Survival probabilities of plaice, sole and turbot discarded by beam trawl and flyshoot fisheries

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Preface

This report is a product of the project *Overlevingskansen van schol, tong en tarbot discards in de boomkor en flyshoot visserijen en de effecten daarvan op de visbestanden* (Survival probabilities of plaice, sole and turbot discards in beam trawl and flyshoot fisheries, acronym DOSTT).

The project was commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality to a consortium consisting of Wageningen Marine Research, Wageningen Plant Research, Wageningen University and Dutch fishers and producer organisations.

The project addressed the following topics:

1. Baseline survival probabilities of undersized plaice, sole and turbot discarded by tickler chain beam trawl fisheries and undersized plaice discarded by flyshoot fisheries.
2. Increasing discards survival probabilities of undersized plaice, sole and turbot by replacing the conventional mesh cod-end of a 12 m tickler chain beam trawl with a Modular Harvesting System.
3. Development of computer vision technology to predict discards survival probability of plaice.
4. Effects of fisheries mortality among discarded undersized plaice on development of the plaice stock, including effects of density dependent growth.
5. Effect of incorporating discards survival probabilities of sole in the stock assessment of North Sea sole.

The current report covers topics 1 and 2.

Summary

The objectives of this study were 1. to establish baseline survival probabilities for undersized plaice, sole and turbot discarded by tickler chain beam trawl fisheries with two 12 m wide gears and for plaice discarded by flyshoot fisheries, and 2. to establish the effect of replacing the conventional mesh lengthener and cod-end of a 12 m wide tickler chain beam trawl by a modular harvest system (MHS) on discards survival probabilities of undersized plaice, sole and turbot. Discards survival was measured by captive observation of test fish sampled at sea during regular commercial beam trawl and flyshoot fisheries.
During all trips, control fish of the same species were used to separate potential effects of the experimental procedures on mortality from fisheries-induced mortality. Average survival of control fish was 83.7% for plaice employed in the flyshoot trips and 86.8% for plaice, 83.3% for sole and 100% for turbot employed in the beam trawl trips.

We conducted three trips with a flyshooter in April, May and July 2023 and sampled a total of 675 plaice. Discards survival probability estimates ranged from 39.7% in April to 1.2% in July. The overall survival probability estimate based on these three trips is 15.0% (95% confidence interval 12.5%-17.9%). We conclude that plaice discards survival is highly variable in flyshoot fisheries for reasons that are not yet fully understood.

We conducted five trips with a tickler chain beam trawler with two 12 m wide gears in the period February to August 2023. During two out of these five trips we tested the effect of the Modular Harvesting System (MHS) on discards survival. The MHS is a novel cod-end consisting of a membrane-like fabric tube with escapement holes that replaces the mesh cod-end of a trawl. The MHS aims to reduce fish damage during trawling, haul back and unloading. Based on the strong relation between the condition in which fish are discarded and their survival probability, this was predicted to increase discards survival probabilities. To test the MHS, the conventional mesh cod-end of one of the two trawls of a double rigged beam trawler was replaced with a MHS and paired samples of test fish were collected from the catches by both gear types. In total 579 plaice, 294 sole and 128 turbot were sampled from the conventional beam trawl gear. From the beam trawl with MHS we sampled a total of 160 plaice, 80 sole and 37 turbot. The overall discards survival probability estimates for the conventional beam trawl are 8.1% (95% confidence interval 6.2%-10.7%) for plaice, 20.4% (95% confidence interval 16.3%-25.6%) for sole and 15.6% (95% confidence interval 10.4%-23.3%) for turbot. For plaice the highest survival (19.9%) was observed in February and the lowest (2.5%) in August. For sole the highest survival (34.1%) was observed in May and the lowest (12.5%) in August. For turbot the highest survival (35.5%) was observed in June and the lowest (0%) in February. Because our observations include annual temperature extremes we conclude that overall discards survival probability estimates for conventional beam trawling lie within these ranges. However additional observations in the periods that were not covered by the current project are needed to determine overall discards survival probabilities that are representative for year-round fisheries. This also applies to flyshoot fisheries. We also recommend to consider discards survival probability data in conjunction with data on discards amounts to obtain insight in absolute fisheries mortality due to discarding.

Survival probabilities of plaice and turbot were significantly higher for the fish sampled from the beam trawl equipped with a MSH. On average the MHS resulted in an elevenfold increase in survival for plaice and a sixfold increase in turbot. For sole no significant effect was detected. This study confirms and provides the first quantitative insight in the potential increase in survival probability of replacing the conventional mesh cod-end of a beam trawl with a MHS. Further increase in discards survival probability is expected with the refinement of the fishing technique. To fully utilize the potential increase in discards survival that can be achieved by the MHS, we also recommend research into the refinement of the catch sorting process to maintain the good condition of the fish while on board.

Samenvatting

De doelstellingen van dit onderzoek waren 1. het vaststellen van de overlevingskansen voor ondermaatse schol, tong en tarbot die worden teruggegooid (discards) door de boomkorvisserij met wekkerkettingen en 12 m brede tuigen en voor schol die wordt teruggegooid door de flyshootvisserij, en 2. het vaststellen van het effect van het vervangen van de conventionele kuil van netwerk in een boomkortuig door het zogenaamde *Modular Harvesting system* (MHS, kiwikuil) op discards overlevingskansen. Overlevingskansen zijn gemeten door observatie in gevangenschap van testvissen die op zee werden bemonsterd tijdens reguliere commerciële boomkorvisserij en flyshootvisserij. Tijdens alle reizen werden controlevissen van dezelfde soort gebruikt om de potentiële effecten van de experimentele procedures op de sterfte te scheiden van de door de visserij veroorzaakte sterfte. De gemiddelde overleving van de controlevissen bedroeg 83,7% voor schol gebruikt voor de flyshoot reizen en 86,8% voor schol, 83,3% voor tong en 100% voor tarbot gebruikt tijdens de boomkorreizen.

In april, mei en juli 2023 hebben we drie onderzoekreizen met een flyshooter uitgevoerd waarbij in totaal 675 schollen werden bemonsterd. De discards overlevingskansen varieerden van 39,7% in april tot 1,2% in juli. De gemiddelde overlevingskans is 15,0% (95% betrouwbaarheidsinterval 12,5%-17,9%). We concluderen dat de overlevingskansen van schol discards zeer variabel is in de flyshootvisserij om nog niet bekende redenen.

In de periode februari tot en met augustus 2023 hebben we vijf reizen met een boomkorkotter uitgevoerd. Tijdens twee van deze vijf reizen hebben we het effect van de MHS op discards overleving getest. De MHS is een nieuwe kuil die bestaat uit een membraanachtige stoffen buis met ontsnappingsgaten die de tunnel en kuil van netwerk in een boomkortuig vervangt. De MHS is ontwikkeld om schade aan de vis als gevolg van de visserij te verminderen. Vanwege de sterke relatie tussen de conditie waarin vissen worden teruggegooid en hun overlevingskansen, werd voorspeld dat de MHS overlevingskansen van discards zou vergroten. Om de MHS te testen werden de van netwerk gemaakte tunnel en kuil van één van de twee tuigen van de boomkorkotter vervangen door een MHS. Uit de vangsten van beide typen vistuigen werden gepaarde monsters van testvissen verzameld. In totaal zijn uit het conventionele boomkortuig 579 schollen, 294 tongen en 128 tarbotten bemonsterd. Voor de MHS hebben we in totaal 160 schollen, 80 tongen en 37 tarbotten bemonsterd. De gemiddelde discards overlevingskansen voor het conventionele boomkortuig zijn 8,1% (95% betrouwbaarheidsinterval 6,2%-10,7%) voor schol, 20,4% (95% betrouwbaarheidsinterval 16,3%-25,6%) voor tong en 15,6% (95% betrouwbaarheidsinterval 10,4%- 23,3%) voor tarbot. Voor schol werd de hoogste overleving (19,9%) waargenomen in februari en de laagste (2,5%) in augustus. Voor tong werd de hoogste overleving (34.1%) waargenomen in mei en de laagste (12.5%) in augustus. Voor tarbot werd de hoogste overleving (35.5%) waargenomen in juni en de laagste (0%) in februari. Omdat onze waarnemingen de jaarlijks hoogste en laagste watertemperaturen omvatten, concluderen we dat de gemiddelde overlevingskansen die representatief zijn voor jaarronde boomkorvisserij tussen de laagste en hoogste gemeten overlevingskansen liggen. Er zijn echter aanvullende waarnemingen nodig in de perioden die niet onder het huidige project vielen om deze gemiddelde overlevingskansen te bepalen. Dit geldt ook voor de flyshootvisserij. We adviseren ook om gegevens over discards overlevingskansen te analyseren in combinatie met gegevens over discards hoeveelheden, om inzicht te krijgen in de absolute visserijsterfte als gevolg van het terug in zee zetten van bijvangsten.

De overlevingskansen van schol en tarbot gevangen met het boomkortuig met MSH waren significant hoger:. gemiddeld 11 maal hoger voor schol en zes maal hoger voor tarbot ten opzichte van het conventionele boomkortuig. Voor tong werd geen significant effect waargenomen. Deze studie bevestigt en levert de eerste kwantitatieve inzichten in de potentiële verhoging van discards overlevingskansen wanneer de kuil van netwerk in een boomkortuig vervangen wordt door een MHS. Verdere verfijning van de visserijtechniek met de MHS leidt naar verwachting tot verdere verhoging van discards overlevingskansen. Om de potentie van de MHS volledig te benutten, adviseren wij onderzoek naar de verfijning van het vangstsorteerproces gericht op behoud van de goede conditie waarin de vis aan boord komt zodat ongewenste bijvangsten in de best mogelijke conditie en zo hoog mogelijke overlevingskans terug in zee gezet worden.

1 Introduction

In commercial fisheries around the world, unwanted bycatches are discarded (Pitcher *et al.*, 2002; Catchpole *et al.*, 2005; Zeller and Pauly, 2005). Because these bycatches are exposed to stressors during capture, handling, and release (Davis, 2002; Cook *et al.*, 2018) and failure to recover from these stressors results in mortality (Cook *et al.*, 2018; Cook *et al.*, 2019), the practise of discarding contributes to fisheries mortality. Fisheries mortality due to discarding depends on the amounts of fish that are discarded in combination with species and gear specific survival probabilities. Insight in discards mortality imposed on a fish stock is important for its management. More precise estimates of discards mortality lead to better estimates of total fishing mortality in stocks which in turn can be expected to improve the predictive ability of stock assessment models. This leads to improved estimates of stock productivity and the expected contribution of strong year-classes to future spawning biomass.

The practice of discarding unwanted catches has been restricted since 2019 for all quota regulated species in European waters by the implementation of a landing obligation under the Common Fisheries Policy (European Union, 2013). Under this landing obligation fishers have to land all undersized, damaged and marketable species that are under quota management. The policy objective of the landing obligation is to create an incentive to avoid and thereby reduce unwanted bycatches. This legislation would result in discards survival probabilities of zero for these species. However, this landing obligation allows exemptions for species which according to the best available scientific advice have a high survival probability when released into the sea, taking into account gear characteristics, fishing practices and the ecosystem. Mainly for that purpose several studies measured discards survival probabilities. Previous work on the survival probability of discards from pulse beam-trawl fisheries resulted in survival probability estimates of 15% (95%CI: 11-19%) (Van der Reijden *et al.*, 2017) and 12% (95% CI: 8% - 18%) for plaice (Schram *et al.*, 2023a). For sole survival probability estimates of 29% (95% CI:24-35%) (Van der Reijden *et al.*, 2017) and 19% (95%CI 13-28%) (Schram and Molenaar, 2018) were reported. For turbot Schram and Molenaar (2018) report a discards survival probability estimate of 30% (95%CI 20-43%) based on a limited number of observations (n = 111). For tickler-chain beam trawling discards survival probability estimates are lacking for plaice, sole and turbot. However, assessment of the condition of fish discarded by tickler-chain beam trawlers suggest that for all assessed species survival probabilities are lower than the estimates for pulse beam trawling, which was attributed to the higher mechanical impact of the tickler chain beam trawls on the fish (Schram *et al.*, 2020). For flyshoot fisheries discards survival probability estimates are lacking for all relevant species except spotted and thornback rays. It was found that survival is higher for rays discarded by flyshoot compared to tickler chain beam-trawl fisheries. Again this was attributed to a difference in mechanical impact (Schram *et al.* 2023b).

Several stressor mitigating measures with the objective to increase the post-capture discards survival probabilities have been explored. Using a water-filled hopper instead of the common practice of discharging catches from the cod-end into a dry hopper was hypothesized to increase discards survival probability by reducing air exposure time during catch processing. However, this measure did not result in a significantly increased survival probability of plaice and this was explained by discards survival being largely determined by capture and hauling processes prior to discharging the fish in hoppers (Schram *et al.*, 2023a). Efforts to increase discards survival probabilities should therefore focus on increasing the proportion of fish in good condition in the catches by reducing stressors inflicted by the capture and hauling processes on fish condition. Indeed, reducing mechanical impacts on fish by reducing haul duration from 100-130 min to 60-70 min was found to promote the survival of plaice discards (Van der Reijden *et al.*, 2017). Although it seems easy to reduce haul duration, it is difficult to implement in practice due to the significant operational impact on board fishing vessels and reduced total fishing time per trip.

A very promising innovation to reduce discards mortality is the so-called Modular Harvesting System (MHS). The MHS is a novel cod-end originally developed in New Zealand by *Precision Seafood Harvesting*

Limited, Timaru, New Zealand to reduce fish damage during trawling, haul back and unloading (Moran et al., 2023). The MHS is a membrane-like fabric tube with escapement holes that replaces the lengthener and mesh cod-end of a trawl. The terminal section of the MHS is non-porous, which allows fish to be lifted aboard in a fluid environment. This and the graded flow reduction and open geometry of the MHS reduces fish damage during trawling, haul back and unloading (Moran *et al.* 2023). Based on the strong relation between the condition in which fish are discarded and their survival probability (Schram *et al.*, 2023a), the reduction in fish damage achieved by the MHS is predicted to increase discards survival probabilities. Indeed, the piloting of a MHS modified for beam trawling showed increased proportions of fish in good condition in its catches compared to conventional beam trawl gear catches (Molenaar *et al.*, *unpublished*). However, discards survival probability of fish caught with beam trawls equipped with the MHS and thus its scope to reduce discards mortality has not yet been established.

The objectives of this study were 1. to establish baseline survival probabilities for undersized plaice, sole and turbot discarded by tickler chain beam trawl fisheries with two 12 m wide gears and for plaice discarded by flyshoot fisheries, and 2. to establish the effect of replacing the conventional mesh lengthener and cod-end of a 12 m wide tickler chain beam trawl by a modular harvest system (MHS) on discards survival probabilities of undersized plaice, sole and turbot. All survival probabilities were measured by captive observation.

2 Assignment

2.1 Objectives

The objectives of this study were twofold:

1. To determine the baseline discards survival probabilities of undersized plaice (*Pleuronectus platessa*), sole (*Solea solea*) and turbot (*Scophthalamus maximus*) that are caught and discarded by tickler chain beam trawl fisheries with 12 m wide gears and undersized plaice that is discarded by flyshoot fisheries.
2. To determine the effect of replacing conventional mesh lengthener and cod-end of a beam trawl with the Modular Harvesting System (MHS) on discards survival probability of undersized plaice (*Pleuronectus platessa*), sole (*Solea solea*) and turbot (*Scophthalamus maximus*).

2.2 Products

The research into the survival probabilities of plaice, sole and turbot discarded by beam trawl and flyshoot fisheries will result in the following products:

1. Scientific report on the discards survival experiments executed to determine baseline discards mortality as well as the effect of the MHS on discards mortality;
2. Two articles on these studies in "Visserijnieuws".

This report covers product 1.

3 Materials and methods

3.1 Ethics statements

The treatment of the fish was in accordance with the Dutch animal experimentation act, as approved by ethical committees (Experiment 2021.D-0007.001). The methodology was in accordance with the guidelines for discards survival studies developed by the Workshop on Methods for Estimating Discard Survival (WKMEDS) of the International Council for the Exploration of the Sea (ICES) (Breen and Catchpole, 2021).

3.2 Experimental design

3.2.1 Trips & test fish sampling

Test fish were sampled during eight regular commercial fishing trips on a commercial tickler chain beam trawler with 12 m wide gears (TBB, 5 trips, Table 1) and a commercial flyshooter (SSC, 3 trips, Table 2). All trips were conducted in period between February and August 2023 and lasted between four and five days, comparable to commercial trip lengths. All fishing operations were conducted in the southern North Sea and eastern English Channel (Figure 2) according to commercial practices of the fishing vessels. Operational and environmental conditions during sea trips were recorded for each haul by the skippers on trawl lists provided by the researchers. Average values per trip are presented in (Table 5).

Test fish were randomly sampled during the catch-sorting process common in these fisheries (Figure 3). In this process, catches were discharged from the cod-ends into one (flyshoot) hopper or two hoppers (beam trawling, one hopper for each of the two cod-ends). From the hoppers, the catches were transported by a conveyor belt onto the sorting belt. Marketable fish were manually collected from the sorting belt by crew members. Test fish were sampled by researchers at the end of the sorting belt, just before the point where the remaining unwanted catch, including fish with no commercial value and undersized fish, dropped into a gutter with a water supply that discharged the catch back into the sea. Numbers of test fish sampled per metier, species and experiment are presented in Table 3. The length-frequency distributions of the sampled fish by species and metier are presented in Figure 1. The sampling schemes used to obtain these numbers of test fish are described below for the baseline and MHS test discards survival measurements.

3.2.2 Baseline discards survival measurements

Baseline discards survival probabilities were measured for undersized plaice, sole and turbot for tickler chain beam trawl fisheries and undersized plaice for flyshoot fisheries by sampling fish for these species from catches during regular commercial fishing trips and monitoring their survival in captivity up to 19 days post catch.

Test fish for the baseline discards survival measurements in beam trawl fisheries were collected in five fishing trips on a commercial beam trawler (TBB, Table 5). During each of the trips 1, 2 and 6 we aimed to sample 140 plaice from seven hauls, 70 sole from seven hauls and 30 turbot from five hauls. Each haul sampled for plaice the total of 20 plaice per haul was realized by sampling five plaice during each quarter of the catch sorting process to account for the potential effect of time spend in catch processing on survival probability (Table 3). Similarly, each haul sampled for sole the total of ten sole per haul was realized by sampling three soles in the first and last quarter and two soles in the second and third quarter of the catch sorting process. The low numbers in which turbot appeared on the sorting belt did not allow for a similar balanced sampling scheme. Turbot were therefore opportunistically sampled (six

per haul) and the quarter of the catch sorting process during which sampling took place was recorded for each sampled turbot.
Trips 4 and 8 (TBB, Table 5) were dedicated to testing the effect of the MHS on discards survival (see below), half of the test fish (80 plaice, 40 sole, 18 turbot) were sampled from catches by the conventional trawl and used for the baseline discards survival measurements (the other half of the test fish were sampled from catches by the trawl equipped with the MHS).

Test fish for the baseline discards survival measurements for plaice in flyshoot fisheries were collected during three fishing trips on a commercial flyshooter (SSC,Table 3,Table 5). During each trip (3, 5 and 7) we sampled between 204 and 300 plaice from 16 to 25 hauls. Each sampled haul, a total of 20 plaice was realized by sampling five plaice during each quarter of the catch sorting process (Table 3).

Table 1. Vessel and gear specifics beam trawler (TBB).

Vessel		Vessel 1
	Gear	TBB
	Engine power (Kw)	1470
	Tonnage (GT)	491
	Length (m)	41
	Fishing speed (kn)	5.6
	Width (m)	9
Beam	Length (m)	12
	Total weight (kg)	~1500
	Beam shoe length (m)	1
Ground rope	Diameter chain (mm)	24
	Length central rubber section ground rope (m)	7
	Mesh size cod-end (mm)	80
Trawl	Total length (m)	36
	Height (m)	0.4
Ticklers	Tickler chains (number)	7
	Tickler chains diameter (mm)	24
	Net ticklers (number)	13
	Net ticklers diameter (mm)	7 x 16 6 x 20

3.2.3 Effect of Modular Harvesting System (MHS)

The effect of a Modular Harvesting System (MHS, see below) on discards survival probability was tested for undersized plaice, sole and turbot for tickler chain beam trawl fisheries. For this purpose the conventional mesh lengthener and cod-end of one of the two trawls of a double rigged commercial beam trawler was replaced by a modular harvesting system (MHS, see below) during two fishing trips (trips 4 and 6, Table 3, Table 5). The effect of the MHS on survival probability was tested by sampling test fish from the catches realized by both gear types during the same hauls. The sampled hauls thus were paired observations with identical trawl duration and weather and seabed conditions. Catches per gear type were discharged in separate hoppers that were separately processed to keep catches per gear separate and thus allow for separate sampling per gear. The order in which the hoppers were processed was alternated between sampled hauls. This way the catch from each gear type intermittently appeared in either the first or the second half of the catch sorting process. During each trip we sampled 80 plaice per gear type from eight hauls, 40 sole per gear type from eight hauls and 18 turbot per gear type from six hauls. Each haul sampled for plaice the total of ten plaice per gear type was realized by sampling five fish per quarter of the catch sorting process to account for the potential effect of time spent in catch processing on survival probability. Each haul sampled for sole the total of 5 sole per gear type was realized by sampling three and two fish per quarter of the catch sorting process. Each haul sampled for turbot, three turbot could be sampled per gear type but the low numbers in which turbot appeared on the sorting belt did not allow for a balanced sampling scheme similar to sole and plaice. Turbot were therefore opportunistically sampled provided equal numbers per gear could be sampled. The quarter of the catch sorting process during which sampling took place was recorded for each sampled turbot. Survival of test fish from both gear types was monitored in captivity up to 19 days post catch.

Table 2. Vessel and gear specifics flyshooter (SSC).

Vessel		**Vessel 6**
	Gear	SSC
	Engine power (Kw)	680
	Tonnage (GT)	340
	Length (m)	31
	Width (m)	9
Trawl	Height (m)	10
	Cod end mesh size (mm)	80
Flyshoot rope	Length (m)	2x 2900
	Diameter (mm)	50
	Weight (kg/m)	1.85
Ground rope	Length (m) incl. chain & sweeps	146.7
	Disc diameter (mm)	280
Square mesh escape panel	North Sea	Yes
	Eastern Channel	No
	Mesh size (mm)	110

Table 3 Number of observations per trip, species and treatment.

Trip	**Metier**	**Plaice**			**Sole**			**Turbot**		
		Baseline	**MHS**	**Ctrl**	**Baseline**	**MHS**	**Ctrl**	**Baseline**	**MHS**	**Ctrl**
1	TBB	139	-	20	71	-	8	30	-	6
2	TBB	140	-	20	70	-	6	30	-	6
4	TBB	80	80	17	41	40	8	18	18	6
6	TBB	140	-	19	72	-	8	31	-	6
8	TBB	80	80	16	40	40	10	19	19	4
Total	TBB	579	160	92	294	80	40	128	37	28
3	SSC	204	-	26	-	-	-	-	-	-
5	SCC	298	-	27	-	-	-	-	-	-
7	SSC	173	-	16	-	-	-	-	-	-
Total	SSC	675	-	69	-	-	-	-	-	-

3.2.4 Control fish

During all trips, control fish of the same species (n = ~9-20% of the number of test-fish for each species, (Table 3) were used to separate potential effects of the experimental procedures on mortality from fisheries-induced mortality. Control fish were exposed to the exact same experimental procedures throughout the experiments as test-fish as of the moment of test-fish collection from the sorting belt. Control fish were obtained by collecting the least damaged fish from commercial catches and by using test fish from previous trips as control fish. Prior to their use in experimental trips, control fish were stored in tanks placed in a climate controlled room for at least three weeks. During this period, fisheries-induced mortality levelled out while surviving fish could recover from injuries and regain good condition. During storage, fish were fed daily with dead, uncooked brown shrimps (*Crangon crangon*) and life rag worms (*Nereus spp.)* to visually observed satiation. Fish in the best available visually observed condition were selected to be used as control fish. Prior to the trip control fish were transported to the vessel, upon arrival at the vessel control fish were stored one day on deck in aerated 600L tanks. At sea the tank water was regularly renewed with surface seawater. Control fish that did not score vitality class A at the start of the experiments and died after deployment in experiments were censored from the data.

Table 4. Waiting and catch processing times per trip.

Trip	Metier	Number of sampled hauls	Waiting time[1] (min)		Catch processing time[2] (min)	
			Average[3]	Range	Average[3]	Range
1	TBB	15	7	2-19	16	12-27
2	TBB	16	6	2-17	14	10-20
4	TBB	20	12	2-24	13	10-20
6	TBB	15	5	2-13	19	12-28
8	TBB	17	6	2-12	15	10-25
3	SSC	25	10	3-20	21	12-49
5	SCC	15	11	2-17	34	9-82
7	SSC	16	17	1-35	18	9-32

1) Waiting time = Time duration between discharge of the catch in hoppers and the start of catch processing.

2) Catch processing time = Time duration between start and end of catch processing.

3) Average time of the sampled hauls per trip.

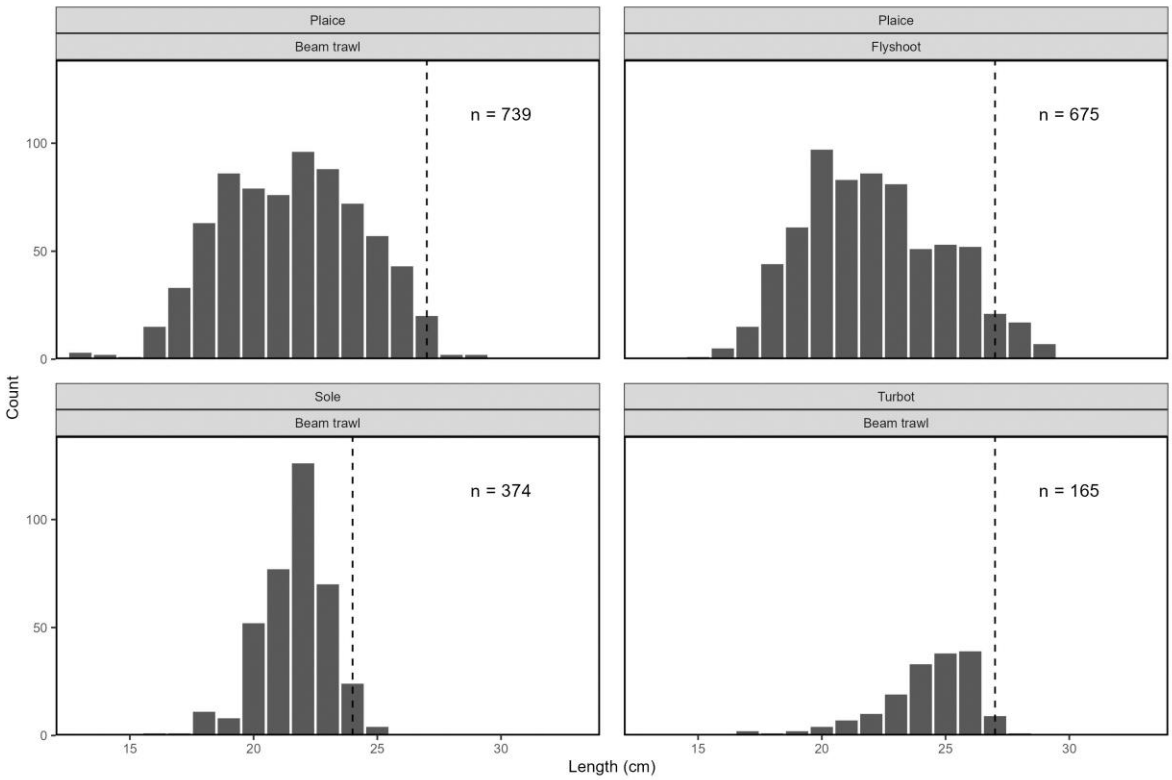

Figure 1 Length-frequency distributions per species and metier for the test-fish sampled for discards survival probability measurements. Horizontal dashed lines indicate the minimum landing size.

Table 5. Conditions during the sea trips.

Trip	Metier	Year	Month	Week	Water temp. (°C)	Wind speed (Bft)	Average wave height (m)	Haul duration (min)	Average fishing depth (m)
1	TBB	2023	Feb	7	8.1	1-4	0.3	118	23
2	TBB	2023	March	10	7.4	2-5	1.1	123	24
4	TBB	2023	May	20	11.7	2-5	0.6	122	25
6	TBB	2023	July	27	15.7	2-7	1.1	120	27
8	TBB	2023	August	34	19.6	1-3	0.2	121	23
3	SSC	2023	April	17	11.0	2-4	0.6	N.A.	35
5	SCC	2023	June	24	16.0	2-3	0.4	N.A.	44
7	SSC	2023	July	31	18.5	2-6	1.6	N.A.	41

3.2.5 Vitality assessment after sampling

After sampling from catches, fish were temporarily stored in 105L holding containers filled with seawater. Seawater in holding containers was each haul renewed to maintain dissolved oxygen levels during storage. Once sampling of a haul had been completed, fish were sequentially taken from the holding containers for condition assessment, to measure total length (TL: in cm below) and for tagging. Fish condition of each individual fish was determined and scored vitality class A to D by scoring reflex impairment and damages according to the flatfish protocol by Van der Reijden *et al.* (2017)

3.2.6 Monitoring of survival

Upon completion of their initial assessment, live plaice and sole were placed in 24 L tanks (n = 5 per tank) and live turbot were placed in 84 L tanks (n = 6 per tank) (see *Experimental facilities*). Fish that were considered dead when sampled (no operculum movement for more than 15 seconds) were recorded as dead at time zero and not placed in tanks. All tanks were inspected for mortalities every 12 hours on board and every 24 hours in the laboratory. Dead fish were detected by visual confirmation of the absence of operculum movement, immediately removed from their tanks and identified by their PIT tags. The date and time at which a fish was found dead was recorded. Lethargic fish were not removed as for their potential recovery and to obtain actual survival time. Dissolved oxygen concentration and water temperature were measured (Hach Lange Multimeter, Oxyguard Polaris C). Water flows to individual tanks were increased if oxygen saturation was below 80%. All experiments were terminated after 14 days of survival monitoring in the laboratory. Maximum monitoring time ranged from 14 to 19 days for surviving individual fish depending on the day of their sampling at sea. Upon termination of the experiment all surviving fish were netted from the tanks and identified by their PIT tags to record their status (alive or dead) species and total length (TL: in cm below).

3.3 Experimental facilities

On board all test fish and control fish were housed in four custom-built monitoring units. Three units consisted of a stainless steel framework holding 16 24L tanks (60 cm L x 40 cm W x 12 cm H), resulting in a total capacity of 48 tanks on a vessel to house 160 plaice (two units) and 80 sole (one unit). The fourth unit held six 84 L tanks (80 cm L x 60 cm W x 17.5 cm H) to house 36 turbot. In all units each tank was equipped with an individual water supply. A pump with a water intake approximately 2 meters below sea surface continuously supplied seawater to the tanks. Water flow rates were approximately two tank volumes per hour to maintain proper water quality. Tanks were covered with transparent lids to limit water loss by sloshing while allowing for visual inspection of fish. Upon return in port, the units were hoisted from the vessel and transported to the laboratory in a temperature controlled truck. Transport time ranged from one to two hours depending on the home port of the vessel. During transport each unit was placed inside a tank that was partly filled with seawater and equipped with a submerged pump to supply water to each fish tank in the unit. Fish tanks discharged their effluents in the tank in which the unit was placed, allowing for recirculation and aeration of the water. Upon arrival at the laboratory, fish were removed from their tanks and housed in a raceway system placed in a temperature controlled room. The raceway system consisted of 12 tanks, each with a bottom surface area of 2.5 m^2 and a water volume of 500 L (2.5 m L x 1 m W x 25 cm H). Maximum fish density was 16 fish per m^2. Control fish were mixed with test fish. Different species were housed in separate tanks. Water temperature was set at the North Sea surface water temperature at time of fish collection. All tanks were connected to a single water recirculation system consisting of a pumping tank, a 420 L moving bed bioreactor (MBBR, filled with 200 L of filter beads) and a 600 L trickling filter and a 80 W UV filter. Water in the system was continuously renewed with filtered seawater from the Eastern Scheldt at a rate of 2 to 3 m^3/d. In the laboratory, all tanks were supplied with coarse sand as bottom substrate and fish were fed daily to visually observed satiation with uncooked brown shrimps (*Crangon crangon*) and life ragworms (*Nereus* spp). Dissolved oxygen concentration and water temperature were measured daily (Hach Lange Multimeter), total ammonia, nitrate and nitrite concentrations were measured weekly.

Table 6 . Description of criteria to assess condition and determine vitality class.

Vitality	
Class	Description
A	Fish lively, no visible signs of loss of scale or mucus layer.
B	Fish less lively, minor lesions and some scales missing, mucus layer affected up to 20% of skin surface area, some point haemorrhaging on the blind side.
C	Fish lethargic, intermediate lesions and some patches without scales, mucus layer affected up to 50% of skin surface area, several point haemorrhaging on the blind side.
D	Fish lethargic or dead, clear head haemorrhaging, major lesions and patches without scales, mucus layer affected for more than 50% of the skin surface area, significant point haemorrhaging on the blind side.
External damage scores	
Damage	Description (1 = present; 0 = absent)
Fin	Fins are damaged or split (including tail fin). Wings in case of rays.
>50%	Damage to skin surface, scale or mucus layer at more than 50% of the dorsal body surface.
Head haemorrhages	Presence of a haemorrhage in the head of the fish
Hypodermic haemorrhages	Presence of a hypodermic haemorrhage
Intestines	Intestines are protruding or are visible through damaged body tissue of the fish.
Wound	Presence of a wound such that flesh is visible.
Reflex impairment scores	
Reflex	Description (1 = impaired; no (clear) response within 5 s of observation; 0 = unimpaired; obvious response within 5 s).
Body flex	Fish is held on the palm of the hand with its ventral side up in the air. Fish actively tries to move head and tail towards each other or wriggle out of the hand.
Righting	Fish is held on the fingers of two hands with the dorsal side touching the water surface. When released the fish actively rights itself under water.
Evasion	Fish is held underwater in an upright position by supporting its ventral side with the fingers and its dorsal side with the thumbs. When the thumbs are lifted the fish actively swims away.
Stabilize	Untouched fish tries to find a stable position flat on the bottom by rhythmic and swift movement of the fins and/or body.
Tail grab	Fish is gently held by the tailfin between the thumb and index finger. Fish actively struggles free and swims away.
Head complex	Fish moves its operculum or mouth during 5 s of observation while laying undisturbed under water.

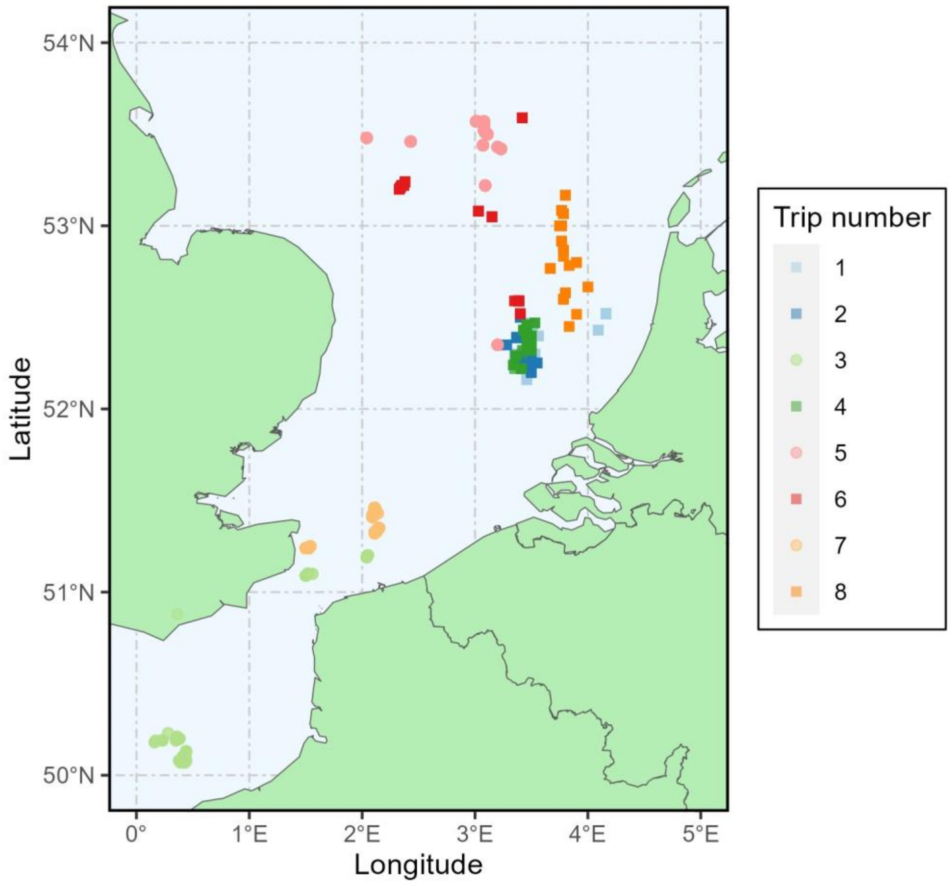

Figure 2. Locations of sampled hauls per discards survival trip. Trips 3, 5 and 7 were flyshoot trips (circles). The remaining trips were TBB trips with MHS trials in trips 4 and 8 (squares).

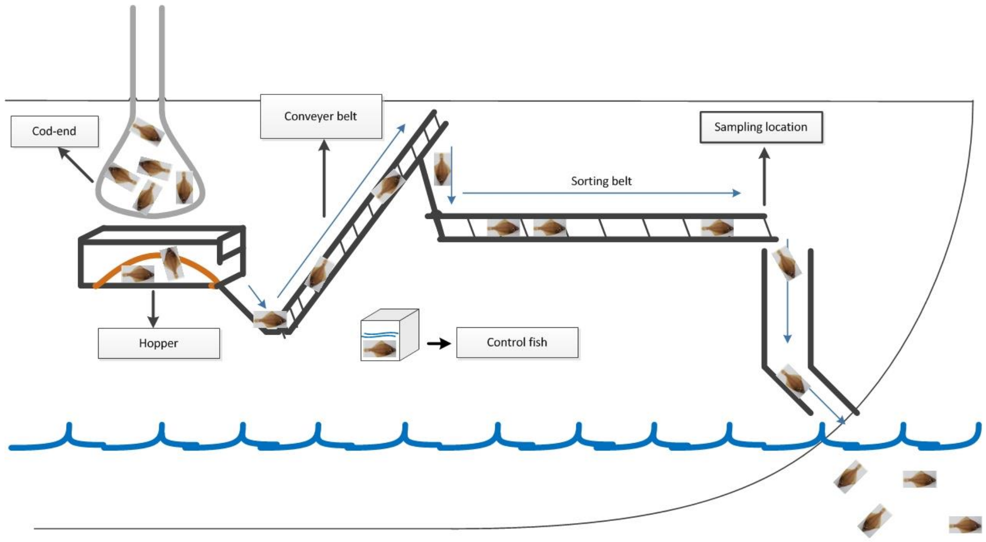

Figure 3. Schematic drawing of semi-automatic catch processing line on board of a beam trawler and flyshooter. All fish collected from the catch for the survival experiment are collected at the location marked with ‘sampling location’.

3.4 Modular Harvesting System

The Modular Harvesting System (MHS) is a novel cod-end originally developed in New Zealand by *Precision Seafood Harvesting Limited, Timaru, New Zealand* to reduce fish damage during trawling, haul back and unloading (Moran *et al.*, 2023). The MHS is a membrane-like fabric tube with escapement holes that replaces the mesh lengthener and cod-end of a trawl. The terminal section of the MHS is non-porous, which allows fish to be lifted aboard in a fluid environment. This and the graded flow reduction and open geometry of the MHS reduces fish damage during trawling, haul back and unloading (Moran *et al.* 2023). Based on the strong relation between the condition in which fish are discarded and their survival probability, the reduction in fish damage achieved by the MHS was predicted to increase survival probabilities of bycatches when returned to sea. A MHS specific for application in beam trawling (Figure 4) was designed, constructed and tested in a collaboration between Precision Seafood Harvesting Ltd and Wageningen Marine Research. The design took into account trawl design, towing speed and minimum landing size of the target species (sole). The technical feasibility, operational experience, effects on landings and discards (catch composition) were established in parallel research (EFMZV OSW SELOV).

Figure 4. Top: Starboard trawl with the white Modular Harvest System (MHS) for a tickler chain beam trawl as used in this experiment. Portside trawl is equipped with a conventional mesh cod-end. Bottom: Tickler chain beam trawl with the MHS (white part of the trawl).

3.5 Fish disease diagnostics

Fish were diagnosed for bacterial and parasitic infections because of suspected fish health issues during survival monitoring causing mortality that was unrelated to fisheries. This mainly occurred during survival monitoring for trips 7 and 8 (warmer summer months). After survival monitoring for trip 8 had been terminated, plaice (n=11), sole (n=5) and turbot (n=10) were sampled and shipped to the fish and shellfish disease laboratory of Wageningen Bioveterinary Research, Lelystad, The Netherlands for diagnostics.

3.6 Data analysis

3.6.1 Data management

During and after each trip, the data for that trip was entered into three excel files: the trawl list, the initial assessment after sampling and the registration of mortality. All these data were joined using R (software) in a file for each trip where each entry is a sampled fish. These files were combined in a single overall file containing all data. Fish that died due to unnatural causes, e.g. by jumping from a tank, were censored: rather than being registered as dead, their experiment was said to have been terminated (alive) at the time of death.

3.6.2 Survival curves

To visualise and analyse the survival of the sampled fish, the R-package *survival* was used. Using the function *survfit*, Kaplan-Meier survival curves (Kaplan and Meier, 2012) were fitted and 95% Confidence Intervals were computed. Survival curves were created for:

- Control fish vs. test fish for both gears and species
- All trips as separate curves for both species
- The different vitality classes for both gears and species

For all plots, except for the plot displaying the survival for each trip for all species individually, the 95% Confidence Intervals computed by the *survfit*-function were plotted.

To determine if vitality class serves as an adequate predictor for post-capture mortality, (Mantel-Haenszel) log-rank tests were performed on the effect of vitality class at the start of the experiment on survival, for all species and gears separately. The function *survdiff* from the *survival* R-package was used.

3.6.3 Effect of MHS on survival probabilities

The *survdiff* function was used to test if the discards survival probability of fish sampled with a MHS differed significantly from the discards survival probability of fish sampled with a conventional cod-end. This was done for all species and trips (4 and 8) separately. To account for the between-haul variation, the tests were stratified by haul.

3.6.4 Vitality classes

To test if the distribution amongst the vitality classes differed significantly between the gear types, Wilcoxon Rank Sum Tests were used on the numerical vitality data (where A =1, B = 2, etc.).

4 Results

4.1 Survival probabilities of plaice sole and turbot discarded by beam trawl fisheries

For beam trawl fisheries the overall discards survival probability estimates are 8.1% (95% confidence interval 6.2%-10.7%) for plaice, 20.4% (95% confidence interval 16.3%-25.6%) for sole and are 15.6% (95% confidence interval 10.4%-23.3%) for turbot (Figure 5). These estimates are based on five trips spread out over the period February to August 2023 under variable environmental conditions (Table 5). Most of the mortality among test fish occurred within the first five days post capture of all three species and survival varied among trips for all species (Figure 5). For plaice the highest survival (19.9%) was observed in February and the lowest (2.5%) in August (Figure 5). For sole the highest survival (34.1%) was observed in May and the lowest (12.5%) in August (Figure 5). For turbot the highest survival (35.5%) was observed in June and the lowest (0%) in February (Figure 5). Thus for turbot highest survival probabilities were observed in summer. For sole, no clear seasonal effect was observed. Direct mortality, i.e. test fish that were defined as dead when sampled, ranged from 0.6 to 27% in plaice with the lowest values observed in winter and the highest in summer. For sole direct mortality was 14.1%. For turbot direct mortality was 2.6%. Average survival of control fish was 86.8% for plaice, 83.3% for sole and 100% for turbot. Most of the mortality among control fish occurred in the second half of the monitoring period.

4.2 Survival probabilities of plaice discarded by flyshoot fisheries

For flyshoot fisheries the overall discards survival probability estimate for plaice is 15.0% (95% confidence interval 12.5%-17.9%) (Figure 6). This estimate is based on three trips conducted in April, June and July 2023 (Table 5). Most of the mortality among test fish occurred within the first five days post capture (Figure 6). The highest survival (39.7%) was observed in April and the lowest (1.2%) in July (Figure 6). Direct mortality, i.e. test fish that were defined as dead when sampled, ranged from 4.8 to 17.2%. Average survival of control fish was 83.7% and most of the mortality among control fish occurred in the second half of the monitoring period.

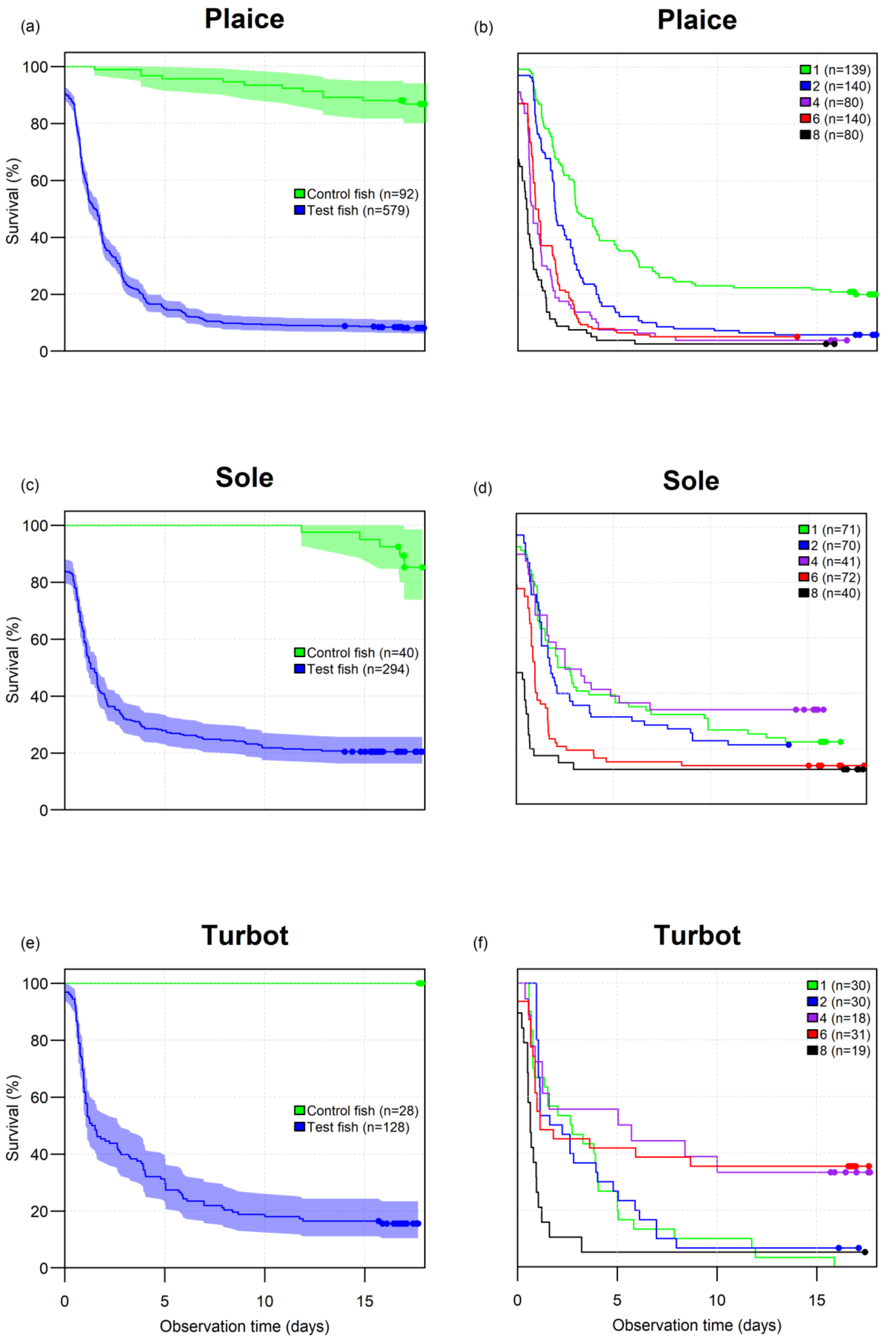

Figure 5. Kaplan-Meier survival curves for plaice (top), sole (mid) and turbot (bottom) discarded by beam trawl fisheries. Left column: curves are plotted for control fish and test-fish employing all fish sampled during five beam trawl trips. Right column: curves are plotted for test-fish per beam trawl trip. Drawn lines indicate mean survival (percentage over time), with shaded areas indicating 95% confidence intervals. Dots indicate the end of the monitoring time for individual fish that were alive at the end of the experiments.

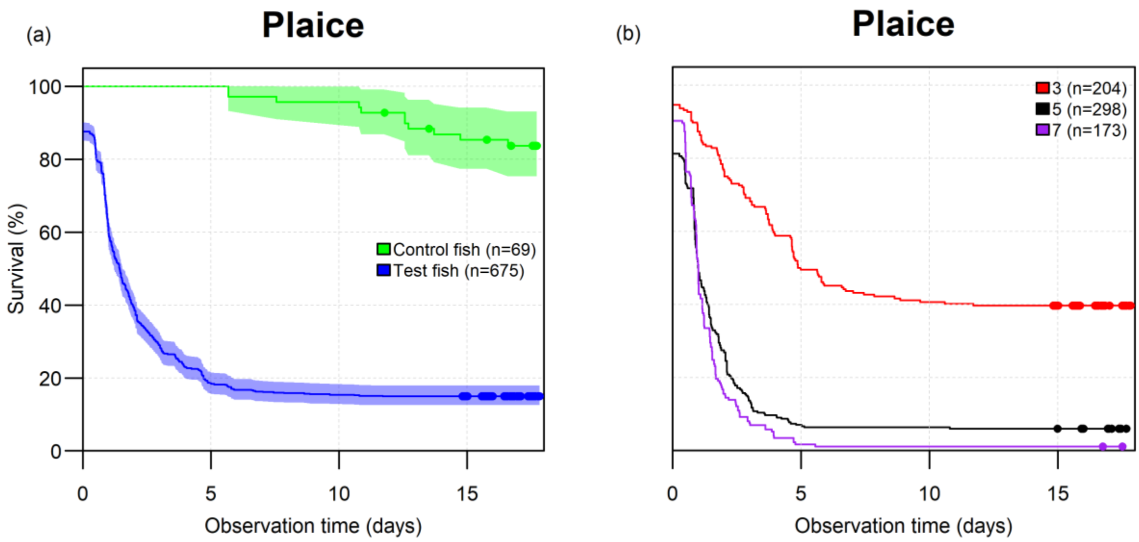

Figure 6. Kaplan-Meier survival curves for plaice discarded by flyshoot fisheries (SSC). Left panel: curves are plotted for control fish and test-fish employing all fish sampled during three SCC trips. Right column: curves are plotted for test-fish per SSC trip. Drawn lines indicate mean survival (percentage over time), with shaded areas indicating 95% confidence intervals. Dots indicate the end of the monitoring time for individual fish that were alive at the end of the experiments.

4.3 Effect of condition on survival probability

The condition in which fish were just before discarding, as expressed by vitality classes A to D, had a significant effect on discards survival probability for plaice (log-rank test, p = <<0.001), sole (log-rank test, p << 0.001) and turbot (log-rank test, p << 0.001) (Figure 7). For all species-métier combinations survival probability declined with deteriorating condition; in all cases survival probability was highest for vitality class A and lowest for vitality class D. This effect of vitality class on survival probability of plaice is consistent across beam trawl and flyshoot fisheries.

4.4 Effect of MHS on discards survival probabilities

Plaice and turbot caught with the MHS were in better condition than when caught with the regular beam trawl gear as shown by the frequency distributions over vitality classes A to D (Figure 8). This difference was significant for plaice (Wilcoxon signed-rank test, p << 0.001) and turbot (Wilcoxon signed rank-test, p = 0.001), but not for sole (Wilcoxon signed-rank test, p = 0.15).

In both trips we observed a significantly higher survival probability for plaice sampled from the MHS compared to the regular beam trawl gear (Table 7, Figure 9). For sole no significant effect of the MHS on survival probability was detected (Table 7, Figure 9). For turbot, survival of fish sampled from the MHS was significantly higher only for trip 8, with results for trip 4 not being significant but indicative of an effect of cod-end type on discards survival probability (Table 7, Figure 9).

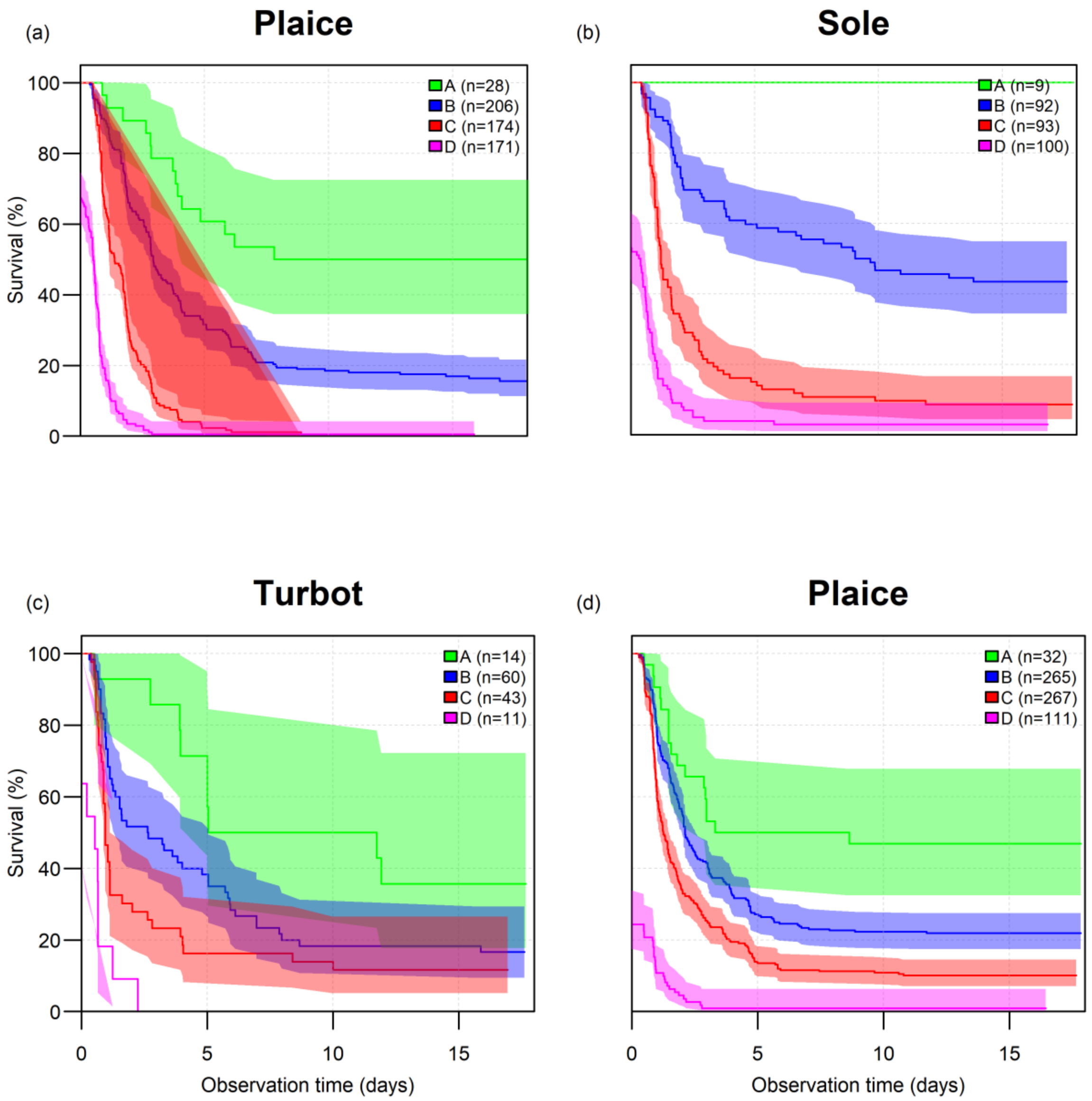

Figure 7. Kaplan-Meier survival curves for test-fish of vitality classes A to D for plaice (top left), sole (top right) and turbot (bottom left) discarded by beam trawl fisheries and plaice (bottom right) discarded by flyshoot fisheries. Note that vitality class D includes fish that were dead at the start of the experiment. Drawn lines indicate mean survival percentage over time, with shaded areas indicating 95% confidence limits.

Table 7: Discards survival probability estimates (%) and their 95% confidence intervals as observed per trip for undersized plaice, sole and turbot discards caught with the MHS or regular beam trawl gear. Note that no comparisons between species were made.

Species	Trip	Survival probability.(95% CI)				Significant?
		Regular TBB	n	MHS	n	(p-value)
Plaice	4	3.8 (1.2-11.4)	80	20.0 (12.9-31.0)	80	Yes (p << 0.001)
	8	2.5 (0.6-9.8)	80	28.9 (20.2-41.2)	80	Yes (p << 0.001)
Sole	4	34.1 (22.3-52.2)	41	37.5 (25.1-55.9)	40	No (p = 0.6)
	8	12.5 (5.5-28.4)	40	20.0 (10.8-37.2)	40	No (p = 0.2)
Turbot	4	33.3 (17.3-64.1)	18	55.0 (36.0-83.9)	18	No (p = 0.06)
	8	5.3 (0.8-35.5)	18	42.1 (24.9-71.3)	11	Yes (p < 0.001)

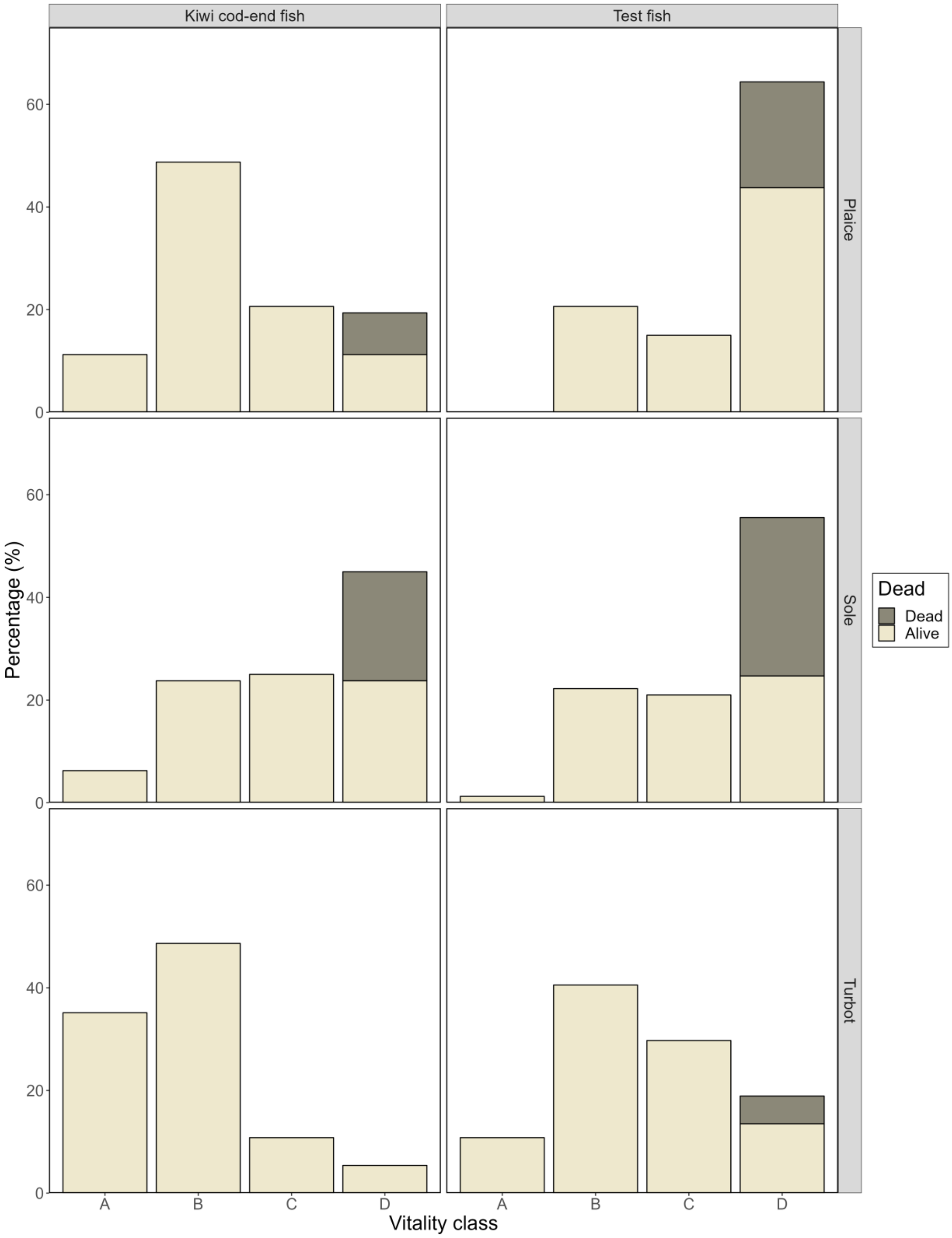

Figure 8. Frequencies (n=2 trips, mean ±SD) per vitality class for plaice (top), sole (mid) and turbot (bottom) caught by beam trawls with conventional mesh lengthener and cod-end (CON, left) and with MHS (right).

4.5 Fish disease diagnostics

Although several potentially pathogenic bacteria and parasites were detected, a single unambiguous cause was not identified. It was concluded that the infections were probably opportunistic and related to the relatively high water temperature. A full report (in Dutch) by the fish disease laboratory is included in Annex 1.

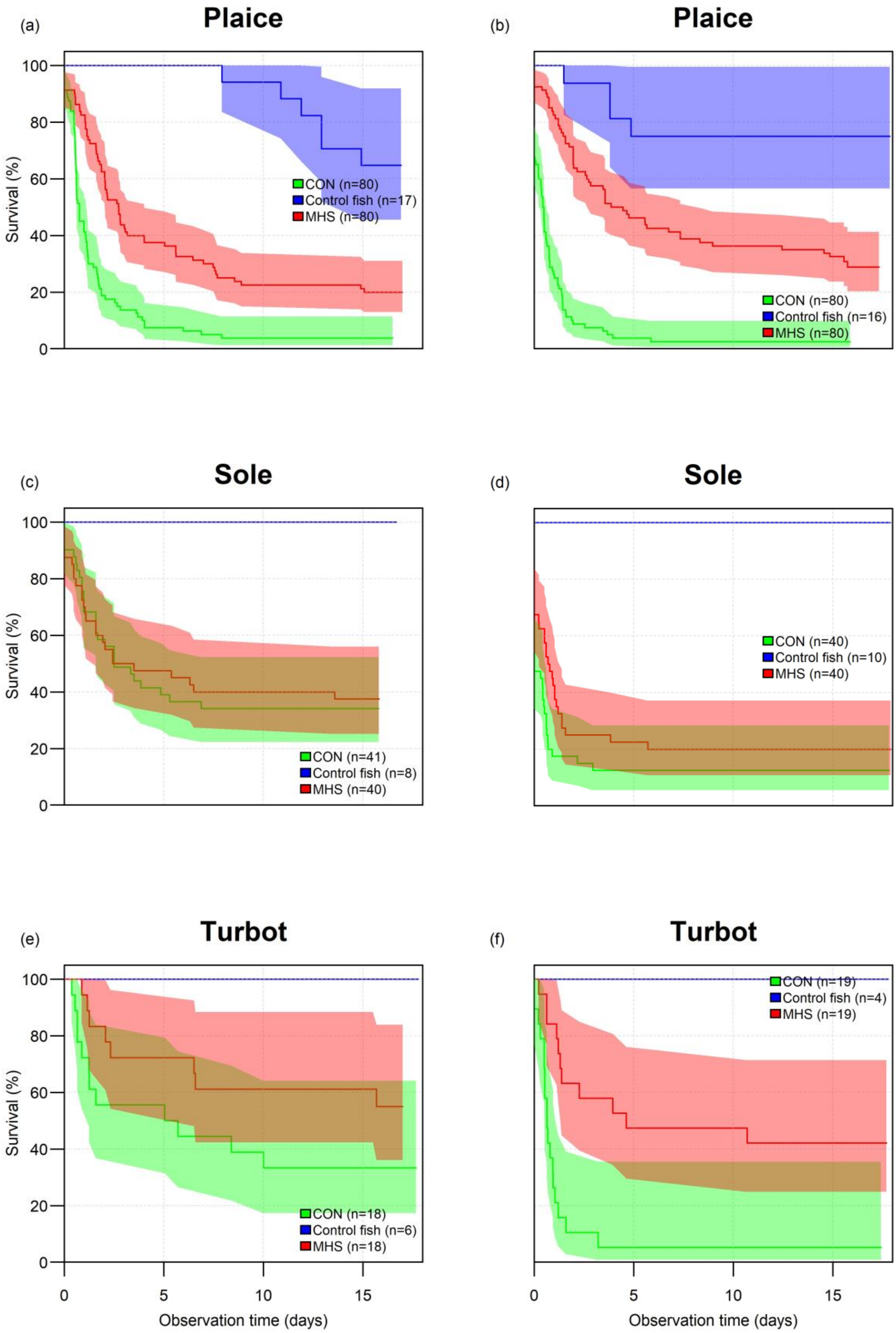

Figure 9. Kaplan-Meier survival curves for plaice (top), sole (mid) and turbot (bottom) discards showing the effect of the MHS on discards survival probabilities. Curves are plotted per trip for the two trips in which the MHS was tested (left column Trip 4, right column Trip 8) for control fish and test-fish sampled from the beam trawl gears with conventional mesh cod-end (CON) and MHS. Drawn lines indicate mean survival (percentage over time), with shaded areas indicating 95% confidence intervals. Dots indicate the end of the monitoring time for individual fish that were alive at the end of the experiments.

5 Discussion

The first objective of this study was to measure survival probabilities of undersized plaice, sole and turbot discarded by beam trawl fisheries and undersized place discarded by flyshoot fisheries under commercial fishing circumstances. Note that turbot and sole were not considered in flyshoot fisheries because their (by)catch is rare in this fisheries. The second objective of this study was to measure the effect on discards survival probabilities of replacing the regular mesh beam trawl lengthener and cod-end with the so-called modular harvesting system (MHS). To meet these objectives we conducted three research trips with a flyshooter and five research trips with a beam trawler. During two out of the five trips with the beam trawler we tested the effect of a MHS.

Control fish were included in the experiments to distinguish fisheries-induced mortality from mortality resulting from our experimental procedures. Because survival was not 100% among control fish for all three species, it is not obvious that all mortality among test-fish was fisheries-induced. Upon termination of the survival monitoring for trip 8, five turbot, 10 sole and 11 plaice were sampled for fish disease diagnostics by Wageningen Bioveterinary Research. Although various bacteria and parasites were found to be present, a single pathogen and the exact cause for mortality among control fish could not be established (full report in annex). It was concluded that fish probably suffered from generic opportunistic pathogens as a result of the relatively high water temperatures. It should be noted that water temperature in the monitoring system was set at the ambient water temperature in the North Sea at the time of sampling and thus corresponded to the water temperature fish would be exposed to when discarded. During trip 8the North Sea water temperature reached 19.5°C, which is exceptionally high and we cannot exclude that this negatively affected discards survival of mainly plaice. Since most control fish died in the second monitoring week while most test fish died in the first week, we suspect that causes for mortality are different. We therefore consider it unlikely that we underestimated survival probability due to additional non-fisheries related mortality among test-fish. Most test fish had already died before effects of experimental procedures manifested among control fish. In other words, given the difference in timing of mortality among control and test fish, mortality among test-fish appears to be largely fisheries-induced while mortality among control fish seems mostly related to experimental procedures and conditions. Captive observation may also overestimate discards survival because it excludes the contribution of predation to discards mortality. Jointly taken, the discards survival probability estimates should be considered as maximum values because captivity related mortality was probably low while the captive observation excluded an unknown level of predation-related mortality.

Fishing always involves some degree of internal or external injury of fish resulting from interactions between fish and fishing gear (Davis, 2002). Fish caught and discarded by commercial fisheries are exposed to stressors such as hypoxia, injury, exhaustion, barotrauma and predation during capture, handling, and release (Davis, 2002; Cook *et al.*, 2019) and failure to recover from these fisheries induced stressors results in mortality (Cook *et al.*, 2019). Because the severity of as well as the resistance to these stressors varies, it is not surprising that large variation in observed discards survival exists between species, métiers and sea conditions (Benoît *et al.*, 2010; Morfin *et al.*, 2017). To account for this variation and to determine representative overall discards survival probability estimates, discards survival probabilities are ideally measured under variable conditions during research trips that are spread out over the year. In this project year-round measurements could not be done.

For beam trawling, survival probabilities were measured from February to August and thus do not cover a full year. The average survival probability estimates per species of the trips done in this project should therefore not be considered representative discards survival probability estimates for year-round fisheries. However, our observations do include the coldest winter and warmest summer months and thus annual temperature extremes. This is relevant because temperature is known to influence survival probabilities (van der Reijden *et al.*, 2017, Schram *et al.*, 2023a) and although we did not perform statistical tests to establish a temperature effect, a temperature effect indeed seems clear from our data. Also the direct mortality, i.e. fish that are defined as dead when sampled, among sampled plaice

appeared to have increased with increasing temperatures. It can thus be argued that because our observations cover the annual temperature range, they probably also cover the range within which survival probabilities vary within a year. Therefore additional observations in the period between September and January will probably result in survival probabilities within the range delimited by the already observed lowest and highest values. Because North Sea water temperatures are higher in autumn than in spring while stormy conditions which can exacerbate mechanical impacts of trawling on fish and thereby reduce survival probability, may be more prevalent in autumn, it seems likely that additional observations in September to November will result in survival probabilities that are lower than those observed in April-June. This would result in a lower overall survival probability estimate than based on the current set of observations. On the other hand, fish may be more fragile towards the end of their spawning seasons in March-April compared to the autumn months which could result in lower discards survival (Breen and Catchpole, 2021). Also, additional observations at low water temperatures in December and January may increase the overall average survival. Jointly taken we conclude that for discarding by beam trawling survival probabilities lie within the range observed in the current study: between 2.5 and 19.9% for plaice, between 12.5 and 34.1% for sole and between 0 and 35.5% for turbot, and that additional observations in the period September – January are needed to determine overall survival probability estimates that are representative for a full year. It should be noted that sea surface temperatures in the North Atlantic were exceptionally high during the sampling period, which may have caused increased discard mortality in plaice. The exceptionally high temperatures are likely to occur more often in the future and might therefore become realistic conditions in the near future, rather than an extreme exception.
Survival probabilities of plaice, sole and turbot as observed in this study for beam trawling with tickler chains are lower than previously observed for these species in pulse beam trawling (Schram *et al.*, 2023a). This lower survival was predicted because of the higher towing speed of tickler chain beam trawls (6-7 kn.) compared to pulse beam trawls (~ 5 kn.) and generally larger catch volumes. Higher towing speeds may lead to faster exhaustion, exacerbate collisions with the mesh, other fish, benthic animals and debris, and lead to more dense crowding and increased compression of fish in the cod-end. All these factors result in poorer condition of fish when landed on deck and lower survival when discarded.

For flyshoot fisheries, plaice survival probabilities were measured in April, May and July. The variation in observed survival probabilities was high among trips and ranged from 1.2% in July to 39.7% in April. As we did not cover a full year the average survival probability of these three trips does not represent survival for year-round fisheries. Because fishing grounds, catch composition, catch size and catch processing time are more variable in flyshoot fisheries compared to beam trawl fisheries (own not yet published data), these factors may also have stronger effects on discards survival. Although we did not formally test for these effects, partly because we lack the necessary data, it seems clear that other factors than temperature alone should be considered when evaluating the variation in observed discards survival among flyshoot hauls and trips. This means that it is difficult to evaluate to what extend the current observations cover the range between which discards survival varies in flyshoot fisheries. Based on temperature effects alone, our current set of observations probably does not include the upper limit of the seasonal variation in plaice discards survival probability because the flyshoot trips did not include the winter period with the lowest water temperature. Additional observations during winter months probably result in higher survival probabilities than the currently observed maximum survival probability of 39.7%. It should be noted that fishing operations vary among flyshoot vessels and that this may affect discards survival probabilities. The vessel used in the current experiment shoots the trawl from its rear deck where most other flyshooters use the net drum. Shooting the trawl from the rear deck occupies the crew and delays the start of the catch sorting process. As a result total catch processing time and air exposure time are probably longer than average and this can negatively affect survival probabilities of discarded fish (Methling *et al.*, 2017; Noack *et al.*, 2020).
Plaice discards survival as observed in the current study for flyshooting is lower than reported for Danish seining, a fishing technique that is comparable to flyshooting. For Danish seining plaice discards survival probabilities as high as 78% at water temperatures ranging from 10 to 17°C were reported by Noack et al. (2020) and this may be attributable to the lighter gear, slower hauling and larger meshes used in Danish seines. Our observation that survival probabilities can be higher in flyshoot fisheries compared to beam trawling is in agreement with our previous work on discards survival of rays in these two metiers (Schram *et al.*, 2023b). Jointly taken we conclude that plaice discards survival is highly variable in

flyshoot fisheries for reasons that are not yet fully understood. In winter survival may be higher than the currently observed highest survival.
It should be noted that in both beam trawling and flyshoot fisheries (and any other metier) absolute fishery mortality due to discarding not only depends on survival probabilities but also on the total amount of discarded fish. As both factors vary throughout the year, absolute discards mortality will also vary. We recommend considering data on discards amounts and discards survival in conjunction because it gives insight in absolute discards mortality and indicates for which periods in the year accurate information on survival probabilities is most essential.

The effect of the modular harvesting system (MHS) (Moran *et al.*, 2023) on discards survival probabilities of plaice, sole and turbot was investigated in this study in beam trawl fisheries. The MHS was predicted to increase survival by reducing mechanical impact on the fish during trawling. Our previous tests already showed improved condition among fish caught with the MHS compared to fish caught with a traditional beam trawl net. Since condition is strongly correlated to discards survival probability (Schram *et al.*, 2023a) a positive effect of the MHS on discards survival probabilities seemed obvious. The objective of the two experiments conducted in the current study was to demonstrate and quantify this predicted positive effect of the MHS. It should be noted that establishing representative overall discards survival probabilities for fish caught with a MHS was beyond the scope of the current study. This would require a larger number of experiments to obtain observations under various sea conditions. The results of the two current experiments should be considered as a proof of principle for the positive effect of the MHS, a first quantitative indication for the potential increase in survival probabilities as well as first insight in differences between species.
Survival probabilities of plaice and turbot were significantly higher for the fish sampled from the MHS. On average the MHS resulted in an elevenfold increase in survival for plaice and a sixfold increase in turbot. This increase in survival is lower than we expected based on our visual observations of the prime condition of the fish directly after MHS catches had been discharged in the hopper. Because we only sampled fish for condition assessment at the end of the sorting belt, we cannot evaluate the effect of the catch sorting process on fish condition. We suspect however that part of the potential for high discards survival probability achieved by the MHS was lost due to deterioration of fish condition in the catch sorting process. Refinement of the catch sorting process aimed at maintaining the good condition of the fish while on board is therefore highly recommend to fully utilize the potential increase in discards survival that can be achieved by the MHS. In our previous research on refining the catch sorting process aimed at increasing discards survival we found no effect of discharging catches in water-filled hoppers instead of standard dry hoppers (Schram *et al.*, 2023a). This was explained by survival being largely determined by capture and hauling processes prior to discharging the fish in hoppers; most fish had already been lethally damaged during trawling. This situation is clearly much improved when fish are caught with the MHS: the proportion of fish that is landed on deck in good condition is much higher. This also means that the way fish are handled in the catch sorting process becomes more important for the chances for survival of discarded fish.
Surprisingly, the survival probability of sole was not significantly affected by the MHS. This may be explained by a proportion of the undersized sole ending up meshed in the openings of the MHS. It seems that the specific escape behaviour of soles prevents them from benefiting from the lower mechanical impacts fish are exposed to in the MHS.
Another observation is that meshed plaice in the openings of the MHS dropped back into the MSH lengthener instead of being landed in the hopper. These plaice were then exposed to a second trawling event before appearing in the catch sorting process where they could be sampled. This observation might explain partly the initial mortality that was observed in the sampled MHS test fish.
As the MHS for a beam trawl is still in a development phase, handing the MHS on board was not optimal yet during the trials. Opening the lift bag (cod-end) of the MHS was difficult during the trials of trip 4, as a result most catch was discharged from a partly opened lift bag through a 20-30 cm wide opening, as a result the catch was flushed under pressure trough this opening against the side of the hopper. This may have reduced the positive effects of the MHS on the discard survival. Opening the MHS was improved during trip 8, as a result the survival difference between mesh and MHS further increased for plaice, sole and turbot. The application of MHS is still in its early stages and practical experiences are still limited. Therefore, further optimization and refinement of MHS handling will probably increase discard survival even more. A similar experiment during the cold winter months may show a higher survival for plaice.

6 Conclusions and recommendations

Discards survival probabilities

Overall survival probability estimates representative for year-round beam trawl fisheries cannot be presented because observations in the period September to January are lacking. However, because our observations include annual temperature extremes we conclude that overall discards survival probability estimates for beam trawling range from:

- 2.5 to 19.9% for plaice;
- 12.5 to 34.1% for sole;
- 0 to 35.5% for turbot.

For flyshooting the overall plaice discards survival probability estimate ranges from 1.2 to 39.7%.

To determine overall discards survival probabilities that are representative for year-round fisheries additional observations in the periods that were not covered by the current project are needed. We also recommend to consider discards survival probability data in conjunction with data on discards amounts to obtain insight in absolute fisheries mortality due to discarding.

Effect of MHS on discards survival

The MHS significantly increases survival probabilities of plaice and turbot discarded by tickler chain beam trawling but not for sole. This study confirms and provides the first quantitative insight in the potential increase in survival probability of replacing the traditional beam trawl mesh lengthener and cod-end with a MHS. For plaice a elevenfold increase and for turbot a sixfold increase in survival probability was observed. To determine the effect of the MHS for year-round fisheries, more observations are needed. To fully utilize the potential increase in discards survival that can be achieved by the MHS we recommend research into the refinement of the catch sorting process to maintain the good condition of the fish while on board.

7 Acknowlegdements

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- Mulder Transport BV for the transport of survival units from the fishing vessels to our laboratory in Yerseke;
- Visserijinnovatie Centrum Zuidwest Nederland for transporting all equipment to the fishing vessels and for maintaining all equipment in proper condition.
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- Nederlandse Vissersbond for supplying supporting research staff during four research trips
- Precision Seafood Harvesting Limited, New Zealand for supplying the MHS and technical assistance in board.

8 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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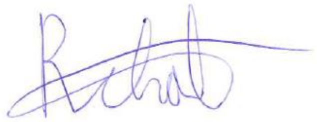
Justification

Report C059/23
Project Number: 4311400052

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Ir. R. van Hal
Colleague scientist

Signature: 

Date: September 28th 2023

Approved: C.J. Wiebinga, PhD
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With knowledge, independent scientific research and advice, **Wageningen Marine Research** substantially contributes to more sustainable and more careful management, use and protection of natural riches in marine, coastal and freshwater areas.

Wageningen Marine Research is part of Wageningen University & Research. Wageningen University & Research is the collaboration between Wageningen University and the Wageningen Research Foundation and its mission is: 'To explore the potential for improving the quality of life'

Annex 1 Analyse certificaat Wageningen Bioveterinary Research

Datum: 20 september 2023

Ons kenmerk: 23014479

Bijlage 1

1. Diagnostiek van visziekten

- **Herkomst inzending:** WMR t.a.v. E. Schram

- **Samenstelling inzending:** 3 partijen levende vis; schol, tarbot en tong

  Partij 1 = 11 levende schol
  Partij 2 = 5 levende tarbot
  Partij 3 = 10 levende tong

- **Datum ontvangst inzending:** 11 september 2023

- **Anamnese volgens inzender:**
  We hebben problemen met schollen die we in Yerseke houden. Waarschijnlijk speelt de hoge watertemperatuur een rol. Omdat deze problemen de interpretatie van de onderzoeksgegevens beïnvloeden, willen we graag vast laten stellen wat er aan de hand is.

2. Bevindingen onderzoek

Partij 1 *Schol*

Sectie:
Uitwendig: Iets slome, bleke vis met kleine laesies op de huid en uitpuilende ogen. Alle vissen hadden ontstekingen rond de bek.
Huid: enkele niet typeerbare flaggelaten, veel bacteriën (allerlei).
Kieuwen: Geen parasieten, wel veel bacteriën (allerlei). 9x iets bleke kieuwen 2 x dieprode kieuwen met iets verdikte epitheel.
Inwendig: bij 2 schollen is lintworm en nematode in de darmen aangetoond, alle schollen hebben een erg bleke lever, de darmen waren iets gevuld, lichte heldere ascites, verder geen afwijkingen.

Bacteriologisch onderzoek:
- Bek: *Aeromonas bestiarum* en een niet determineerbare stam.
- Darm, ascites en nier een niet determineerbare stam.
- Lever en milt geen groei

<u>Ziehl Neelsen-kleuring</u> lever: **negatief;** er is geen verdenking op *Mycobacterium* spp.-infectie.

Partij 2 *Tarbot*

Sectie:
Uitwendig: Iets beschadigde huid , alle vissen hadden ontstekingen rond de bek.
Huid: meerdere *Trichodina* sp., veel bacteriën (allerlei).
Kieuwen: veel *Trichodina* sp. en *Cryptocaryon* sp. (marine witte stip), wel veel bacteriën (allerlei) verder is het epitheel verdikt.
Inwendig: bij alle tarbotten is lintworm aangetroffen, 3 x was de lever heel erg bleek, de darmen waren iets gevuld met fel gele darminhoud. Uit en inwendig van de darmen doorbloedingen, heldere ascites, verder geen afwijkingen.

Bacteriologisch onderzoek:
- Uitwendig: rein *Vibrio harveyi*
- Inwendig: uit de darm is *Allivibrio fischeri*, uit de organen en ascites is geen groei ontstaan.

<u>ZN-kleuring</u> milt/lever: negatief, er is geen verdenking op *Mycobacterium spp.*-infectie

Partij 3 *Tong*

Sectie:
Uitwendig: Alle vissen hadden beschadigde bek, drie hadden uitpuilende ogen meerdere hadden rafelige vinnen
Huid: Geen parasieten, redelijk wat bacteriën (allerlei).
Kieuwen: Veel *Cryptobia*, veel bacteriën (allerlei),verder geen afwijkingen.
Inwendig: Iets bleke lever en opgezette nier, verder geen afwijkingen.

Bacteriologisch onderzoek:
- Uitwendig: Vanuit de bek is *Vibrio europaeus* geïsoleerd.
- Inwendige organen: geen bacteriegroei.

<u>Ziehl Neelsen-kleuring</u> lever: negatief, er is geen verdenking op *Mycobacterium spp*-infectie

WAGENINGEN
UNIVERSITY & RESEARCH

Datum: 20 september 2023

Ons kenmerk: 23014479

3. Diagnose

Tussen de partijen, schol, tarbot en tong zijn overeenkomsten te vinden in de pathologie wat betreft de waargenomen leasies (bijv. de laesies op de huid en rond de bek) en aangetroffen parasieten (bijv de lintwormen). Echter er komt geen eenduidige ziekteverwekker naar voren als oorzaak van de problemen. Dit komt overeen met de waarneming dat de hoge watertemperaturen mogelijk de achtergrond zijn van de problemen.

Opvallend zijn de leasies bij de bek waaruit ook een aantal bacteriën zijn geïsoleerd. Zowel *Aeromonas bestiarum* bij de schol als *Vibrio harveyi* en *Allivibrio fischeri* gevonden bij de tarbot, zijn beschreven als vispathogene bacteriën.

Gezien het type huidlaesie kunnen ook infecties met Lymphocistes virus niet worden uitgesloten.

Met vriendelijke groet,

Dr.ir. Marc Y. Engelsma
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LELYSTAD

Ons kenmerk	Uw kenmerk	Relatienummer	Rapportdatum
23014479		41024587	20/09/2023

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Nederland

Diersoort : Vis
Reden van onderzoek : Visonderzoek
Import/exportland :
Aantal monsters : 1
Datum monstername : 10/09/2023
Datum ontvangst : 11/09/2023

Uitslagen onderzoek zijn van toepassing op de monster(s) zoals ontvangen door Wageningen Bioveterinary Research.

Nr.	Identiteit	Monstertype	Ond. code	Omschrijving onderzoek	Uitslag
001	vis	Vis		Visonderzoek	Zie bijlage 1.

Namens Wageningen Bioveterinary Research, nationaal veterinair referentielaboratorium,

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