*-test, $p = 0.10$, df = 1369). These average results hide large variations and further analysis was therefore carried at a finer scale (i.e. on a regional and vessel level).

Major differences were observed across the three areas (North Sea, Skagerrak, and Baltic Sea; Table 2). In the North Sea mixed demersal fishery (six vessels), the control and test fisheries landed on average the same quantity per haul (Welch *t*-test, p = 0.84, df = 832). By species, the test fishery landed significantly less haddock than the control fishery (Welch *t*-test, p < 0.01, df = 397) (Figure 1). Discards were higher in the North Sea test fisheries than in the control fisheries (Welch *t*-test, p < 0.05, df = 668),

Table 2. Average landings (kg), discard (kg) and discard ratio (%) per haul in the three areas and all areas combined.

	Control			Test			
Area	Landings	Discards	Ratio	Landings	Discards	Ratio	Change in ratio
North Sea	713	13*	1.87*	704	18*	2.6*	0.75*
Skagerrak	172	25*	12.6*	175	18*	9.5*	−3.1*
Baltic Sea	1 066	328′	23.5*	1 275	256′	16.7*	−6.8*
All areas	622	65	9.4	654	52	7.4	−2

Significant differences between test and control gear are marked with (*$p < 0.05$) and (′$p < 0.10$).

mainly owing to an increase in plaice discards (Figure 2). This led to a higher overall discard ratio in the test fisheries (two-sample test for equality of proportions with continuity correction, p < 0.01, df = 1, $\chi^2 = 406$). Discards ratios remained low compared with the other two areas.

Landings per haul in the Skagerrak *Nephrops* fishery (three vessels) were the same in the test and control fisheries (Welch *t*-test, $p = 0.83$, df = 376). However, discards were here lower in the test fisheries (Welch *t*-test, $p < 0.05$, df = 302) (Figure 2), with significantly less discards of whiting (Welch *t*-test, $p = 0.05$, df = 26) and cod (Welch *t*-test, $p = 0.05$, df = 272). This resulted in a lower discard ratio in the test fishery (two-sample test for equality of proportions with continuity correction, $p < 0.01$, df = 1, $\chi^2 = 179$), arising from lower discard ratio in the control fishery for cod, haddock, and whiting.

In the Baltic Sea cod fishery (three vessels), the test fisheries had higher landings than the control, although the difference was not significant (Welch *t*-test, $p = 0.12$, df = 202) (Figure 1). Discards were lower in the test fisheries, although also not significantly (Welch *t*-test, $p = 0.06$, df = 211). Nevertheless, the landings were sufficiently high and discards sufficiently low in the test fishery to result in a significantly lower discard ratio (2-sample test for equality of proportions with continuity correction, $p < 0.01$, df = 1, $\chi^2 = 2315$). Plaice was also caught in the Baltic, however, the fishers did not report plaice catches differentiated into test and control fishery, as their main target and concern was cod, which was newly subjected to the landing obligation as one of the first species in the implementation. From the electronic logbook it was estimated that only 360 kg plaice was landed in total by all vessels, while one vessel reported 1.8 ton discard of plaice.

These average outcomes are on the basis of the results of different vessels with different strategies and different numbers of hauls. The analysis was therefore expanded to individual vessels (Table 3). The results showed that two vessels increased their landings in the test fisheries (Vessel 8 in the Skagerrak and Vessel 10 in the Baltic Sea), while Vessel 6 in the North Sea had significantly decreased landings in the test fisheries. Seven vessels in the test fishery (Vessels 2, 4, 6 in the North Sea, Vessels 7 and 9 in Skagerrak, and Vessels 11 and 12 in the Baltic Sea) significantly reduced discards ($p < 0.05$). Vessels 3 and 5 in the North Sea had significantly ($p < 0.05$) increased discards in the test fishery. Overall, nine vessels reduced the discard ratio in the test fisheries (three in the North Sea, three in Skagerrak and three in the Baltic Sea), while two vessels (from the North Sea) increased the discard ratio and only one North Sea vessel showed no difference in discard ratio.

The analysis on landings, discard and discard ratio at vessel level was expanded to include landings-per-unit-effort (LPUE),

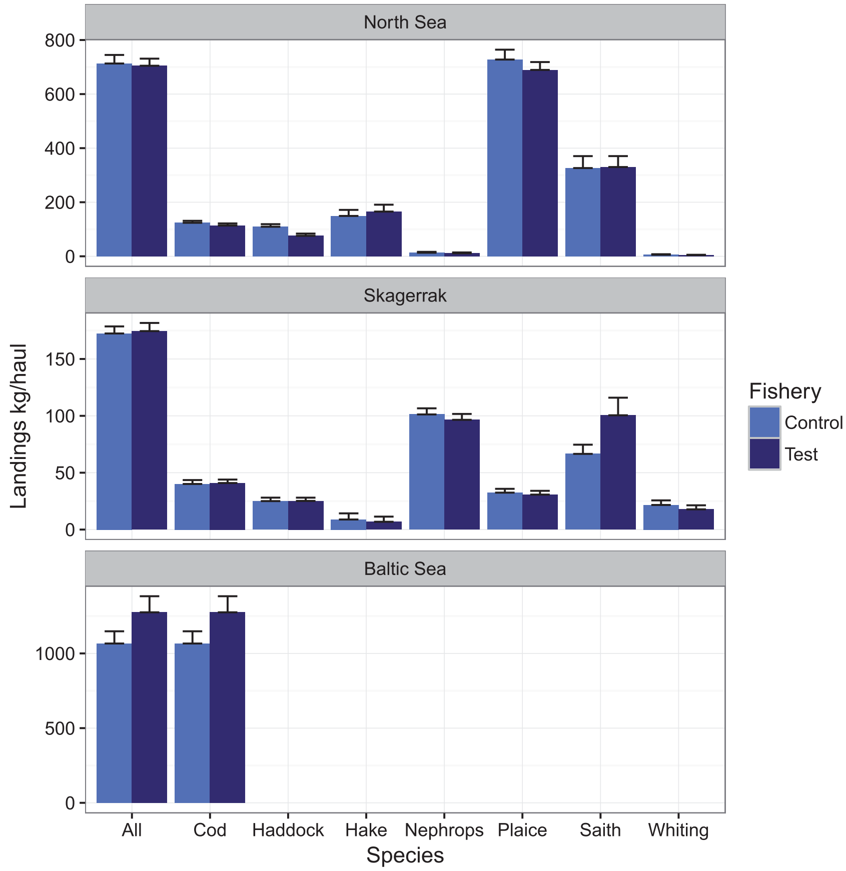

Figure 1. Barchart showing the average overall landings per haul from each area and the average landings per haul of individual species in each area. Error-bars signify standard error. Note that y-axis differs between areas.

discard-per-unit-effort (DPUE), and value-per-unit-effort (VPUE) to reflect the effect of the trial on catch economics, where effort was measured as time at sea (hours) (Table 4). Contrary to the results from the catch analysis, where almost all vessels showed changes in discard ratio between the test and control fishery, only one vessel (in the Baltic Sea) displayed significant ($p < 0.05$) increased VPUE in the test fishery. Thus, as nine vessels were able to reduce discard ratio with no significant effect on the VPUE, this result indicates that the participating fishers were able to meet the challenge of reducing discard while keeping revenues by using free gear selection. Lastly, because discards were not penalized, it is unsure whether the two vessels (3 and 5) with discard increases would have suffered significantly reduced VPUE in a landing obligation scenario.

The analysis of size distribution (i.e. market category) could only be done for vessels in the North Sea and Baltic Sea, as the Skagerrak vessels were all twin trawlers, using both the test and control gears simultaneously. The average size distribution of each species in the test and control fishery per trip can be seen in Figure 3 for the two areas. In the North Sea, the test fisheries landed a significant ($p < 0.05$) higher proportion of large (size class 2 of 6) cod than in the control fishery and large haddock (size class 1 of 3). The test gear also landed a higher proportion of large hake (size class 1 of 3), large whiting (size class 1 of 3), small plaice (size class 4 of 4), and saithe (size class 3 of 4); however, the difference was not significant ($p > 0.05$). In contrast, the control fishery landed a significant ($p < 0.05$) higher proportion of small cod (size class 4 of 6), while the landing of smaller haddock (size class 3 of 3), hake (size class 2 of 3), and whiting (size class 2 of 3) was higher in the control fishery, but not significant ($p > 0.05$). In the Baltic Sea the test fisheries landed a significant larger proportion of both large (size class 4 of 6) and small (size class 6 of 6) cod.

Discard patterns over time were also analysed, by using discard ratios per haul in a generalized additive model with quasi-binomial errors. No significant trend in discard ratio over time was evidenced and model fit was low [overall model: adjusted-R^2 (adj.R^2) = 0.02, GCV = 0.20, deviance explained (dev.exp) = 2.3%, $n = 1497$; including test vs. control fishery: adj.R^2 = 0.003–0.16, GCV = 0.04–0.24, dev.exp = 1–17%, n = 219–892]. The temporal trends in discard ratio were also analysed at a vessel level (Figure 4). Four vessels (2, 5, 8, 11) showed a significant decreasing trend in the discard ratio across all hauls, although the model fit was generally poor for all four vessels (adj.R = 0.03–0.26, GCV = 0.04–0.26, dev.exp = 6–29%, n = 114–258). However, there was no effect of the test and control fishery, showing that the decrease in discard ratio occurred in both fisheries.

Discussion

The overall average from this trial showed that the free gear choice resulted on average in slightly higher landings and slightly lower discards, which verified the expected outcome of the trial.

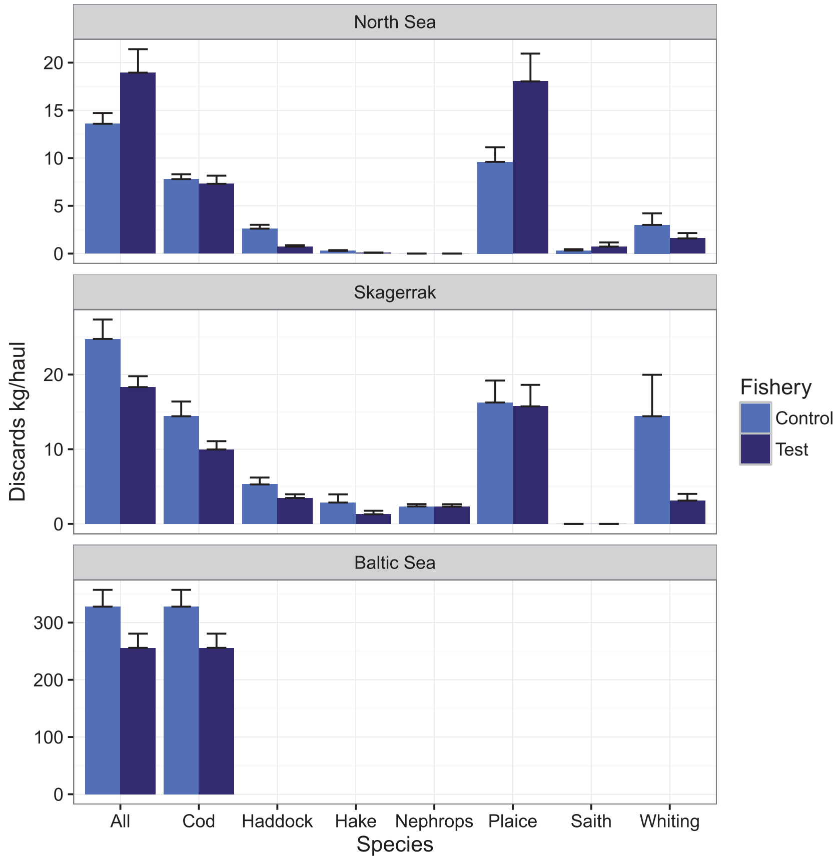

Figure 2. Barchart showing the average overall discards per haul from each area and the average discards per haul of individual species in each area. Error-bars signify standard error. Note that y-axis differs between areas.

Table 3. Average landings (kg), discard (kg) and discard ratio (%) per haul in the individual vessels.

		Control				Test				
Area	**Vessel**	**Hauls**	**Landings**	**Discards**	**Ratio**	**Hauls**	**Landings**	**Discards**	**Ratio**	**Change in ratio**
North Sea	1	32	1 314	3	0.2	32	1 177	3	0.3	0.1
	2	104	367	8*	2.2*	104	357	6*	1.7*	−0.5*
	3	35	704	5*	0.7*	138	784	23*	2.8*	2.1*
	4	81	460	13*	2.8*	74	457	4*	0.9*	−1.9*
	5	104	814	24*	2.9*	103	913	46*	4.8*	1.9*
	6	56	1 197*	16*	1.3*	29	948*	6*	0.6*	−0.7*
Skagerrak	7	15	193′	74*	27.6*	15	150.1′	17*	10.0*	−17.6*
	8	129	160*	16	9.3*	129	173*	16	8.5*	−0.8*
	9	49	199′	32*	13.8*	49	186′	25*	11.7*	−2.1*
Baltic sea	10	19	1 004*	217	17.7*	19	1 367*	184	11.9*	−5.8*
	11	61	615	197*	24.3*	53	570	130*	18.6*	−5.7*
	12	30	2 024	665*	24.7*	37	2 238	474*	17.5*	−7.2*

Significant differences between test and control gear are marked with (*$p < 0.05$) and (′$p < 0.10$).

The differences were however not significantly different. The overall discard ratios observed were smaller than the overall the discard ratio calculated from Storr-Paulsen *et al.* (2012) on same areas and species (20%), which may be explained by the absence of high-grading in vessels carrying camera (Ulrich *et al.*, 2015).

However, the calculated averages are not necessarily indicative of what would be the actual outcomes if the entire fleet was managed this way, as each fisher conducted its experience in its own way (Eliasen *et al.*, 2015). In the current study, the majority of the fishers altered their catch composition and reduced the discard ratio; however, this effect was masked in the average by few fishers where discard ratio increased significantly. The contradiction between the result of the average and the results from the individual fishers highlights a challenge for less restrictive technical regulations in a CQM management scheme, as the overall result would argue against a less restrictive TCM, while the individual results would argue for it. The changes in landings and discard ratio did not appear to impact on the economic profitability of the vessels, except for vessel 10 where VPUE increased by using the test fishery. Thus, as the challenge to the fishers was to reduce discards while keeping or increasing revenues, almost all participants were able to meet this challenge using free gear selection.

Table 4. Average LPUE (kg/h), DPUE (kg/h), and VPUE (DKK/h) per trip in the individual vessels.

		Control				Test			
Area	Vessel	Trips	LPUE	DPUE	VPUE	Trips	LPUE	DPUE	VPUE
North sea	1	4	92*	0	2 522	4	83*	0	1 967
	2	9	28	1′	815	9	27	0′	796
	3	3	79	1*	1 162	9	97	3*	1 215
	4	7	58	2′	798	6	64	1′	746
	5	7	91	3	1 128	9	106	6	1 312
	6	3	69	1	759	4	121	2	1 142
Skagerrak	7	10	17	6*	1 151	10	14	1*	839
	8	78	22′	2	1 085	78	23′	2	1 087
	9	26	21	3′	1 436	26	20	3′	1 407
Baltic sea	10	19	78*	17	832*	19	106*	14	1 119*
	11	39	99	32′	533	29	105	24′	625
	12	15	259	86*	1 844	21	249	53*	1 803

Significant differences between test and control gear are marked with (*$p < 0.05$) and ($'p < 0.10$).

Most vessels in the trial reduced discards in the test fisheries, resulting in a subsequent reduction in discard ratio. Assuming that such discards were mainly undersize fish, reducing their catch under the landing obligation may result in increased revenues, as that would reduce the share of the quota that cannot be sold for direct human consumption (EU, 2013). The results from the North Sea and Skagerrak indicate that the free gear choice may enable fishers to minimize revenue loss, by reducing catch of choke species. This was emphasized by the low number of vessels with reduction in VPUE in the test fishery.

The situation is different in the Baltic Sea, where the fishery primarily targets cod, with limited bycatch. Owing to the relatively small size of cod in the Baltic Sea (ICES, 2015), the discards were relatively high (compared with North Sea and Skagerrak results). With the current gear it is likely that fisheries in the Baltic Sea would lose revenues, as a high percentage of the quota would be used to cover landings of fish below MCRS or cod just above the MCRS (EU, 2013; Mangi and Catchpole, 2014). Additionally, plaice is estimated to become a choke species for the Baltic cod in 2017 (Zimmermann *et al*., 2015; Fitzpatrick and Nielsen, 2016), which could exacerbate losses further. However, owing to the lack of enforcement, no change has happened in the Baltic cod fishery during the first year of implementation of the discard ban (Borges, 2016).

The results from the current trial demonstrated that fishers in the Baltic Sea were able to increase landings and decrease discards

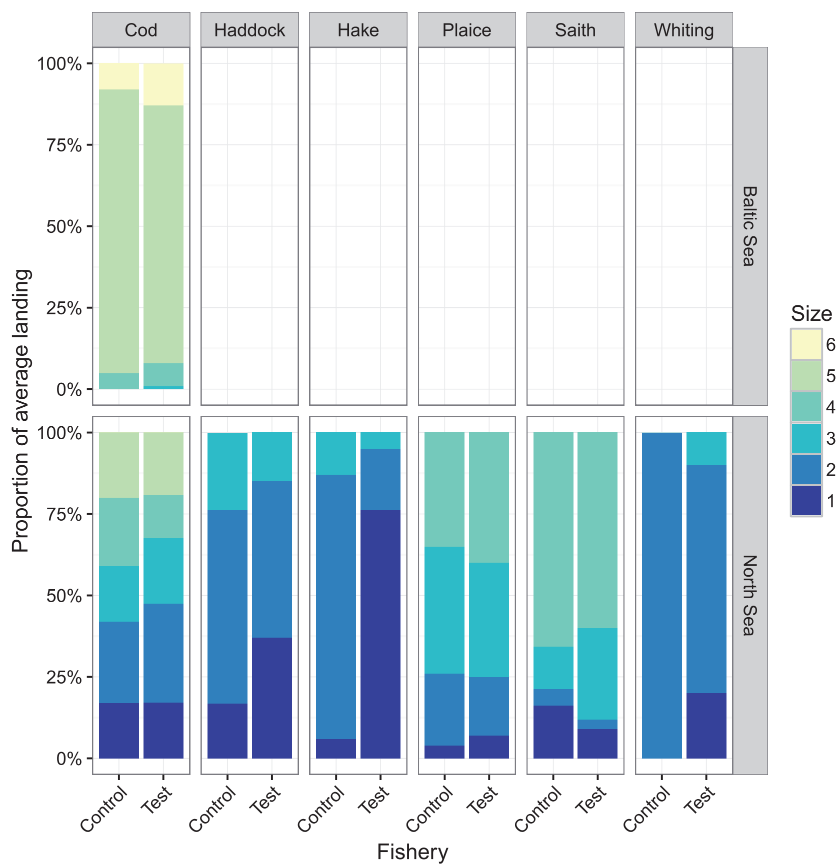

Figure 3. Size distribution of species caught in test and control gears in the North Sea (top) and the Baltic Sea (bottom). Size 1 is the largest size class and size decrease with increasing numbers. For haddock, hake and whiting there are 3 size classes, for plaice and saithe there are 4, 6 for cod in the Baltic Sea and 5 for cod in the North Sea. Only the size distribution from vessels with single trawls has been used, as catches on twin trawl were not size sorted from the individual gear type. Data are from vessels 3, 4, 11, 5, 12, 6, covering 33 trips in the North Sea and 97 trips in the Baltic Sea.

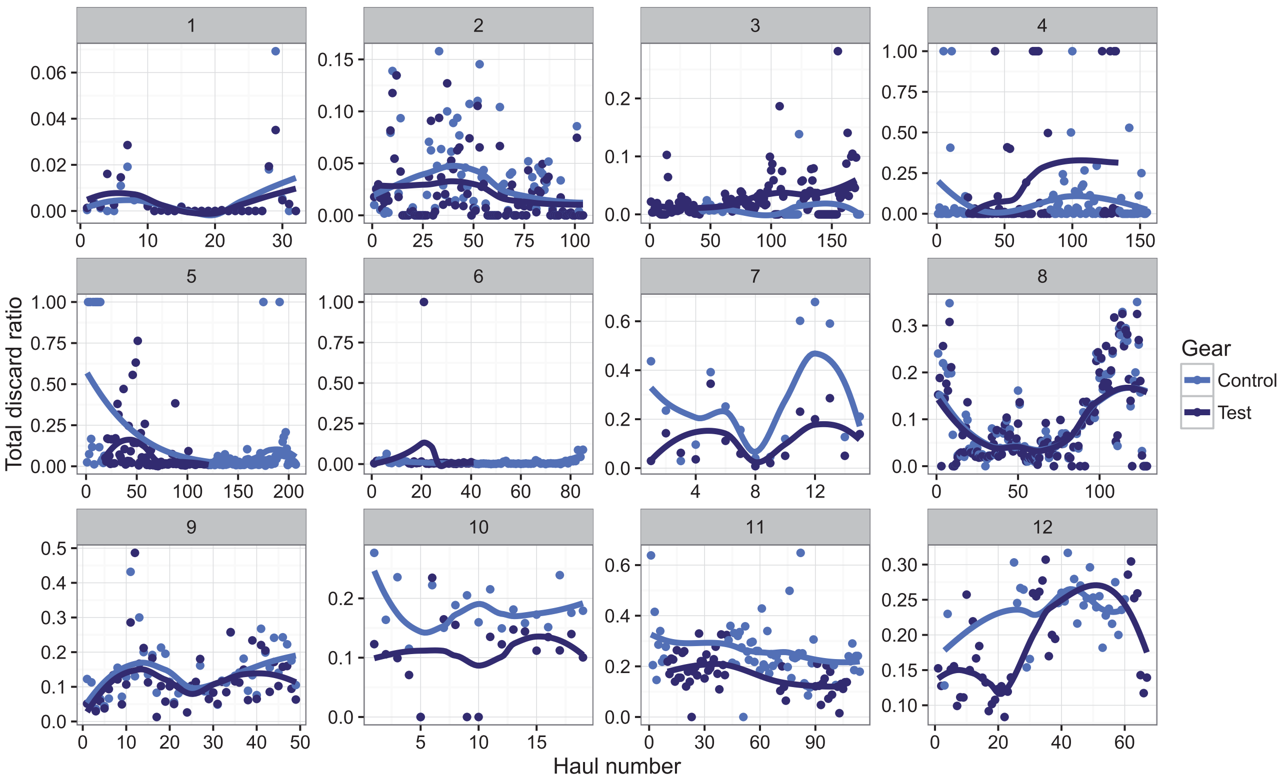

Figure 4. Temporal changes in the discard ratio of each vessel (vessel numbers in grey) and type of fishery per haul. Light colour indicates control fishery, while dark colour indicates test fishery. Discard ratio was calculated as the total discard per haul divided by the total catch per haul. Curves are smooth splines using a local polynomial regression fitting (LOESS).

by increasing the relative size distribution of the catches. More flexible TCM under the landing obligation may allow increasing revenues as less TAC would be used to cover undersized cod catches and quotas would be filled with less fishing effort, hence reduced variable costs. The free gear choice may thus help alleviate some of the potential economic losses predicted to result from the landing obligation (Sardà *et al*., 2013). Alternatively, the current low price on non-marketable cod are estimated from sale for fish meal, however new uses with higher value could raise the price of non-marketable undersized cod, further alleviating economic setback from the landing obligation. However, the LO is based on the premise that low prices for unwanted catches will incentivize fishers to target larger sizes of fish, while still covering the cost for handling and storing the small fish, providing some incentive not to illegally discarding them at sea.

The trial also demonstrated that the free gear choice resulted in changes of size composition of the landed species. In the North Sea, the test fisheries caught larger individuals, which indicates that the free gear choice in the North Sea primarily have led fishers to focus on reducing the number of smaller individuals in the catch. It is therefore possible that despite reductions in landings, revenues can be maintained or increased by landing larger fish with a higher price, which is also reflected in the relatively unaltered VPUE. In the Baltic Sea, the test fisheries landed more fish. Fishers were therefore able to fill quotas faster, with no evident penalty from catching only low value small fish.

It must however be kept in mind that this trial suffered from a number of weaknesses linked to its self-sampling set-up in a result-based management approach, and to its large scope regarding the duration and the number of vessels involved. Key lessons have here been learnt regarding which operational challenges would occur if results-based management would be implemented for the entire fleet.

A first key weakness of the trial was that half the hauls had to be discarded from the analysis owing to various errors in the data. While technical errors, such as faulty gears, are unavoidable in any setting, human errors in data collection can be reduced by training and instruction. In the current study, hauls were removed from the analysis owing to human errors, such as crew forgetting to separate landings or forgetting to input data into the camera system. This is likely owing to unsufficient information and instruction in the beginning and during the trial. In self-reporting trials, some errors must be expected when receiving data from non-scientific personal, however, with instruction and regular reminders on the importance of precision in the self-reporting, it is likely that errors can be kept to a minimum.

Second, the trial was challenged by half the vessels being single trawlers, applying test and control fishery interchangeably. The fishery from these vessels could therefore also be subjected to a temporal and spatial change in populations of the fished species. Additionally, some of the vessels (4, 5, 6) did not change gear frequently enough, resulting in the trial being divided into longer periods of fishery of either test or control fishery. However, while a spatial and temporal change in populations could induce false gear effects into the trial, we consider that the data from these vessels are still valid enough to be retained in the analysis, for two reasons. First, the trial lasted almost 6 months and a systematic trend that would display significant differences between the fishery types would mean that the populations should change in accordance with the gear shift. Second, a biased trend would also only occur if different gears were used to target different areas. It is more likely that owing to large population variations in the single trawl catches, differences between standard and test fisheries would not be detected. Thus, the differences detected should be large enough to overcome the large population variations. However, the experience from the trial supports the perception that when trials are conducted by non-scientists, extra care must be given to ensure that participants follow protocol, as it is likely that the participants are not aware of the data consequences of not complying with it. Clearly, a main challenge lies in developing quality control protocols that allow: (1) identifying issues, (ii) analysing their source and (iii) providing feedbacks to the skippers in real-time while the trial is still running. In our case, it was experienced that many issues were discovered after the end of the trial when the data were scrutinised and analysed in depth, but by then it was too late to improve the set-up.

Third, another challenge was the difficulty to capture the precise technical details of how fishers conducted their test experiments, how they changed and set up their test gears, and how they explored how the new gear seemed to perform compared with the control one. In this sense, the causal interpretation of the results presented here remains limited in terms of which factors contributed most to discard reduction and why. The evaluation interviews demonstrated that the fishers experimented on a trial and error basis, combining elements from previous legal gear or gear from other fisheries. Development of protocols for documenting technical changes in the gear as well as real-time structured registration of effects of test gear would enable the fishers to provide better documentation of changes and effects. This documentation could at one hand help the fisher in his individual "innovation-process" for adjusting the gear to catch opportunities and on the other hand provide basic documentation of the effects of the gear if it is to be accepted in a system of relative detailed technical regulation.

In conclusion, the trial with free technical regulation combined with proper incentives demonstrated a possibility for fishers to adapt their fishing operations and gears to comply with quota availability and possibly contribute to reducing some of the negative short-term impact of the landing obligation. The lessons learnt have been used to set-up a follow-up Danish fisheries science partnership with improved protocols, launched in early 2016 (http://www.fast-track.dk/). At a broader scale, the new EU framework for technical rules (EU, 2016) requires rethinking the fundamental principles used for controlling and monitoring the selectivity of fisheries, and it is certain that the experience gained with the trial presented here will contribute to an improved knowledge base for the implementation of the landing obligation in European fisheries.

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