DTU Aqua

NOTAT

Til UM, Fiskeripolitisk kontor

Vedr. Discard survival of plaice (*Pleuronectes platessa*) caught in the bottom otter trawl (OTB) demersal mixed fishery in Skagerrak during summer 2017 and winter 2018

Fra DTU Aqua

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Request

DTU Aqua has received a request from UM to present the results on the discard survival of plaice collected in the bottom otter trawl fishery during summer 2017 and winter 2018 under the EMFF-project COPE (grant no. 33113-B-16-086).

Summary

The North Sea-Skagerrak stock of plaice is considered to have full reproductive capacity and to be sustainably harvested.

Discard survival was investigated for the bottom otter trawl (OTB) fisheries during Aug-Oct 2017 and Mar-Apr 2018 in Skagerrak. The assessments were done onboard a commercial vessel, and according to guidelines made by ICES WKMEDS. In the summer, two commercial 90 mm diamond codends representative for the mixed demersal fishery were used in a twin rig to target plaice. In the winter, in addition to the standard commercial 90 mm diamond codend, a modified horizontally divided codend with 120 mm square mesh upper compartment and 60 mm square mesh lower compartment to separate fish from *Nephrops* and limit surface damages was tested. All other operational factors of the experiment were representative of commercial practices in Danish waters.

Regarding the commercial standard codend (90mm diamond), the mean survival rate for undersized plaice was higher in the winter 75% (95%-confidence interval including variability from the captivity experiment, haul and fish uncertainty: 67-83%) than in the summer, 44 % (37-52%). The mean survival rate for undersized plaice commercially caught when targeting *Nephrops* during winter was 41% (28-57%), i.e. lower than when targeting plaice in the same season, and similar to when targeting plaice during summer. The larger amount of *Nephrops* in the catch caused more damages to the fish due to contact between the hard, spiny surface of the *Nephrops* and the soft skin of the plaice, leading to higher mortalities. In Skagerrak, the highest discard survival was found when the amount of discarded individuals in the fishery is the highest.

In the summer when targeting plaice, discard survival was affected by air exposure duration, dropping to 8% (CI: 2-31%) if released after 60 min of air exposure. This was, however, not the case in the winter. The air exposure times used in the experiment were within commercial practice, but it is not known if air exposure time are higher at the fleet level. The length range of the sampled fish was limited in the

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summer and larger in the winter, explaining why this biological factor had an effect on discard survival in the winter only.

The upper compartment of the modified codend (120mm square) showed a better discard survival, but also less undersized (and commercial) individuals due to a higher selectivity. The lower compartment of the modified codend (60mm square) did not seem to improve discard survival compared to the standard commercial codend. An ongoing project is aiming at improving its selectivity for flatfish.

The survival of the four control groups were high, but there might be some influence of transportation on survival.

Species and stock status

Plaice (*Pleuronectes platessa*) has no swim bladder and is considered robust with respect to surviving the fishing process, partly due to its sedentary life style that likely has evolved towards enhanced metabolic adaptation to hypoxia (Benoît et al., 2013; Morfin et al., 2017a). It is therefore a candidate species for obtaining an exemption from the landing obligation. Plaice in the Skagerrak has been assessed together with the North Sea stock since 2015 (ICES Advice 2017). The stock is considered to have full reproductive capacity and to be sustainably harvested (Table 1, Fig. A1). At the stock level, the proportion of unwanted catch is on average 57% (years 2011-2016, ICES Advice 2017).

Table 1. Plaice in North Sea and Skagerrak. State of the stock and fishery relative to reference points (ICES Advice 2017).

	Fishing pressure					Stock size				
		2014	2015	2016			2015	2016	2017	
Maximum Sustainable Yield	F_{MSY}	✓	✓	✓	Below	MSY $B_{Trigger}$	✓	✓	✓	Above trigger
Precautionary Approach	F_{pa}, F_{lim}	✓	✓	✓	Harvested sustainably	B_{pa}, B_{lim}	✓	✓	✓	Full reproductive capacity
Management plan	F_{MGT}	–	–	–	Not applicable	B_{MGT}	–	–	–	Not applicable

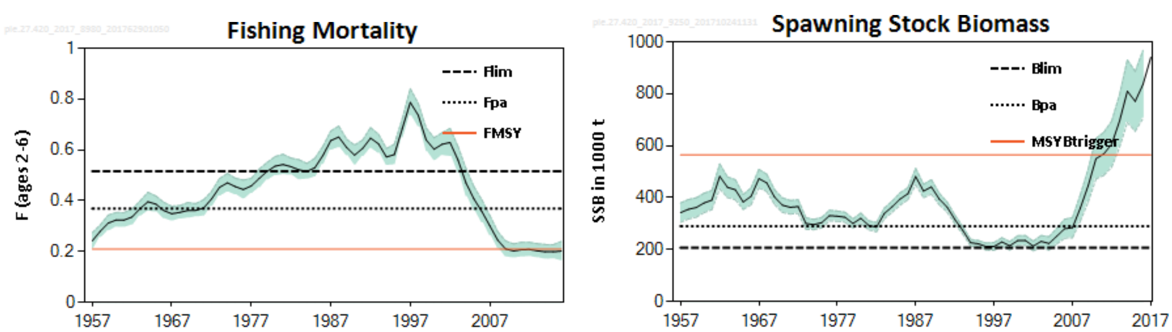

Fig. 1. Plaice in North Sea and Skagerrak. Summary of the stock assessment. Shaded areas (F, SSB) indicate ±2 standard errors (approximately 95% confidence intervals) (ICES Advice 2017).

Methods

Study design, vessel, and fishing gear

The survival rate and vitality of plaice under the MCRS of 27 cm in the trawl fishery in Skagerrak was investigated during summer (August, September and October) 2017 and winter (March and April) 2018. The study was done onboard the commercial vessel S84 'Ida Katrine' chosen in collaboration with the Danish Fishermen Organisation DFPO (Fig. 2). The trawler represents the mixed demersal fishery targeting fish (including plaice *Pleuronectes platessa*) and *Nephrops* (*Nephrops norvegicus)*, with a length of 15.1m and a power of 221kW, working in a twin rig.

Fig. 2. The commercial vessel used in the study to represent the bottom otter trawl fleet in the demersal mixed fisheries.

In the summer, two commercial 90 mm diamond codends representative for the mixed demersal fishery were used to target plaice. A 90mm mesh size was chosen to account for the 'worst case scenario', but fishermen commonly use a 120mm diamond codend instead when targeting plaice. Together with improving size selectivity, a larger mesh size in the codend is expected to reduce potential damages in fish and therefore improve discard survival.

In the winter, in addition to the standard commercial 90 mm diamond codend, a modified experimental codend was tested (Fig. 3). This horizontally divided codend with 120 mm square mesh upper compartment and 60 mm square mesh lower compartment had previously been used to separate fish from *Nephrops* (Karlsen *et al.*, 2015), and therefore seemed promising to reduce catch damage by limiting frictions in the codend. In the winter, half of the hauls targeted plaice and half of the hauls targeted *Nephrops*.

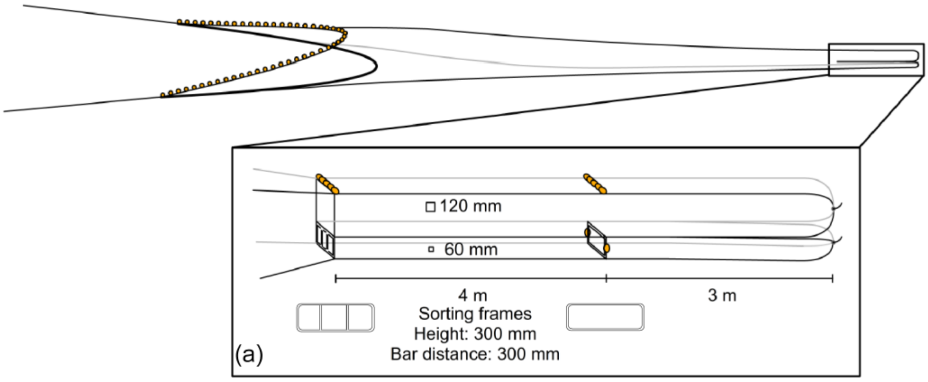

Fig. 3. A conceptual drawing of the horizontally divided codend used as one of the codends in the twin-rig of the trawler in the winter.

Data collection

Data was collected for a total of 10 days divided on five sub-cruises conducted from 17 August to 10 October 2017 and from 08 to 27 March 2018 on commercial fishing grounds north of Hirtshals (Fig. 4). Due to space limitations during transport and holding on land, repetition of the experiment allowed collecting a higher number of individuals to increase the robustness of the survival estimates. The two codends were fished on each side of the twin-trawl rig.

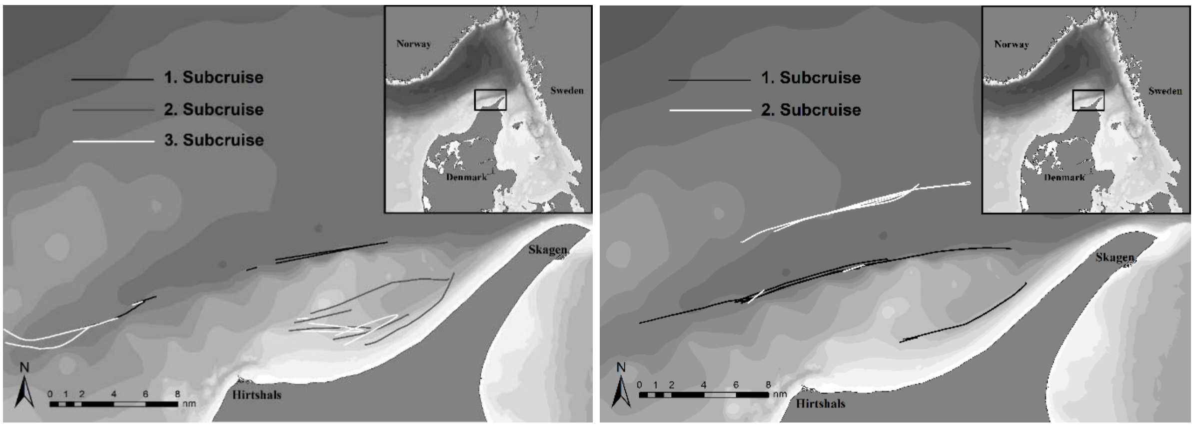

Fig. 4. Data collection at commercial fishing grounds in Skagerrak. The five sub-cruises were conducted in the summer (August, September and October 2017, on the left) and the winter (March and April 2018, on the right).

When using the modified codend to target *Nephrops* in the winter (second sub-cruise in 2018), clogging of the lower compartment at the point of the second frame was observed for some of the hauls. This had not been experienced when using the same gear during previous trials (Karlsen *et al.*, 2015). It is expected that clogged individuals would suffer higher levels of damages and therefore show lower survival than expected in the absence of clogging. Additionally, few individuals experienced rough handling accidentally caused by a sudden degradation in weather conditions at the end of the second sub-cruise in 2018. Potential negative effects was tested for as part of the data analysis.

In the summer, the catch of both codends was hauled on deck, emptied together into the pounder, and sorted by the crew according to normal commercial practices. Six fish were sampled at five time intervals during the sorting process to cover the entire air exposure time of the catch sorted normally by the crew.

In the winter, each of the first two codends hauled onboard were, one after the other, emptied into the pounder and collected from the sorting belt into separate tanks on deck while the catch of the last codend stayed in the pounder/on the sorting belt while being sorted. All three catches were sampled and assessed in parallel. The catches were held separately at all times until the individuals were tagged and identifiable. The handling order of the three catches was alternated at each haul. The effect of being hauled first on discard survival was tested in the analysis. Four fish were collected at four time intervals during the sorting process. The total sorting time was decided together with the crew according to usual practices, i.e., about 1 h when targeting plaice and up to 2.5 h when targeting *Nephrops*.

Fish were assessed for vitality, length measured and tagged for individual recognition. Fish were stored in custom-made survival units to minimize the effects of handling, holding and transportation on mortality. The survival units were continuously supplied with running seawater, and oxygen and temperature were monitored. Fish were transported to the close-by holding facilities at DTU-Aqua and transferred into 1x1m tanks in a common garden set-up to prevent a tank-effect on mortality. The tanks had a semi-circulated water supply and the bottom was covered with a 2 cm sand layer. Mortality was assessed and water parameters monitored for 14 days. After the first week, the fish were fed each day.

Controls

Four control groups were used to control for the effect of handling, assessing, transporting and holding the fish, i.e. all the experimental steps which took place after the fish would normally be discarded in commercial fisheries. Plaice in control groups 1 and 2 were caught prior to the study using the trawler R/V Havfisken. These fish were allowed to acclimatise before entering the study. Control group 1 (land) was used to control for the land-based holding facilities. Plaice in control group 2 (HV) were brought onboard the commercial vessel, and thus underwent the transportation to and from the fishing ground, and vitality assessment, length measurement and tagging. This group controlled for transport and assessment when held up against control group 1. Plaice in control group 3 (S84) were caught with the commercial trawler (short hauls) and entered the experiment without acclimatisation. This group controlled for the same as control group 2 in addition to the fishing process and commercial handling. A fourth control group was added during the winter sub-cruises to disentangle the effects of transportation and fish assessment. Plaice in control group 4 (land+tag) were caught by Havfisken and acclimatized beforehand, and experienced the assessment and tagging procedure, but no transportation process.

Analysis

A Weibull mixture model was used to estimate survival probabilities including uncertainty from the fish selection when appropriate, i.e., when the covariate of interest was dependent on individual fish, the haul selection and the conditions of the captivity experiment, and investigate the effect of air exposure, bottom temperatures, and fish length on survival (Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a, see Annex for more details). Information on other operational and environmental factors, i.e., haul duration, fishing depth, cloud cover, sea state, wind force and wind direction, were collected but not included in the modelling approach as data exploration showed no relationship or high correlation with the already chosen explanatory variables.

Results

Data collected

The operational conditions during the experimental trials are given in Table 2.

Table 2. Characteristics of the control and experimental hauls, separated by season, target species and haul type (control, experimental). Values shown as mean (min-max).

Condition	Hauls	Haul duration (min)	Catch weight (kg)	Bottom temp. (°C)	Number of individuals sampled	Fish length (sampled) (cm)
Summer						
Plaice						
Control	6	15 (13-16)	47 (30-60)	14 (10-17)	60	22.4 (14-27)
Experimental	12	141 (37-185)	387 (65-1509)	14 (10-17)	333	23.4 (17-26)
Winter						
Nephrops						
Control	2	18 (16-19)	38 (30-45)	6 (6-7)	10	22.3 (20-24)
Experimental	4	210 (180-239)	375 (200-500)	7 (7-7)	274	22.2 (11-26)
Winter						
Plaice						
Control	2	18 (16-19)	4 (2-5)	6 (6-7)	10	22.3 (20-26)
Experimental	6	181 (177-185)	150 (100-200)	7 (6-7)	279	22.1 (13-26)

Survival of the control groups

The survival of the four control groups were high, but there might be some influence of transportation on survival (Table 3).

Table 3. Survival of the control groups, separated by season and target species.

Season	Target	Control group	Number of individuals	Observed survival
Summer	Plaice	Control 1 (land)	50	1.00
		Control 2 (HV)	60	0.92
		Control 3 (S84)	60	0.87
Winter	*Nephrops*	Control 1 (land)	16	1.00
		Control 2 (HV)	10	1.00
		Control 3 (S84)	10	1.00
		Control 4 (land+tag)	16	0.94
	Plaice	Control 1 (land)	10	1.00
		Control 2 (HV)	10	1.00
		Control 3 (S84)	16	1.00
		Control 4 (land+tag)	16	1.00

Overall survival rates by season and target species for the commercial standard codend

Regarding the commercial standard codend (90mm diamond), the mean survival rate for undersized plaice was higher in the winter than in the summer, respectively 44% (95%-confidence interval: 37-52) and 75% (67-83%) (Table 4). A lower survival at higher temperatures was observed in previous studies. The mean survival rate for undersized plaice commercially caught when targeting *Nephrops* was lower than when targeting plaice, as observed in the winter, reaching survival rates similar to those when targeting plaice in the summer, i.e., 41 (28-57) % (Table 4). The larger amount of *Nephrops* in the catch caused more damages to the fish by friction in the codend, leading to higher mortalities.

Caution must be made when doing direct comparisons. Mean discard survival (with uncertainty estimates) are limited by the conditions during the trials, especially by the factors found to affect the survival rates.

Table 4. Estimated overall survival rates in % with 95%-confidence interval (* including uncertainty from the haul selection and the conditions of the captivity experiment when the chosen covariates did not depend on the fish selection, ** including uncertainty from the fish selection, the haul selection and the conditions of the captivity experiment) of undersized plaice in the Skagerrak for the OTB targeting plaice and *Nephrops* in the summer and winter for the standard commercial codend.

	Target: Plaice	Target: *Nephrops*
Summer	44 (37-52*, *n*=333)	-
Winter	75 (67-83**, *n*=142)	41 (28-57*, *n*=123)

Effects of operational factors on discard survival for the commercial standard codend

In the summer when targeting plaice, discard survival was affected by air exposure duration (Table 5). This was not observed in winter, also when targeting *Nephrops*, as discard survival was primarily driven by damages/loss of reflexes in an overall cold/mild environment.

The length range of the sampled fish was limited in the summer but larger in the winter, explaining why this biological factor had an effect in the winter only (Table 5).

Table 5. Effects of operational, environmental and biological covariates on the parameters of the fitted survival function and mixture proportion for discard survival of undersized plaice caught by a Danish otter trawler targeting plaice and *Nephrops* with a standard commercial codend in the summer and winter. Only the mixture proportion affects the overall survival estimate (as observed at the end of the experiment when an asymptote is reached).

Target	Season	Survival function (*α, γ*)	Mixture proportion (*π*)
Plaice	Summer	-	*Operational:* Air exposure
	Winter	*Operational:* Sorting order *Biological:* Fish length	*Biological:* Fish length
Nephrops	Winter	*Operational:* Sorting order, fail due to bad weather condition	-

Note the caution mentioned in the above section when comparing overall mean survival rates. Because overall survival rates estimated above are, for some, dependent on the number of observed fish for each level of the selected covariates, we also predicted survival rates for given values of the selected operational covariates independently, within the ranges of the experimental data, i.e., air exposure from 0 to 62 min for OTB targeting plaice in the summer (Fig. 5).

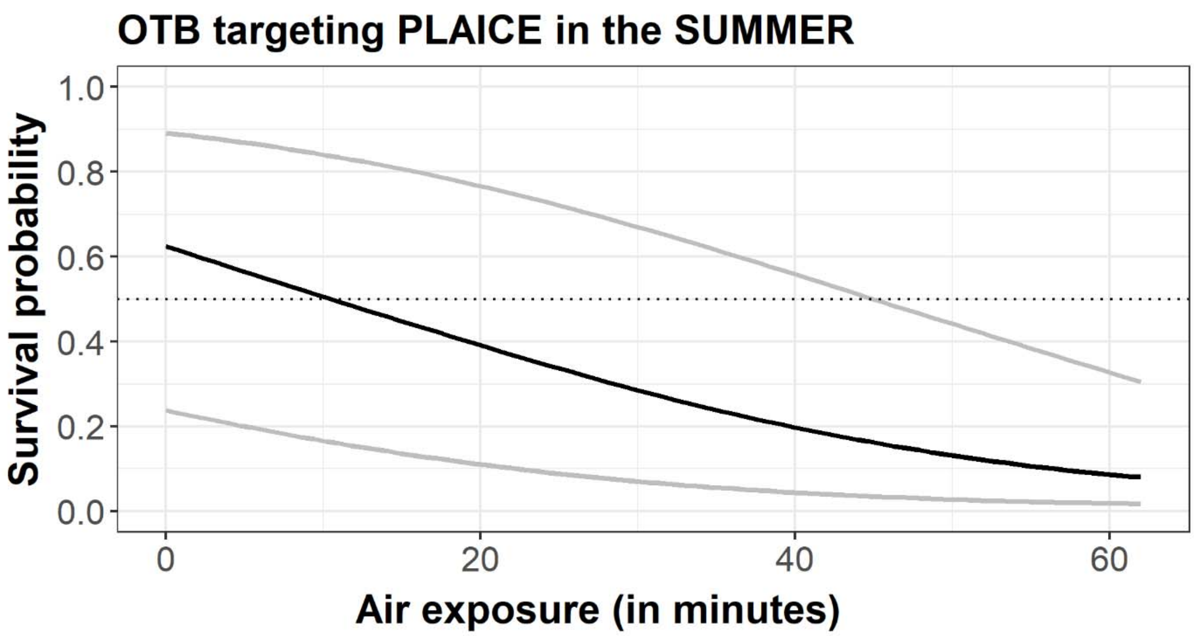

Fig. 5. Discard survival as a function of air exposure (black) with 95% confidence intervals estimated by parametric bootstrap accounting for variability from the captivity experiment (grey) for undersized plaice caught by the OTB targeting plaice in the summer.

Effect of the modified codend on discard survival

The upper compartment of the modified codend (120mm square) showed a better discard survival, but also less undersized (and commercial) individuals due to a higher selectivity. The lower compartment of the modified codend (60mm square) did not seem to improve discard survival compared to the standard commercial codend. An ongoing project is aiming at improving its selectivity for flatfish.

Discard survival in the context of the Danish demersal mixed otter trawl fishery

Fleet description: number, size and power of the vessels in the Skagerrak and North Sea

The OTB fleet in the MCD fishery in Skagerrak counts 102 vessels in the size range 11.00-19.99 m and power range 67-365 kW (2017, logbook database). The same fleet segment in the North Sea counts only 11 vessels (size and power ranges of 11.00-16.99 m and 126-365 kW, respectively; 2017, logbook database) (Fig. 8).

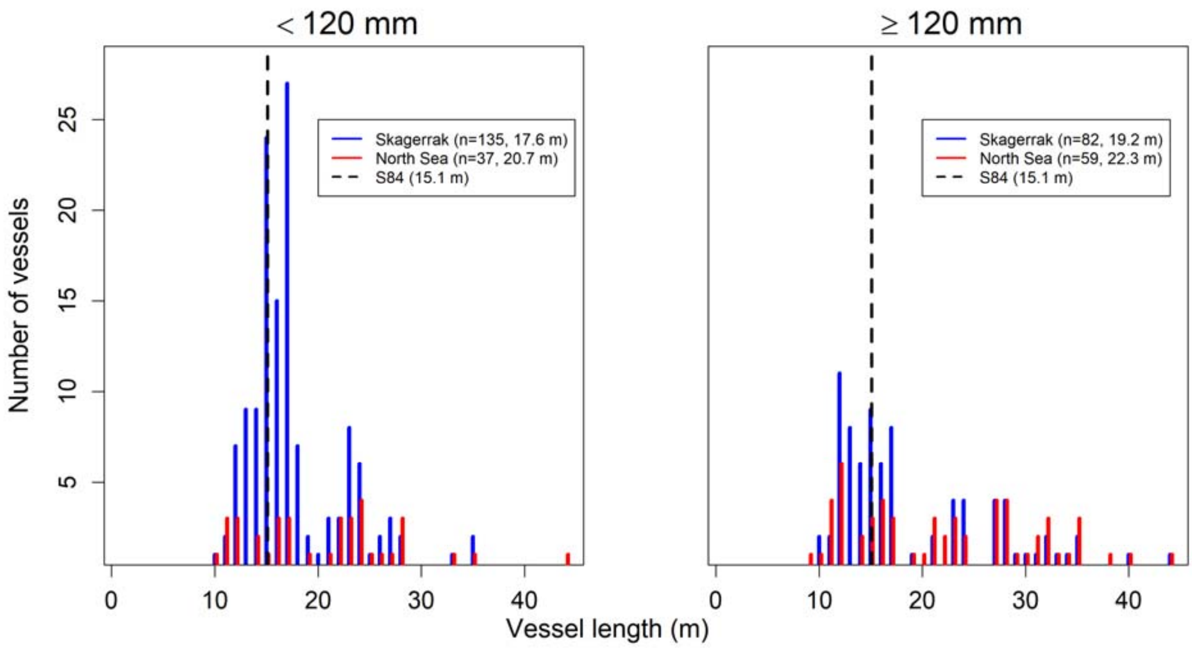

Fig. 8. Number of Danish vessels in the OTB fleet by length category in m by area and mesh size (2017, logbook database). The dashed black line represents the length of the vessel used in the experiment (S84). In brackets in the legend is the average vessel length for each area and mesh size.

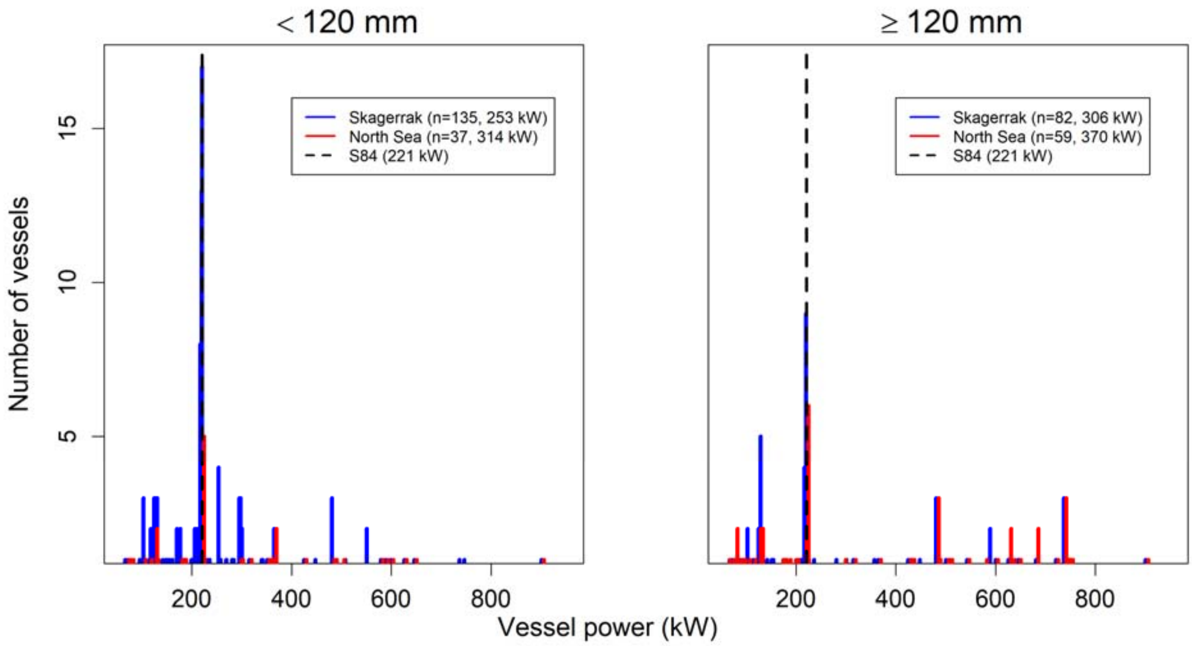

Fig. 9. Number of Danish vessels in the OTB fleet by power category in kW by area and mesh size (2017, logbook database). The dashed black line represents the power of the vessel used in the experiment (S84). In brackets in the legend is the average vessel power for each area and mesh size.

Catch data: catch pattern and seasonality

Plaice and *Nephrops* are caught year round both in the Skagerrak and the North Sea (Fig. 10 and 11). However, fish and *Nephrops* are usually caught on separate fishing operations (Fig. 10), which should be highlighted as the presence of *Nephrops* in the catch can increase damages and therefore fish mortality (Karlsen et al. 2015). I.e. when *Nephrops* dominates the catch the proportion of plaice is low and vice versa.

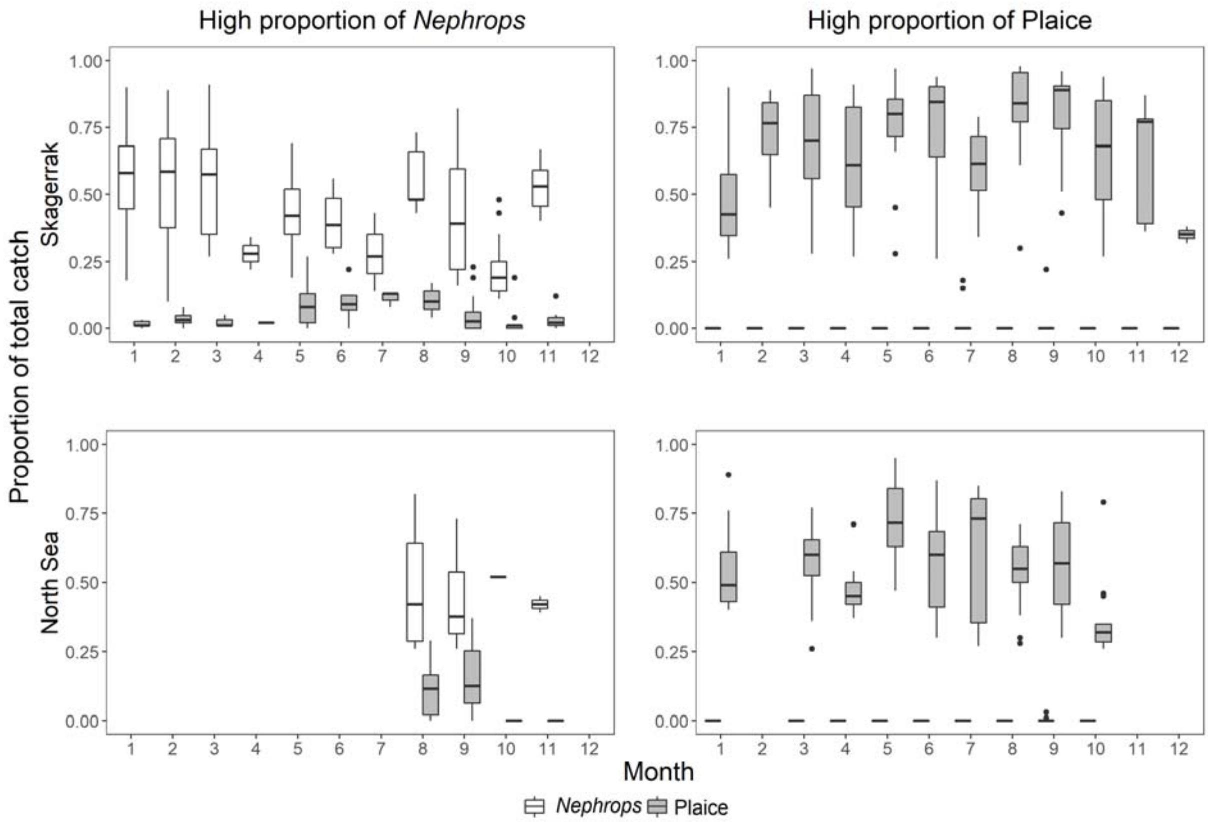

Fig. 10. Proportion of plaice and *Nephrops* in the total catch when targeting plaice (high proportion of plaice) and *Nephrops* (high proportion of *Nephrops*) by month for the Danish OTB fleet separated by area (2015-2017, logbook database).

In the Skagerrak, the largest landings of plaice take place in the autumn and winter. In the North Sea, the largest landings take place in the summer, but are all year round at least as big as in the Skagerrak (Fig. 11). Although discard ratios of plaice are usually higher for smaller mesh sizes, i.e. often targeting *Nephrops* in all seasons except for autumn in the Skagerrak (Fig. 11), absolute numbers of discarded plaice are usually higher when the proportion of plaice in the total catch is larger, i.e., using larger mesh sizes. The proportion of unwanted catch of plaice is on average 60.4% in volume with 90-119 mm mesh size and 7.4% with >120 mm mesh in the Skagerrak, and 6.4% in volume with 90-119 mm mesh size and 3.4% with >120 mm mesh in the North Sea (data from the Data Collection Framework database from 2015-2017).

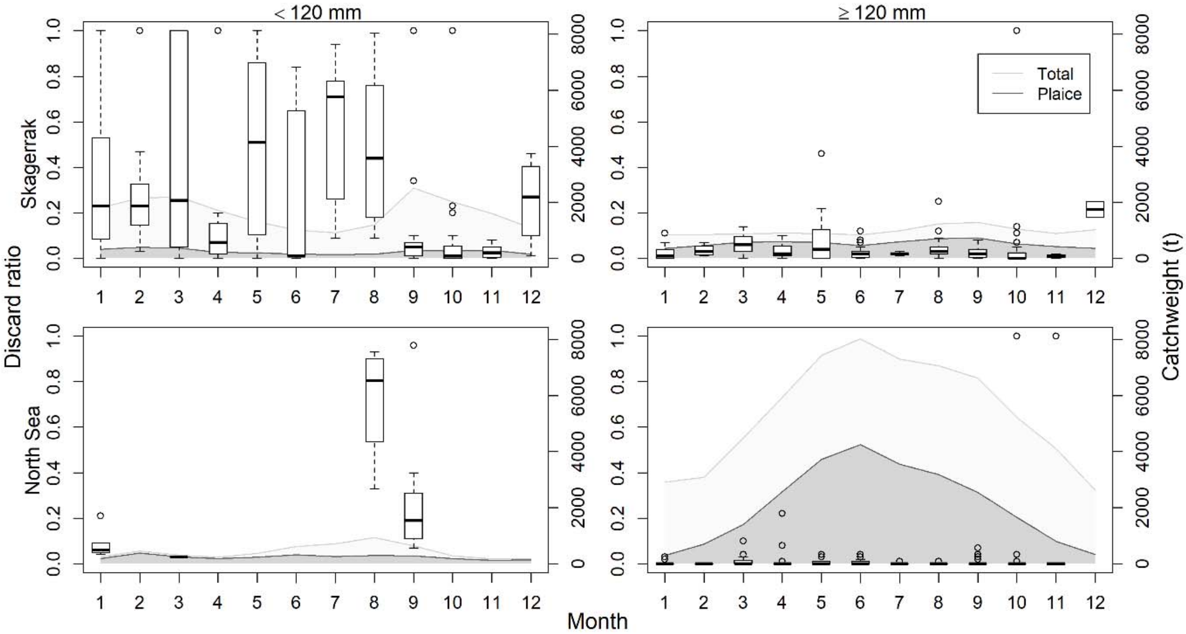

Fig. 11. Total landed catch in tons (light grey), plaice landed catch in tons (dark grey) and discard ratio (boxplot) by month for the Danish OTB fleet by area and mesh size (2015-2017, logbook database, Data Collection Framework database).

Biological and operational factors influencing discard survival

All biological and operational factors of the experiment were representative of commercial practices in Danish waters. All our sampled plaice were representative of the biological conditions at the time of the experiment, i.e., in line with the length distribution of the fish discarded in the fishery between 2015 and 2017 (Table 2, Table 6).

Air exposure is in close relation to sorting time. The sorting times during the experimental trials were within commercial practices, as discussed with the crew and the DFPO. There is no data available on the sorting times at the fleet level from which we could assess the proportion of hauls with sorting times within the range of sorting times included in our study. The sorting time depends on catch weight (and thus also vessel size) and composition, and the size of the crew onboard the vessel. Experience from DTU-Aqua observers at sea programme suggests that in commercial conditions, sorting time is up to 1 h depending on catch weight when plaice is the main target species, and up to 2.5 h when *Nephrops* is the main target species. A proxy for sorting time is catch weight. For hauls, conducted between 2015 and 2017 in the Skagerrak, the average catch weight per haul for trawlers using mesh sizes ≥120 mm (i.e. mainly targeting plaice or roundfish) was 674 (53-2957) kg (Table 6). For trawlers using mesh sizes <120 mm (mainly targeting *Nephrops*), it was 559 (121-2236) kg (Table), i.e. catches of our experiment (Table 2) are within the range of these values.

Table 6. Characteristics of commercial hauls conducted between 2015 and 2017 (Data Collection Framework database). Values shown as mean (min-max).

Area	Mesh size	Haul duration (min)	Catch weight (kg)	Length of plaice discarded (cm)
Skagerrak	<120 mm	248 (142-300)	559 (121-2236)	23 (11-37)
	≥120 mm	215 (75-300)	674 (53-2957)	25 (13-39)
North Sea	<120 mm	296 (290-299)	985 (226-1932)	26 (18-40)
	≥120 mm	258 (34-300)	1643 (175-4949)	26 (17-39)

Discard survival rates with respect to the amounts discarded in the fishery

Discard survival of undersized plaice caught by a standard commercial codend (90mm diamond) by a Danish otter trawler was higher in winter and when targeting plaice. In the Skagerrak, this is also when the amount of discarded individuals is the highest compared to when targeting *Nephrops* or in the summer. In the North Sea, the discard ratio is low when targeting plaice.

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Annex

Parametric Weibull mixture distribution model

A parametric Weibull mixture distribution model was used, allowing some proportion of individuals to survive (Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a). The probability that a fish was mortally affected by capture, handling and discarding is π. For those affected fish, according to the shape of the non-parametric Kaplan-Meier curves (Kaplan and Meier, 1958), a reasonable model for the survival function is a two-parameter Weibull distribution, with parameters α (the scale, with $\alpha>0$) and γ (the shape, with $\gamma >0$). Natural mortality is considered negligible at the time scale of the observation period, and therefore the survival rate is expected to eventually converge to an asymptote $1 - \pi$ (for further detail, see Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a).

Explanatory variables (e.g., air exposure, fish length, bottom temperatures) were tested as covariates on the three parameters describing the survival model, i.e., α, γ and π (for further detail, see Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a).

Model parameters were estimated by a maximization of the model likelihood using a quasi-Newton optimization algorithm (Byrd et al., 1995).

Model selection and validation

An information-theoretic approach was used to identify which of the covariates were important determinants of survival probability using Akaike Information Criterion (AIC) (Akaike, 1981; Burnham and Anderson, 2002). Models with a relative difference in AIC less than two with the model with the lowest AIC could be interpreted as having similar support in the data, while larger values suggested less support for the competing model (Burnham and Anderson, 2002). Among all models with a relative difference in AIC less than two, the simpler model was then selected as the best model. Model fit was assessed visually by superimposing the predicted survival curves on the non-parametric Kaplan-Meier curves (Morfin et al., 2017a; Morfin et al., 2017b).

Model estimation and confidence intervals providing with an overall survival rate for the observed fisheries. Confidence intervals of the survival rates were estimated by a parametric bootstrap based on Monte Carlo simulation with 5000 iterations (Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a). At each iteration, based on asymptotically normal behavior of the maximum likelihood estimators, the regression parameters were simulated according to a multivariate Gaussian distribution (for further detail, see Benoît et al., 2012; Benoît et al., 2015; Morfin et al., 2017a). Uncertainty due to the selection of hauls was estimated by randomly re-sampling m hauls with replacement from the m observed hauls. The observed fish were re-sampled to capture the variability due to the selection of fish in each haul, only when the covariates in the chosen best model depended on the sampled fish, i.e., fish length. These steps were repeated 5000 times. The overall survival rate was given as the median, and its 95%-confidence interval as the range between the 5th and the 95th centile.

Model prediction and confidence intervals for assessing operational covariate effects on survival rate

Overall survival rates for each gear estimated above are dependent on the number of observed fish for each level of the selected covariates. Thus, we also predicted survival rates for given values of the selected operational covariates independently, within the ranges of the experimental data, i.e., air exposure from 0 to 62 min for OTB targeting plaice in the summer. Survival was estimated at the asymptote, i.e., calculated as 1- π. As previously, confidence intervals of the survival rates were estimated by a parametric bootstrap based on Monte Carlo simulation with 5000 iterations, but we accounted only for the variation of the regression parameter π, similarly simulated according to a multivariate Gaussian distribution. Survival rate was also given as the median, and its 95%-confidence interval as the range between the 5th and the 95th centile of the 5000 iterations.

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