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Identifying choke species challenges for an individual demersal trawler in the North Sea, lessons from conversations and data analysis

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Abstract :

A likely side-effect of introducing the landing obligation of the 2013 Common Fisheries Policy into mixed fisheries is the occurrence of the "choke species" problem. When discarding no longer is an option, leasing quota or changing fishing practices remain important tools to avoid choke species. Here, the scale and tactics linked to using avoidance behaviour to reduce choke species is investigated by analysing the fishing behaviour of a single demersal trawler in the North Sea. Analysis combined qualitative information collected from through interviews with the vessel owner and skipper, along with quantitative analysis on fisheries data. From the interviews, saithe and cod were identified as potential choke species and subsequent analysis focused on these two species. The analysis of catch and quota composition showed that cod would choke the fishery early if no catch-quota balancing options were available, resulting in a 87% reduction in revenue, while saithe could choke the fishery later, resulting in a 43% reduction in revenue. Avoidance behaviour was difficult to detect from fisheries data, which was explained by avoidance taking primarily place through very fine-scale tactical choices rather than large displacements. Catch composition showed that saithe is distributed more patchily than cod, with most hauls containing small amounts of saithe and a few hauls containing large amounts. In conclusion this paper supplies an view on the choke species problem seen from the perspective of an individual fisher and highlights the amount of real-time tactical decisions and trade-offs that need to be made when operating in mixed-fisheries.

1 Introduction

When the landing obligation of the 2013 Common Fisheries Policy is fully implemented in 2019, and provided that it is accurately enforced and controlled, fishers will no longer have the option to discard, i.e. return fish to the sea, in order to avoid landing unwanted catches [1]. The landing obligation requires that all catches (i.e. everything retained in the fishing gear when hauling) of stocks under catch limits and/or with a legal minimum conservation reference size (MCRS) are to be recorded and, where applicable, counted against quotas. Some exemptions might apply, such as for protected species, for species with a high survivability and for small amounts of discards, that cannot be easily reduced further through selectivity and avoidance measures (*de minimis* exemptions). However, many species occur frequently as bycatch to the targeted species, especially in mixed fisheries, where it can be difficult to reduce catches of a single species when several species are caught together [2–4]. Thus, one of the main concerns raised against the landing obligation is the risk for early closures of fisheries, when the quota of one species is exhausted before the others. This is referred to as the "choke species" effect. The choke species can be either target or bycatch species, and they can be limiting either because of low productivity of the stock and reduced fishing opportunities, or because of discrepancy between historical right allocation compared to current abundance (e.g. Northern hake) [5]

Within the EU, the national quotas are fixed shares of the overall TAC by stock, using the relative stability key established in the early times of the CFP [6]. They are themselves shared across the various quota users, using often complex allocation systems that differ from country to country. These various layers of quota sharing have traditionally been based on some historical records of landings, not of catches, and have largely not been updated over time in spite of changes in fisheries' and fish stocks' distribution. For some stocks, discarding has thus emerged from the mismatch between the catching capacity of an individual vessel and the vessels landing opportunities. Historically, this mismatch has been partially mitigated through bilateral quotas exchanges ("quotas swaps") between countries, but uncertainty remains on how these informal agreements will develop under the new CFP [7]. Addressing this mismatch by renewing the allocation keys with the implementation of the landing obligation would thus in theory relax one of the main drivers of discarding, but in practice the political complexity of this update means that at the time of writing, it still appears unlikely to take place in European fisheries.

In Denmark, the demersal fisheries management switched in 2007 from a system based on weekly rations to a Vessel Quota Share (VQS) system, a form of individual transferable quota where the share is linked to the vessel, implying that quota transfer requires buying the corresponding vessel out. The shares were based on the 2004-2006 recorded landings, but not on total catches [8]. Thus, fishers were granted a fixed share of the national quota. However, as at the national level, the issue of quota mismatch between actual catch and quota allocation was created at individual level as well. To overcome this, fishers quickly formed quota pools, enabling the fishers to lease quota, either directly between vessels or through common pools (e.g. www.puljefisk.dk), correspondingly to the national quota swaps. However, the situation might change with the landing obligation. Hatcher [9] predicted that fishers would likely have more difficulties to predict their own needs for quota, as the catches previously discarded would need to be landed and deducted from their quota. This would mean that fishers would become reluctant to lend quota to others to safeguard their own needs, and rental prices may increase, due to less supply and a larger demand. Thus, if the landing opportunities of the vessel cannot be adjusted to its catching capacity, the choke species issue will have to be addressed the other way around, by adjusting the catching capacity to its landing opportunities. Incentivizing fishers to reduce unwanted bycatch is indeed the underlying objective of the landing obligation. This takes place by modifying the catch composition of the fishing operation, either by switching to more selective gears [10] or through changes in when, where and how to fish [11,12] Changes in gear selectivity have often proven effective in reducing bycatch, however the voluntary uptake of selective gears has so far remained very low by lack of appropriate incentives to fish more selectively. Additionally, the current technical measures regulations, along with complex approval guidelines, limits the possibility to develop new gears [13], although some work is ongoing to address this [14,15]. The other option is thus changing where, when and how to fish, also referred to here as avoidance behaviour, where the fisher selects areas known to contain few choke species or displace the fishery if a large catch of choke species is encountered. The effectiveness of avoidance behaviour depends on the skills and choices of the skipper; nevertheless, its outcomes can also remain uncertain if the species to be avoided is largely distributed over the same areas as the target species or has a patchy distribution in large numbers [9].

To investigate the scale and tactics linked to using avoidance behaviour to reduce the choke species problem, the fishing behaviour of a single demersal trawler in the North Sea was analysed. The aim is to understand how a fisher perceives and decides upon changes in behaviour, and to analyse whether these changes can be detected with high-resolution fisheries data derived from the vessel.

2 Material and Methods

The analysis was based on a quantitative analysis of fisheries data from a Danish demersal trawler, supported by information collected from a suite of meetings and interviews with the owner and the skipper of the vessel. The vessel is a 28 meters trawler, with at-sea packing facilities, conducting a mixed fishery primarily in the North Sea. The vessel was participating in a Fully Documented cod catch quota management (CQM) trial, where discarding was still allowed but all catches of cod were to be deducted from the vessel quota, against a 30% quota uplift on cod only [16]. As participant in the CQM trial, the vessel was conducting fully documented fishery (FDF), including remote electronic monitoring (REM) with CCTV cameras and reporting catches on a haul-by-haul basis. Additionally, the vessel was obliged to land all TAC species above MCRS [17]. Interviews with the owner and the skipper of the vessel revealed that the main challenge during the CQM trials was to avoid cod *(Gadus morhua)* and saithe *(Pollachius virens)*, as the vessels initial quota was not sufficient to land all catches of these species, when targeting valuable species such as monkfish (*Lophius piscatorius*) and hake (*Merluccius merluccius*). It was thus decided to focus the analyses on these two species, while all other species caught was grouped into a single group.

2.1 Data

Data from the vessel was collected both from the fisher and from the Electronic logbook and fishery auction. Data included position at haul-in, species composition in the landings, weight and value of landings, size sorting from the fishery auction, initial VQS of the vessel and quota lease through the period. The data also included information on cod discard collected from the participation in the CQM trial [16], where cod discard was estimated by electronic monitoring. Data from 2013 – 2015 were used, to investigate whether and how choke species were a problem for the fisher. During this period, the stock of cod in the North Sea and Skagerrak experienced a slight increase in biomass and Total Allowable Catch (TAC), while the TAC for saithe in the North Sea, Skagerrak and West of Scotland decreased by 28% whereas its biomass remained stable [18]. The data covered fishing operations in the years 2013, 2014 and 2015 and included a total of 140 trips with 47 trips annually in 2013 and 2015, and 46 trips in 2014. A trip lasted on average 7.4 days [2-11 days] and contained on average 15 hauls [2 – 27]. The total landings in the years were between 1,023 tons and 1,357 tons, with approx. 20% cod, 35% saithe and 45% other species. There were no records of discards of saithe, however as the vessel was a part of a cod quota management scheme, discards data on cod were available. A total of 6 tons of cod was discarded over the three years (2013:1.6 ton, 2014:2.5 ton, 2015:1.9 ton) with an average discard ratio per trip of 0.2%. The low discard was a part of the CQM directives, as the vessel was only allowed to discard damaged fish and fish below MCRS. The estimated discard ratio for the entire stock of North Sea cod is around 25 % [19]. Thus, the discard was a negligible part of the catch and was not included in the subsequent analysis.

2.2 Interviews

Knowledge on fine-scale tactics was obtained through informal discussions and interviews with the vessel owner and the vessel skipper (hereby referred together as “the fisher”) in three meetings, conducted prior and during the analysis work. The interviews aimed to obtain information on perceived current and expected challenges with the landing obligation, along with fishing strategies during the period 2013 to 2015. The unstructured interviews were chosen to maintain an open dialogue, where the interviewees would not feel restricted by a line of questioning and where unforeseen topics could arise.

2.3 Time of choke and quota usage

Estimation of if and when a choke species problem occurs in the fishery were conducted, using an analysis of the temporal development in quota accumulation and quota usage. Catches data was extracted from the electronic logbook of the vessel and the accumulated catches across the year for each of the three years were calculated. The time of year where the catch accumulation intercepted with the start of year quota was used as an indicator of when the fishery would be choked if no other quota acquisition options were available. This analysis was supplemented by a quota acquisition analysis, where the quota accumulation across the year, which included quota leasing, adjustments and CQM trial quota additions, was calculated. This was conducted to evaluate the tactical decisions made by the fisher to acquire quota in relation to the catch.

2.4 Economic effect of choke

To evaluate the effect of potential choke species, the potential loss in revenue following a choke was calculated. Trip by trip revenue was derived from the sale slips and were separated into cod, saithe and others. Assuming that no extra quota would be available, the fishery would stop when the initial quota of a species would be exhausted and all revenue after this point would not have been met. Thus, all revenue following the choke date was summarized to express the potential forgone revenue due to the choke effect. This measure must however be considered as indicative of the maximum expected choke effect, because it could be expected that the fisher may have taken other decisions if he had been certain that no extra quota would be available to lease.

2.5 Selected trips

The fisher was also asked to select two specific trips performed in 2015, one where he perceived that he had specifically tried to avoid saithe and one where no specific attention was paid to saithe catches. This was done to evaluate whether standard fishing practices were most comparable to either the avoidance or non-avoidance trip. Initially, the spatial distribution of the two trips was visually inspected and compared to other trips within that year. Furthermore, to investigate whether the catch of each type of trip differed significantly with respect to all the other trips, the haul by haul landings (L) was compared using an ANOVA, with trip type (T: normal, avoidance, non-avoidance) and species (S: saithe, cod, others) as explanatory variables, along with an interaction term between the two:

$$L = T * S \qquad \text{Equation 1}$$

2.6 Haul composition

The catch structure of each trip was analysed to estimate the potential for the fisher to predict catches, under the assumption that the occurrence in catches of evenly dispersed species is easier to predict than for patchy distributed species. To account for the distribution type of each species in the catch, the mean and the median catch per haul of saithe and cod for each trip were calculated and the median was subtracted from the mean. A large deviation from zero would indicate either few hauls with large catches in a trip with generally small catches (mean > median) and vice versa, demonstrating either fragmented catches or evenly distributed.

Haul composition was also analysed in terms of weight and economic value proportion of saithe and cod in each trip, to evaluate whether the two species made up the same proportion around the year or if periods of high and low catch proportions could be identified.

2.7 Spatial distribution of catches

To analyse the spatial dimension of the fishery, the fishing trips were mapped and the density estimation of catch per haul, was calculated for each year and species. The density estimation was a 2D kernel density estimation, estimated using the function *kde2d* in the R-library MASS. All species other than cod and saithe were pooled together. This shows areas of high catches per haul of the potential choke species and others species. Any overlap of the catches would indicate that the species could potentially act as a choke species, as they would co-occur with other species, unless there is a temporal displacement in the occurrence of the species.

2.8 Spatial avoidance behaviour

Additionally, distance moved after haul-in was calculated to investigate whether any significant displacement would be detectable after catching large quantity of saithe and cod. This was done by calculating the Euclidian distance between haul-in sites, using the function distCosine, in the R-package geosphere (geosphere version 1.5-1). Lastly, changes in depths after haul-in were also analysed in the same manner as distance moved, by calculating the depth change between haul-in and the subsequent haul-in, to investigate whether the size of catch of cod, saithe or others could induce a change in fishing depth. Fishing depth was derived from a bathometry map (DYNOCS, Dynamics of Connecting Seas, EEC-MAST Research project), where depth was inferred from the position at haul-in.

3 Results

3.1 Interview with skipper and owner on HM635

The discussions with both the skipper and the owner of the vessel resulted in a comprehensive description of the challenges experienced by the fisher and revealed the amount of real-time decisions made at every haul to fully utilize quotas. A primary concern raised by the fisher in relation with the landing obligation, was the potential for cod and saithe to choke the fishery. The fisher felt that the quota allocation for the two species did not match the catch opportunities and that the introduction of the landing obligation would result in few options for adjusting catches to the quota composition. The strategy agreed between the skipper and the owner was thus to avoid saithe as much as possible.

The skipper expressed a detailed knowledge of the spatial distribution of species, identifying specific areas of a few square nautical miles with unique species compositions; and as such told that it is possible to avoid saithe and cod in the catches, by targeting areas known to contain few of these species. However, according to the skipper, these areas may also have a varying abundance of other valuable species, primary monkfish and hake, but also lemon sole (*Microstomus kitt*), turbot (*Scophthalmus maximus*) and Atlantic halibut (*Hippoglossus hippoglossus*). Thus, in some trips where catch rates are low in these areas, decision must be made whether fishing should continue there or move towards other areas with known high densities of valuable species, though with the risk of encountering high concentrations of cod and saithe. The skipper reported that in recent years, cod was perceived as having a more homogeneous distribution, while high-density patches would exist mainly for saithe. In particular the area north of 59.30 N° on the ridge of the Norwegian trench [Figure 4] was no longer fished by the skipper in 2015 due to especially high risk of large saithe catches. Similarly, "the bird cage" east of Shetland [Figure 4] was considered a good fishing-ground, but where saithe catches after 2013 were so high that the area was visited only as a last resort, if catch rates elsewhere were insufficient.

According to the skipper, the tactic employed if large catches of saithe were encountered, was to continue along a transect, deploying the gear where it was hauled in and subsequently continuing along the current heading, expecting lower catch rates just behind the patch. To underpin the challenges with choke species, the owner of the vessel told that he decided in 2015 to switch fishery and started targeting plaice instead. A period of 4 months was spent in that fishery (from May 1th 2015 to September 1th 2015), where a quota of 70 tons of plaice was leased, a new gear was purchased and new areas were fished. Both the skipper and owner acknowledged that the change in target species reduced the choke problem as fewer saithe were caught.

From the interviews it was also advocated that the challenge of choke species was more difficult to cope with for small vessels than for larger ones like HM635, as the storage size on smaller vessels limits the action range and the number of hauls that can be carried out in a single trip. Thus, smaller vessels experience more difficulties navigating between areas and are subsequently more restricted in the number of choices they can make. Additionally, operation costs are proportionally higher for small vessels than large ones.

To explore what is perceived as avoidance and non-avoidance behaviour, the owner specified two trips (starting on April 15th (1) and May 12th (2) 2015, respectively), where saithe avoidance was applied during the first trip and non-avoidance was applied during the second. Saithe avoidance was described as fishing in areas with suspected low abundance of saithe and if hauls contained an unacceptable amount of saithe, gears would be deployed at haul-in site, but heading would be maintained, assumed that the encountered saithe patch would be behind the vessel. Non-avoidance would be that the vessel targeted its primary species (monkfish and hake) with no consideration for the amount of saithe in the bycatch.

3.2 Quota leasing and quota uptake

Initial individual quotas were 23, 22 and 35 tons for cod in 2013, 2014 and 2015, while the initial quota for saithe was 187, 204 and 176 tons, respectively. An additional 206, 149 and 229 tons of cod quota and 268, 189 and 241 tons of saithe quota were leased in the three years respectively, to supplement the initial quota [Figure 1], while the cod quota was supplemented with 44, 49 and 42 tons in the three years respectively, from the Cod Catch Quota management trials and other adjustments. The visual inspection of the accumulated catches per trip each year demonstrated a steady increase throughout the year for each species, except for cod in 2014 (where catch rates increased during the fall) and saithe in 2015 (where catches were low during summer when the vessel switched to plaice fishery) [Figure 1]. It was also variable when the initial quota was passed. In 2013, the initial saithe quota was exhausted on May 1st; while in 2014 and 2015, the quota was not exhausted until September. For cod, the initial quota was exhausted in 2013 by February 21th, in 2014 by February 22th and in 2015 by April 8th. Thus, the cod quota was the first to be exhausted all years.

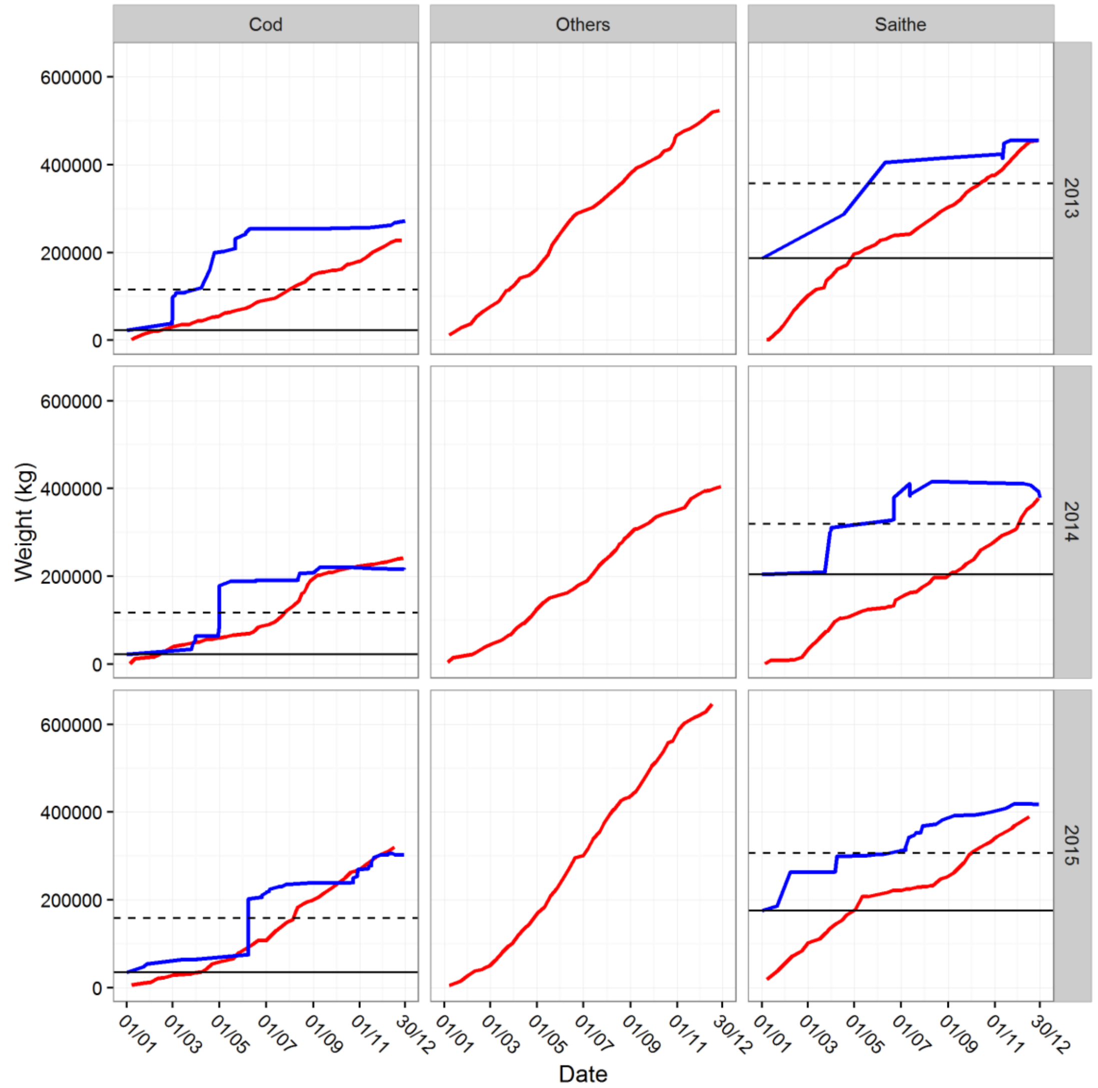

Figure 1 Plot showing the landing (red) and quota (blue) development of saithe, cod and other species (OTH) in the years 2013, 2014 and 2015. Horizontal lines indicates the initial quota (solid) and initial quota including transferred quota from partner vessel (dashed).

3.3 Economic effect of choke

The maximum short-term economic importance of the choke species effect can be estimated from the revenue yielded before and after exhaustion of the first quota. Landing sales after exhaustion of the cod initial quota with no quota lease or added quota from the CQM trials summed up to 17 mill. DKK on average (2013:16 mill, 2014:16 mill, 2015:19 mill) or 87% of the average total annual revenue (2013: 90%, 2014: 95%, 2015: 79%) (Table 1). Looking at saithe as choke-species alone, the landings sales after exhaustion of saithe initial quota with no quota lease summed up to 9 mill. kr.DKK on average (2013:13 mill, 2014:6 mill, 2015:6 mill) or 43% of the average total annual revenue (2013: 72%, 2014: 34%, 2015: 27%) (Table 1).

Table 1 Overview of annual revenue (total, ‘000 DDK) on cod, saithe and other species and the theoretical revenue loss (Loss) after initial cod or saithe quota is exhausted.

	2013			**2014**			**2015**		
	Total	*Loss saithe*	*Loss cod*	*Total*	*Loss saithe*	*Loss cod*	*Total*	*Loss saithe*	*Loss cod*
cod	4,496	3,491	4,094	4,914	1,228	4,625	7,026	2,110	6,319
saithe	4,135	2,616	3,483	2,869	1,861	3,777	4,518	1,144	2,875
Others	9,512	6,965	8,641	8,708	2,828	8,161	11,980	3,173	9,448

3.4 Haul composition.

The catch composition across trips [Figure 2] showed that cod represented around the same proportion in landing weight and value, while saithe represented a larger part of the landing weight than of the landing value. The size of catch in each haul was also variable across each year for each species [Figure 3], where the catch size per haul was more constant for cod than for saithe (F-test, $p<0.01$ for all years). The larger discrepancies between the mean and the median catch per trip for saithe indicated a very patchy occurrence of saithe in the catches, with most hauls containing little saithe, but a few hauls in a trip containing large amount of saithe. In the same trips, cod occurred in equal amounts in each haul, with some seasonal variation. Additionally, it can be noted from Figure 2 and Figure 3 that there was a period between May and September in 2015, where saithe only occur in small amounts in the catch. This coincides with the period where the fisher switched to plaice fishery.

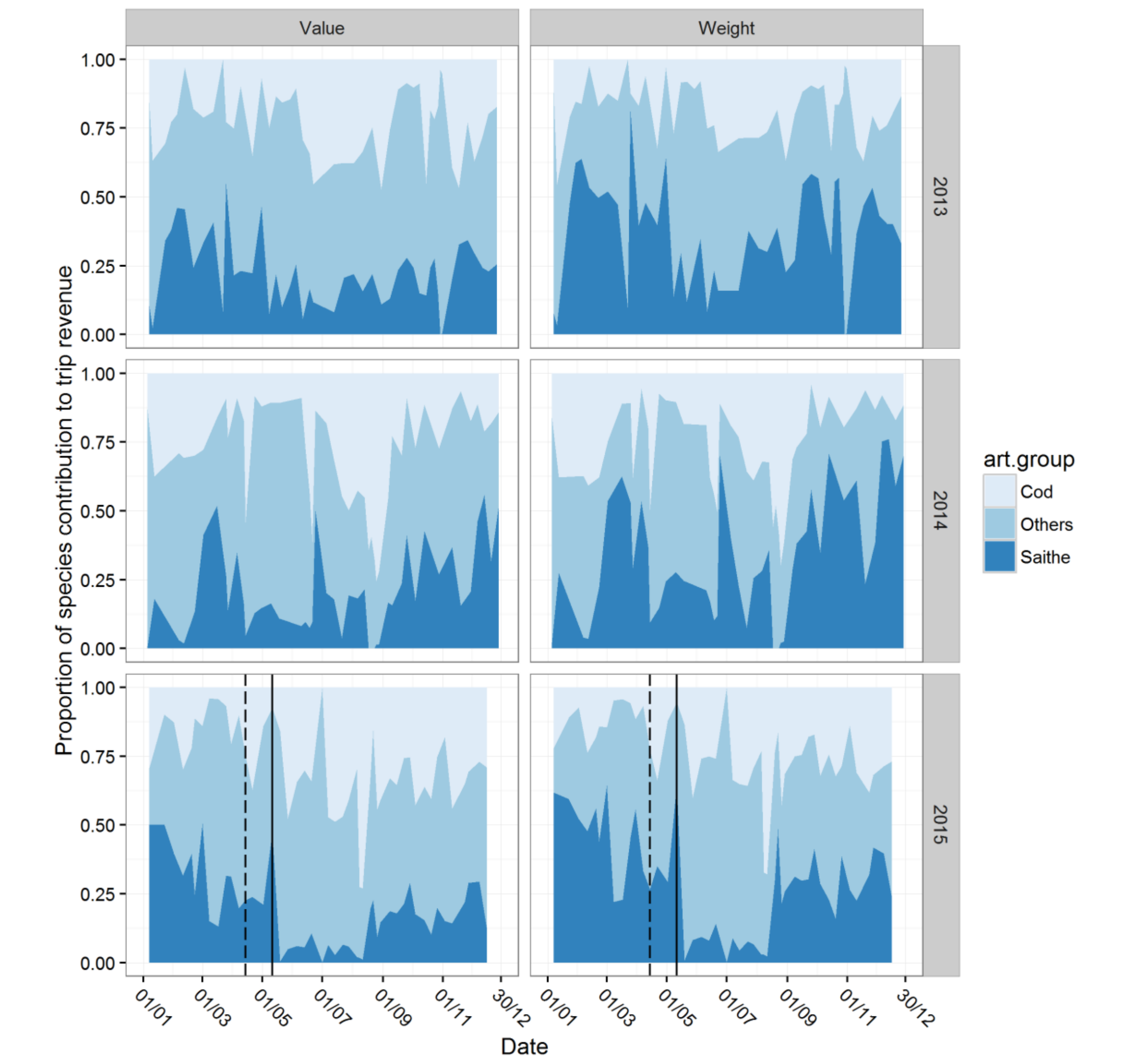

Figure 2 Stacked plot of the composition of landings per haul for Karbak HM635 across the year, divided into Value (left) and Weight (right). Solid line in 2015 indicates non-avoidance trip and dashed line in 2015 indicated avoidance trip.

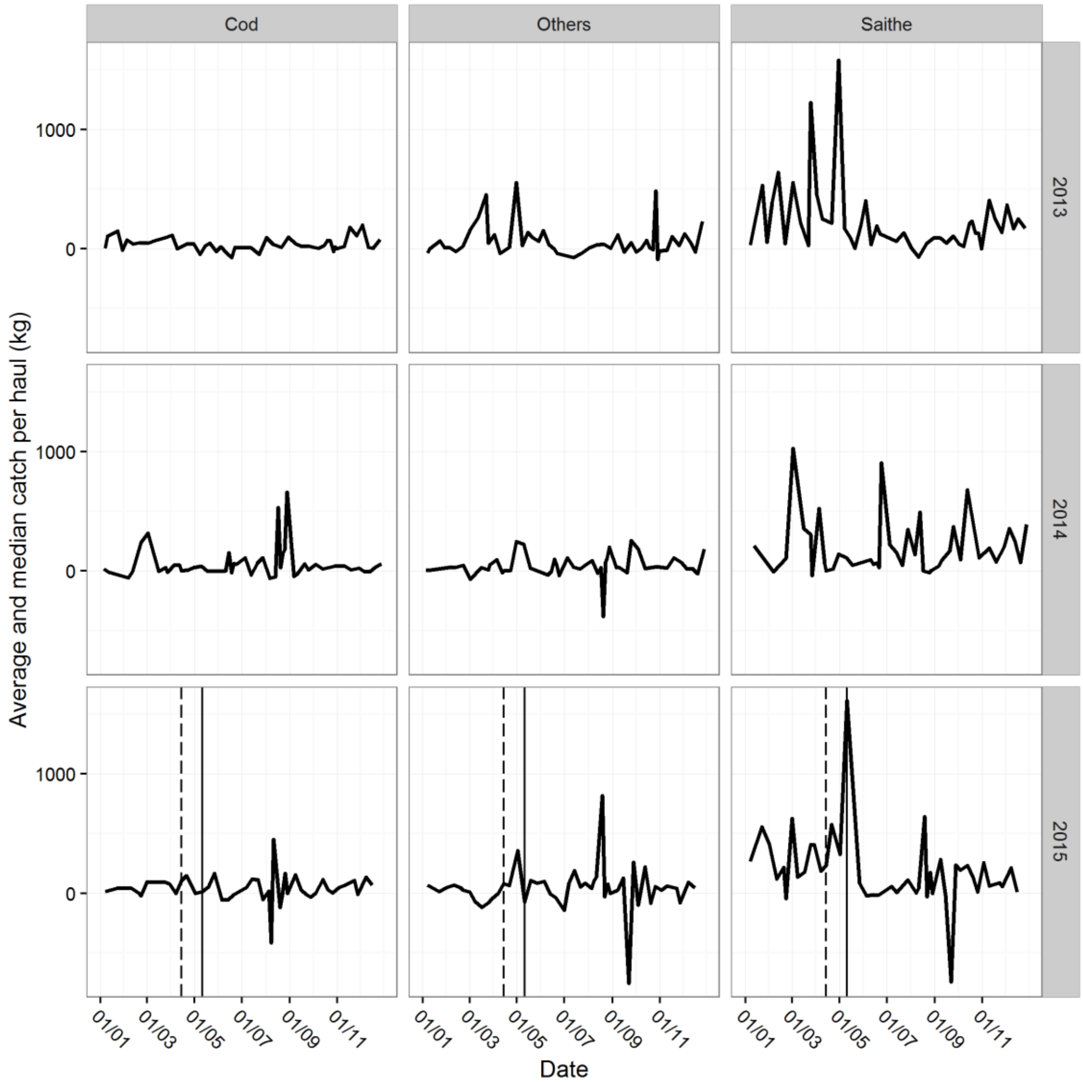

Figure 3 Map showing hauls location in 2013, 2014 and 2015 (blue dots). The 2015 map shows also the hauls where the vessel targeted plaice, between 1/5-2015 and 1/9-2015 (yellow), hauls between 10/04-2015 and 15/04-2015 with saithe avoidance behavior (orange) and hauls between 4/5-2015 and 12/5-2015 with saithe non-avoidance behavior (green). Color gradients show the haul sequence, with light colors indicating initial hauls and dark colors indicating last hauls. Grey boxes indicates the area called "the bird cage" and the area north of 59.30°N highlighted by the skipper.

3.5 Selected trips

The two trips specifically selected by the fisher were compared. There was little spatial overlap between the two trips [Figure 4], with the avoidance trip being located near the Shetlands and the non-avoidance trip near the southern part of the Norwegian trench. The avoidance trip landed less saithe than the non-avoidance trip (avoidance trip: 7 tons in total, non-avoidance: 30 tons in total). However the variability between hauls was too high to detect a significant difference between saithe landings in the two trips (Welch t-test: $p=0.2$, $df = 17$), as the average saithe catch per in the non-avoidance trip was 1.7 kg (± 3953 kg, SD), relies on one extraordinary large haul (16 tons of saithe) and three lesser hauls (3-4 tons of saithe in each).

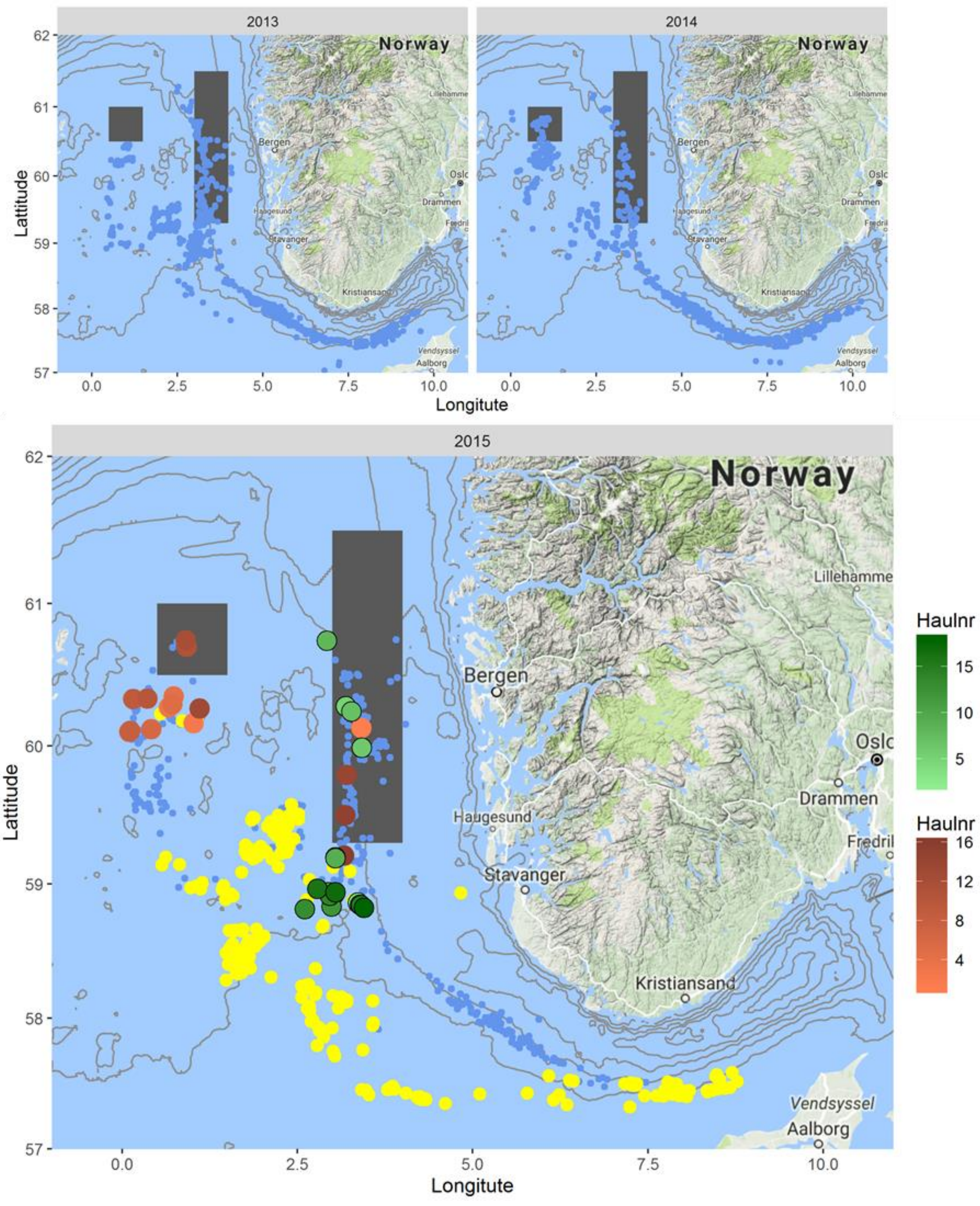

Figure 4 Mean catch per haul minus median catch per haul. Deviation from zero demonstrates uneven catches across a trip, indicating a patchy occurrence of the species. Solid line in 2015 indicates non-avoidance trip and dashed line in 2015 indicated avoidance trip.

3.6 Spatial distribution of catches

Plotting the spatial distribution of catches rates in the three years showed a substantial change in fishing areas between 2013-2014 and 2015 [Figure 4]. In 2013 the primary fishing occurred around the west coast of Norway, with little fishing effort allocated nearer the Shetlands. In 2014 more fishing effort was allocated around the Shetlands, but still with a high occurrence of fishing activities in the Norwegian trench. The 2015 switch to plaice fishery changed the distribution of fishing activities, which included a reduced fishing activity in the northern part of the Norwegian trench and near the Shetlands.

The results from the density estimates [Figure 5] showed that saithe and other species were often caught in the same areas, however there is a patch around 59 N° where there is cod and other species, but no saithe. Additionally, cod is not caught in the Norwegian trench north of 60 N°. In 2014, on the category Other species were caught in the Norwegian trench, while cod and saithe catches fully overlapped west of the trench. In 2015 the catch pattern was more patchy and saithe was caught where it was not in 2013. Overall, the results from Figure 5 do not show any stable pattern in the spatial distribution of the catch.

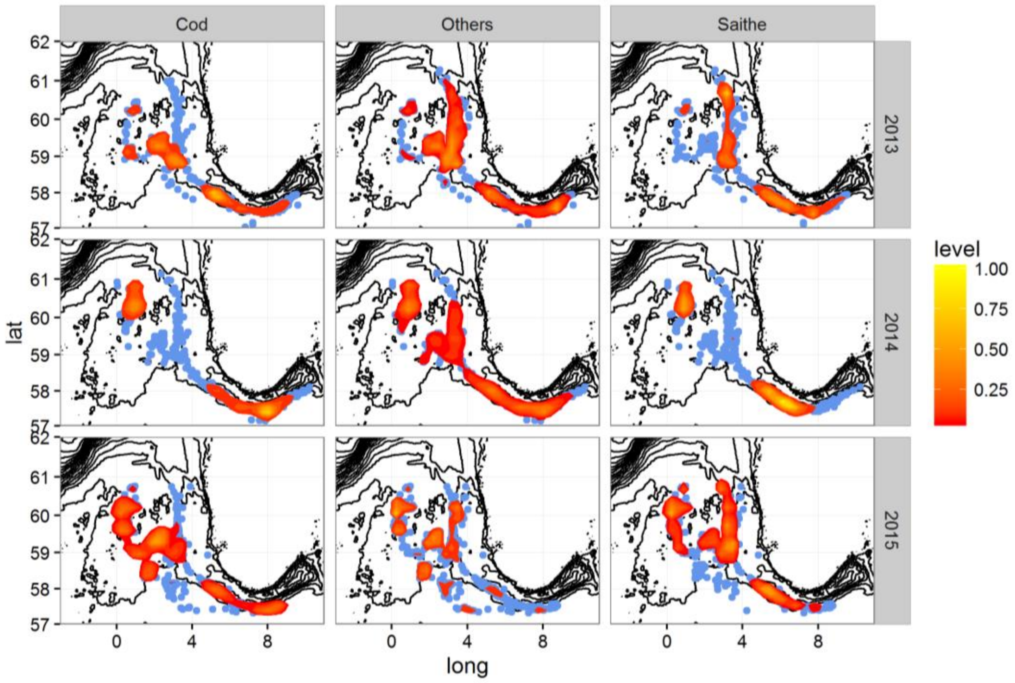

Figure 5 Spatial distribution of catches per haul, along with a density analysis. Blue dots represent a haul with a catch of cod, saithe or other species, while black lines represent depth curves. Red/yellow represents weighted density estimates of catches per haul, with level as a probability estimate.

The spatial distribution was also analysed in relation to catch size, by calculating the Euclidian distance moved between two sequential haul-in sites and comparing the distance with the catch size of the individual species before the move [Figure 6]. Assuming that the average haul time lasted 5 hours with a haul speed of 4 knots [20] means an average haul length of 37 km. Here, the average distance moved between two haul-ins' was estimated at 38.6 km, close to the estimated standard length of a haul, indicating that the vessel did not change location after haul-in before deploying gear again. However there is no correlation between the catch weight of cod, saithe or others and the distance moved following haul-in in either 2013, 2014 and 2015 (Pearson: -0.11 – 0.08, Spearman: -0.27 – 0.03), indicating that changing fishing area was not directly relying on the catch weight and species composition of the haul.

Change in depth as an effect of catch size of the individual species was also analysed as with the spatial change after haul-in [Figure 7]. The average haul depth was 151 meters (±47m SD). Analysing the depth change between haul-ins did not show any correlation between the change in depth and catch weight of either cod, saithe or others (Pearson: -0.14- 0.04, Spearman: -0.16-0.05).

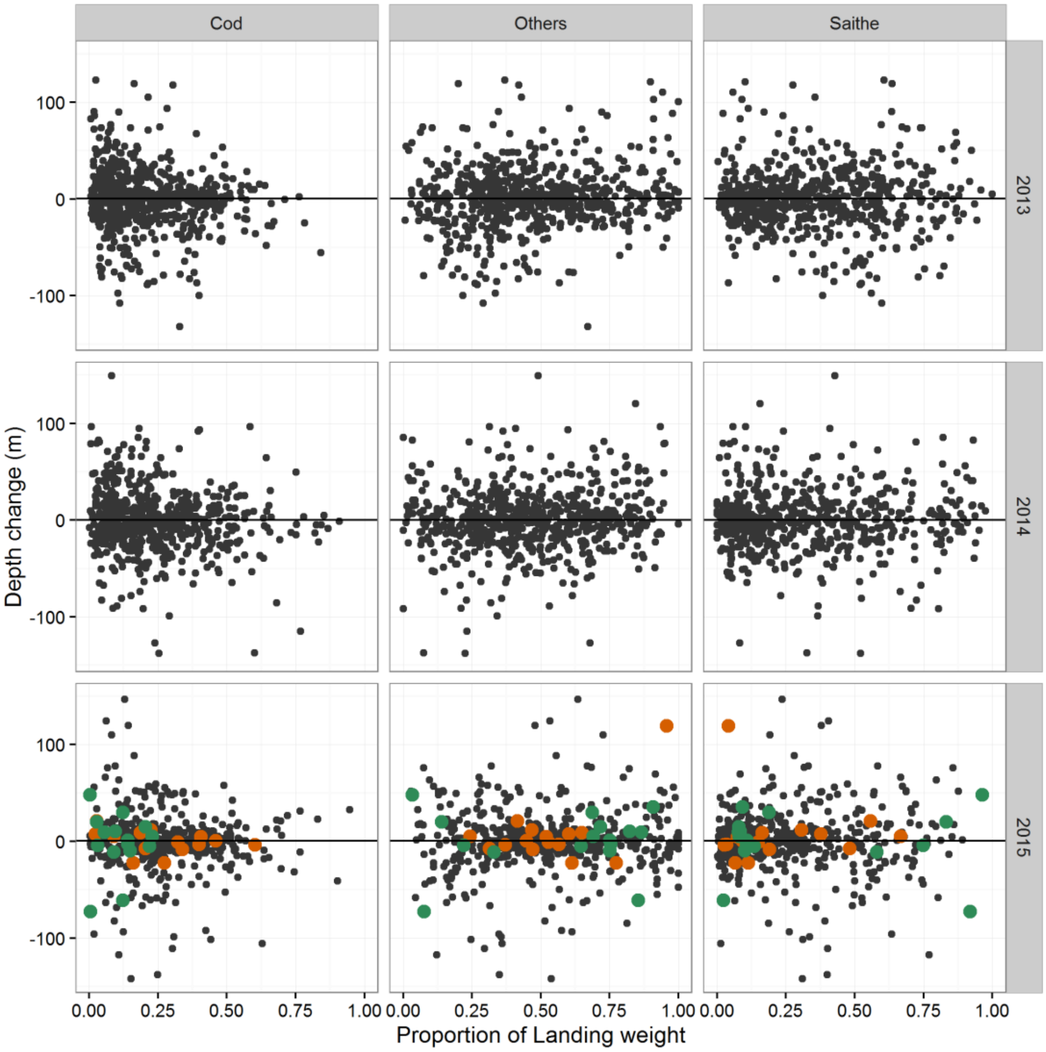

Figure 6 Scatter plot showing the correlation between the proportion of the landing weight in a haul for cod, saithe and other species and the distance moved after haul-in. Black line indicates average moving distance after haul-in across all hauls. Coloured points indicates hauls between 10/04-2015 and 15/04-2015 with avoidance behavior towards saithe (green) and hauls between 4/5-2015 and 12/5-2015 with non-avoidance behavior towards saithe (orange).

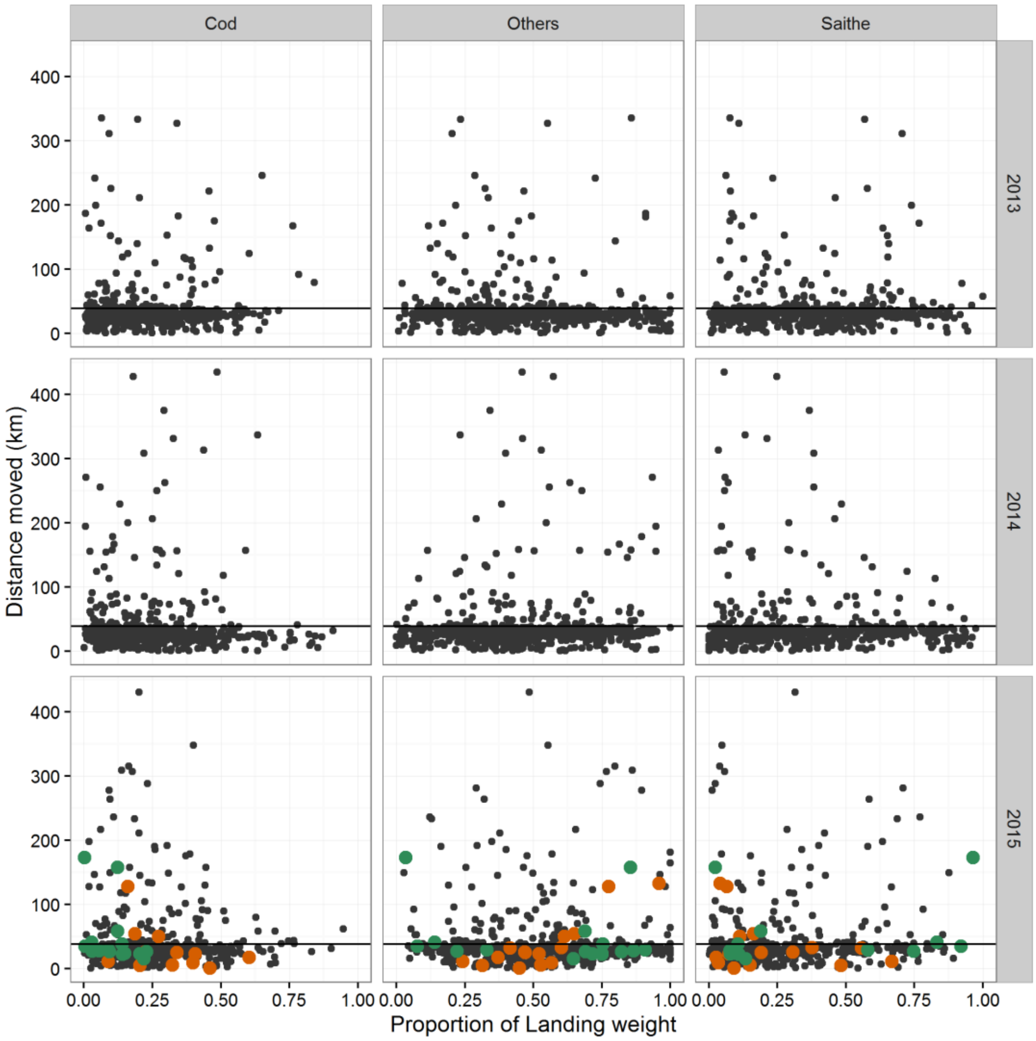

Figure 7 Scatter plot showing the correlation between the proportion of the landing weight in a haul for cod, saithe and other species and the depth change after haul-in. Black line indicates average fishing depth across all hauls. Coloured points indicates hauls between 10/04-2015 and 15/04-2015 with avoidance behavior towards saithe (green) and hauls between 4/5-2015 and 12/5-2015 with non-avoidance behavior towards saithe (orange).

4 Discussion

The vessel owner perceived that cod and saithe are likely to be choke species when they are included into the landing obligation, unless significant increase in TAC would be granted. He feared that leasing quota would become more difficult, for the same reasons as advocated by Hatcher (2014). Indeed, high prices on saithe quota leasing were also experienced in 2016 where the TAC was further reduced by 10% compared to 2015, at approx. 13 DKK/kg (price date: 17/06/2016, Dansk Puljefiskeri, www.puljefisk.dk, pers.com) vs. 5 DKK/kg in 2013-2014 and 7-8 DKK/kg in 2015 (data from HM635). This supports the perception that supply and demand for saithe quota was mismatched in 2016. According to Dansk Puljefiskeri (pers.com), the mismatch was due to higher quota utilization on the individual vessels, and a limited quota available. On contrary, the price of cod quota lease remained relatively unaltered around 9 DKK/kg in 2016 (price date: 17/06/2016, Dansk Puljefiskeri, pers.com) compared to 2013-2015. A first explanation can be that the TAC for cod was slightly higher in 2016. But another interesting factor is the indirect effect of the limited saithe TAC: Cod and saithe co-occur in the Norwegian waters of the North Sea and Skagerrak. However, the Danish fishers are not allowed to fish in Norwegian waters if they do not own enough quotas to cover their catches (Dansk Puljefiskeri, pers.com). When they are limited by their saithe quota, fishers reduce their activity in Norwegian waters, which in return limit their ability to target cod and thus reduce the demand on cod quota. Additionally, the severity of the choke species problem largely depends on the discard of the individual vessel. When the landing obligation is fully implemented, all vessels receive a top-up indexed to the expected average discard, which was estimated for saithe in the North Sea in 2016 to be 6% [21]. However, in 2015 the estimates discard in Skagerrak increased to 15%, reflecting that the TAC had become more limiting. For vessels with a previous discard lower that the top-up, the extra quota will signify a revenue increase, however the opposite is true for vessels with a previous discard higher than the top-up. Notably though, significant revisions in the perception of the saithe stock have led to a major increase of the scientific advice for the TAC in 2017, implying that most of the concerns expressed here may likely not apply anymore in 2017 [21].

The data and results collected in this research support the fisher's view on saithe and cod having acted as chokes in the fishery on HM635 in 2013-2015, with saithe as the primary choke species, followed by cod. For saithe, the initial quota was exhausted around May in these years. In a landing obligation scenario and if no other leasing opportunities had been available and the TAC would not have been increased significantly, the quota exhaustion would have hampered the fishery, forcing the fisher to find alternative options.

The haul composition on HM635 showed that saithe and cod together make up more that 50% of most hauls in weight, except when the vessel trialled a different fishery in 2015, switching to plaice fishery. In this period the catches of saithe dropped. The fisher reported that, during the switch to plaice fishery, he changed area since saithe and plaice do not co-exist, which was verified by visual inspection of the fishing positions [Figure 4]. Thus, it is not possible to distinguish if the drop in saithe landings was due to a switch in gears or fishing area. Regarding the usual fishing grounds for cod and saithe no overall change over time in haul composition was observed, indicating that there are no obvious periods in a year where saithe or cod are at higher risk of limiting the fishery. At the same time, it suggests that fishing practice has been largely the same throughout the year. The two trips supplied by the fisher were not statistically different from the other trips, except for a single haul in the non-avoidance trip, with extraordinary large saithe landings, although the trips were spatially different.

The density estimation maps demonstrated an overlap in catches between saithe, cod and other species, which supports the fishers claim that saithe, cod and other species often co-exist, which would hinder the possibility for more selective fishing. It could also indicate that areas with high co-existence of saithe, cod and other species were mainly fished on and alternatives rarely sought. However, the analysis on the discrepancy between the median and the mean shows that hauls generally contained low saithe catches, except for one or two hauls per trip, while cod catches were more constant. This indicates that the spatial distribution of saithe was patched, while cod distribution was more even. From the catch patterns, this indicates that the vessel mainly targeted areas with low saithe occurrence, however in each trip, hauls over areas with higher concentrations of saithe were risked. This supports the tactical choices explained by the skipper, that depending on the catches of other valuable species in areas known to have little saithe, real time decisions to try areas with higher concentrations of both saithe and other valuable species are made. Thus, it is likely that the primary avoidance behaviour of the fisher is to avoid areas with known high concentrations of potential choke species, however to utilize all quotas, risks are sometimes taken to fish in these areas anyway.

As saithe is likely occurring in patches, a secondary avoidance behaviour is possible when encountering high catches of saithe, by changing fishing area or depth. However, there was no significant evidence that the distance moved or change in depth was related to the value or weight proportion of either saithe or cod. The absence of evidence in the data was explained by the skipper, that secondary avoidance behaviour mainly consisted on maintaining heading after haul-in to avoid doubling back over the same saithe patch as just encountered.

5 Conclusion

This study has brought interesting perspectives on the concept of choke species and its impact in the daily tactical decisions made by fishers. In the frame of the analysis of the impact of the landing obligation, choke species have mainly been considered at the fishery scale, comparing the catching capacity and the landing opportunities of a fleet or a nation [2,22–24]. In reality, choke species may affect differently individual fishers within the same fishery, since the most crucial factor is the individual quota share held by the fisher and his ability to lease additional quota, more than the national quota itself. Decisions are made every day regarding either discarding, avoiding or leasing quota for a given choke species, but such fine-scale decisions are difficult to capture by scientific models and data [4] and to integrate into management strategies that make sense for every individual fisher while achieving the overall policy objectives. This study has tried to link various sources of knowledge, bringing together fishers' tactic knowledge at local scale with scientists' explicit knowledge at wider scale. This helped assess some potentials and trade-offs of avoiding choke species, and contributed to building common grounds of understanding between stakeholders and scientists.

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