Survival of plaice caught and discarded by Belgian beam trawlers

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1 Overview of the Belgian beam-trawl fishery

1.1 Introduction

While the Belgian fishing fleet is relatively small, its activity is widespread fishing in both the North Sea and the English Channel as well as the Western waters and the Bay of Biscay (ILVO, 2016). Over the past 60 years the number of vessels has continuously decreased and since 1990, also total engine power and tonnage has decreased. In 2008, total landings were at a minimum. Since then landings have gradually increased again (ILVO, 2016). In 2016, Belgian vessels landed a total of 24.583 tonnes in Belgian and foreign harbours (Departement Landbouw & Visserij, 2017). After years of steady increase, this amount is now comparable to what was landed 15 years ago. European plaice (*Pleuronectes platessa*) and Common sole (*Solea solea*) dominate the landings, namely 8.946 tonnes and 2.481 tonnes, respectively (Figure 1A, Departement Landbouw & Visserij, 2017). However, in terms of value, sole is clearly the main target species of the Belgian fleet (Figure 1B). A considerable proportion of the Belgian landings (7.870 tonnes) is sold in foreign harbours, mainly to the Netherlands, the UK and France. Most of these foreign landings are crustaceans and molluscs, particularly, langoustine (*Nephrops norvegicus*, 671.131 kg), brown shrimp (*Crangon crangon*, 658.210 kg) and scallops (*Pecten maximus*, 414.711 kg, Departement Landbouw & Visserij, 2017).

The Belgian fishing fleet consists of vessels of either ≤ or > 221 kW engine power and is therefore segregated into a small (KVS) and large (GVS) fleet segment, respectively. These two segments are further subdivided according to the type of fishing gear (ILVO, 2016). Both the small and large segments of the Belgian fishing fleet are dominated by beam trawlers (Figure 2). Among the 71 licensed and active Belgian beam trawlers in 2017, 37 are classified into a small (≤221 kW), and 34 into a large (>221 kW) engine power segment (Departement Landbouw & Visserij, personal communication Martine Velghe, 26-3-2018). Each of these fleets has a distinct fishing pattern: for instance, coastal vessels of the small fleet segment spend ≤48 hours at sea fishing, targeting demersal fish between March and June (70-99 mm mesh size), off the Belgian coast in the Southern North Sea (Figure 3).

In conclusion, the Belgian fishing fleet is highly diverse with respect to its activity ranging across a large geographical area which is characterized by different seafloor substrate types (Figure 4).

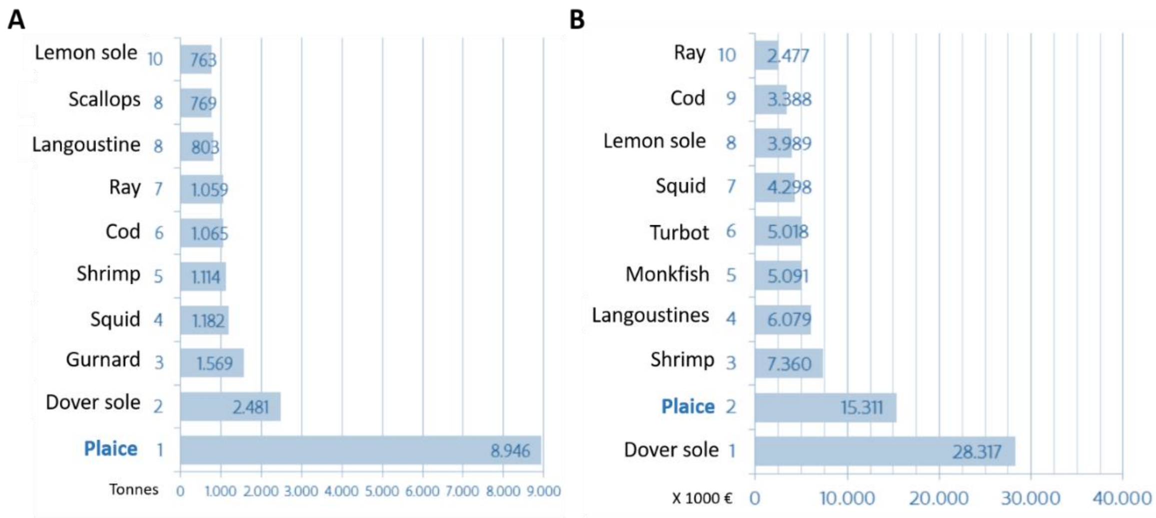

Figure 1 Top 10 fish species with respect to A) landed weight (in tonnes) and B) value (in x.1000 EUR) and for the Belgian fisheries in 2016 (Modified from Figures 6 & 11 in "Aanvoer & Besomming 2016", Departement Landbouw & Visserij).

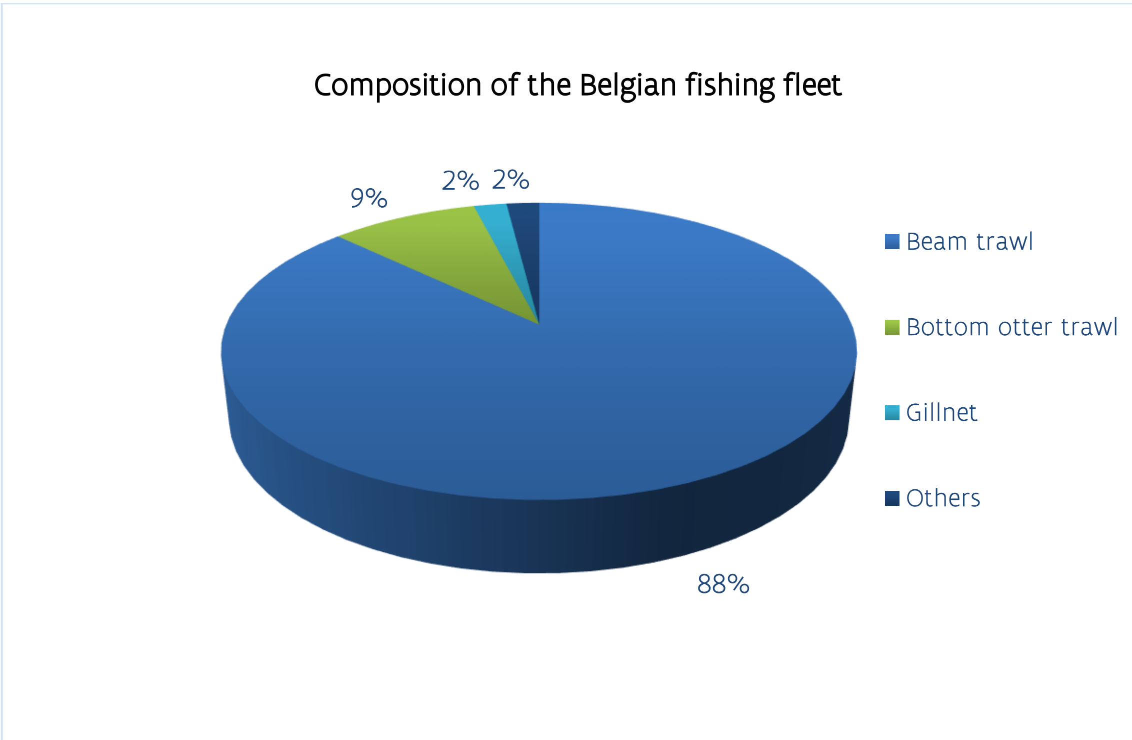

Figure 2 Share of the most important fishing techniques used in the Belgian fisheries (ILVO, 2012).

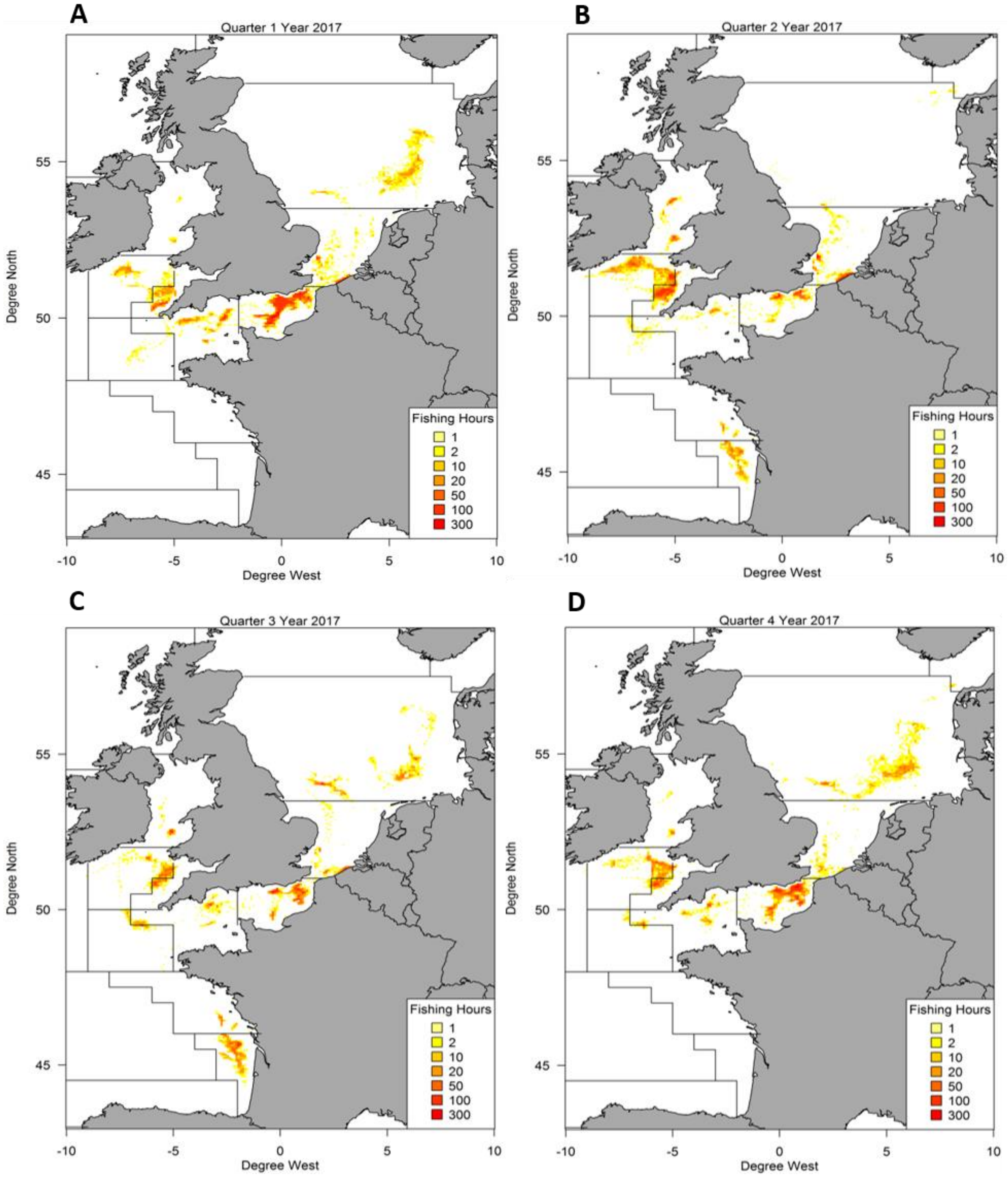

Figure 3 Heat map of the number of fishing hours (based on filtered VMS pings of Belgian beam trawlers (mesh size 70-99 mm) in 2017.

1.2 Data for 2017

In 2017, Belgian beam trawlers spent most effort (i.e. number of fishing hours) in ICES-area 7d (Figure 3): an area mainly characterized by rocks and hard substrate (Figure 4). The Eastern English Channel (7d) was attributed to the second highest fishing quota (in tonnes) during the past three years after ICES-area 4 (North Sea) (Appendix Table 1). Table 1 (Appendix) also shows the weight-based (in tonnes) discard ratios (DR) for plaice in five different ICES sub-Divisions for two beam-trawl métiers with different mesh sizes. The discard ratio is highest for beam trawling with 70-99 mm mesh size in ICES sub-Division 7a (DR = 0.57). In ICES sub-Divisions 4 and 7d the highest numbers of discards are between 0-3 years, most landed fish are between 4 and 7 years old.

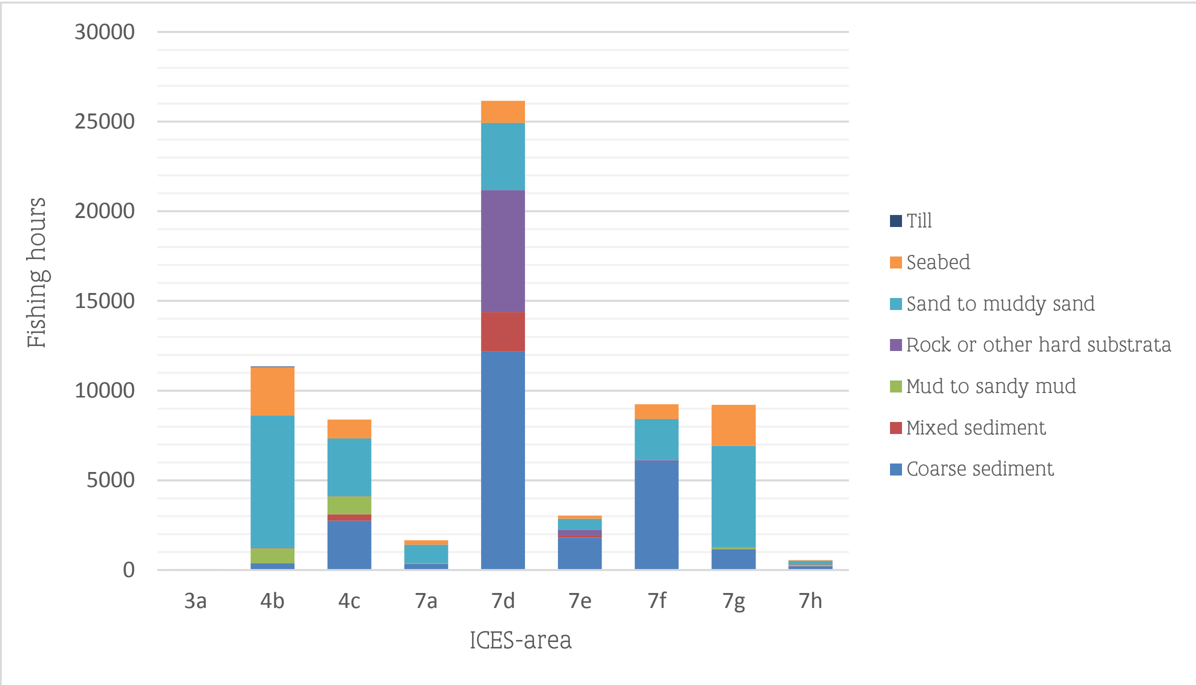

Figure 4 Mean number of fishing hours (= calculated as the sum of the interval time between VMS pings where fishing activity is expected) per substrate type and per ICES sub-Division between 2015 and 2017.

1.3 Managing discards

1.3.1 Landing Obligation

Discarding is a widely recognized problem in many fisheries, particularly in multi-species trawl fisheries (Kelleher, 2005). Discards have become more important in the public eye in Europe with increasing public awareness to ocean conservation, with the intensification of overexploitation of fisheries resources, and, recently, with concerns raised about widespread discarding of commercial species (Borges 2015). To address the discarding problem in European (EU) waters, a Landing Obligation (LO) was introduced as part of the reformed EU Common Fisheries Policy (CFP, European Union, 2013).

The LO requires all catches of regulated commercial species on-board to be landed and counted against quota. This radical change in fisheries management aims to improve fishing behaviour through avoidance of unwanted catches and also through improvements in selectivity. However, discarding of fish and crustaceans at sea may still be allowed if it can be scientifically proven that they stand a high chance to survive the capture-and-discarding process (high survival exemption). In response to a European Commission request, an ICES working group was established to provide guidance on how to quantify this (unaccounted) survival or mortality probability.

1.3.2 Selective discard measures

To improve avoidance, selectivity and survival of unwanted bycatch/discard species, different measures may be implemented. The effectivity of these measures varies mainly according to the type of fishery, gears used, and species of interests. For the Belgian fleet, advances in the reduction of ecological impact in the past decade were particularly resulting from fleet reduction and gear modifications and/or replacements to reduce fuel consumption (Depestele, 2015). Gear modifications focused on reducing fuel consumption by reducing seabed interactions, for instance by using lighter beam trawls, Sumwings or outrigger trawls (Depestele, 2015). Gear modifications to increase selectivity were during this period not introduced, except for a panel of larger mesh sizes in the top panel (Departement Landbouw & Visserij, 2013). This "Flemish panel" is a 3-m long, large mesh (120-mm) panel in front of the codend to reduce the retention of <MCRS sole (Bayse & Polet, 2015). Since January 2016 all Belgian beam trawlers are obliged to use this panel to allow escape of undersized sole (Bayse & Polet, 2015). Additionally, when targeting brown shrimp (*Crangon crangon*), coastal vessels are obliged to use bycatch reduction panels (BRD, named "zeeflap") between Dec 1 and May 31 with 16-31 mm nets. Such panels separate and exclude unwanted bycatch of invertebrate and fish species from the shrimp catch. Another modification, is a wing profile to replace conventional beams (termed "seewing"). The most promising modification to both reduce discards, reduce fuel consumption, seabed impacts and in turn increase catch efficiency is the pulse trawl, which is currently banned in Europe and only used based on experimental exemption licenses. After conducting a comparative fishing experiment, Van Marlen et al. (2014) showed that pulse fishing resulted in fewer discards (57%) compared to conventional beam trawls, including 62% undersized plaice and 80% benthic invertebrates (Van Marlen et al. 2014).

2 Survival research

2.1 Methodology

2.1.1 Selection of participating vessels

Commercial vessel operators were invited via an open letter to participate in the survival project in 2015/2016 this study. Out of the pool of volunteers, a selection was made based on the following criteria: i) sufficient space and suitable infrastructure on board (i.e. copper-free deck water pumps with a guaranteed continuous > 25 L discharge volume) to accommodate two scientific observers and their equipment; ii) fishing gear configuration typical for Belgian beam trawlers; iii) activity within a management-relevant fishing area; and iv) willingness by the crew to co-operate. Vessel owners were compensated for any costs accrued due to loss of fishing time and/or catch. For three extra trips in 2017/2018, vessels were selected based on their activity patterns and voluntary commitment.

Five trips were done with a commercial coastal Belgian beam trawler (coastal fleet segment) and five trips with a Eurocutter (small fleet segment) targeting sole in waters of the Southern North Sea and English Channel between November 2014 and September 2015. Both the coastal and Eurocutter beam trawlers were conventionally rigged with two 4-m beam trawls with chain mats (each weighing ~1200 kg). Five trips were done with three vessels from the >221 kW segment fishing in the North Sea (two trips in July/August 2015), English Channel and Celtic Sea (three trips in October/November 2017 and January 2018) with beam trawls between 11 and 12 m in length. Two vessels used conventional chain-mat gears and the other vessel a sumwing with an estimated single-beam gear weight of 6000 kg and 4500 kg, respectively. All vessels used 80 mm diamond mesh codends.

2.1.2 At-sea sampling and monitoring

The following technical, environmental and biological data were recorded for each trawl: start and end positions; trawl duration; wind force; average water depth; and catch weight. Catch weights of plaice were estimated in kg and where necessary 'number of boxes' converted to weights by a factor of 35 kg. Additional measurements such as maximum wave heights, air and surface seawater temperatures were received from weather stations "Trapegeer", "Westhinder", and "Wandelaar", respectively (Flemish Government, 2015). A sample of plaice discards from these fifteen commercial Belgian beam-trawl trips was assessed for reflex responsiveness severity of injury types to establish an individual's vitality when it arrived on deck (see Uhlmann et al., 2016a for details). Where possible all undersized plaice were collected inside a water-filled 244-L white PVC container positioned at the end of the conveyor belt. At the end of the sorting process, >30 plaice were randomly selected. Ten of which were assessed for their reflexes and injuries as described below, and from another 20 the ratio of alive and dead was determined. An individual that did not respond to its tailfin being grabbed and which did not show any breathing movements of the operculum and/or mouth was considered to be dead. A sub-sample of fish were monitored in both water-filled on-board and lab-based containers (for delayed mortality up to 14 days).

For the quantification of delayed mortality, batches of between five undersized, < 27 cm MLS plaice (22 ± 3 cm TL, Table Appendix 2) were collected from the sorting conveyor at the beginning, mid- and end points of the sorting process (see Uhlmann et al., 2016a, for details) except for an extra batch collected straight from the hopper (a large container holding the discharged catch after the codend was emptied), placed into a 10-l ambient seawater-filled PVC bucket and within ~5 min tested for their reflexes. Air exposure for each fish was expressed as the minutes it spent on deck before being placed inside a water-filled bucket plus one third of the handling time during reflex testing (because 1/3 of the reflex tests were done in air out of the water-filled container). Prior to a commercial trip, fish were sourced from the *R/V* Simon Stevin, transferred to 124-L monitoring containers and checked daily for any mortality. Between 10 and 20 individuals were brought on-board for a trip and considered as controls.

Both controls and caught-and-discarded fish were assessed for their reflex responsiveness and injuries. A response to a reflex stimulus was scored as present (unimpaired, 0) when clearly visible, or absent (impaired, 1) when not visible, weak or in doubt within 3 s of observation. Reflex and injury assessments took approximately 30 seconds per fish. Each plaice was scored for the body flex, righting, head complex, evasion, stabilize, and tail grab reflexes, and a presence/absence of injury (e.g. extent of point bleeding and bruising around head or body; scored on a 4-point categorical scale). These injuries were associated with mortality in earlier work (Depestele et al., 2014a, J. Depestele, pers. comm.). Fish that were unresponsive to reflex tests were considered to be dead and registered as immediate mortality. All reflex-tested fish were length-measured to the nearest cm of TL and all alive fish T-bar (29 x 8 mm) anchor tagged with Bano'k© guns in the dorsal musculature following McKenzie et al. (2012). All tagged plaice were 'discarded' into stacks of independently arranged, water-filled, onboard 30-l monitoring containers (60 cm L x 40 cm W x 12 cm H; Figure 1) and at the end of a trip transferred within <2 h to laboratory-based, 124-l monitoring containers for 14 days of at least daily monitoring. Fish were offered defrosted brown shrimp (*Crangon crangon*) as food at <5% of their biomass after 7 days of monitoring. Any food remains and/or dead fish were removed and the time to mortality noted. Fish were monitored three times per day within the first and daily within the second week of monitoring. At each monitoring interval, the status of a fish was classified as either alive (0) or dead (1). The corresponding impairment score for each fish was calculated as the mean score of impaired reflexes (and present injuries – in experiment 3).

2.1.3 Statistical analyses

Data were analyzed separately for immediate and delayed mortality. Immediate mortality was analyzed as a function of independent biological, technical and environmental factors such as single gear weight, beam length, gear deployment duration, total catch weight, sea surface temperature, air exposure, sorting and handling durations, and sediment type, using generalized logistic regression (GLM). Based on correlations, if any, among the explanatory variables and univariate GLM analyses, a selection was made on which factors to include for a full candidate model.

For the analysis of delayed mortality, non-parametric Kaplan-Meier curves were used to plot survival as a function of time to illustrate when mortality began to level off and to explore which biological, technical or environmental factors may contribute towards mortality. To explore which of the status indicator scores (i.e., damage class, reflex index, reflex and injury index, individual reflexes) may be associated with delayed mortality, logistic regression models were used to model the probability of dying (within 9 days of monitoring) as a linear function of the above explanatory variables. Univariate analyses of variance (type III ANOVA) were used to test the null hypothesis (H0) of no differences between the probability of dying within 9 days of monitoring at each status indicator's score level. To select the most discriminating combination of (non-collinear) reflexes, the % dead fish out of the total which were reflex tested as either un-/ or impaired for a given reflex were plotted against the ratio for when another given reflex was either un-/ or impaired to graphically depict whether the risk of dying was generally greater when a reflex became impaired and whether this held true, also when another reflex was already recorded as impaired. To validate the logistic regression model which included the number of absent body flex, righting and evasion reflexes as one of the best explanatory variables, a training set was built from all observations, except those from a given trip. Predicted average survival probabilities per number of absent reflex were compared to observed probabilities.

Deviations between 1 and 2% were considered to be a good fit. Based on the validated relationships between reflex impairment (i.e., the number of absent body flex, righting and evasion reflexes and also reflex impairment index) and mortality, average survival probability was predicted using logistic regression for those trips were undersized plaice were scored for reflex impairment and injury, but not monitored in captivity for recording any delayed mortality (trips 13-15; Appendix table 2c). Model parameters were estimated based on a training set which comprised all reflex observations of fish that were monitored for delayed mortality (up to 9 days). Based on these model parameter estimates, mortality was predicted for all the reflex-scored fish sampled during the trips where no monitoring for delayed mortality took place. Total mortality was calculated based on the proportion of fish that were dead immediately on-board plus the remaining number of fish from the total (1-immediate mortality) multiplied by either the observed or predicted delayed mortality proportion.

2.2 Results & Discussion

2.2.1 Immediate mortality

From 147 trawls and 15 trips of five Belgian beam trawlers a total of 4815 undersized plaice (24 ± 5 cm, mean ± SD) were assessed for their on-board immediate mortality status. Immediate mortality was low for most trips, except those with vessels from the >221 kW fleet segment (ranging between 8 and 62%). Immediate mortality was greater during monitored trips in the summer compared with autumn and winter (Table 1c). Due to collinearity with gear deployment duration and total catch weight, sorting duration and depth was excluded from the analysis. Immediate mortality was positively related with gear deployment duration (broken line in the slope from >80 min; $p < 0.001$), sea surface temperature ($p < 0.001$), total catch weight ($p < 0.001$), and wave height ($p < 0.01$), with an adjusted R-square of 60%.

To test whether the assumptions and choice of statistical model were appropriate, the residuals were examined through a frequency distribution (Figure 5B) and a QQ-plot (Figure 5C). Figure 5B shows that residuals are normally distributed, although slightly skewed to the right (Figure 5B). Small departures from the straight line in the QQ-plot are common and were expected (Figure 5C)., Hence, based on these Figures, it was concluded that the assumption for normality was met.

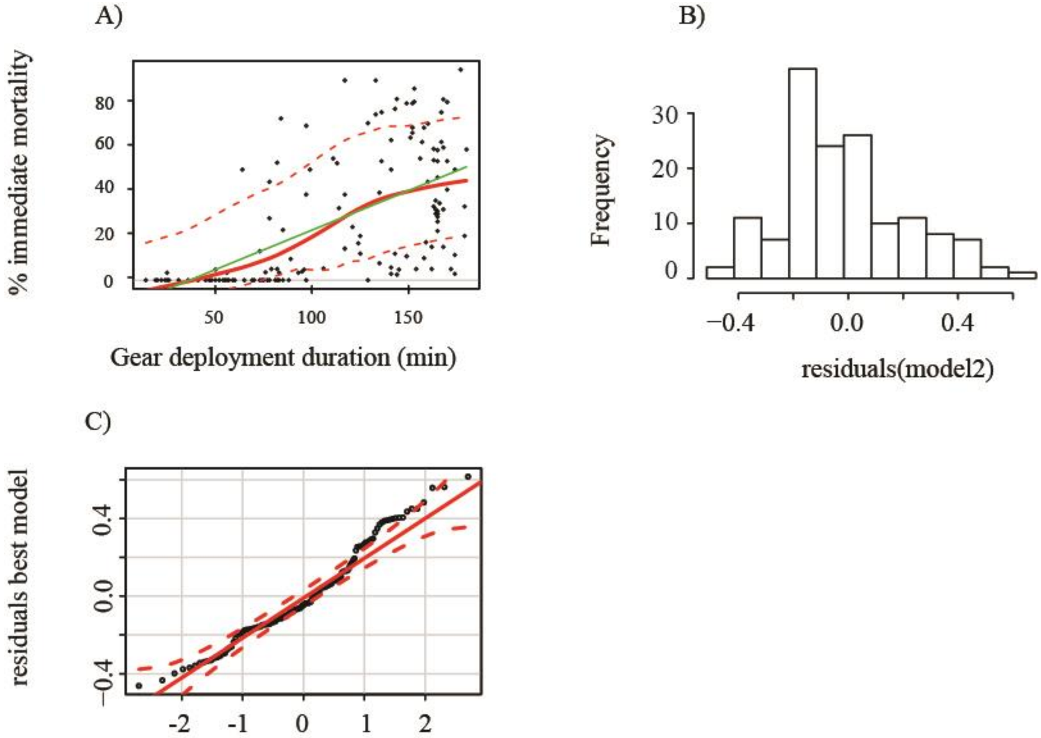

Figure 5 Average immediate mortality (%) per monitored trawl in relation to A) gear deployment duration (in min). Dashed red line indicate 95% confidence interval around the smoother line (red); green line corresponds to a linear regression line. B) frequency distribution of the residuals illustrating normality; C) QQ plot of the residuals for validation.

2.2.2 Delayed mortality

To quantify any delayed mortality, 903 plaice (from 53 deployments; 22.6 ± 3.1 cm TL, mean ± SD) were assessed for injury and reflex impairment and subsequently 'discarded' into holding containers. Of these, 231 and 672 were randomly selected from short (<40 min) and conventional trawls (~60 min gear deployment duration for the <221 kW vessels; or ~140 min for the >221 kW vessels), respectively. Except for two trips, fish were monitored, alongside 160 control plaice, for an average of 15 days until no more mortality attributable to the catch-and-discarding process was observed (Table 1a-c). All but three control fish survived. Non-parametric Kaplan-Meier curves were neatly segregated for reflex, reflex and injury indices, trawl duration, sorting duration, wave height, sea surface temperature, and total catch suggesting that these variables are potentially associated with delayed survival (Figure 6). For sediment type, if catches were scored as having >25% in volume stones or sand or both present, survival probability for fish was lower.

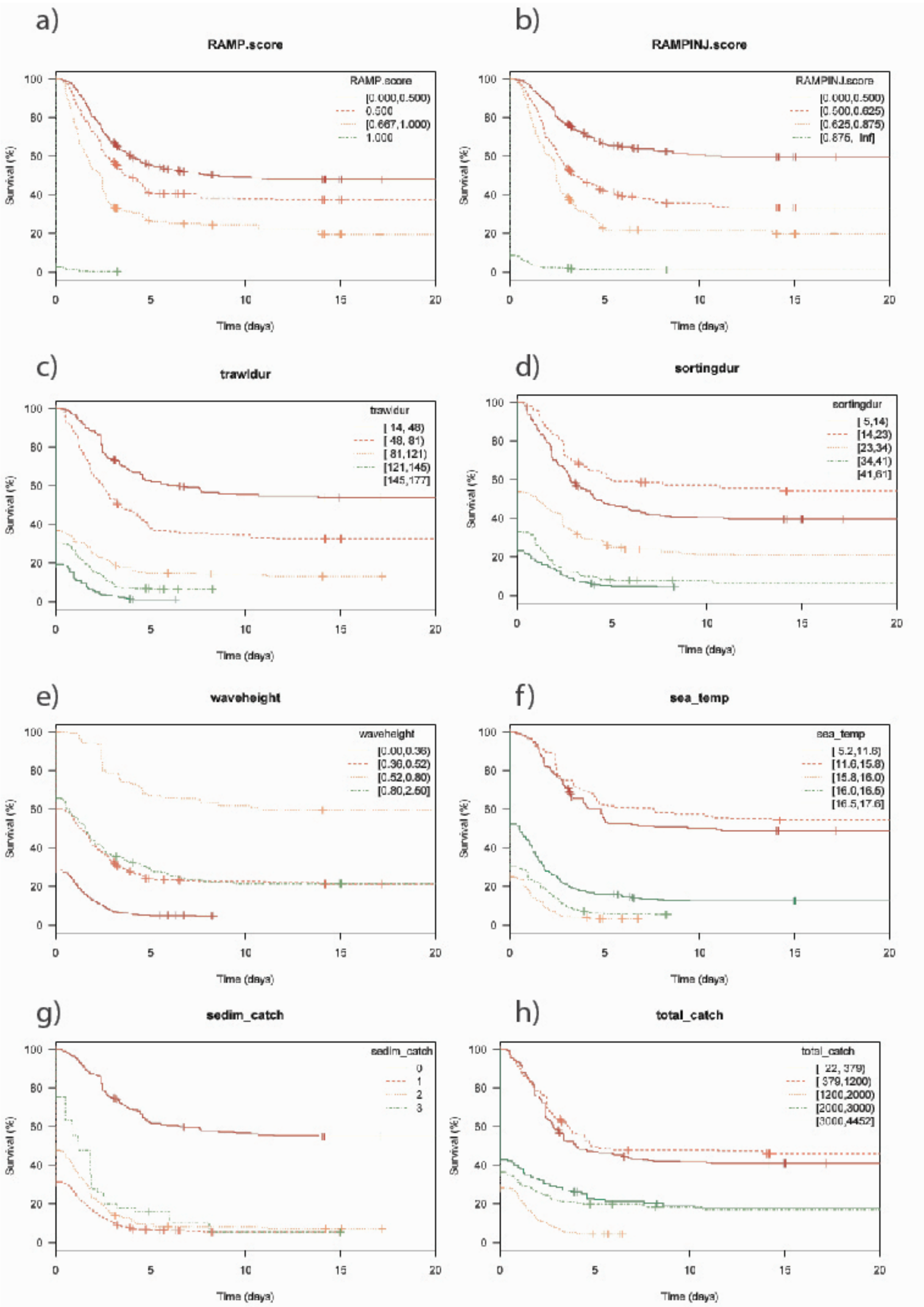

Figure 6 Non-parametric Kaplan-Meier survival probability estimates based on monitoring over time (between 9 and 20 days) (%) at a corresponding level of an potentially explanatory variable such as reflex impairment index (RAMP.score, a), reflex impairment and injury index (RAMPINJ.score, b), trawl duration (min, c), sorting duration (min, d), wave height (m, e), surface seawater temperature (°C, f), sediment type (0 : < 25% stones and/or < 25% sand; 1 : > 25% sand; 2 : > 25% stones; 3 : > 25% sand and stones), and total catch (kg, g), Crosses indicate censored values.

Based on the univariate analyses of variance (type III ANOVA) models, there was a significant relationship between delayed mortality and several status indicators (Table 1). The number of absent body flex, righting and evasion reflexes were positively related in a linear relationship with delayed mortality (Figure 7).

Table 1 Summary of univariate analyses of variance (type III ANOVA) models used to investigate the effects of status indicator scores (i.e., damage class, reflex index, reflex and injury index) on delayed mortality probability. ***p < 0.001; **p < 0.01; *p < 0.05. DF = degrees of freedom.

VARIABLE AND LEVEL	CHI-SQUARE	DF
Bellybend reflex	1.848	1
Righting	39.759***	1
Headcomplex	0.274	1
Evasion	62.381***	1
Stabilize	27.994***	1
Tailgrab	3.851*	1
No. absent reflexes	51.921***	1
No. absent reflexes (reduced)	67.361***	1
Headbruises	56.936***	1
Bodybruises	27.986***	1
Point bleeding – head	24.63***	1
Point bleeding – body	11.066***	1
Damage class	122.61***	3
Reflex index	60.357***	1
Reflex and injury index	123.42***	1

Based on non-parametric Kaplan-Meier models, it was reported previously (Uhlmann et al. 2016b) that at vessel level (each participating vessel represented a different Belgian beam-trawl fleet segment), survival of plaice discarded from conventional trawls ranged between 43-57%, 10-26%, 3-5% (95% confidence interval) for trips of the coastal (trips 1-5), small (trips 6-10) and large fleet segment (trips 11 and 12), respectively (Figure 8). Using a Kaplan-Meier model, Figure 8 shows the observed survival over time. The majority of fisheries-related mortality was observed within the first five days of monitoring. These data are representative for the specific conditions during the sampled trips.

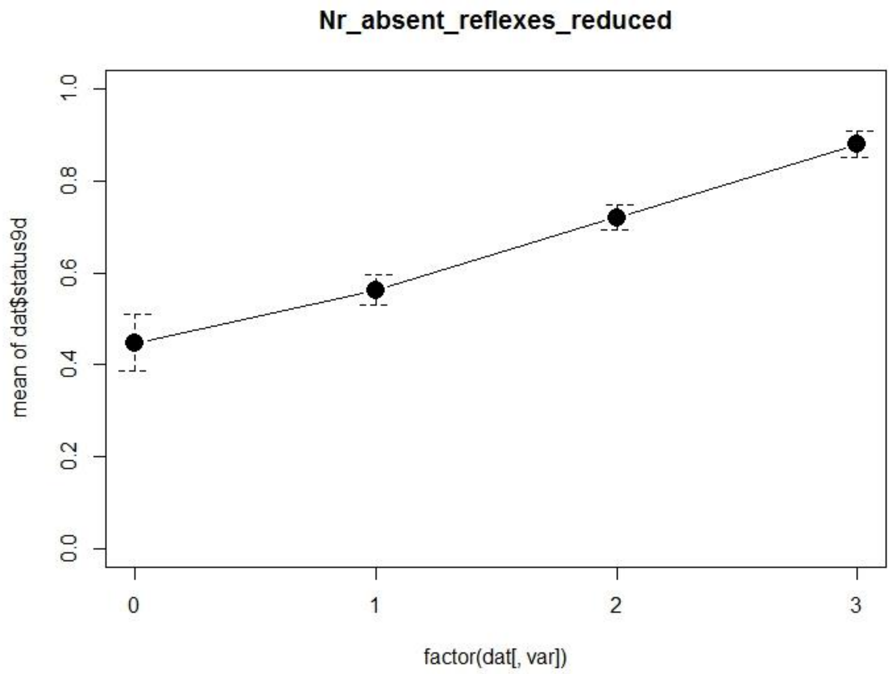

Figure 7 Validated relationship between the number of absent reflexes (body flex, righting and evasion) observed among discarded plaice and their post-capture mortality rate.

2.2.3 Predicted and total mortality

Based on the logistic prediction model and i) the observed immediate and delayed (monitored for up to 9 days) mortality estimates from 10 Belgian beam-trawl trips[1] and ii) the observed immediate and predicted delayed mortality from three recent trips, it was estimated that for 50% of the monitored trips[2], mortality probability may have ranged between 65 and 88% or in other words survival may have ranged between 12 and 35% (Table 2). **Hence, for 50% of the monitored trips, the survival percentage falls within the range of 12-35%, which corresponds to recent estimates for this species caught-and-discarded by beam-trawl gear (~19%; van der Reijden et al., 2017).**

[1]Two trips were excluded from this analysis because the monitoring period was truncated after three days and so fisheries-related mortalities were not observed until asymptote.
[2]This 50% is the interquartile range: i.e; the % of observations that lies between the 25 and 75 percentile. Considering that three estimates of the >221 kW vessel trips are predictions which are based on input data stemming in the majority from observations of <221 kW vessels.

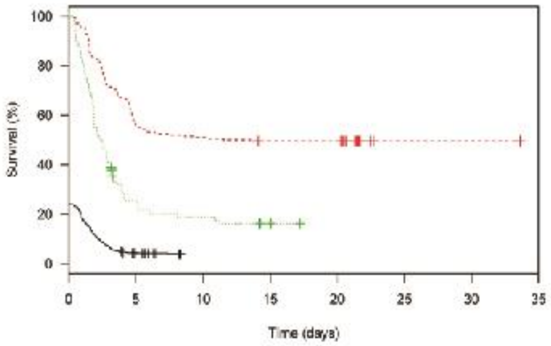

Figure 8 Non-parametric Kaplan-Meier survival probability based on monitored observations over time (between 9 and 33 days) averaged over all conventional trawls done during monitored trips for each of the participating vessels (between 2014 and 2016).

Table 2 Non-parametric Kaplan-Meier survival estimates (mean ± SE) of discarded plaice at the end of the monitoring period per trip and trawl duration (short/experimental vs conventional gear deployment durations). NA = not available. For the three trips in 2017/2018, total mortality was estimated based on the validated relationship between the number of absent reflexes and delayed mortality observed from the other trips.

TRIP ID	MONTH	YEAR	MONITORING- PERIOD (DAYS)	SURVIVAL PROBABILITY (%)		
				SHORT	CONVENTIONAL	CONTROL
1	November	2014	20	55.0 ± 4.8	59.2 ± 3.5	NA
2	December	2014	22	80.0 ± 17.9	14.9 ± 5.2	100.0
3	February	2015	14	84.2 ± 8.4	92.5 ± 4.1	100.0
4	March	2015	3	80.0 ± 8.9	72.5 ± 7.1	100.0
5	March	2015	3	95.0 ± 4.9	54.8 ± 8.9	100.0
6	April	2015	17	60.0 ± 10.9	7.7 ± 4.3	100.0
7	June	2015	23	80.0 ± 8.9	50.0 ± 7.9	100.0
8	July	2015	14	0.0	3.5 ± 2.4	90.0 ± 2.7
9	July	2015	8	15.0 ± 8.0	3.9 ± 0.8	NA
10	August	2015	8	11.8 ± 8.0	4.2 ± 0.9	NA
11	September	2015	34	85.0 ± 7.9	35.0 ± 7.5	NA
12	September	2015	15	25.0 ± 9.6	17.9 ± 6.2	95.0 ± 5.0
Predicted survival based on the validated reflex impairment-survival relationship:						
13	October	2017	NA	NA	30*	NA
14	November	2017	NA	NA	30*	NA
15	January	2018	NA	NA	32*	NA

***Disclaimer:** The survival predictions of the last three trips are still under revision and should be interpreted with care.

Table 3 shows the calculated number (x1000) of potentially surviving plaice after discarding in the North Sea and the English Channel, based on the estimated survival interval (12-35%) from this study and the discard data for 2017.

Table 3: Number of potentially surviving plaice that are being discarded in the North Sea and the English Channel using the predicted survival range of 12-35% and the number of discards for 2017.

AREA	NUMBER OF DISCARDS (X 1000, FOR 2017)	SURVIVING PLAICE (X 1000)
North Sea (4b,c)	21680	2602 - 7588
English Channel (7d)	8820	1058 - 3087

3 Appendix

Appendix Table 1* An overview of the fishery statistics for plaice (year 2017) and literature estimates for survival for plaice per ICES-area and geographical region, the number of trips and fishing hours of the Belgian beam-trawl fishery (métiers ≤221kW and >221kW) are presented. For each area, quotum (in tonnes), landings, discards and catch (x 1000, summed for all age classes) and the discard ratio (only for 70-99mm mesh sizes) are presented. Mean delayed survival (± Standard Deviation, SD) and mean observation (captive) period (hours±SD) were obtained from literature. NA = not available.

AREA	REGION	TRIPS	FISHING HOURS	QUOTUM	LANDINGS	DISCARDS	CATCH	DISCARD RATIO	MEAN DELAYED SURVIVAL (± SD)	MEAN OBSERVATION PERIOD (± SD)
4B	North Sea	139	12964	8409,16	6189,572	21679,85	27869,42	0.49	0.28 ±0.21 (Kelle 1976) 0.51 ± 0.35 (Berghahn et al. 1992) 0.28 ± 0.27 (Van Beek et al. 1990) 0.42 (Catchpole et al. 2015) 0.146 (Van der Reijden et al. 2017)	186 (Kelle 1976) 79.56 ± 11.46 (Berghahn et al. 1992) NA (Van Beek et al. 1990) 120 (Catchpole et al. 2015) 600 (Van der Reijden et al. 2017)
4C		678	10944							
7A	Irish Sea	69	3023	90	NA	NA	NA	0.57	NA	NA
7D	Channel	647	48320	2572,93	5584,556	8819,743	14404,299	0.35	0.44 ± 0.19 (Revill et al. 2013) 0.58 ± 0.19 (Catchpole et al. 2015)	84.20 ± 27.28 (Revill et al. 2013) 182.33 ± 142 (Catchpole et al. 2015)
7E		151	7029		NA	NA	NA	0.14		
7H		72	1979	11,20	NA	NA	NA	NA		
7J		6	58		NA	NA	NA			
7F	Celtic Sea	204	14082	190,01	NA	NA	NA	0.54	NA	NA
7G		248	19266		NA	NA	NA			
8A	Gulf of Biscay	15	1113	5	NA	NA	NA	NA	NA	NA
8B		61	7191		NA	NA	NA			

***Disclaimer:** The mean delayed survival estimates that are listed in this Table come from studies that applied normal commercial catching and sorting practices (Berghahn et al. 1992, Catchpole et al. 2015, Kelle 1976, Revill et al. 2013, Van Beek et al. 1990). As can be observed from these estimates in Table 1 (Appendix), the mean (delayed) discard survival for plaice ranges between 0.28 and 0.58 for the North Sea and English Channel, with large standard deviations. The listed studies are characterized by a wide array of different technical (e.g. gears, métiers) and environmental (e.g. area, temperature) parameters. Additionally, immediate mortality has not been taken into account. Hence, an estimate of total mortality cannot be provided. The mean captive observation period ranges between 79,56 hours (±3 days) and 186 hours (±7 days). This enormous variability makes generalizations extremely difficult. It is clear from Table 1 that data are still lacking for many ICES-areas and that more research is needed to feel these gaps.

Appendix Table 2a Summary of mean ± SD key technical, environmental, and biological variables collected during each monitored trip of a commercial coastal beam trawler with < 221 kW engine power, 4-m beam- length and 1300 kg single gear weight (*n* observations). NA = not available.

TYPE	VARIABLE	TRIP 1	TRIP 2	TRIP 3	TRIP 7	TRIP 11
General	Month of year	November ´14	December ´14	February ´15	June ´15	September ´15
	ICES sub-Division	4c	4c	4c	4c	4c
	Total no. of deployments	16	15	15	15	15
	Short deployments sampled	2	1	1	1	1
	No. plaice sampled	29	10	19	20	20
	Conventional deployments sampled	4	5	2	2	2
	No. plaice sampled	50	42	40	40	40
	% immediate mortality	0	0	0	0	<1
Technical	Depth (m)	8.8 ± 2.7 (16)	16.1 ± 4.1 (15)	9.6 ± 3.6 (15)	9.7 ± 3.6 (15)	7.8 ± 4.2 (15)
	Duration (min)	44.9 ±12.9 (16)	51.2 ± 9.1 (15)	52.3 ± 9.6 (15)	42.9 ± 14.4 (15)	48.4 ± 10.8 (15)
	Hopper	4.8 ± 1.6	7.2 ± 2.5	5.9 ± 0.9	3.5 ± 0.9	4.4 ± 2.2
	Begin of sorting	8.3 ± 2.3	15.2 ± 3.2	7.0 ± 3.0	7.7 ± 3.0	6.0 ± 1.8
	Mid	16.5 ± 3.3	19.6 ± 0.2	10.0 ± 2.7	9.2 ± 2.7	7.7 ± 1.3
	End	NA	NA	12.7 ± 2.4	10.7 ± 2.4	9.7 ± 1.3
Environmental	Wind force (Bft)	2.1 ± 0.7 (16)	4.8 ± 1.4 (15)	2.6 ± 0.8 (15)	2.7 ± 0.8 (15)	3.9 ± 0.8 (15)
	Wave height (cm)	62.4 ± 9.9 (9)	106.8 ± 45.9 (5)	50.6 ± 14.2 (12)	36.4 ± 6.01 (4)	117.4 ± 18.9 (3)
	Air temperature (°C)	10.9 ± 0.1 (6)	8 ± 0.4 (6)	8.1 ± 0.4 (3)	12.8 ± 0.2 (4)	17.0 ± 0.2 (3)
	Seawater temperature (°C)	11.7 ± 0.1 (6)	7 ± 0.1 (6)	5.3 ± 0.1 (3)	14.4 ± 0.2 (4)	16.9 ± 0.1 (3)
Biological	Total catch (kg)	2012.3 ± 1854.8 (6)	NA	481.3 ± 440.9 (3)	333.5 ± 233.7 (4)	349.1 ± 105.1 (3)
	TL of plaice (cm)	21.5 ± 3.7 (79)	19.5 ± 4.2 (57)	23.6 ± 3.2 (59)	20.6 ± 2.8 (60)	23.0 ± 3.1 (60)
	TL of plaice (cm) – controls	NA	22.6 ± 4.0 (20)	23.2 ± 2.9 (20)	NA (20)	NA

Appendix Table 2b Summary of mean ± SD key technical, environmental, and biological variables collected during each monitored trip of a commercial Eurocutter beam trawler with < 221 kW engine power, 4-m beam- length and 2000 kg single gear weight (*n* observations). NA = not available.

TYPE		VARIABLE	TRIP 4	TRIP 5	TRIP 6	TRIP 8	TRIP 12
General	For all plaice	Month of year	March '15	March '15	April '15	July '15	September '15
		ICES sub-Division	7d	7d	7d	7d	7d
		Total no. of deployments	52	55	47	43	45
	Sampled and monitored for survival	Short deployments sampled	1	1	1	1	1
		No. plaice sampled	20	20	20	20	20
		Conventional deployments sampled	2	2	2	3	2
		No. plaice sampled	40	40	39	58	39
		% immediate mortality	<1	<1	3	2	0
	Sampled for reflexes	Conventional deployments sampled	4	4	9	5	2
		No. plaice sampled	79	80	206	88	34
		% immediate mortality	<1	<1	3	22	<1
Technical		Depth (m)	43.1 ± 12.4 (7)	36.3 ± 4.4 (7)	36.3 ± 15.9 (12)	35.8 ± 6.5 (9)	31.8 ± 7.6 (5)
		Duration (min), conventional	75.7 ±11.8 (6)	72.6 ± 8.2 (6)	86.4 ± 9.6 (11)	69.2 ± 9.4 (8)	69.7 ± 10.5 (4)
		Duration (min), short	25.0 (1)	26.0 (1)	25.0 (1)	36.0 (1)	24.0 (1)
		Hopper	3.4± 1.5	1.4 ± 0.6	2.2 ± 0.9	2.9 ± 0.9	1.6 ± 1.0
		Begin of sorting	5.9 ± 1.8	5.3 ± 1.8	4.6 ± 1.6	4.7 ± 0.7	2.9 ± 1.1
		Mid	8.3 ± 1.8	6.7 ± 1.6	5.7 ± 1.5	6.3 ± 0.8	4.8 ± 1.2
		End	10.3 ± 2.3	7.8 ± 1.9	7.2 ± 1.8	7.9 ± 1.1	6.5 ± 1.5
		Sorting time (min)	18.6 ± 5.6 (7)	12.4 ± 2.6 (7)	10.8 ± 2.1 (12)	14.9 ± 5.1 (9)	7.4 ± 1.7 (5)
Environmental		Wind force (Bft)	3.0 ± 0.8 (7)	3.4 ± 0.5 (7)	2.0 ± 1.9 (12)	3.6 ± 0.7 (9)	5.8 ± 0.8 (5)
		Wave height (cm)	67.9 ± 31.3 (7)	57.1 ± 18.9 (7)	20.8 ± 25.7 (12)	37.8 ± 18.6 (9)	190.0 ± 41.8 (5
		Wave height (cm)	67.9 ± 31.3 (7)	57.1 ± 18.9 (7)	20.8 ± 25.7 (12)	37.8 ± 18.6 (9)	190.0 ± 41.8 (5)
		Air temperature (°C)	7.6 ± 1.7 (7)	8.6 ± 1.2 (7)	10.1 ± 1.7 (12)	20.3 ± 3.0 (9)	15.5 ± 1.5 (5)
		Seawater temperature (°C)	8.1 ± 0.2 (7)	8.1 ± 0.2 (7)	9.9 ± 0.2 (12)	16.2 ± 0.7 (9)	16.6 ± 0.1 (5)
		Total catch (kg)	466.2 ± 270.2 (7)	515.1 ± 299.9 (7)	291.7 ± 296.9 (12)	726.7 ± 481.6 (9)	270.0 ± 163.1 (5)
		TL of plaice (cm)	22.6 ± 3.1 (138)	22.4 ± 3.0 (170)	22.8 ± 2.8 (256)	22.7 ± 2.4 (196)	25.9 ± 2.1 (123)
		TL of plaice (cm) – controls	22.6 ± 2.4 (20)	NA (20)	NA (20)	NA (20)	NA (20)

Appendix Table 2c Summary of mean ± SD key technical, environmental, and biological variables collected during each monitored trip of three commercial beam trawlers (*n* observations). NA = not available

TYPE		VARIABLE	TRIP 9	TRIP 10	TRIP 13	TRIP 14	TRIP 15
General	For all plaice	Month	July '15	August '15	October '17	November '17	January '18
		ICES sub-Division	4b,c	4b,c	7e,h,g	7d	7d,e
		Beam length (m)	11.4	11.4	12	11	11.4
		Single gear weight (kg)	5750	5750	5500	4500	5750
		Total no. of deployments	88	61	42	36	54
	Sampled and monitored for survival	Short deployments sampled	1	1	0	0	0
		No. plaice sampled	20	17	NA	NA	NA
		Conventional deployments sampled	6	8	0	0	0
		No. plaice sampled	114	126	NA	NA	NA
	Sampled for reflexes	Conventional deployments sampled	12	8	11	29	11
		No. plaice sampled	951	694	154	794	366
		% immediate mortality	70	74	18	51	8
Technical		Depth (m)	63.4 ± 15.1 (19)	61.0 ± 16.7 (17)	67.7 ± 7.1 (11)	42.4 ± 7 (35)	62.0 ± 4.4 (42)
		Duration (min), conventional	132.3 ±17.5 (18)	141.3 ± 18.5 (16)	164.7 ± 5.8 (8)	165 ± 8 (29)	145.4 ± 19.9 (54)
		Duration (min), short	31.0 (1)	24.0 (1)	n/a	n/a	n/a
		Hopper	1.5 ± 1.5	2.6 ± 3.1	4.5 ± 2.2 (40)	3.1 ± 1.9 (139)	1.4 ± 0 (51)
		Begin of sorting	5.5 ± 1.6	6.5 ± 2.7	11.3 ± 5.4 (39)	11.6 ± 4.7 (251)	7.3 ± 1 (51)
		Mid	9.2 ± 2.3	10.3 ± 3.1	14.7 ± 5.4 (40)	25.1 ± 6.4 (322)	14.9 ± 6.5 (216)
		End	14.0 ± 4.4	15.9 ± 5.6	19.8 ± 6.5 (35)	34.9 ± 3.5 (82	28.4 ± 5.9 (99)
		Sorting time (min)	45.9 ± 10.9 (19)	33.5 ± 7.3 (17)	23.1 ± 5.5 (8)	36 ± 6.7 (29)	38.6 ± 9.9 (11)
Environmental		Wind force (Bft)	2.4 ± 1.7(19)	2.6 ± 1.1 (17)	5.9 ± 0.9 (11)	4.1 ± 1.5 (35)	5.5 ± 1.5 (42)
		Wave height (cm)	43.2 ± 39.0 (19)	53.5 ± 27.6 (17)	2.0 ± 0.6 (11)	0.3 ± 0 (6)	160.9 ±110.2 (42)
		Air temperature (°C)	17.8 ± 4.1 (19)	16.4 ± 2.2 (17)	13.4 ± 0.9 (11)	9.7 ± 1 (35)	7.2 ± 1.6 (42)
		Seawater temperature (°C)	16.0 ± 0.3 (19)	16.2 ± 0.6 (17)	15.8 ± 0.2 (11)	10.6 ± 0.2 (35)	7.3 ± 0.4 (42)
Biological		Total catch (kg)	2600.0 ± 1032.8 (19)	1665.9 ± 487.6 (17)	643 ± 111 (11)	NA	1127 ± 119 (11)
		TL of plaice (cm)	23.9 ± 2.3 (546)	23.6 ± 2.4 (511)	25.9 ± 1.9 (154)	NA	23.9 ± 2.4 (366)
		TL of plaice (cm) – controls	NA	NA	NA	NA	NA

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