Selectivity of shrimp pulse trawling versus traditional shrimp beam trawling

Results of a baseline and innovation study

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Wageningen University & Research report C105.21

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Funded by European Union

European Union, European Maritime and Fisheries Fund

This research project was carried out by Wageningen Marine Research and the Flanders Research Institute for Agriculture, Fisheries and Food and was subsidized by the ministry of Agriculture, Nature and Food Quality

Wageningen Marine Research
IJmuiden, December 2021

CONFIDENTIAL no

Wageningen Marine Research report C105/21

WAGENINGEN UNIVERSITY & RESEARCH

ILVO Flanders Research Institute for Agriculture, Fisheries and Food

Keywords: Fisheries, Beam trawl, Pulse gear, Brown Shrimp, Innovation

Client: Ministerie van Landbouw Natuur en Voedselkwaliteit
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Bezuidenhoutseweg 73
2594 AC, Den Haag

Ordernr. 1300023914

This report can be downloaded for free from https://doi.org/10.18174/560348
Wageningen Marine Research provides no printed copies of reports

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Summary

In the Southern North Sea, fishermen have been trawling for brown shrimp (*Crangon crangon*) since the first half of the 20th century using beam trawls with bobbins (traditional gear). In the last decades fishermen are challenged to fish more efficiently and there is a need to reduce bycatch and discard rates. A proposed solution is the use of pulse trawls. This pulse trawl gear consists of a number of electrodes, attached to the gear in the tow direction, that emit short electric pulses. The electrodes partly replace the bobbins that are used in traditional beam trawl fishery for shrimp. In earlier studies the use of pulse trawl has already proven to reduce bycatch and discard rates. Nevertheless, for the new pulse trawl to be allowed to be used commercially in the Natura2000 areas in the Netherlands, where most of the shrimp fishing takes place, more information on the performance of the gear is required.

As most of the Dutch shrimp fisheries takes place in designated Natura2000 areas its is important to know this new pulse gear does *at least* not bring more harm to the environment than the standard traditional (beam trawl) gear. For that reason the Dutch ministry of Agriculture, Nature and Food quality (LNV) has formulated an assignment with the aim to implement a baseline study that answers the question whether or not shrimp fishing using pulse gear resulted in higher amounts of bycatches of small "non-commercial" shrimp (< 50 mm), fish and benthos when compared to traditional shrimp fisheries, and if these possible differences are affected by the location of the fisheries and the time of the year. This baseline study is being described in part 1 of the underlying report. In part 2 of the report several innovative ideas to improve the pulse gear are being explored in order to contribute to further development and innovation of the current pulse gears.

Part 1

In order to answer the main research question of whther of not a new technique like the pulse gear does *at least* not bring more harm to the environment than the traditional beam trawl data was collected on board of commercial shrimp vessels. The fishermen of these vessels, equipped with either pulse gear or traditional gear, recorded their catches and landings year-round. Additionally to these 'self-recording' trials, 'comparative gear trials' were undertaken on vessels equipped with on one side pulse gear and on the other side traditional gear. During these comparative trials (or gear trials) detailed information on the composition of the catches and amounts of individuals of bycatch species caught was collected and analysed by researchers.

The overall conclusion of the study is that shrimp fishing using pulse gear does not result in higher amounts of undesired bycatches of small shrimp, fish and benthos when compared to the traditional shrimp beamtrawl fisheries. In more detail; the weigth of small shrimps in the catch relative to the commercial shrimps was the same for pulse gear and traditional gear. The weight of undesired bycatch of other species in relation to the total shrimp weight, on the contrary, was higher for the traditional gear than for pulse gear. The bycatch consisted of fish, crabs, mollusks and other bentic species. The use of a sievenets prevented large species for entering the nets and the commercial species like herring, plaice, sole, dab were (largely) all juveniles. Based on the comparative studies it seemed there was no significant difference in selectivity for both gears for the majority of species in the bycatches in most areas and seasons. Although there were some exeptions: the pulse gear was significantly more selective for catches of the flatfish species plaice and flounder in all areas, dab in the North Sea Coastal Zone and the Voordelta and for sole in the Wadden Sea and the North Sea Coastal Zone. Meaning that more individuals of these species were found in traditional gears. The pulsetrawl was also *significantly* more selective for the round-fish species bullrout, hooknose, viviparous blenny and bib (only in the Wadden Sea). Sand eels on the other hand were in some cases significantly more abundant in the pulse trawl nets, just as the Clupea species in the first quarter of the year (Q1) and five-bearded rockling in the Voordelta and the flatfish species scald fish in the North Sea Coastal Zone (contrasting catches in other areas). The reason why some species are more

abundant in traditional gear when compared to the pulse gear or vice versa can be explained by a combination of the reaction of a fish species to the initial exposure to the electric field and the presence of more escape openings between the bobbins in the pulse gear. The seasonal and local differences can most probably be explained by differences in abundance of the species in different areas/seasons; the more a species is abundant, the more likely it is that a significant difference in is statistically detected.

Part 2

For next step of the study a workshop was organized with the involved fishermen, scientists from WMR, ILVO and Thünen Institute, a representative of the ministry (Ministry of Agriculture, Nature and Food Quality) and natuurmonumenten (NGO). During the workshop, innovations were proposed that might improve the efficiency of pulse gear, especially during cold months as these are months when pulse gear has lower catch rates than traditional gear. Five innovations resulted from the workshop. These were subsequently tested on three fishing vessels and compared with the "traditional" pulse gear. The length of the electrodes and distance to the bobbin was changed, pulse settings were altered, discs were added between the bobbins, a sieve mat instead of a sieve net was put in place, and a replacement of the bobbins with discs were the tested innovations. The electrodes, the pulse settings, and sieve mat did not prove to be efficient or useful innovations compared to the "traditional" pulse. Adding discs to the bobbin rope of a pulse gear led to an increase in the catch of commercial cooked shrimp by 3% while reducing bycatch and discard volume by 9% and 14% respectively, compared to a traditional trawl with 36 bobbins on a round bobbin rope. The replacement of bobbins by discs, resulted in a 5% decrease in catch, this was accompanied by an approximate reduction of 11,5% and 24% in bycatch and discard volume compared to the "traditional" pulse. This relatively cheap solution can help fishermen catch enough shrimp in colder water and have a lower impact on the ecosystem.

Samenvatting

Sinds de eerste helft van de 20e eeuw gebruiken vissers boomkorren met een klossenpees om garnalen (*Crangon crangon)* te vangen in het zuidelijke deel van de Noordzee. In de laatste jaren wordt de visserij steeds meer uitgedaagd om efficiënter en duurzamer vissen, onder andere door ongewenste bijvangst en daarmee teruggooi (ook wel discards) van deze bijvangst te verminderen. Een mogelijke oplossing is het gebruik van een tuig waarbij elektrische pulsen gebruikt worden om garnalen te vangen en daarmee het aantal te gebruiken klossen terug te brengen. Eerdere studies hebben al eens aangetoond dat met dit zogenaamde pulstuig een reductie van de bijvangst kan worden gerealiseerd. Daar een groot deel van de garnalenvisserij in Nederland plaatsvindt in de zogenaamde N2000 gebieden was behoefte aan een uitgebreide studie naar de effectiviteit van het pulstuig in relatie tot het traditionele boomkor tuig.

Om de pulstuig commercieel te mogen toepassen in Natura2000 gebieden is het belangrijk om te weten of een nieuwe techniek zoals het pulstuig in ieder geval niet meer schade toebrengt aan het milieu dan het standaard traditionele boomkortuig. Om deze reden heeft het ministerie van Landbouw Natuur en Voedselveiligheid (LNV) een onderzoeksopdracht geformuleerd om middels een zogenaamde nulmeting te achterhalen of garnalenvisserij met pulstuig al dan niet resulteerde in grotere hoeveelheden bijvangsten van kleine "niet-commerciële" garnalen (< 50 mm), vis en benthos in vergelijking met traditionele garnalenvisserij, en of deze mogelijke verschillen worden beïnvloed door de locatie van de visserij en de tijd van het jaar. Het voorliggende rapport beschrijft de resultaten van deze nulmeting in deel 1. Deel 2 gaat vervolgens verder in op mogelijke verbeteringen van het pulstuig, een verkennend onderzoek dat is uitgevoerd in nauwe samenwerking met de deelnemende vissers.

Deel 1: nulmeting

Om de vraag "of garnalenvisserij met pulstuig al dan niet resulteerde in grotere hoeveelheden bijvangsten van kleine "niet-commerciële" garnalen (< 50 mm), vis en benthos in vergelijking met traditionele garnalenvisserij, en of deze mogelijke verschillen worden beïnvloed door de locatie van de visserij en de tijd van het jaar" te beantwoorden werden op verschillende wijzen en niveaus gegevens verzameld:

1. Datarecording: jaarrond registratie van vangsten en aanlandingen door de schippers van van commerciële garnalenschepen; zowel door de deelnemende (puls)schepen met pulstuigen aan beide zijden als door schepen met traditionele boomkorren aan beide zijden.
2. Vergelijkende visreizen: aan boord van de deelnemende (puls)schepen die aan de ene kant waren uitgerust met een pulstuig en aan de andere kant met traditionele boomkor. Tijdens deze vergelijkende visreizen werd gedetailleerde informatie over de vangsten en bijvangsten verzameld en geanalyseerd door onderzoekers van ILVO en WMR, hetzij aan boord van de schepen, hetzij in het lab.

De algemene conclusie van de nulmeting is dat garnalenvisserij met een pulstuig niet resulteert in grotere hoeveelheden ongewenste bijvangst van kleine garnalen, vissen en benthos in vergelijking met een traditioneel boomkor tuig. Een modelstudie naar de verhoudingen in de vangst van commerciële garnalen, bijvangst garnalen (kleine garnalen, <50 mm) en de overige bijvangst wezen uit dat:

- De gewichten van kleine niet commerciële (<50 mm) garnalen in de vangst ten opzichte van de commerciële garnalen hetzelfde was voor het pulstuig en het traditionele boomkor tuig.
- Het gewicht van ongewenste bijvangst van de overige soorten in de bijvangst tot het totale garnalengewicht hoger was voor het traditionele tuig dan voor het pulstuig.

De bijvangst bestond uit vissen (platvissen en rondvissen), krabben en andere (bodem) dieren (zie bijlage 4 voor een overzicht van alle gevangen soorten). Het gebruik van zeefnetten voorkwam dat grote soorten/individuen in de netten kwamen en de commerciële soorten zoals haring, schol, tong,

schar die in de vangsten zijn aangetroffen waren (grotendeels) allemaal juvenielen (<10 cm). Voor een meerderheid van de gevangen soorten en in de meeste gebieden en seizoenen werden tijdens de vergelijkende visreizen geen significante verschillen in vangsten tussen de beide tuigen waargenomen. Voor enkele soorten werden was het verschil wel significant, al was dat ook niet altijd jaarrond en in ieder gebied hetzelfde. Het pulstuig was significant selectiever voor vangsten van de platvissoorten schol en bot in alle gebieden, voor schar in de Noordzeekustzone en de Voordelta en voor tong in de Waddenzee en de Noordzeekustzone. Er werden, met andere woorden, meer individuen van deze soorten aangetroffen in het traditionele tuig dan in het pulstuig. Het pulstuig was ook significant selectiever voor de rondvissoorten zeedonderpad, harnasmannetje, puitaal en steenbolk, maar dat gold alleen voor de Waddenzee en niet in de andere gebieden. Zandspieringen daarentegen kwamen in sommige gevallen significant meer voor in het pulstuig. Ook Clupea-soorten haring en sprot werden in het eerste kwartaal van het jaar (Q1) in significant grotere hoeveelheden in het pulstuig aangetroffen. Tot slot was in de voordelta vijfdradige meun en in de Noordzeekustzone de platvissoort schurftvis ook in significant grotere hoeveelheden aangetroffen in het pulstuig. Waarom sommige soorten ofwel in het pulstuig ofwel in de traditionele tuig in grotere hoeveelheden werden aangetroffen kan worden verklaard door een combinatie van de reactie van een (vis)soort op de initiële blootstelling aan het elektrische veld en de aanwezigheid van meer ontsnappingsopeningen tussen de klossen van het pulstuig. Waarschijnlijk worden de seizoensgebonden en lokale verschillen verklaard door de verschillen in aanwezigheid van de soorten in die verschillende gebieden/seizoenen; zijn er meer individuen van een soort aanwezig, dan is de kans dat een verschil in respons ook wordt aangetoond met statistische toetsen hoger.

Deel 2

Als volgende stap werd er een workshop georganiseerd waarbij zowel de deelnemende vissers als onderzoekers, bedrijven, overheden en een NGO aanwezig waren. Hier werden mogelijke innovaties besproken die het pulstuig zouden kunnen verbeteren, zeker gedurende de koude wintermaanden wanneer het tuig minder vangsten bovenhaalt dan het traditionele tuig. Hieruit werden er vijf innovaties uitgewerkt en uitgevoerd in het kader van deze studie op drie vissersschepen. Deze werden dan vergeleken met het "traditionele" pulstuig. De lengte van de electroden en de afstand tot de klossenpees werd aangepast, de instellingen van de puls werden aangepast, sommige klossen werden vervangen door schijven, een zeefmat in plaats van een zeefnet werd geïntroduceerd in het net en het vervangen van de klossen door schijven op de klossenpees. De elektrodes, puls instellingen en zeefmat gaven geen positieve resultaten of nuttige innovaties in vergelijking met het "traditionele" pulstuig. Het toevoegen van de schijven aan de klossenpees leidde tot een toename in de hoeveelheid commerciële, gekookte garnalen met 3% en daarenboven een afname van de bijvangst en teruggooi met 9% en 14% respectievelijk, vergeleken met een traditioneel vistuig met ronde klossenpees. Het vervangen van alle klossen door schijven leidde tot een afname van 5% bij de garnalen maar dit ging gepaard met een afname van om en bij de 11,5% en 24% respectievelijk voor de bijvangst volumes vergeleken met een traditioneel pulstuig. Deze relatief goedkope oplossing kan de vissers helpen om zuiverder en efficiënter te vissen, ook in kouder water, en verlaagt de impact op het ecosysteem.

1 Introduction

1.1 Background

The shrimp trawl fishery has a long history in the waters of the Southern North Sea in which the Netherlands, Germany and Denmark are responsible for the majority of the landings (ICES, 2015). In the last few decades, pressure on fish stocks and marine ecosystems increased, posing serious challenges regarding sustainable fishing. In order to fish more sustainably, the bycatch and discard rates need to be reduced and kept at a minimum. A proposed solution is the use of pulse gear. This gear operates on the same principle as the traditional gear with a bobbin rope in that it stimulates shrimp from the seafloor to swim over the lower tendon into the net. The difference is that pulse gear uses an electrical stimulus and less so a mechanical one, as less bobbins are used with the pulse gear. Using electrical pulses on the trawls has proven to be an effective tool to achieve large reductions in the bycatch in shrimp trawls; like for example on board of the fishing vessel HA31 (Verschueren et al., 2014). However, electric fishing is prohibited in the EU and was, during the time of the research, only possible under derogation (EC Regulation 850/1998). Initially 5% of the beam trawl fleet (aimed at both flatfish and shrimp) got an exemption to experimentally fish with the pulse gear in 2006 (Rijnsdorp, 2020). This permit was extended in 2010 and 2014, to a total of 84 pulse permits. The exemption condition was that the vessels would contribute to the research of the consequences of the usage of pulse trawl on sustainable exploitation of fisheries and its effects on ecosystems.

Because the brown shrimp fishery mainly takes place within the 12 miles coastal zone, the fishery is also managed by national regulations. In the Netherlands, the majority of the shrimp fisheries occurs in designated Natura2000 protected areas (Glorius et al, 2015). To be able to fish in these areas additional special permission[1] is needed (Steenbergen et al, 2017). This permit is evaluated every 5 years and at the time of the research, only granted for the traditional fishing for shrimp with a beam trawl. Fishing for shrimp with the pulse gear was only permitted for the purpose of scientific research to gather more information on the performance of this gear.

1.2 Shrimp pulse developments

The use of a startle pulse (5 Hz) to catch shrimp has its origin in the 80’s and passed a decade in oblivion after a European ban was passed on electrotrawls. Two decades later, the first commercial pulse trawl for brown shrimp was developed by the Institute for Agricultural and Fisheries Research (ILVO) in Belgium (Verschueren et al, 2019). The ‘Hovercran’ was an ambitious design eliminating all the bobbins, making the gear hover over the seabed and reducing the bottom contact by over 75% (Verschueren et al., 2019). The first commercial fishers adopting the technique however choose to use bobbins. After several trials, a straight bobbin rope with±12 bobbins was seen as a good alternative (Verschueren et al., 2014). Ensued by many discussions around possible miss-use of the pulse gear for shrimp fisheries, the Dutch ministry decided to come up with regulatory measures for the technical specifications of the pulse fishing gear (Annex 1; *in Dutch*). Due to these implemented strict measures further development of the gear was slowed down, leading to frustration for the fishermen and the sector.

[1] in Dutch; de vergunning op grond van wet natuurbescherming Wnb

1.3 Assignment

This report presents the results of the Shrimp Pulse project; a research project that was funded by the ministry of agriculture nature and food quality (LNV). The aim of the project was to 1) investigate the differences in selectivity of pulse and traditional (beam trawl) gears in the Dutch shrimp fishery in a so-called baseline study and 2) contribute to further development and innovation of current shrimp pulse gears. The outcome of this project supports the evaluation of sustainable management of shrimp fisheries in general and in marine conservation areas, Natura2000 areas in particular, while also assessing the effectiveness of the pulse gear for shrimp fisheries in these areas.

The project was implemented by a cooperation of three international research institutes: Wageningen Marine Research (WMR) in The Netherlands, the Institute for agricultural and fisheries research (ILVO) in Belgium and Thünen-Institute of Baltic Sea Fisheries (Thünen) in Germany. Where WMR and ILVO where both responsible parties for the 2 main elements of the project; the baseline study (part 1; responsible party Wageningen Marine Research) and the innovation of the shrimp pulsegears (part 2; responsible party ILVO). The Thünen Institute was involved in the set up of the project, the baseline study and in a workshop were the options for innovation were discussed.

1.4 Reading Guide

The report consists of two parts describing the approach, methods, results and conclusions of the two main elements of the research; Part 1 Baseline Study and Part 2 Innovations.

Part 1: baseline study

1 Approach

1.1 Goal and background

Despite earlier research to the performance of the pulse gear, the technique was at the time of the project, still considered experimental. The existing information was considered too limited for proper evaluation of the pulse gear in relation to the traditional beam trawl. This study aims to collect the data required for establishing the baseline selectivity of pulse trawling versus traditional (beam) trawling in shrimp fisheries. In doing so the results of the study can be used as the knowledge base for policy makers in their decision to allow pulse fisheries in general (Europe) and in Natura2000 areas specifically (in the Netherlands).

1.2 Research questions

The general question of the baseline study was whether or not shrimp fishing using pulse gear results in higher amounts of undesired bycatches of small 'non-commercial' shrimp, fish and benthos when compared to traditional shrimp beamtrawl gear, and if these potential differences are affected by time and location of the fisheries. This lead to the following research questions:

1. Is there a difference in selectivity between shrimp pulse gear and traditional gear for:
    a. Commercial[2] brown shrimp (targeted species)?
    b. Bycatches of small (non-commercial) brown shrimp?
    c. Bycatches of fish?
    d. Bycatches of benthos?

2. Is the difference between the shrimp pulsetrawl and the traditional beamtrawl in selectivity for the above mentioned catches affected by:
    a. Time of the year?
    b. Location of the fisheries?

1.3 Study design

To collect the data required for establishing a baseline for the technical selectivity of pulse trawling versus traditional trawling in shrimp fisheries, the following three data collection schemes were implemented:

1. Self-recording of catch and bycatch volumes by commercial shrimp fisheries using either pulse trawling or traditional beam trawling;
2. Self-sampling during gear trials in commercial shrimp fisheries;
3. Observer trips during gear trials in commercial shrimp fisheries.

The gear trials allow for a detailed comparison of catch and bycatch composition for both gear types under comparable conditions: during the gear trials (data collection scheme 2 and 3) a single vessel was equipped with both pulse and traditional gear, therefore paired measurements of the catches could be made. By doing so, the inter-vessel variation is largely elemininated. The data of the gear trials is analysed by difference in Catch (in total, all caugth species) per Unit of Effort (CPUE),

[2] Shrimp that is selected on board for landing; selection is done with sorting grids based on width of the shrimp. The length of these commercial shrimp is approx. 50 mm.

Landings (of commercial shrimp) per Unit of Effort (LPUE), in catch composition (weight of species groups in kg's) and in bycatch per species in numbers/ha. The data is also analysed per area and per period of the year to detect ant potential temporal and/or spatial effects.

1.4 Alterations

Initially five Dutch shrimp fishers owning a permit to fish with pulse and in possession of operational pulse gear were involved in this project namely the WR40, WR109, ST24, HA31 and TH10. After a kick-off meeting in September 2018 agreements on the following prerequisites for the cooperation of the fishers were made;

- A very rough fishing plan will be made on forehand
- Fishers are free to decide where to fish and when, depending on the availability of the shrimp in different locations and seasons

The start date of the baseline study was 1st of January in 2018. However, the participating fishers did not fish for shrimp in the first months of 2018 due to extreme low availability of shrimp in the Dutch waters at that time. As the catch sampling only started in May 2018 the baseline study was extended into 2019 in an attempt to include periods and regions that were not covered in the previous year. The WR109 had to withdraw as pulse trawler from the project due to operational problems of its gear. The only vessel that usually operates in the south (TH10; Vlakte van de Raan and Voordelta) only switched from fish to shrimp in autumn of 2018. After two weeks of comparative gear trials the vessel was facing engine problems and the vessel did not return to shrimp fishing that year. In 2019, three additional comparative gear trials were conducted in the south.

2 Materials and Methods

2.1 Preparations

1. Selection of paired traditional "buddies"

For the data recording program, the pulse fishers had to arrange a "buddy": a traditional shrimp trawler with overlapping fishing grounds.

2. Training of crewmembers

Crew members of selected vessels were trained and instructed to measure and record the volumes of total catch and market sized shrimp in an individual haul. Per recorded haul all relevant information (time, date, location, haul duration, etc.) were documented.

3. Measuring catch volumes

On board of the fishing vessels the total catch was collected in two hoppers; one for each net. These hoppers are often especially designed for the vessel, have sloping bottoms and come in different sizes. To be able measure the volumes of the catch the hoppers were measured and the volume per cm (of the deepest point) in the hopper was calculated. The fishers were instructed to use a ruler to measure the catch in cm. The cm recoded by the fishermen could then be converted to the total catch volume in the hopper. Conversions of the vessels are available at WMR.

2.2 Data recording

2.2.1 Data collection

Data recording took place from January 2018 till the end of March 2019. During the data recording the pulse trawlers and their 'buddies' collected information on every haul in a trawl-list (treklijst; annex 2)

2.2.2 Overview of the trips and gear used

Like the pulse fishers, the buddies were not directed and the fishers followed their own fish-plans and strategies. Data recording only took place in the Wadden Sea and the North Sea Coastal Zone. The cooperation with one of the buddies was difficult because the vessel changed owners just before the start of the fishery in May. After some weeks of incomplete data collection the cooperation with this buddy was ended. A new buddy was found, but only started in September of the same year. In 2018, only two weeks of sampling was done by one buddy pair in January, after that sampling started again in May 2018.

In the Netherlands shrimp fishers are obliged to use a sievenet throughout the year. A sievenet is an alteration to the standard gear, aiming to direct unwanted bycatch to an escape hole. Upon request an exemption can be made in the Wadden Sea in the summer months; fishermen can use the letterbox instead. The letterbox (in Dutch brievenbus) is developed as an alternative to the sievenet and was first tested in 2010 in the Wadden Sea (Steenbergen et al, 2011).

In the months 6-9 the letterbox was used by one pulse fisher, the three buddies used the letterbox resp. in month 7-10, 6-10 and 9-10 (one of the buddies only started in month 9). Table 1 gives an overview of the amount of hauls that were recorded by the pulse and traditional fishers per area (Wadden Sea or North Sea Coastal Zone) and per month.

Table 1 Registered hauls for data recording per area, month, gear type and gear subtype. Between brackets: number of vessels collecting this data.

	Waddensea				North Sea Coastal Zone			
	pulse		traditional		pulse		traditional	
	letterbox	sievenet	letterbox	sievenet	letterbox	sievenet	letterbox	sievenet
2018	195	1071	1134	430	393	39	353	130
Jan		88 (1)		75 (1)				
Feb								
Mar								
Apr								
May		38 (1)		84 (1)				2 (1)
Jun	30 (1)	250 (2)	113 (1)	124 (1)	68 (1)			1 (1)
Jul	58 (1)	147 (2)	378 (2)	2 (1)	156 (1)		4 (2)	
Aug	88 (1)	44 (1)	108 (2)		143 (1)	10 (1)	67 (2)	
Sep	19 (1)	231 (2)	308 (3)		26 (1)	5 (1)	141 (2)	
Oct		137 (2)	227 (3)			2 (1)	141 (2)	
Nov		63 (2)		80 (3)		21 (1)		91 (2)
Dec		73 (2)		65 (1)		1 (1)		36 (1)
2019		129		109		1		31
Jan		39 (1)		39 (1)		1 (1)		12 (1)
Feb		62 (1)		49 (1)				6 (1)
Mar		28 (1)		21 (1)				13 (1)
Grand Total	**195**	**1200**	**1134**	**539**	**393**	**40**	**353**	**161**

2.2.3 Data analyses

The data that was collected during the self-recording trials is treated as qualitative data so no statistical analyses can be applied. As the fishers were not directed in their fishing movements and behaviour, the "buddy-pairs" were not always fishing close enough to each other to be treated as pairs. Thus the collected information on the catches were summarized per week and region;

- Based on the recorded location (lat-lon) the hauls were divided in Wadden Sea or North Sea Coastal Zone. The areas are based on the N2000 borders from: nationaalgeoregister.nl
- Per region per week averages of CPUEs (volume total catch per ha) and LPUEs (landings of boiled shrimp in kg per ha) are calculated for the traditional vessels and the pulse vessels (together)

2.3 Comparative Gear Trials

The comparative gear trials are paired comparisons between the traditional beam trawl and pulse trawl on a single vessel. During the gear-trials detailed information was collected of shrimp (amounts and lengths) and bycatch consisting of fish, benthic species and other species. Additionally, like the self-recording data, landed (boiled) shrimp and total catch volumes was registered for each side. This paired comparison gave a detailed view into the differences in selectivity between pulse and traditional beam trawl gear for the parameters landings per unit of effort, the total catches per unit of effort, numbers of bycatch species (non-shrimp) per ha and the catch composition (weight).

A total of 21 observer trips and 15 self-sampling trips on board of 4 vessels were carried out in 2018/2019 (Table 2).

Table 2 Trips conducted for comparative gear trials per vessel, year, month, week and area. Trials were carried out by an observer on board (obs) or through self-sampling (self). Two trips were invalid, meaning that the data collected in these trips could not be used (red).

Vessel	Type	Year	month	Week	Area
ST24	Obs	2018	5	19	Wadden Sea
ST24	Obs	2018	5	20	
WR40	Obs	2018	5	21	Wadden Sea
ST24	Self	2018	5	21	Wadden Sea
WR40	Obs	2018	5	22	Wadden Sea
WR40	Self	2018	6	23	Wadden Sea
HA31	Self	2018	6	23	Wadden Sea
HA31	Obs	2018	6	24	Wadden Sea
ST24	Self	2018	7	27	Wadden Sea
ST24	Obs	2018	7	28	Wadden Sea
ST24	Obs	2018	7	29	Wadden Sea
HA31	Obs	2018	8	33	Wadden Sea
HA31	Obs	2018	8	34	Wadden Sea
HA31	Self	2018	8	35	Wadden Sea
TH10	Obs	2018	9	36	Voordelta
TH10	Obs	2018	9	37	Voordelta
WR40	Self	2018	9	37	North Sea CZ / Wadden Sea
WR40	Obs	2018	9	38	North Sea CZ / Wadden Sea
WR40	Obs	2018	9	39	North Sea CZ / Wadden Sea
WR40	Obs	2018	10	40	North Sea CZ / Wadden Sea
WR40	Self	2018	10	41	
WR40	Self	2018	10	43	Wadden Sea
HA31	Obs	2018	10	44	Wadden Sea
WR40	Self	2018	10	44	North Sea CZ / Wadden Sea
ST24	Obs	2018	11	45	North Sea CZ / Wadden Sea
HA31	Self	2018	11	45	Wadden Sea
HA31	Self	2018	11	46	Wadden Sea
ST24	Self	2018	11	46	Wadden Sea
ST24	Self	2018	11	47	North Sea CZ / Wadden Sea
TH10	Obs	2019	2	7	Voordelta
ST24	Self	2019	3	10	Wadden Sea
ST24	Obs	2019	3	12	North Sea CZ / Wadden Sea
WR40	Obs	2019	3	13	North Sea CZ
WR40	Obs	2019	4	15	North Sea CZ
TH10	Obs	2019	10	41	Wadden Sea
TH10	Self	2019	10	41	Voordelta

For comparing the gear it is important that other variables are as equal as possible. Therefore, the fishermen were asked to change the netting before each trial (of three weeks). In Table 3 an overview of measured mesh sizes is provided per trial.

Table 3 Overview of mesh-sizes per side during the gear trials. Between brackets p: pulse gear, nm: not measured. PS: Portside, SB: Starboard-side

Vessel	Trials(week)	PS	SB
ST 24	19,20,21	23.3	23.2 (p)
WR40	21,22,23	22.8 (p)	22.8
HA31	23,24	nm	nm
ST 24	27,28,29	22.8	23 (p)
HA31	33,34,35	25.6	26.1 (p)
TH10	36,37	19.8	23.6 (p)
WR40	37,38,39,40,41,43	25.3	25.2 (p)
HA31	44,45,46	22.1	22.6 (p)
ST24	45,46,47	23.3	22.4 (p)
TH10	7	22.5 (p)	22.9
ST24	10,12	23	23.1 (p)
WR40	13,15	23 (p)	22.9
TH10	41	21 (p)	21.5

2.3.1 Sampling on board

The sampling procedure to collect data on discards and shrimps was based on the standard procedure used for discards sampling on board shrimp vessels. This procedure is internationally agreed upon at the Crangon workgroup of ICES in 2008 (Tulp et al, 2010). The specific procedure used in this research was adapted and designed jointly with the research partners of the project; ILVO and Thünen institute.

The trips of the gear trails were carried out with pulse gear at one side and traditional beam trawl with bobbins at the other side. In this way a paired comparison of each haul could be made.

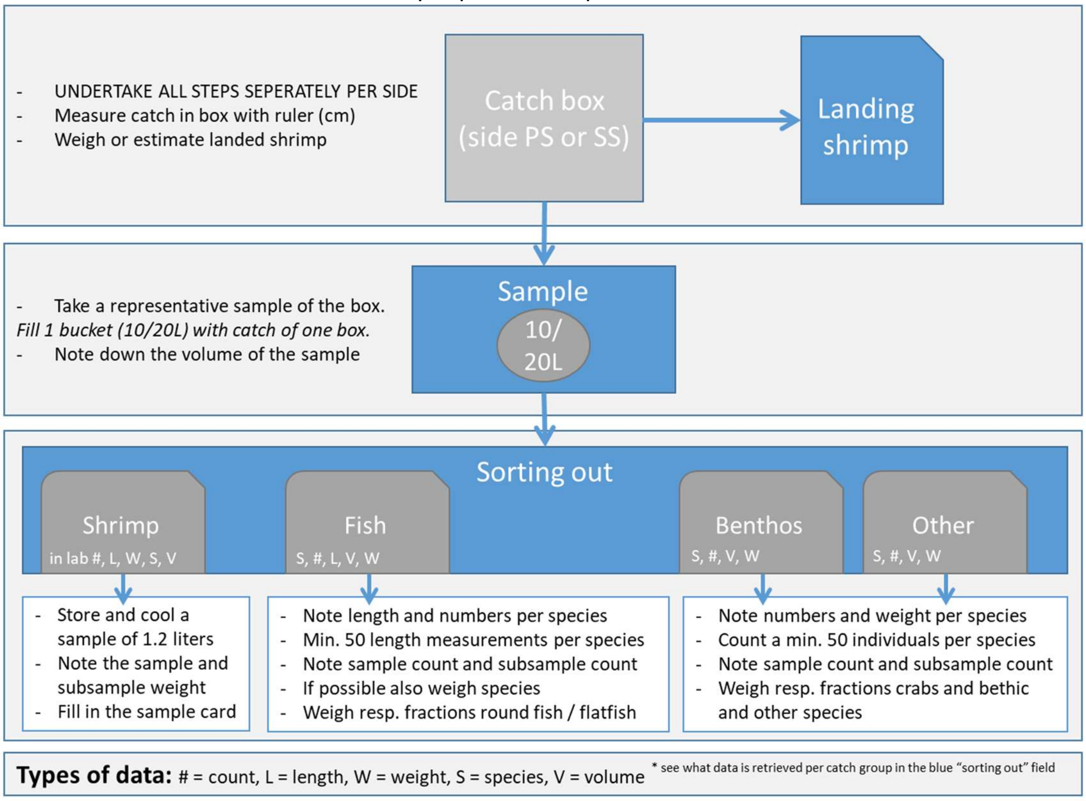

Figure 1: Sampling scheme of the comparative gear trials.

For each haul, data on position, haul duration, wind direction, fishing depth were recorded on a trawl list (Annex 2).

Then for starboard and portside nets the following steps were undertaken separately (Figure 1):

1. Estimate the total catch volume per side. Registration of total catch in cm on the trawl list (see 2.1 point 3).
2. A sample of minimal 10L, but preferably 20L was taken from the <u>total catch</u>:
   - In case of self-sampling the sample was taken by the crew on board and stored in plastic bags at cool temperatures. The bags were collected by WMR in the harbour and step 3 was conducted in the lab. The vessels were instructed to take 5 samples per week.
   - In case of observer trips the sample was taken by the observers and step 3 was conducted immediately thereafter. The observer took as much samples as possible.
3. All shrimp, fish and benthos were sorted by species and registered as follows:
   a. The total amount of shrimp in the sample was measured in volume and weight. A subsample of 1.2L. was collected for further analysis in the lab (paragraph 2.3.3)

b. All fish species were sorted, then length measurements were made and registered by species and length class. Then weights were measured and registered for all flatfish species together and all round fish species together.
c. Total number per species were registered for all benthos and other species. Then weights of all crabs and all other benthic species together where measured and registered.
d. In cases of large quantities of fish/benthos a subsample was taken.
e. Weight of rubble was measured.

4. Marketable shrimps were boiled in the boiling pot and collected after sieving (Figure 1; sieve II). Total weight of marketable shrimp per haul per side in kg was registered.
5. Back at the laboratory all data of the baseline study were entered and uploaded into the WMR database. Before uploading into the database the data was checked.

2.3.2 Measuring length of shrimp with the Smart Shrimp

Measuring the lengths of shrimps in the samples was automated with “Smart Shrimp" which makes use of a camera setup and the Smart Shrimp software. ILVO developed this electronic method as an alternative for the time consuming manual measuring of shrimp lengths (ICES, 2016). The Smart Shrimp application is run on a computer, which is connected to a camera (Figure 2). The camera is mounted above a glass plate and headlight where the shrimps are positioned on in a systematic and organised manner. Using a specific algorithm, the contour of the shrimp is recognised and the shortest line from antenna basis to telson is identified and used to generate measurement data. For each picture taken, measurements from all shrimp on the glass plate are directly registered.

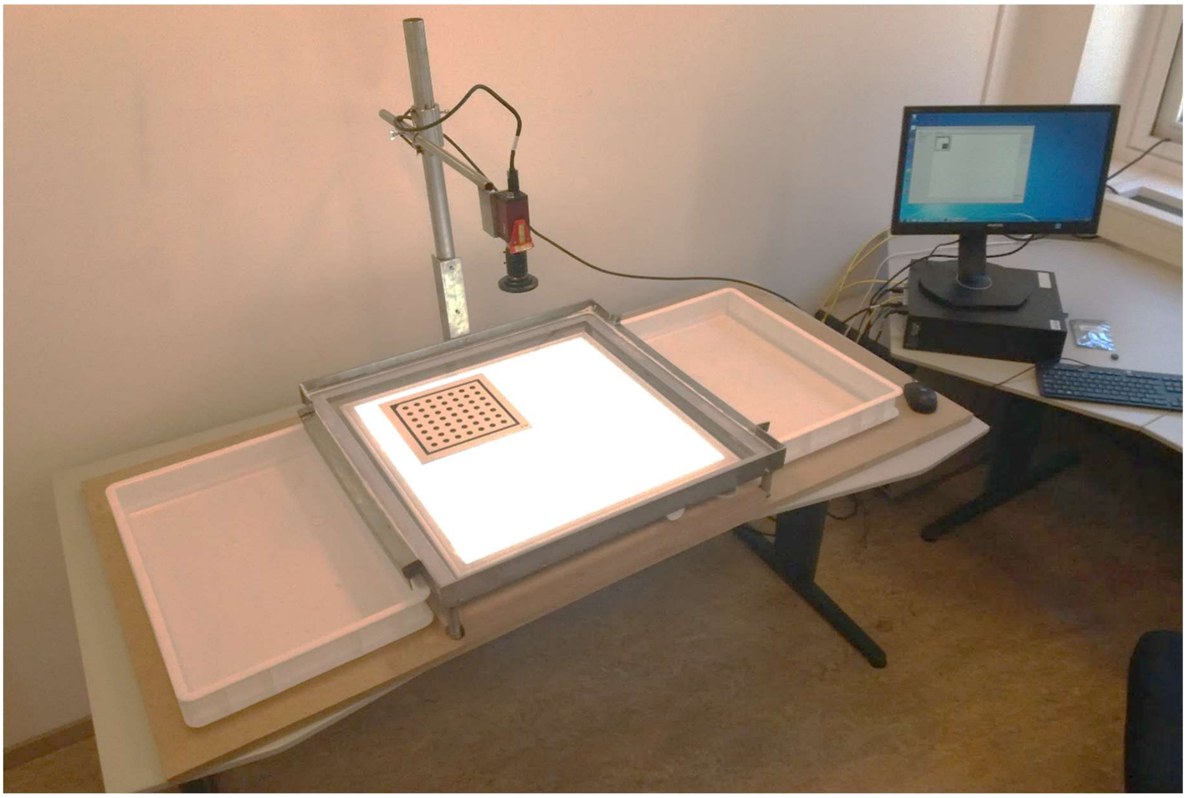

Figure 2 Smart Shrimp set up in the WMR lab.

2.4 Raising procedures

The raising procedure (from sample to catch) is done per sample and is the same for the trawls on each side of the vessel.

Fish, benthic and other species (n):
Total number discards per species, haul and side ($DN_{hs,s}$) had been calculated by multiplying the number of the species in the catch sample ($Dn_{hs,s}$) by the ratio of the estimated total catch volume (CV_{hs}) to the volume of the catch sample (Cv_{hs}).

$$DN_{hs,s} = Dn_{hs,s} * \left(\frac{CV_{hs}}{CSv_{hs}}\right)$$

Shrimp fractions (weight in kg's):

The numbers of shrimp per length in the samples was split into commercial shrimp and noncommercial (small) shrimp as follows: based on literature shrimps with a length of ≥50 mm were considered commercial size and shrimps with a lenght <50 mm were considered noncommercial size (Tulp et al., 2016).

The weight of the commercial and small shrimp fractions is calculated by converting the length measurements (commercial $Lsn_{l,n}$ and noncommercial $Dsn_{l,n}$) to weight by use of the Tom Neudecker length-weight relationship (LW).

The percentage of these two fractions by weight ($PLs_{hs,s}$ or $PDs_{hs,s}$) was calculated per sample.

$$(1)\ PLsw_{hs,s} = \frac{(Lsn_{n,l} * LW)}{(Lsn_{l,n} * LW) + (Dsn_{l,n} * LW)}$$

$$(2)\ PDsw_{hs,s} = \frac{(Dsn_{n,l} * LW)}{(Dsn_{l,n} * LW) + (Lsn_{l,n} * LW)}$$

Finally for each fraction (commercial and non-commercial size) total weight shrimps per haul and side ($Lsw_{hs,s}$ resp. $Dsw_{hs,s}$) has been calculated by multiplying the total weight of the shrimp sample ($Sw_{hs,s}$) by percentage of commercial or noncommercial shrimp ($PLs_{hs,s}$ resp $PDs_{hs,s}$) and multiplying this by the ratio of the estimated total catch volume (CV_{hs}) to the volume of the catch sample (Cv_{hs}).

$$Lsw_{hs,s} = (Sw_{hs,s} * PLs_{hs,s}) * \left(\frac{CV_{hs}}{CSv_{hs}}\right)$$

$$Dsw_{hs,s} = (Sw_{hs,s} * PDs_{hs,s}) * \left(\frac{CV_{hs}}{CSv_{hs}}\right)$$

Fraction of fish, flatfish, crabs and benthic and other species (w):
Total weights of discards per fraction, haul and side ($DfW_{hs,s}$) had been calculated by multiplying the measured weigths of the species fractions in the catch sample ($Dfw_{hs,s}$) by the ratio of the estimated total catch volume (CV_{hs}) to the volume of the catch sample (Cv_{hs}).

$$DfW_{hs,s} = Dfw_{hs,s} * \left(\frac{CV_{hs}}{CSv_{hs}}\right)$$

2.5 Analyses

In total 58 hauls were sampled in the North Sea Coastal Zone (North of Wadden Sea), 58 hauls were sampled in the Voordelta and 245 hauls were sampled in de Wadden Sea (Table 4). Sievenets were used in most cases; 67 samples were collected with a letterbox at both sides, 37 samples using either a sievenet or a letterbox at both sides. During the two sample weeks that " no sub gear " was used enormous amounts of seaweed were present, making the use of a sievenet impossible (Figure 3Figure 3).

Figure 3 Catches with seaweed in the Voordelta on board of the TH10 in September 2018

Table 4 Number of samples used for analyses of the gear trials per area. * Letterbox, ** without sievenet

Year/month	Week	Wadden Sea	North Sea Coastal Zone	Voordelta
2018		223	35	37
5	19	13		
5	21	15		
5	22	11		
6	23	10		
6	24	17		
7	27	5		
7	28	15		
7	29	17		
8	33	18		
8	34	19		
8	35	5		
9	36			19**
9	37	2*	3*	18**
9	38	9*	6*	
9	39	5*	10*	
10	40	16*	6*	
10	43	5*		
10	44	1*/14	4*	
11	45	14	5	
11	46	9		
11	47	3	1	
2019		22	23	21
2	7			10
3	10	5		
3	12	10	3	
3	13		10	
4	15	7	10	
10	41			11

2.5.1 Total Landings and Total Catch

To show the (statistical) differences in shrimp landings and in total catch volumes the following variables were used:

- The boiled shrimp weight (in kg) per square hectare (or "csh_kg_gekookt_ha").
- The total catch volume (in litres) per square hectare (or "tot_volume_ha").

Both variables were treated as log-normal distributed variables. Linear models were used where each group of observations (a group is a vessel, identified by its PPY_ID value) was allowed to have its own variance. This is a form of a Generalized Least-Squares (GLS) model and thus GLS models with a log-transformed response were used. It should be noted that there were several ships used in the data, and these ships may be a source of non-constant variance. A constant variance is an important assumption in linear models, so a correction was made for this possibility.

The GLS models used the following covariates:

- Months: a categorical variable for the months, going from 2 (February) to 11 (November).
- TOR_MAIN: a binary covariate indicating whether a catch was made using pulse or traditional gear.

- WaddenSea: a binary covariate indicating whether a catch was made in the WaddenSea (1), or elsewhere (0).
- GEAR_SUBTYPE: a categorical variable indicating which additional gear adjustment was used to reduce discards in shrimp fisheries; possible categories are: "letterbox", "sievenet", or "none".

Statistical inference

Normalized residuals were used for assessing the Generalized Least-Squares model diagnostics. Residuals-versus-fitted plots and normal quantile plots were made from these residuals to check for violations of the model assumptions.

The model fit was assessed in 2 ways to check how well the model predictions correspond to the actual observations:

- The mean absolute deviation ("MAD") was calculated. The lower this number, the better the fit.
- The predicted response (on the x-axis) was plotted against the observed response (on the y-axis), and a straight line was fitted through the points with an ordinary least-squares. The closer the slope of this line (the "fit slope") is to 1, the better the fit.

P-values less than 0.05 were considered to be significant. Diagnostic plots of the models are available upon request by the first author.

2.5.2 Bycatch (non-shrimp) in numbers per ha

Concerning the number per square hectare (or "nha") seven tables were made to show the difference in bycatch between pulse and traditional vessels: three tables where each region was taken as a whole, and four tables where each year quarter was taken as a whole. Each table shows various statistical measures for each species for the pulse nets, and those for the traditional nets. From the left to right, these measurements are: mean, median, standard deviation, minimum-maximum range, and the proportion of the number (per square hectare) that is equal to zero ("prop.zero").

For each bycatch "non-shrimp" species in the catch, the absolute difference in number per square hectare between pulse net samples and traditional net samples ("difference.means") was computed. The ratio of the mean number per square hectare of the pulse samples divided by those of the traditional samples ("ratio.means") was also computed. When this ratio was meaningful (so not equal to 0, 1, or Infinity), the difference in means was statistically tested. A Wilcoxon signed-rank test was chosen for this because traditional and pulse samples are paired, and the distribution of the numbers per square hectare was not known.

P-values less than 0.05 were considered to be significant.

2.5.3 Catch composition

Data used

Weights of the following groups were used to analyse differences in catch compositions between pulse and traditional gear (for raising procedures, see 2.4):

- Shrimp divided in commercial sized shrimp (≥50 mm) and non-commercial (discard) sized shrimp (<50 mm)
- Other species in the catch represented in fractions of; flatfish, round fish, marine crabs and other/benthic species

Unfortunately, not for all trips was the above weight data available due to weather conditions such as strong winds making it impossible to use the scales, or due to broken scales. These trips; week 28, 34, 44 & 45 in 2018 and week 15 in 2019 were removed for the analyses below.

To investigate if pulse nets do indeed catch more shrimp over other marine life in comparison to traditional nets, three models were made to answer the research questions:

- What is the difference between pulse and traditional nets regarding the “shrimp VS non-shrimp” ratio?
- What is the difference between pulse and traditional nets regarding the “commercial shrimp VS rest” ratio?
- What is the difference between pulse and traditional nets regarding the “commercial shrimp VS discard shrimp” ratio?

Linear models were used where each group of observations (a group is a vessel, identified by its PPY_ID value) is allowed to have its own variance. This is a form of a Generalized Least-Squares (GLS) model. All models used the same covariates:

- Months: a categorical variable for the months, going from 2 (February) to 11 (November).
- Pulsenet: a binary covariate indicating whether a catch was made using a pulse net (1) or traditional net(0).
- Wadden Sea: a binary covariate indicating whether a catch was made in the Wadden Sea (1), or elsewhere (0).
- SUBGEAR: The same as GEAR_SUBTYPE - a categorical variable indicating which gear adjustment was used to reduce discards in shrimp fisheries; possible categories are: “letterbox”, “sievenet”, or “none”. Sievenet was the reference level.

Model interpretation

There were three models, one model for each of these ratios as the response variable. The ratios in question were the following:

$$\text{shrimp VS non-shrimp:} \frac{\text{Catch}_{\text{csh}}}{\text{Catch}_{\text{total}} - \text{Catch}_{\text{csh}} + 75}$$

$$\text{commercial shrimp VS rest:} \frac{\text{Catch}_{\text{commercial\_csh}}}{\text{Catch}_{\text{total}} - \text{Catch}_{\text{commercial\_csh}} + 75}$$

$$\text{commercial shrimp VS discard shrimp:} \frac{\text{Catch}_{\text{commercial\_csh}}}{\text{Catch}_{\text{discard\_csh}} + 75}$$

So, if the “shrimp vs non-shrimp” - ratio for an observation was 2, it meant that the weight per square hectare of shrimp was twice as large for an observation, compared to the weight per square hectare of non-shrimps. And if this ratio was 0.25, it means that the weight per square hectare of non-shrimps was four times larger than the weight per square hectare of shrimps.

Similarly, if the “commercial vs discard shrimp” - ratio for an observation was 0.5, it meant that the weight per square hectare of commercial shrimps (shrimps with length ≥ 50mm) was two times smaller for an observation than the weight per square hectare of discard shrimps (shrimps with length < 50mm).

And if the “commercial shrimp vs the rest” - ratio was 2, it meant that the weight per square hectare of commercial shrimps was two times larger than the weight per square hectare of everything that wasn't commercial shrimp.

Note that +75 was added to the denominator to each of the ratios. This was done to prevent the ratios getting extremely high values, which was necessary for modelling purposes, but has no effect on the interpretation of the model as explained above.

Interpretation of the model covariates

All covariates in the models were binary or categorical variables. And all models were log-linear.

The interpretation of a binary covariate in a log-linear model is as follows. Suppose x_1 is a binary covariate, and corresponds to a coefficient β_1. If x_1 is 1 the response ratio will be multiplied by $\exp(\beta_1)$ compared to if x_1 is 0, provided all other covariates do not change.

The interpretation of a categorical covariate is as follows. Suppose x_{month} is the categorical covariate for months, with levels 2 to 11, where level 2 (February) is the reference level, and levels 3 (March) to 11 (November) correspond to the coefficients β_{mar}, β_{apr}, …, β_{nov}. Each of these coefficients show the difference between that corresponding month and February. So if an observation is on month 3 (March), the response ratio will be multiplied by $\exp(\beta_{\text{mar}})$ compared to the same observation in February, provided all other covariates do not change. If an observation is on month 10 (October), the response ratio will be multiplied by $\exp(\beta_{\text{oct}})$ compared to the same observation in February, provided all other covariates do not change.

2.6 software used

R version 3.6.3 (64 bit) (R Core Team 2020) and R-Studio version 1.3.959 (RStudio Team 2020) were used for all programming and all computations.

3 Results

3.1 Landings and total catches

Data on landings per unit of effort (kg boiled shrimp per ha, LPUE) and catch per unit of effort (in volume of the catch per ha, CPUE) are available from data-recording (2.2) from the comparative gear trials (2.3). The amount of data from data-recording in the North Sea Coastal zone area is limited and in the Voordelta no data-recording data is available.

3.1.1 LPUE

Looking at the data of the comparative gear trials (Figure 4) and the self-recording trials (Figure 5) the difference in landings of shrimp are practically all within the confidence intervals, and thus no large differences of shrimp landings can be observed between traditional gear and pulse gear. The GLS that was applied on the data of the gear trials, showed no statistical differences between the LPUE's of traditional and pulse gear. The model does show that the month of the year is a distinctive variable to determine the LPUE, as well as the sub gear type that was used (Table 5).

Table 5: Model coefficients table for boiled shrimp weight per square hectare (LPUE)

covariate	estimate	exp(estimate)	std.error	t-value	p-value	
(Intercept)	0.82086	2.2724	0.12597	6.516	1.402e-10	***
pulsenet	0.06944	1.0719	0.05152	1.348	0.1781432	
WaddenSea	0.10846	1.1146	0.07946	1.365	0.1727426	
month3	0.6025	1.8267	0.16053	3.753	0.0001894	***
month4	0.32274	1.3809	0.17562	1.838	0.0665436	.
month5	-0.08355	0.9198	0.16676	-0.501	0.6165301	
month6	0.38263	1.4661	0.17855	2.143	0.0324715	*
month7	0.95826	2.6072	0.16755	5.719	1.601e-08	***
month8	1.38959	4.0132	0.16904	8.22	1.022e-15	***
month9	0.29097	1.3377	0.15459	1.882	0.0602260	.
month10	0.7154	2.045	0.1497	4.779	2.158e-06	***
month11	0.61833	1.8558	0.16476	3.753	0.0001896	***
SUBGEAR letterbox	-0.15179	0.8592	0.0993	-1.529	0.1268498	
SUBGEAR none	0.71362	2.0414	0.13092	5.451	7.008e-08	***

Note: ^^ The reference level used for the months here is 2(February)

Figure 4 Landings per Unit of Effort (LPUE): landed shrimp weight in kg boiled shrimp per square hectare collected during the gear trials using paired hauls to compare pulse gear with traditional gear (per region, month, week and the gear subtypes sievenet, letterbox and none)

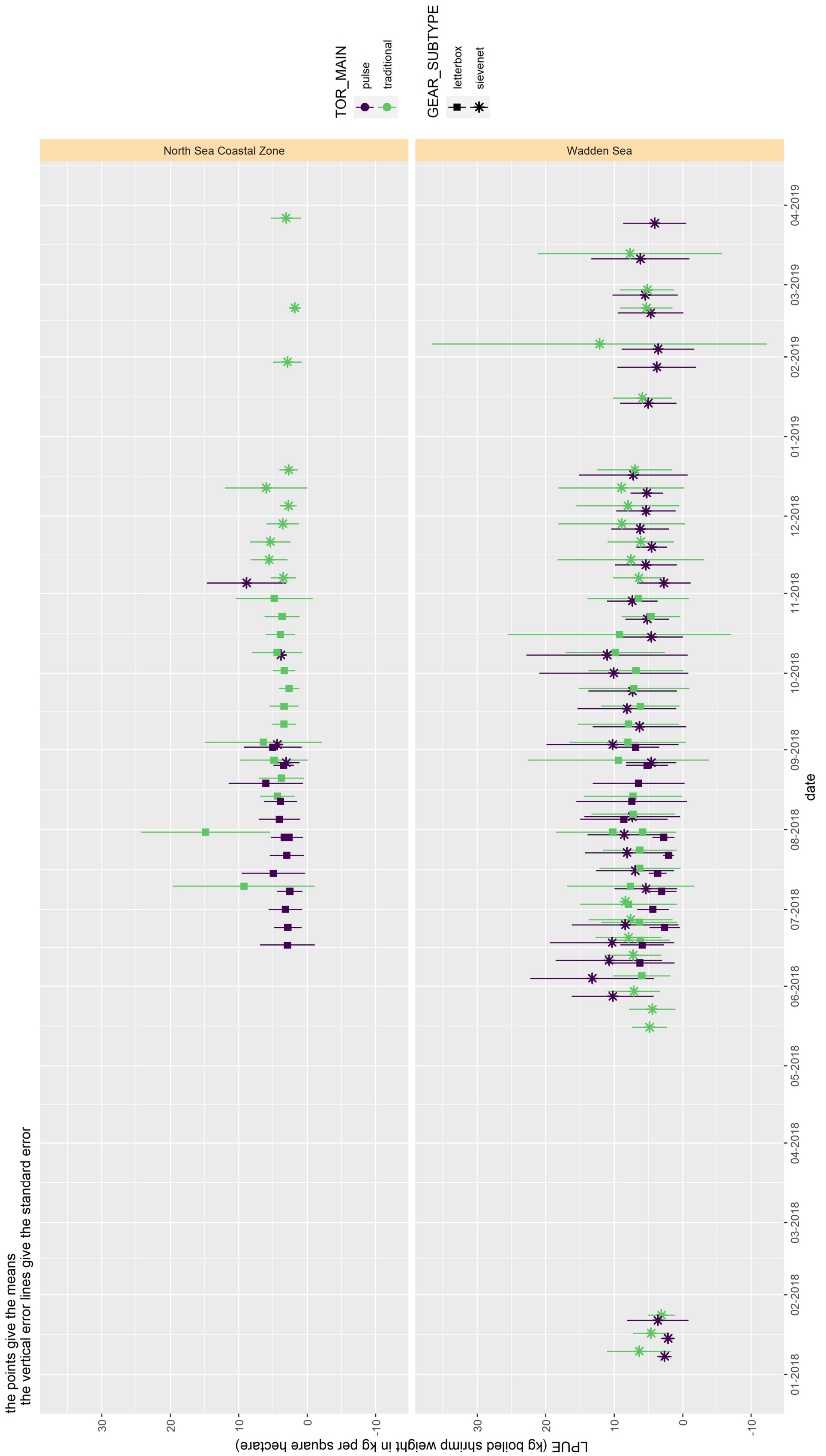

Figure 5: Self-recorded Landings Per Unit Effort (LPUE): boiled shrimp weight in kg per square hectare collected during the gear trials using paired hauls to compare pulse gear with traditional gear per area (North Sea Coastal Zone, Wadden Sea) and gear subtype (sievenet or letterbox).

3.1.2 CPUE

Looking at the data of the comparative gear trials (Figure 6) the difference in total catch volumes are practically all within the confidence intervals, and thus no large differences can be observed between traditional gear and the pulse gear. The GLS that was applied on the data of the gear trials showed no statistical differences between the CPUE's of traditional and pulse gear. The model does show that the month of the year is a distinctive variable to determine the LPUE, as well as the sub gear type that was used (Table 6). Also, the area was found to be an important factor to determine the catch volumes; the volumes were on average higher in the Wadden Sea and in the months July-November. When looking at the data recording (Figure 7); the CPUE's of the traditional vessels in the Wadden Sea were, especially in Q4 of the year 2018, often much higher than the CPUE's of the pulse vessels. Although this picture was opposite in 3 weeks where the CPUEs of pulse nets was higher than the traditional nets. In all cases the data showed large variation.

Table 6: Model coefficients table for total catch volume per square hectare (CPUE)

covariate	estimate	exp(estimate)	std.error	t-value	p-value	
(Intercept)	2.77001	15.9588	0.17883	15.49	< 2.2e-16	***
pulsenet	0.02722	1.0276	0.04766	0.5712	0.5680559	
WaddenSea	0.46029	1.5845	0.06533	7.0454	4.532e-12	***
month3	-0.18926	0.8276	0.19689	-0.9613	0.3367547	
month4	0.26132	1.2986	0.19847	1.3167	0.1883897	
month5	-0.13758	0.8715	0.19973	-0.6888	0.4911598	
month6	-0.26976	0.7636	0.21137	-1.2762	0.2023106	
month7	0.72038	2.0552	0.20717	3.4772	0.0005388	***
month8	1.28379	3.6103	0.20811	6.1689	1.179e-09	***
month9	0.79161	2.207	0.20797	3.8064	0.0001537	***
month10	0.60363	1.8288	0.20376	2.9625	0.0031580	**
month11	1.07151	2.9198	0.20689	5.179	2.940e-07	***
SUBGEAR letterbox	0.40686	1.5021	0.10469	3.8865	0.0001116	***
SUBGEAR none	0.07912	1.0823	0.17114	0.4623	0.6440215	

Note: ^^ The reference level used for the months here is 2(February)

Figure 6 Catch per unit of effort (CPUE): total catch volume in litre per square hectare collected during the gear trials using paired hauls to compare pulse gear with traditional gear (per region, month, week and the gear-subtypes sievenet, letterbox and none).

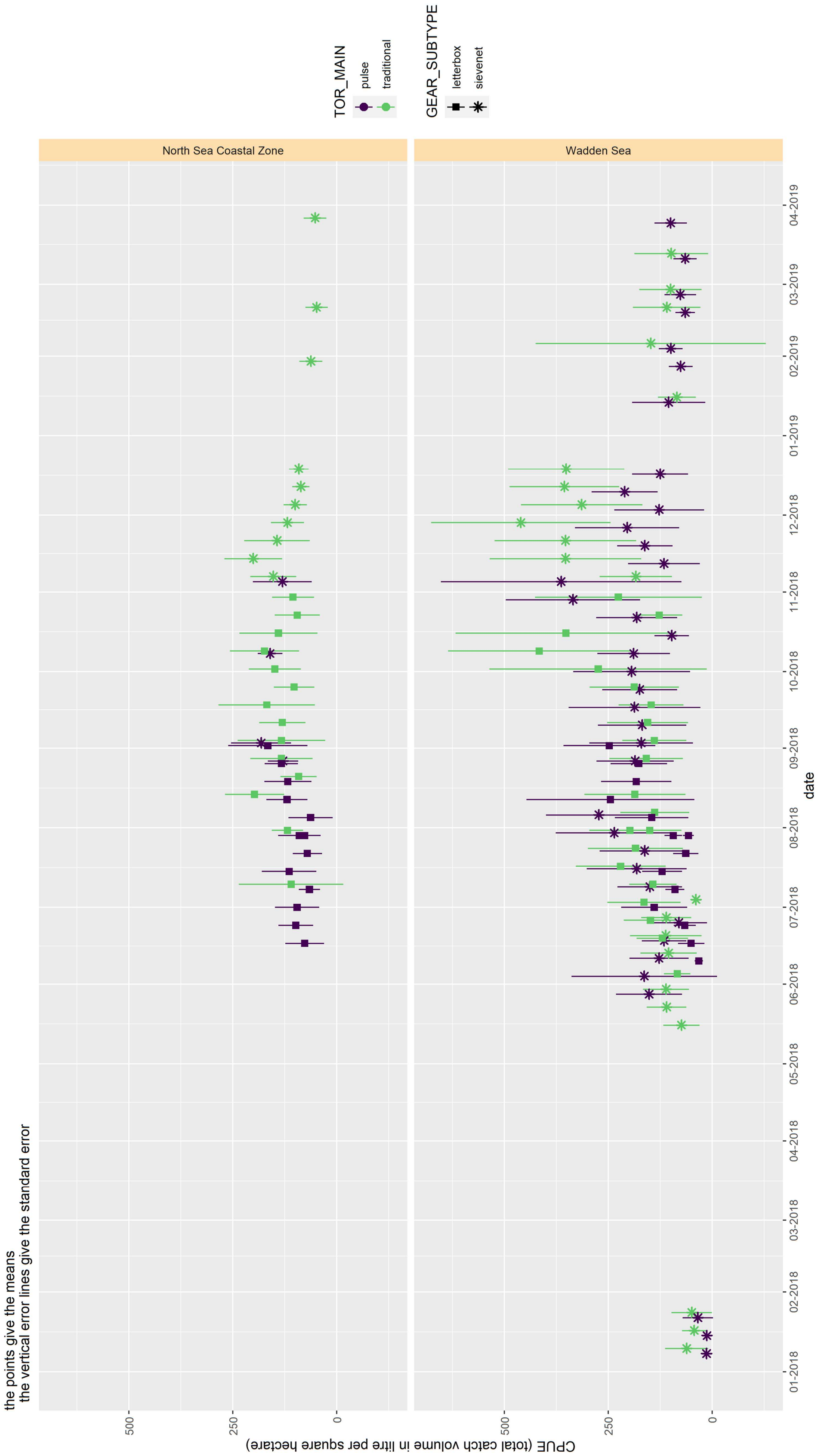

Figure 7: Self-recorded Catch Per Unit Effort (CPUE): total catch volumes in litre per square hectare recorded by vessels using pulse gear and the buddy vessels using traditional gear, per region and gear subtype (sievenet or letterbox).

3.2 Catch composition

The proportional distributions "pulse vs traditional" of the different species groups found in the catches are shown in Figure 8; flatfish, fish and benthos weights were proportionally higher or (close to) equal in the samples of the traditional gears. For the two shrimp fractions and the marine crabs the results were varying.

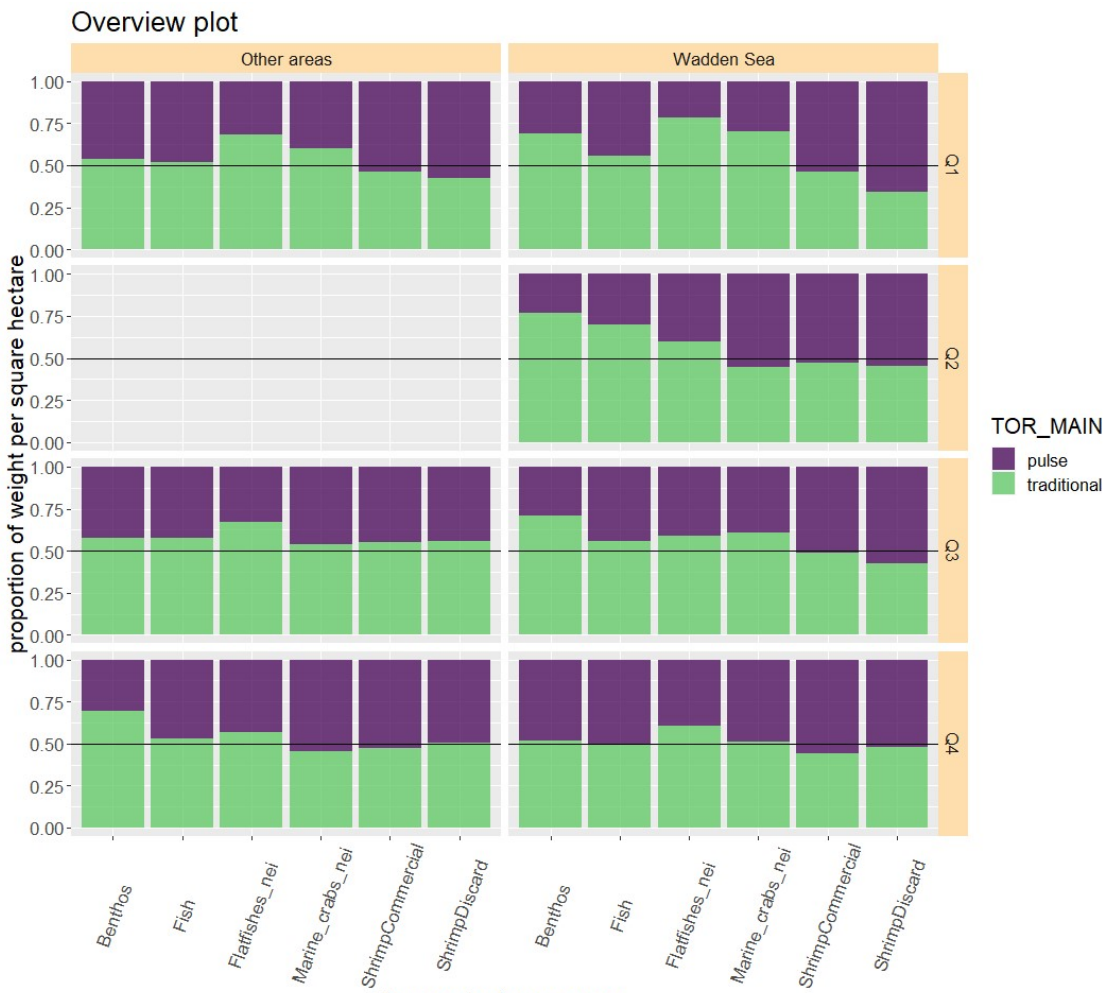

Figure 8 the catches in weight per square hectare per "species group" and its proportional distribution over the pulse and traditional methods in "other areas" (Voordelta and North Sea Coastal Zone together) and the Wadden Sea and per quarter of the year. For visual clarity, a horizontal line is added to each plot on the 0.5 proportion (50%) point. The group fish are all fish excepted from flatfish. Benthos are all invertebrates except marine crabs and shrimps. Shrimp discards are the shrimp found in the catches <50mm, commercial shrimps are shrimps with length ≥ 50mm.

The results of the three models providing insight into the ratio's "Shrimp vs non-shrimp", "Commercial Shrimp vs Discard Shrimp" and "Commercial Shrimp VS the rest" are shown in resp. Table 7, Table 8 **and**

Table 9. The model outcomes show that:

- Whether pulse gear or traditional gear is used is significant for the "Shrimp vs non-shrimp" ratio (Table 7). For pulse gear the ratio is 1.55 times higher than traditional nets, meaning that the pulse gear caught 55% more shrimps in relation to non-shrimp bycatches when compared to the traditional gear.
- There is no significant difference between pulse and traditional gear for the ratio commercial shrimps (shrimps with length ≥ 50mm) versus small shrimps (shrimps with length < 50mm) (Table 8).

- There is a significant difference between pulse and traditional gear for the "commercial vs the rest" ratio (p-value < 0.05): For pulse gear the ratio of commercial shrimps versus the bycatch (small shrimp and other species together) is 1.12 times higher than for traditional gear (Table 9). This means that in the nets of pulse gear 12% more commercial shrimps are caught in relation to the other (by)catch when compared to nets from traditional gear.

Furthermore, with regards to the covariates month, area and gear subtype we see that:

- Month is an important factor in all models; meaning that the catch composition is also dependent on the month in which the fisheries took place.
- The covariate "area of fishing activity": in or outside the Wadden Sea made a significant difference for both the "commercial shrimp vs discard shrimp" and the "commercial shrimp vs the rest" ratios, and in both cases the proportion of commercial shrimps in the catches are higher in the areas outside the Wadden Sea.For the "shrimp vs non-shrimp" ratio, the area the fishing activity took place did not make a (significant) difference.
- Catch composition also depends on the gear subtype that was used for the " shrimp vs non-shrimp ratio" in both cases (using a letterbox instead of a sievenet or using " no subgear" instead of a sievenet). and for the "commercial shrimp vs the rest" ratio when using a letterbox instead of a sievenet.

Table 7 Model coefficients table for Shrimp VS non-Shrimp. Exp(estimate) provides the ratio of the provided "covariate" compared to a given reference. WS = Wadden Sea

covariate		estimate	exp(estimate)	std.error	t-value	p-value	
(Intercept)		0.88767	2.4295	0.17335	5.1206	4.362e-07	***
Gear type	Pulse gear versus traditional gear	0.44112	1.5544	0.07563	5.8327	9.835e-09	***
Area of fishing activity	Outside WS versus inside WS	0.18799	1.2068	0.12918	1.4553	0.1462241	
month	March versus February	1.36865	3.93	0.21473	6.3738	4.213e-10	***
month	May versus February	-0.53488	0.5857	0.23826	-2.2449	0.0252121	*
month	June versus February	0.14317	1.1539	0.26317	0.544	0.5866551	
month	July versus February	0.98472	2.6771	0.24459	4.026	6.559e-05	***
month	August versus February	1.89891	6.6786	0.28391	6.6884	6.088e-11	***
month	September versus February	-0.69248	0.5003	0.20382	-3.3975	0.0007346	***
month	October versus February	-0.8599	0.4232	0.21169	-4.062	5.652e-05	***
month	November versus February	1.15814	3.184	0.26433	4.3814	1.439e-05	***
SUBGEAR	Letterbox versus sievenet	1.44839	4.2563	0.14856	9.7493	< 2.2e-16	***
SUBGEAR	None versus sievenet	0.06341	1.0655	0.16755	0.3785	0.7052484	

Table 8: Model coefficients table for Commercial Shrimp VS Discard Shrimp. Exp(estimate) provides the ratio of the provided "covariate" compared to a given reference.

covariate		estimate	exp(estimate)	std.error	t-value	p-value	
(Intercept)		2.33919	10.3728	0.14126	16.5595	< 2.2e-16	***
Gear type	Pulse gear versus traditional gear	-0.06132	0.9405	0.05333	-1.1499	0.250748	
Area of fishing activity	Outside WS versus inside WS	-0.35883	0.6985	0.08998	-3.9881	7.660e-05	***
month	March versus February	-0.75801	0.4686	0.16771	-4.5197	7.750e-06	***
month	May versus February	-1.23808	0.2899	0.18314	-6.7603	3.872e-11	***
month	June versus February	-0.89479	0.4087	0.18478	-4.8425	1.715e-06	***
month	July versus February	-1.43838	0.2373	0.19276	-7.4619	3.841e-13	***
month	August versus February	-1.74742	0.1742	0.18956	-9.2182	< 2.2e-16	***
month	September versus February	-1.15377	0.3154	0.16583	-6.9578	1.096e-11	***
month	October versus February	-1.13541	0.3213	0.17075	-6.6494	7.772e-11	***
month	November versus February	-0.6441	0.5251	0.19569	-3.2915	0.001067	**
SUBGEAR	Letterbox versus sievenet	0.08803	1.092	0.111	0.7931	0.428094	
SUBGEAR	None versus sievenet	-0.47325	0.623	0.1358	-3.4848	0.000536	***

Table 9: Model coefficients table for Commercial Shrimp VS the rest. Exp(estimate) provides the ratio of the provided "covariate" compared to a given reference.

covariate		estimate	exp(estimate)	std.error	t-value	p-value	
(Intercept)		0.6285	1.8747	0.12897	4.873	1.481e-06	***
Gear type	Pulse gear versus traditional gear	0.117	1.1242	0.05205	2.249	0.02497	*
Area of fishing activity	Outside WS versus inside WS	-0.23	0.7946	0.08984	-2.56	0.01077	*
month	March versus February	0.3878	1.4737	0.15642	2.479	0.01351	*
month	May versus February	-0.7984	0.45	0.17224	-4.636	4.556e-06	***
month	June versus February	-0.2461	0.7818	0.17873	-1.377	0.16911	
month	July versus February	-0.2501	0.7787	0.17713	-1.412	0.15859	
month	August versus February	-0.4096	0.6639	0.18498	-2.214	0.02728	*
month	September versus February	-0.9252	0.3964	0.15173	-6.098	2.158e-09	***
month	October versus February	-0.9954	0.3696	0.15707	-6.337	5.247e-10	***
month	November versus February	0.3506	1.4199	0.18469	1.898	0.05825	.
SUBGEAR	Letterbox versus sievenet	0.9296	2.5335	0.1067	8.712	< 2.2e-16	***
SUBGEAR	None versus sievenet	-0.2098	0.8107	0.12455	-1.685	0.09268	.

3.3 Numbers per hectare

A list of all species found in the catch is provided in Annex 4.

3.3.1 Numbers of fish in the bycatch

Table 10, 11 and 12 show the numbers of fish/ha found in respectively the Wadden Sea, North Sea Coastal Zone and the Voordelta during the gear trials.
Table 13, 14, 15 and 16 show the numbers of fish/ha found per quarter of the year during the gear trials.

In most cases gobies, clupea (herring and sprot) and either plaice or dab (in the North Sea coastal Zone and in Q1) were the top three species found in the catches.

Clupea (herring and sprat)
For clupea only in Q1 a significant difference was found: 12% more clupeas were caught with the pulse trawl than with traditional gear. No significant differences between other areas or between seasons were established.

Gobies
For gobies the outcomes varied: in Q1 no difference between pulse and traditional gear was found, in Q2 and Q3 more gobies were found in the traditional gear (resp. 55% and 44%) and in Q4 more gobies were found in the pulse gear (38%). In the North Sea Coastal Zone and Voordelta more gobies were found in the traditional gear (resp. 40 and 46%). However, in the Wadden Sea the pulse gear caught (34%) more gobies.

Other roundfish
In the Wadden Sea significant higher numbers of bullrout, hooknose, viviparous blenny and bib were caught with traditional gear. Differences between the other species of round fish were not significant in this area. Significantly more five bearded rockling were caught with the pulse gear in the Voordelta. For the sand eels in the catches also significant differences were found in as well the North Sea Coastal Area and the Voordelta as in Q2 and Q3. Interesting enough in Q2 significantly less sand eels were caught with the pulse gear as opposed to Q3 were significantly more sand eels were caught with the pulse gear.

Plaice
Significantly more plaice were caught with traditional gear than with pulse in all areas (31-38%). Considering the time of the year, only in Q2 and Q3 significantly more plaice was caught with traditional beam trawl than with the pulse trawl. In the other quarters of the year no significant differences were established.

Dab
In Q3, the North Sea Coastal Zone and the Voordelta dab was found in significantly higher numbers in the traditional gear nets. In the Wadden Sea no significant difference was found.

Other Flatfish
Significantly less sole and flounder were caught with the pulse gear in all areas. Scald fish is the only flatfish (though in low numbers) that was caught in higher numbers with the pulse gear (in the NSCZ and in Q2).

Table 10 Bycatches of fish in the pulse trawl and traditional trawl in the Wadden Sea, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse gear	Traditional gear	Difference %	pvalue
Goby	Grondels indet.	292.87	219.24	**-34**	0.001
Plaice	Schol	265.11	426.63	**38**	0.000
Clupea	Haringachtigen	53.41	50.47	-6	0.056
Sole	Tong	16.80	18.70	**10**	0.011
Bullrout	Zeedonderpad	9.85	16.24	**39**	0.000
Dab	Schar	9.28	9.23	-1	0.437
Whiting	Wijting	6.21	5.13	-21	0.340
Flounder	Bot	4.57	8.20	**44**	0.002
Pipefish indet.	Zeenaalden indet.	4.58	5.32	14	0.113
Smelt	Spiering	3.14	3.40	8	0.921
Hooknose	Harnasmannetje	2.63	2.71	**3**	0.002
Viviparous blenny	Puitaal	1.57	2.36	**34**	0.001
Butterfish	Botervis	1.18	1.24	5	0.597
Bib	Steenbolk	0.66	1.70	**61**	0.001

Table 11 Bycatches of fish in the pulse trawl and traditional trawl in the North Sea Coastal Zone, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse gear	Traditional gear	Difference %	p-value
Goby	Grondels indet.	270.31	451.09	**40**	3E-04
Clupea	Haringachtigen	40.33	74.40	46	0.727
Dab	Schar	23.55	32.64	**28**	0.006
Pipefish indet.	Zeenaalden indet.	17.76	25.83	31	0.867
Whiting	Wijting	15.90	12.59	-26	0.345
Plaice	Schol	6.05	8.83	**31**	0.022
Sole	Tong	5.12	10.24	**50**	0.003
Scaldfish	Schurftvis	2.50	0.91	**-174**	6E-04
Solenette	Dwergtong	2.50	2.67	6	0.807
Greater sand eel	Smelt	1.79	0.79	**-126**	0.015
Five-bearded rockling	Vijfdradige meun	1.40	1.05	-33	0.78
Callionymus sp.	Pitvissen indet.	1.14	0.97	-18	0.162
Sandeel indet.	Zandspieringen indet.	1.14	1.16	1	0.522
Hooknose	Harnasmannetje	0.98	1.17	16	0.167
Flounder	Bot	0.57	2.28	**75**	0.002

Table 12 Bycatches of fish in the pulse trawl and traditional trawl in the Voordelta, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English name	Dutch name	Pulse gear	Traditional gear	Difference %	p-value
Goby	Grondels indet.	237.10	438.93	**46**	7E-05
Clupea	Haringachtigen	115.41	174.24	34	0.329
Plaice	Schol	56.09	84.45	**34**	0.015
Whiting	Wijting	40.62	58.53	31	0.147
Dab	Schar	35.79	82.02	**56**	0.008
Sole	Solea	22.02	35.60	38	0.171
Pipefish indet.	Zeenaalden indet.	10.38	8.43	-23	0.148
Callionymus sp.	Pitvissen	7.88	14.07	44	0.136
Hooknose	Harnasmannetje	4.19	7.31	43	0.141
Sand eel indet.	Zandspieringen indet.	3.21	0.34	**-830**	0.029
Five-bearded rockling	Vijfdradige meun	2.79	1.40	**-100**	0.01
Bullrout	Zeedonderpad	2.64	2.47	-7	0.942
Bobtail indet.	Dwerginktvissen indet.	1.79	1.14	-58	0.175
Scaldfish	Schurftvis	1.57	1.45	-8	0.077
Smelt	Spiering	1.00	1.21	17	0.394
Flounder	Bot	0.83	2.31	**64**	0.019

Table 13 Bycatches of fish in the pulse trawl and traditional trawl in Q1 (January, February, March, all areas), expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse gear	Traditional gear	difference %	pvalue
Goby	Grondels indet.	170.00	195.79	13	0.632
Clupea	Haring, sprot	71.68	63.50	**-13**	0.047
Dab	Schar	9.37	12.87	27	0.139
Plaice	Schol	4.37	5.58	21	0.493
Whiting	Wijting	2.00	2.24	10	0.915
Solenette	Dwergtong	1.79	1.32	-36	0.249
Sand eel indet.	Zandspieringen	1.61	0.61	-165	0.061
Viviparous blenny	Puitaal	1.47	0.97	-51	0.338
Sole	Tong	1.42	2.42	41	0.196
Smelt	Spiering	1.34	2.45	45	0.656
Pipefish indet.	Zeenaalden indet.	1.18	0.55	-114	0.164
Sea bass	Zeebaars	1.16	1.68	31	0.098
Flounder	Bot	1.13	4.29	73	0.073

Table 14 Bycatches of fish in the pulse trawl and traditional trawl in Q2 (April, May, June, all areas), expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse	Traditional	difference %	p-value
Plaice	Schol	732.75	1181.06	**<u>38</u>**	1.30E-08
Clupea	Haring, sprot	39.70	44.60	11	0.06
Goby	Grondels indet.	14.42	32.10	**<u>55</u>**	2.34E-04
Pipefish indet.	Zeenaalden indet.	5.98	6.35	6	0.63
Whiting	Wijting	4.58	5.90	22	0.23
Dab	Schar	3.75	6.00	**<u>38</u>**	0.03
Smelt	Spiering	3.35	4.28	22	0.19
Scaldfish	Schurftvis	1.67	0.93	**<u>-81</u>**	0.01
Solenette	Dwergtong	0.95	1.39	31	0.20
Flounder	Bot	0.77	1.01	**<u>24</u>**	0.04
Hooknose	Harnasmannetje	0.55	1.18	**<u>53</u>**	0.03
Sand-eel indet.	Zandspieringen indet.	0.45	1.19	**<u>63</u>**	0.01

Table 15 Bycatches of fish in the pulse trawl and traditional trawl in Q3 (July, August, September, all areas), expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English name	Dutch name	Pulse	Traditional	difference %	p-value
Goby	Grondels indet.	170.66	304.84	**<u>44</u>**	2.61E-05
Clupea	Haring, sprot	82.41	106.75	22	0.06
Plaice	Schol	32.95	52.63	**<u>37</u>**	5.16E-08
Sole	Tong	32.60	40.94	**<u>20</u>**	2.96E-04
Dab	Schar	30.16	47.97	**<u>37</u>**	0.03
Whiting	Wijting	23.26	26.99	13	0.49
Bull-rout	Zeedonderpad	13.97	23.89	**<u>41</u>**	2.40E-05
Pipefish indet.	Zeenaalden indet.	12.53	13.72	9	0.72
Hooknose	Harnasmannetje	5.16	6.09	**<u>15</u>**	3.81E-03
Callionymus sp.	Pitvissen indet.	3.07	5.36	**<u>43</u>**	0.04
Five-bearded rockling	Vijfdradige meun	1.72	1.53	-12	0.09
Sand-eel indet.	Zandspieringen indet.	1.64	0.53	**<u>-209</u>**	0.04
Butterfish	Botervis	1.36	1.26	-8	0.69
Flounder	Bot	1.26	2.22	**<u>43</u>**	0.04
Bib	Steenbolk	1.24	2.59	**<u>52</u>**	0.01

Table 16 Bycatches of fish in the pulse trawl and traditional trawl in Q4 (October, November, December, all areas), expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse gear	Traditional gear	Difference %	p-value
Goby	Grondels indet.	796.64	575.88	**<u>-38</u>**	0.000
Clupea	Haring, sprot	39.82	50.52	21	0.868
Plaice	Schol	14.92	18.81	21	0.238
Flounder	Bot	10.58	19.86	**<u>47</u>**	0.000
Whiting	Wijting	9.37	8.169	-15	0.534
Sole	Solea	6.52	9.518	32	0.106
Dab	Schar	5.04	7.072	29	0.197
Bull-rout	Zeedonderpad	4.53	4.952	9	0.550
Smelt	Spiering	4.25	3.518	-21	0.457
Pipefish indet.	Zeenaalden indet.	3.42	7.578	**<u>55</u>**	0.014
Viviparous blenny	Puitaal	2.72	2.759	1	0.293
Five-bearded rockling	Vijfdradige meun	2.39	1.458	-64	0.700
Sand-eel indet.	Zandspieringen indet.	1.19	1.253	5	0.350
Hooknose	Harnasmannetje	0.98	1.229	21	0.488

3.3.2 Numbers of invertebrates in the bycatch per area

Table 17, 18 and 19 show the numbers of invertebrates/ha found in respectively the Wadden Sea, North Sea Coastal Zone and the Voordelta during the gear trials. Especially in the Wadden Sea the differences found between the pulse and traditional gear were found to be significant; starfish (39%), swimming crab indet. (2%), green crab (48%), serpent star indet. (66%), sea anemones (62%), common mussel (70%) and hermit crabs (80%) were al found in higher numbers in the traditional gear. In North Sea Coastal Zone this was the case for starfish (21%), hermit crabs (57%) and sea anemones (51%) and in the Voordelta for green crab (45%), common squids (75%) and common spider crab (81%).

Table 17 Bycatches of invertebrates in the pulse trawl and traditional trawl in the <u>Wadden Sea</u>, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gear types expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English names	Dutch names	Pulse gear	Traditional gear	Difference %	p-value
Starfish	Zeester	136.98	223.00	<u>**39**</u>	0.000
Swimming crab indet.	Zwemkrabben indet.	119.79	122.43	<u>**2**</u>	0.040
Green crab	Strandkrab	80.32	153.57	<u>**48**</u>	0.000
Serpent star indet.	Slangsterren indet.	10.65	31.55	<u>**66**</u>	0.000
Sea anemones	Zeeanemonen	10.77	28.20	<u>**62**</u>	0.000
Common mussel	Mossel	8.35	27.56	<u>**70**</u>	0.001
Razor clams	Zwaardschedes indet.	2.98	3.68	19	0.704
Common squids nei	Pijlinktvissen indet.	1.63	2.69	39	0.872
Hermit crab indet.	Heremietkreeften indet.	0.43	2.08	<u>**80**</u>	0.000

Table 18 Bycatches of invertebrates in the pulse trawl and traditional trawl in the <u>North Sea Coastal Zone</u>, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gear types expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English name	Dutch name	Pulse gear	Traditional gear	Difference %	p-value
Swimming crab indet.	Zwemkrabben indet.	423.93	417.28	-2	0.405
Serpent star indet.	Slangster	29.86	30.10	1	0.336
Starfish	Zeester	25.59	32.33	<u>**21**</u>	0.008
Razor clams	Zwaardschedes indet.	6.69	12.41	46	0.076
Green crab	Strandkrab	4.17	5.55	25	0.096
Hermit crab indet.	Heremietkreeften indet.	1.40	3.26	<u>**57**</u>	0.007
Sea anemones	Zeeanemonen	0.66	1.34	<u>**51**</u>	0.015

Table 19 Bycatches of invertebrates in the pulse trawl and traditional trawl in the <u>Voordelta</u>, expressed as mean number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gear types expressed as percentage (traditional vs pulse). In case the difference was significant it is made bold and underlined. Species caught in amounts lower than 1/ha at both gear types are excluded from the table.

English name	Dutch name	pulse gear	traditional gear	Difference %	p-value
Swimming crab indet.	Zwemkrabben indet.	536.50	568.52	6	0.551
Serpent star indet.	Slangsterren indet.	249.50	482.47	48	0.23
Razor clams	Zwaardschedes indet.	21.86	26.41	17	0.134
Blunt gaper	Afgeknotte gaper	12.86	37.98	66	0.813
Spisula sp.	Strandschelpen indet.	9.83	33.71	71	0.066
Green crab	Strandkrab	9.38	17.05	<u>**45**</u>	0.008
Hermit crab indet.	Heremietkreeften indet.	5.36	4.52	-19	0.659
Abra sp.	Abra sp.	4.12	9.84	58	0.203
Norwegian egg cockle	Noorse hartschelp	3.03	11.55	74	0.112
Common cockle	Kokkel	2.64	21.29	88	0.083
Starfish	Zeester	1.59	7.09	78	0.588
Nassarius sp.	Fuikhoorns indet.	1.26	3.24	61	0.167
Common squids nei	Pijlinktvissen indet.	0.59	2.33	<u>**75**</u>	0.007
Common spider crab	Hooiwagenkrab	0.52	2.69	<u>**81**</u>	0.021

4 Conclusion & Discussion

The *overall* conclusion of the baseline study is that shrimp fishing using pulsetrawls does not result in higher amounts of undesired bycatches of small (non-commercial) shrimp, fish and benthos when compared to the traditional shrimp beamtrawl fisheries.

The weigth of small shrimps (<50 mm) in the catch relative to the commercial shrimps was the same for pulse gear and traditional gear. The weight of undesired bycatch of other species in relation to the total shrimp weight, on the contrary, was higher for the traditional gear than for pulse gear. This bycatch is all unwanted in the shrimp fishery and thus being discarded. The bycatch consisted of fish, marine crabs and other invertebrates. When a sievenet wat used it prevented large animals from entering the nets, however these were prone to getting full of algae rendering the net unusable. The Dutch coastal zone & the Wadden Sea functions as an important nursery area for young fish (Glorius et al., 2015) and the commercial fish species in the catches; plaice, clupea species (herring and sprot), whiting, dab and sole were indeed young individuals. Like in other studies (Steenbergen et al, 2015; Glorius et al, 2015) the amounts did depend on season and location; plaice for example was found in high numbers in the months April, May, June and in the Wadden Sea while dab numbers were higher in the North Sea Coastal Zone and the Voordelta and in the months July, August and September.

When it comes to the difference in selectivity between the pulsetrawl and the traditional beamtrawl on a species level there was no significant difference in selectivity between pulse gear and traditonal gear for the mayority of the the species. In the results some species showed seasonal and locational variance; in the period April – September more significant differences were found between the two gear types than in the other months for fish and invertebrate species. In most cases the pulse gear was more selective than the traditional gear, in other words higher numbers were found in the traditional gear. The pulse gear was significantly more selective for catches of the flatfish species plaice and flounder in all areas, for dab in the North Sea Coastal Zone and the Voordelta and for sole in the Wadden Sea and the North Sea Coastal Zone. The pulsetrawl was also *significantly* more selective for the round-fish species bullrout, hooknose, viviparous blenny and bib (only in the Wadden Sea). Sand eels on the other hand, were in some cases significantly more abundant in the pulsetrawl nets, just as the clupea species in Q1 and five-bearded rockling in the Voordelta and the flatfish species scald fish in the North Sea Coastal Zone. For the highly abundant goby contradicting outcomes showed more gobies in traditional trawl nets in Q2 and Q3 and more gobies in the pulse trawl nets in Q4.

The reason why some species are more abundant in traditional gear versus pulse gear or vice versa can be explained by a combination of the reaction of a fish species to the initial exposure to the electric field and the presence of more escape openings between the bobbins in the pulse gear (Verschueren et al (2019). Desender et al. (2016) studied the behavioural response of some fish species to the 5 Hz startle pulse; some (the round fish species shorthorn sculpin, hooknose bullhead and in particular cod) showed active and agitated swimming activity during laboratory exposure where others (adult plaice and the majority of sole) showed only minor reactions and remained close to the seafloor during laboratory experiments. In both cases less bycatch can be expected with the current configuration of the pulse gear as less bobbins are used in that gear and fish either have more escape opportunities (in case of active response) or less chance of being caught (in case of minor reaction). A possible cause for species found more abundantly in pulse gear nets, can be the reaction to the stimulus (in upward direction), however as these species were not studied in the lab: this remains unclear. Also, the fact that gobies showed different response to the gears dependent of different areas is difficult to explain. For most of the species however these seasonal and local differences can most probably be explained by differences in abundance of the species in different areas/seasons; When more individuals of a certain species are caught, then the chance of finding a significant difference is higher. In the Natura2000 areas Allis shad (*Allosa alosa*) and Lamprey's (*Petromyzon marinus,* *Lampetra fluviatilis*) where present in in the Wadden Sea only, but numbers and frequency were so low that no statements can be made about significant differences in selectivity between the two gear types.

Part 2: Innovations

1 Approach

The innovation part started with an innovation workshop on 12/10/2018 in IJmuiden. The aim of the workshop was to collect and discuss existing ideas of possible pulse gear improvements. This meeting was attended by pulse fishermen, a government representative, international gear technology scientists, a representative from the Dutch NGO natuurmonumenten, net makers, and fishing industry representatives. The outcome of the meeting was a variety of innovative ideas for pulse gear improvements, which the fishermen wanted to experiment with (see annex). Ideas included different electrode lengths (where shorter was hypothesised to be better), raising the height of the electrodes above the seabed, changing the distance between the ground rope and electrodes, trying a sieve mat in the square net mouth instead of the classic sieve net which is difficult to clean, using letterbox type meshes in front of the cod-end, using thinner and/or higher bobbins, testing different pulse settings (amplitude, current & hertz), changing the trawl design for deeper waters (cfr. a sole pulse trawl design). An overview of the proposed innovations is given in Table 20, providing additional information on the challenges or opportunities they addressed.

Table 20: Overview of the chosen innovations discussed during the workshop and why and when they should be used.

Challenge Opportunity	*Reduced effectiveness Pulse*	*General development*	*Bycatch small flatfish*	*Bycatch small Sole*
Elaboration	When the water temperature drops below ± 15 degrees Celsius the pulse method becomes drastically less effective in capturing shrimp and therefore the traditional method that catches more benthos is preferred	The pulse gear is a very recent technique and has great opportunity to be improved. A greater capture ability allows fishermen to adopt otherwise less favourable selective devices in favour of a more selective fishery	During summer, a large quantity of small flatfish are caught (up to 50% of the total catch volume). Timing is dependent on Plaice (consistent) and Dab (irregular) spawning	Large quantities of small Sole are caught
Season	End of fall, winter and early spring (Nov-May)	All year	Summer (Jul-Aug)	End of fall to early spring (Jan-Mar)
Innovation	Different footrope with more and/or thinner bobbins	Height electrodes, length electrodes, distance between ground rope and electrodes, sieve mat, trawl design, pulse settings	Higher bobbins and/or adjustments in the height of the electrodes	Higher bobbins and/or an escape letterbox mesh in front of the cod-end
Goal	To increase effectiveness in periods with cold water to strive towards a similar functioning as the traditional gear or pulse gear in summer	To explore the full potential of the pulse gear, improving shrimp catches and decreasing bycatches and discards. Potential elevations in shrimp catches could be used to counteract the negative effects on shrimp catches using a more selective method and as such accomplish a more selective and sustainable fishery without financial losses for the fishermen	To reduce the bycatch of small flatfish in periods when this is most problematic. This innovation could potentially be used all summer long, during which the pulse method works more effective than the traditional one	To reduce the bycatch of Sole in periods when this is most problematic

2 Material & Methods

2.1 Experimental design

Innovating in fisheries is an interactive process between scientists and fishermen, where theory is constantly tested against the findings of the fishermen at sea. Due to limited funds, it is nearly impossible to imitate large scale gear innovations on a research vessel, and it is especially difficult to take the seasonal and spatial dependencies of the shrimp fishery into account. To solve these difficulties, the fishermen themselves deployed innovative gear systems on their ships and they were allowed to adjust the settings on a weekly basis, which also helped to keep them motivated for the project. This allowed us to test for the greatest variety of innovations and settings and by doing so, it maximized the chances to find appropriate improvements to drive the sector towards a more sustainable future.

During the innovation process, haul data and catches were collected in the same way as was done during the baseline study. A clear log of the changes made to the gear was included for every haul in excel, according to the data recording protocol. To facilitate direct interpretation of the data by the fishermen, the excel showed total catch per side and proportions of landings versus discards (see section 2.2).

In discussion with the fishermen, the three most promising and practically feasible innovations were selected for an observer trip. For most innovations, the fishermen were able to compare the normal pulse gear to the innovative pulse configuration. When catch losses with the normal pulse method were too substantial to force fishermen to use this technique without compensation (ex. winter period), the innovative gear was compared with traditional gear (round bobbin rope).
An overview of the fishing grounds and tested innovations during this part of the project (2019-2020) is presented in Table 21.

Table 21: Overview of the fishing grounds on which the participating fishing vessels were active during the innovation period, along with the innovation that was tested during each month.

2019		HA31	ST24	WR40
January	fishing ground	Wadden Sea	-	Wadden Sea or slightly above
	Experiment	Varying lengths of electrodes and distance to the bobbins	-	Discs between the bobbins
February	fishing ground	Wadden Sea	-	Wadden Sea or slightly above
	Experiment	Varying lengths of electrodes and distance to the bobbins	-	Discs between the bobbins
March	fishing ground	-	-	-
	Experiment	-	-	-
April	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Sieve mat	-
May	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Sieve mat	-
June	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Sieve mat	-
July	fishing ground	Wadden Sea	-	-
	Experiment	Varying lengths of electrodes and distance to the bobbins	-	-
August	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying lengths of electrodes and distance to the bobbins	Discs between the bobbins	-
September	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying lengths of electrodes and distance to the bobbins	Discs between the bobbins	-
October	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying lengths of electrodes and distance to the bobbins	Discs between the bobbins	-
November	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying lengths of electrodes and distance to the bobbins	Discs between the bobbins	-
December	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-

Table 21 continued.

2020		HA31	ST24	WR40
January	fishing ground	-	-	-
	Experiment	-	-	-
February	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-
March	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-
April	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-
May	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-
June	fishing ground	-	Wadden Sea or slightly above	-
	Experiment	-	Discs between the bobbins	-
July	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying pulse settings	Discs between the bobbins	-
August	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying pulse settings	Discs between the bobbins	-
September	fishing ground	Wadden Sea	Wadden Sea or slightly above	-
	Experiment	Varying pulse settings	Discs between the bobbins	-
October	fishing ground	Wadden Sea	-	-
	Experiment	Varying pulse settings	-	-
November	fishing ground	Wadden Sea	-	-
	Experiment	Varying pulse settings	-	-
December	fishing ground	Wadden Sea	-	-
	Experiment	Varying pulse settings	-	-

The protocol for the data recording and the observer trips was identical to the protocols during the baseline study (part 1, 2.2 and 2.3). A brief summary of both protocols is given below.

2.2 Data recording

During the entire project, the skipper collected and reported his key fishing data. This way, both skipper and scientists were able to track the performance of the adapted fishing gear over a longer period and on different fishing grounds throughout the year and assess the impact of possible fine tuning of the rigging.

For each trip, the skipper indicated general information such as departure and arrival time from harbour, which innovation he was testing and the type of sieve net he used. Next, the following data was provided for each haul:

- the time and location of shooting and hauling;
- meteorological conditions and water depth;
- total catch volume obtained with the gear (measured as the height of the catch in the hopper);
- the total kg of cooked commercial shrimp for each gear.

2.3 Observer trip

Two scientific observers joined the fishing trip for ± 48 h carrying out about 15 to 20 direct catch comparisons between the reference gear and the experimental gear. Catches from both sides were processed separately in several steps:

1. Measuring the total volume in each hopper;
2. Taking a representative sample of about 12-20 L of the catch from the hopper and weighing it;
3. Sorting the entire sample per species;
4. Determining the volume and weight of the shrimp in the sample and taking a 1 L subsample to perform length-measurements in the laboratory;
5. Counting the number of individuals per invertebrate species and determining their total volume (and weight if possible);
6. Measuring the length of each flatfish and round fish and determining their total volume (and weight if possible;
7. Determining the total volume (and weight if possible) of the rubble fraction, consisting of non-organic materials such as stones and thrash, or unwanted organic material such as vegetal substances, empty shells, and jelly fish.

At the end of each trip, the average mesh opening of both cod-ends was determined using an omega mesh gauge to ensure that the results obtained with both configurations could correctly be compared.

3 Results

3.1 Testing of different electrode set-ups (HA31)

3.1.1 Introduction

HA31 experimented with different setups regarding the length and position (distance to bobbin rope) of the electrodes. These setups were compared to the standard pulse gear to see whether changes in the length and/or distance would have benefits on the catch of commercial shrimp and/or whether the changes can reduce the amount of bycatch.

3.1.2 Results & discussion

3.1.2.1 Fishing grounds

During the data recording, HA31 was active in the Wadden Sea (Figure 8).

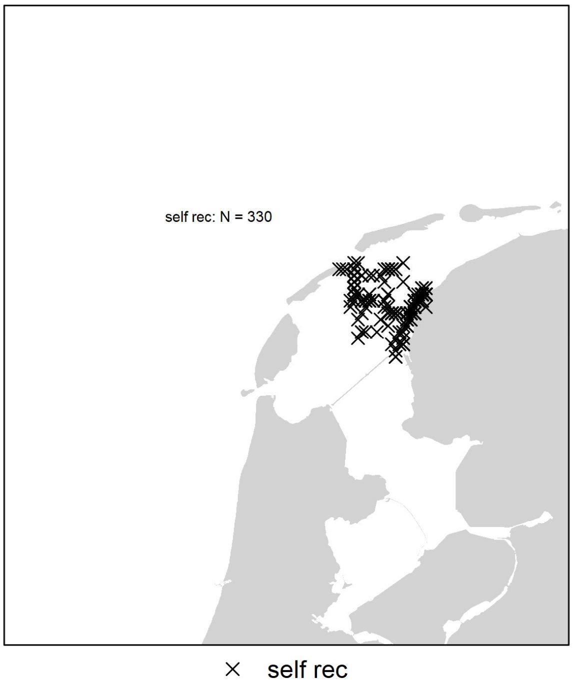

Figure 8: The locations where HA31 fished during the period she tested the different electrode setups. Each black cross indicates a haul during which data recording took place (week 3 until 50 of 2019).

3.1.2.2 Data recording

The results of the gathered data by HA31 with the different electrode setups are summarized in the tables below (Table 22 and 23). The data in all the tables is aggregated by weekly fishing trips, containing multiple hauls. Two different setups were compared with standard pulse gear, or the "reference gear" which has electrodes with a length of 110 cm and a distance of 55 cm between the electrodes and the bobbins located at the front of the net. For the two experimental setups the length of the electrodes was reduced to 80 cm with a respective distance of 80 cm (Table 22) or 55 cm (Table 23) to the bobbins.
The experimental pulse setup in which the electrode length was reduced from 110 cm to 80 cm and the distance from the electrodes to the bobbins was increased from 55 cm to 80 cm (Table 22) did not manage to provide promising results regarding the shrimp catch, total volume catch, or the discard

volumes. The results (haul data aggregated over fishing trips) showed a slight, although negligible, increase of less than one percent in the catch of cooked shrimp (+0,93%), but there is great variation from -46% (low amount of hauls with very small catch on both sides) to +16%. The results for the total catch volume show a stronger increase with 2,55%, which is more than double the increase found for the shrimp catches. The variation here is lower, and generally comprises of an increase in the total volume caught (between -9% and +26%). For the discard volumes an increase of 4,87% was found. The data showed mostly an increase per sampling week with some variation (between -9% and +35%) although it was generally an increase in the amount of volume discarded.

Table 22: Comparison of cooked commercial shrimp catch (S), total catch volume (V), and total discard volume (D) between an electrode length of 110 cm with a 55 cm distance from the electrodes to the bobbins (reference) and an electrode length of 80 cm with an 80 cm distance from the electrodes to the bobbins (experimental).

Week	# hauls	Reference			Experimental			Exp vs Ref		
		S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D
3 – 2019	10	590	2126	1344	595	2339	1536	1%	10%	14%
4 – 2019	14	1050	4239	2840	995	4133	2893	-5%	-3%	2%
5 – 2019	13	585	2388	1433	575	2513	1734	-2%	5%	21%
6 – 2019	10	400	1639	1000	400	1648	1022	0%	1%	2%
7 – 2019	16	600	2477	1586	605	2625	1759	1%	6%	11%
8 – 2019	11	295	1098	670	315	1248	811	7%	14%	21%
27 – 2019	31	1125	6847	5204	1140	6216	4724	1%	-9%	-9%
28 – 2019	5	280	1436	1048	150	1365	1120	-46%	-5%	7%
30 – 2019	22	780	5880	4645	770	5781	4625	-1%	-2%	0%
34 – 2019	18	1060	6588	5336	1005	6075	4860	5%	8%	10%
37 – 2019	9	190	917	642	210	1159	869	11%	26%	35%
38 – 2019	23	1310	7339	5577	1445	8288	6464	10%	13%	16%
39 – 2019	16	880	4970	3827	1025	5777	4448	16%	16%	16%
Total	198	9145	47944	35151	9230	49165	36864	0,93%	2,55%	4,87%

The experimental pulse setup in which the electrode length was reduced from 110 cm to 80 cm but the distance from the electrodes to the bobbins was kept at 55 cm as is in the traditional pulse setup (Table 19), showed a different pattern. A slight increase of 0,56% is notable in the amount of cooked commercial shrimp with a low amount of variation (-3% to +5%) while at the same time the total caught volume and total discard volumes decrease with 2,61% and 2,51% respectively, although this is mostly due to week 48 in which the experimental pulse caught much less bycatch (-19% total volume and -17% discard), while the other weeks, these two parameters are mostly increasing and vary between -6% and +4%.

Table 23: Comparison of cooked commercial shrimp catch (S), total catch volume (V), and total discard volume (D) between an electrode length of 110 cm with a 55 cm distance from the electrodes to the bobbins (reference) and an electrode length of 80 cm with a 55 cm distance from the electrodes to the bobbins (experimental).

Week	# hauls	Reference			Experimental			Exp vs Ref		
		S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D
41 – 2019	14	1180	4391	2854	1220	4570	2925	3%	4%	2%
42 – 2019	9	560	2766	2047	590	2785	2033	5%	1%	-1%
43 – 2019	22	1645	6390	4218	1590	6551	4389	-3%	3%	4%
44 – 2019	27	2035	7569	4920	2085	7903	5137	2%	4%	4%
46 – 2019	26	1785	7619	5257	1740	7229	4916	-3%	-5%	-6%
48 – 2019	21	1650	6253	4064	1680	5037	3375	2%	-19%	-17%
Total	119	8855	34989	23360	8905	34076	22775	0,56%	-2,61%	-2,51%

3.1.2.3 Observer trip

Due to the negative, or low impact results mentioned above, this project was not continued further in 2020 and no observer trip was added to gather data.

3.1.3 Conclusion

To see whether the length of the electrodes or the distance from the electrodes to the bobbins would have had a positive effect on the catch of commercial shrimp and a negative effect on bycatch and discard rates, these setups were altered and compared to a traditional pulse setup. From the obtained results we could see that reducing the length of the electrodes from 110 cm to 80 cm and increasing the distance from the electrodes to the bobbins from 55 cm to 80 cm is not ideal as all three parameters were slightly elevated. A less than one percent increase in commercial shrimp catch was obtained although the total catch volume increased by more than double and the discard volume had a fivefold increase compared to the commercial shrimps caught. On the other hand, the combination of shorter electrodes (80 cm) but with the same distance of the electrodes to the bobbins as a traditional pulse trawl (55 cm), had positive but still negligible effect as there is half a percent increase in shrimp catch while the total catch volume and discard volume decreased with over two and a half percent.

We can conclude by saying that altering the setup of the electrodes, related to their length or their distance to the bobbins, is not useful or preferred as the obtained results showing a negligible increase in the amount of cooked commercial shrimp with limited reductions in catch volumes and discard volumes. There was even an increase in discards that is proportionally multiple times higher than the gained amount of shrimps that accompanied these setup changes. As such, the traditional pulse setup is preferred over the tested experimental pulse setups.

3.2 Testing of different pulse settings using the EPLG Pulse gear (HA31)

3.2.1 Introduction

Pulse trawls use electrical pulses to catch fish or shrimp. When the pulse reaches the shrimp, the muscles in the animal automatically contract or cramp. This results in the shrimp "leaping" from the bottom into the trawl mouth. HA31 investigated if it was possible to obtain cleaner catches by making small changes in pulse characteristics. To do so, on one side the standard Marelec pulse trawl gear was replaced by gear from EPLG (see 9). An advantage of the EPLG pulse gear, is that it allows alteration of the pulse settings by the fishermen themselves (within certain boundaries) while the settings of the Marelec gear are fixed and thus could not be altered. The three settings of the pulse that were tweaked between trawls were the voltage of the given pulse, the duration of the pulse, and the frequency of the pulse.

Figure 9: Marelec (top) and EPLG gear (bottom).

3.2.2 Results & discussion

3.2.2.1 Fishing grounds

During both data recording and the observer trip, HA31 was only active in the Wadden Sea, as indicated in Figure 10.

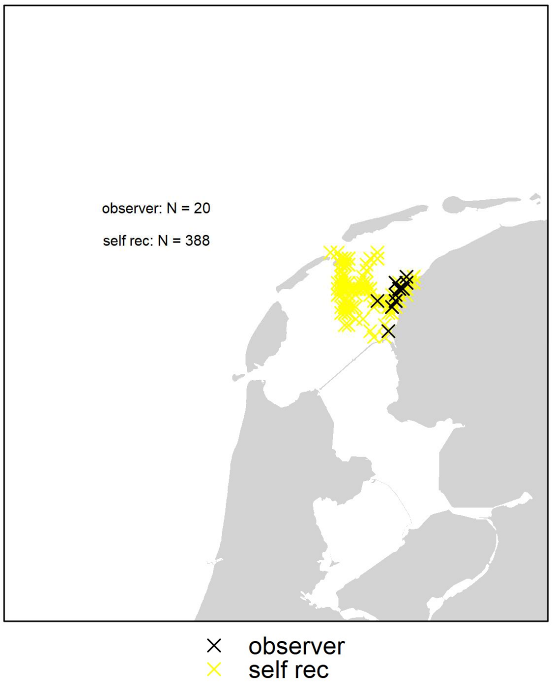

Figure 10: The locations where the HA31 fished during the period she tested his experimental gear. Each yellow cross indicates a haul during which data recording took place (week 26 until week 51 of 2020), the black crosses indicate the hauls that were sampled, sorted and analysed for a detailed direct catch comparison during the observer trip (week 43 of 2020).

3.2.2.2 Data recording

The data recording took place from week 26 until week 51 of 2020. In total, 388 hauls were sampled. Because of malfunctions in the EPLG gear during the first weeks of deployment, 80 hauls had to be excluded from further analysis. The experimental gear (EPLG) was deployed on starboard, the reference gear (Marelec) on portside. The results of the gathered data by HA31 with the EPLG pulse equipment and the different settings are summarized in Table 24. Rather than piling all the data of the experimental setting into one result table, a comparison has been made between a reference pulse trawl from *Marelec* with the standard pulse settings of 70 Volt, a 0,5 ms pulse duration, and a frequency of 5 Hz and ten other experimental sets of settings. These sets vary in the amount of voltage, pulse duration and frequency. From the ten different sets of settings, only two have positive results. These are highlighted in bold. The impact of the other 8 sets on the three measured parameters: cooked commercial shrimp catch, total catch volume, and discard volume, which was generally minimal and without use for further implementation or investigation.
One pulse setting provided positive results and is highlighted in bold in Table 24. With a lower voltage (55V), shorter pulse duration (0,3ms), and a higher frequency (6Hz) than the traditional pulse settings showed a 3% increase in the amount of cooked commercial shrimp accompanied by a 1% reduction in total catch volume and a 2% decrease in discard volume. Another remarkable result was obtained with a lower voltage (65V), shorter pulse duration (0,3ms), and lower frequency (3Hz) than the traditional pulse settings (also indicated in bold). These settings showed a very strong decrease in all three parameters. There was a decrease of almost 20% in the total catch volume and just over 20% in the discard volume. These reductions where however accompanied by an unacceptable loss of ≈10% in the amount of commercial shrimp.

Table 24: Comparison of cooked commercial shrimp catch (S), total catch volume (V), and total discard volume (D) between a reference pulse setting of 70 Volt, a 0,5 ms pulse duration, and a frequency of 5 Hz, and an experimental variable pulse setting system.

# hauls	Reference			Experimental			Exp vs Ref			Experimental settings		
	S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D	Pulse (V)	Duration (ms)	Frequency (Hz)
35	1300	6245	4521	1265	6058	4399	-2,69%	-3,01%	-2,71%	55	0,3	5
20	***970***	***4150***	***2864***	***1000***	***4121***	***2802***	***3%***	***-1%***	***-2%***	***55***	***0,3***	***6***
37	1965	8308	57842	1925	81462	56728	-2,04%	-1,95%	-1,94%	55	0,5	5
44	1350	6341	4529	1370	657	4767	1,48%	3,62%	5,33%	55	0,5	7
16	***835***	***5438***	***4352***	***755***	***4455***	***3465***	***-9,58 %***	***-18,08 %***	***-20,38 %***	***65***	***0,3***	***3***
22	545	3782	2912	525	3502	2697	-4%	-7%	-7%	65	0,3	4
20	585	4830	3864	575	4502	3602	-2%	-7%	-7%	65	0,3	6
12	670	2495	1622	680	2467	1628	1%	-1%	0%	65	0,5	3
39	2540	11669	8230	2435	11302	7970	-4,13%	-3,14%	-3,16%	65	0,5	5
63	3155	13694	9423	3070	13339	9251	-2,69%	-2,59%	-1,83%	65	0,5	6

3.2.2.3 Observer trip

The observer trip took place during week 43 of 2020, during this trip 20 hauls were sampled. The experimental gear (EPLG) was deployed on starboard, the reference gear (Marelec) on portside. Pulse settings of the EPLG gear varied during the trip. Because of bad weather conditions during the trip, no weight measurements could be done for 5 hauls.

Table 25: Pulse settings of both EPLG and Marelec gear and number of sampled hauls for each setting during the observer trip. The number of sampled hauls including weights are noted between brackets.

	PS = Marelec	SB = EPLG		
	Ref.	Config. 1	Config. 2	Config. 3
Sampled hauls (including weights)		7 (6)	9 (9)	4 (0)
Pulse duration [ms]	0,5	0,5	0,3	0,5
Pulse frequency [Hz]	5	5	5	3
Peak voltage [Vpeak]	70	65	65	65

Catches during the observer trip were very clean, consisting of 92% and 94% shrimp (all sizes) on SB and PS respectively. This suggests that the sampling rate of bycatch on both SB and PS was very low, making it difficult to compare the bycatch (other than small shrimp) of both gear types. The difference in catch rate for each fraction between the Marelec gear and the EPLG gear is illustrated in Figure 11, Figure 12, and Figure 13 for pulse settings configuration 1 (6 hauls), configuration 2 (9 hauls), and configuration 1 + 2 (15 hauls) respectively. No weights were available for configuration 3.

The very large confidence intervals are caused by the very low bycatch rates. However, the EPLG gear had significantly higher bycatch rates of small (<50 mm) shrimp for both configuration 1 and 2. No significant differences were observed for commercial sized shrimp. The only other bycatch rates that differed significantly between both gears were flatfish (configuration 2, higher catch rates with EPLG) and benthos (configuration 1 + 2, lower catch rates with EPLG).

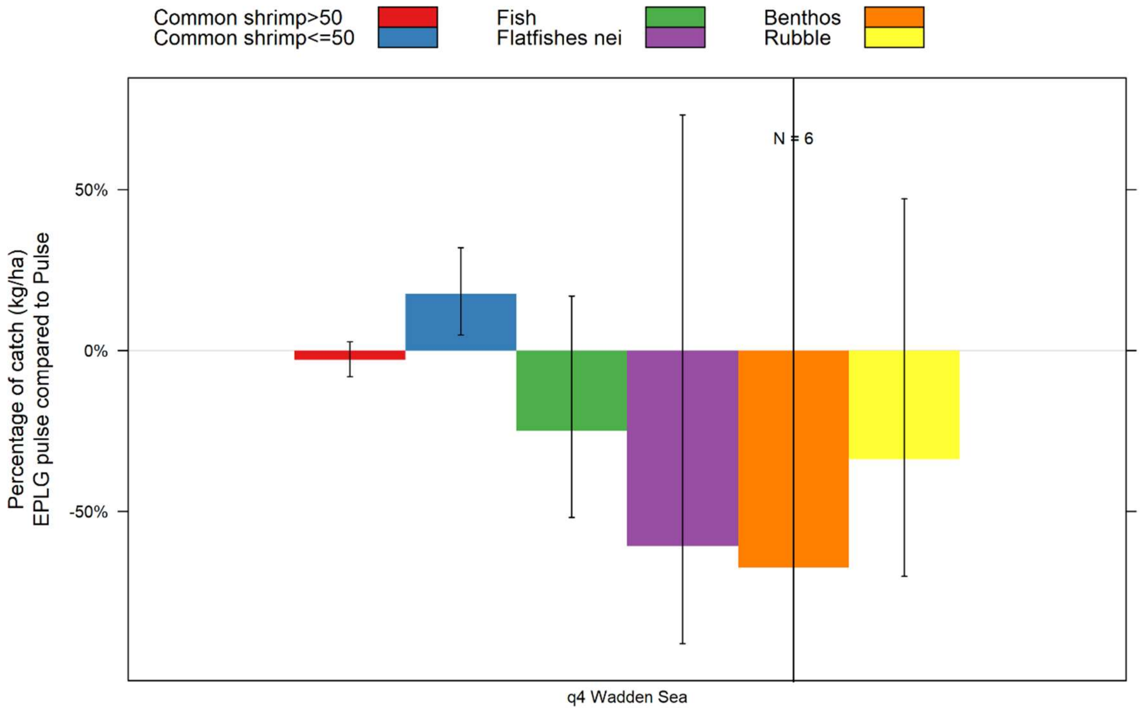

Figure 11: Differences in catch rate (kg/ha) for each fraction sampled during the observer trip, pulse settings "Configuration 1".

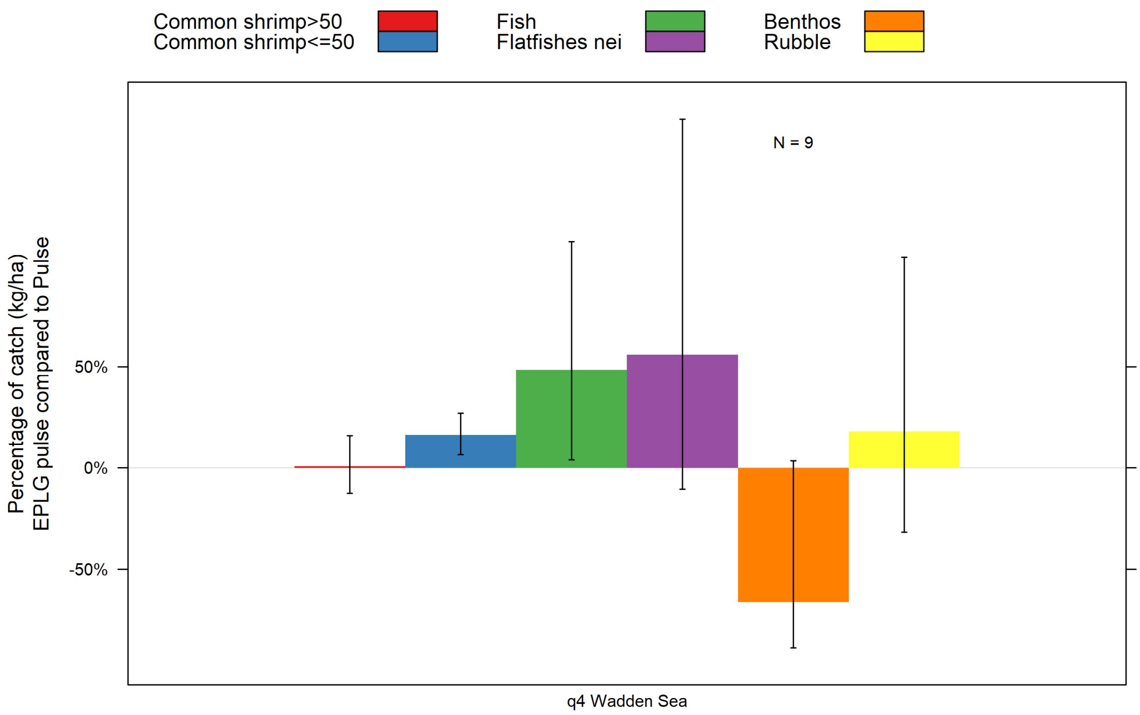

Figure 12: Differences in catch rate (kg/ha) for each fraction sampled during the observer trip, pulse settings "Configuration 2".

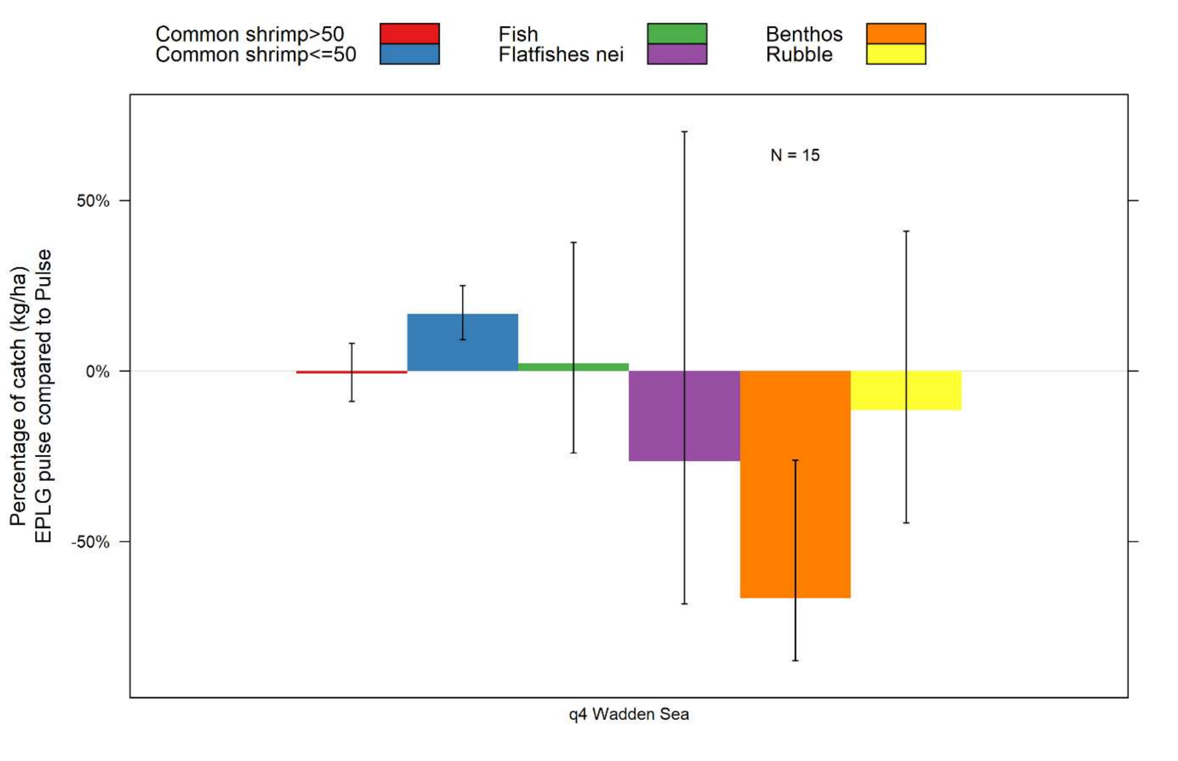

Figure 13: Differences in catch rate (kg/ha) for each fraction sampled during the observer trip, pulse settings "Configuration 1" + "Configuration 2".

The difference in catch rates between the 2 gear types/settings for shrimp can also be observed in their length-frequency distributions (LFD's), which show that the EPLG gear caught systematically more shrimp smaller than 50 mm whereas the catch rates of commercially sized shrimp are variable and do not show a clear pattern (Figure 14, Figure 15, and Figure 16 for configuration 1, configuration 2 and configuration 1 +2 respectively).

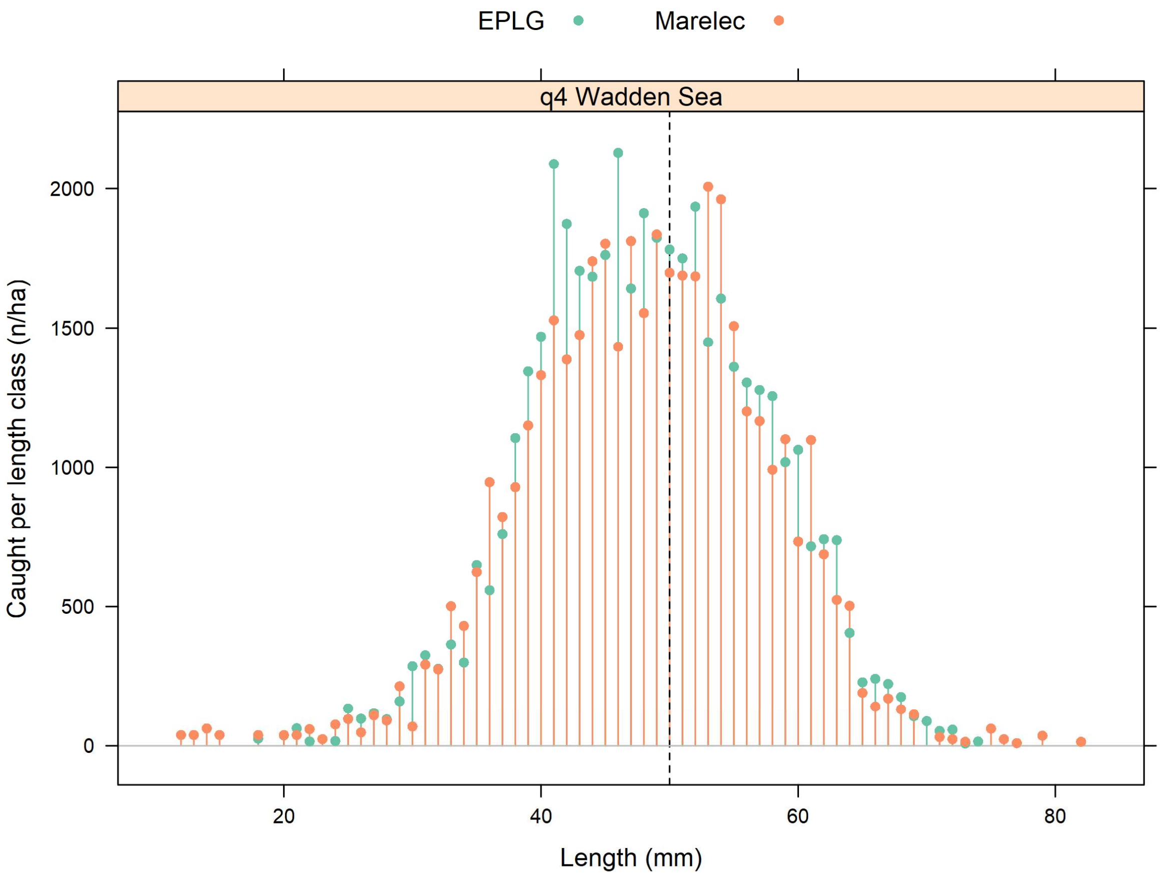

Figure 14: The number of shrimp per length class caught per hectare (n/ha) by the EPLG (green) and Marelec gear (orange) for "Configuration 1". The vertical dotted line at 50 mm represents the threshold between small and discarded shrimp (left) and shrimp of commercial size (right).

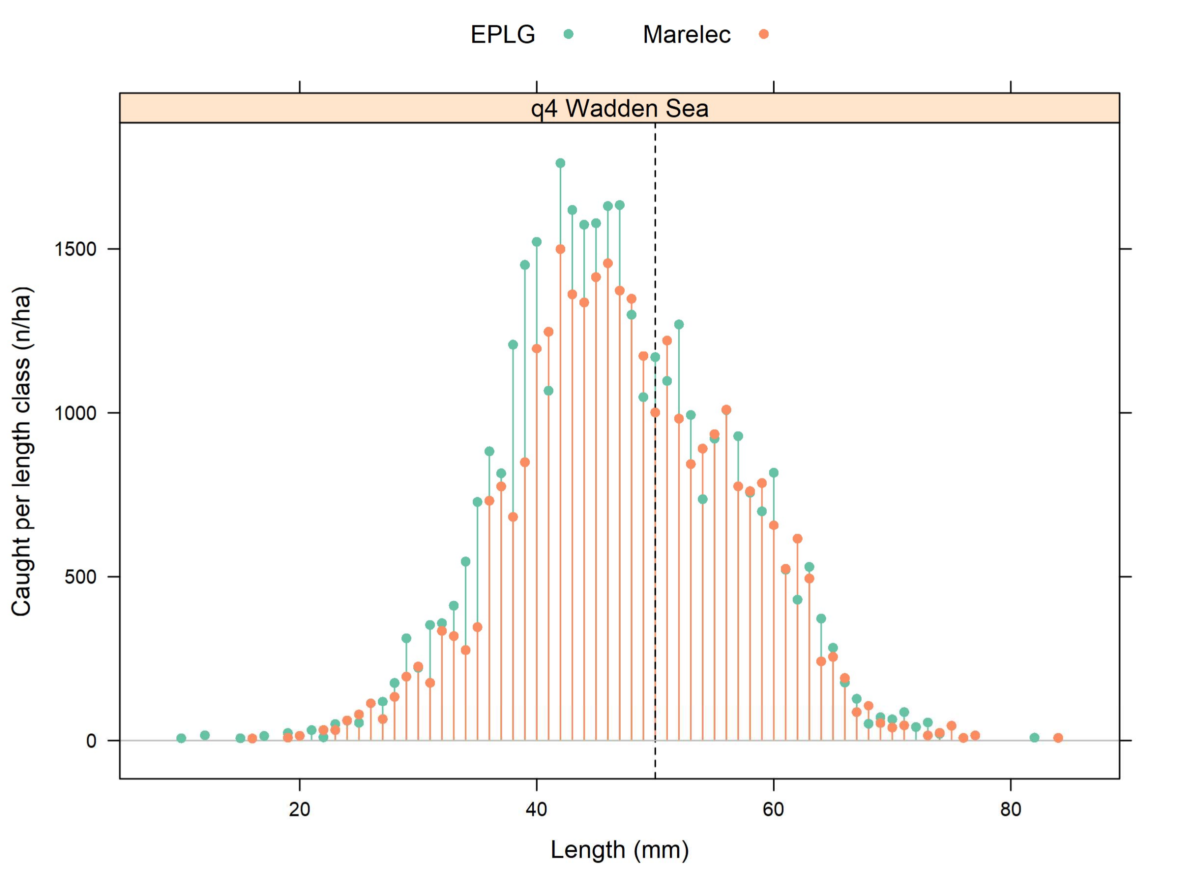

Figure 15: The number of shrimp per length class caught per hectare (n/ha) by the EPLG (green) and Marelec gear (orange) for "Configuration 2"). The vertical dotted line at 50 mm represents the threshold between small and discarded shrimp (left) and shrimp of commercial size (right).

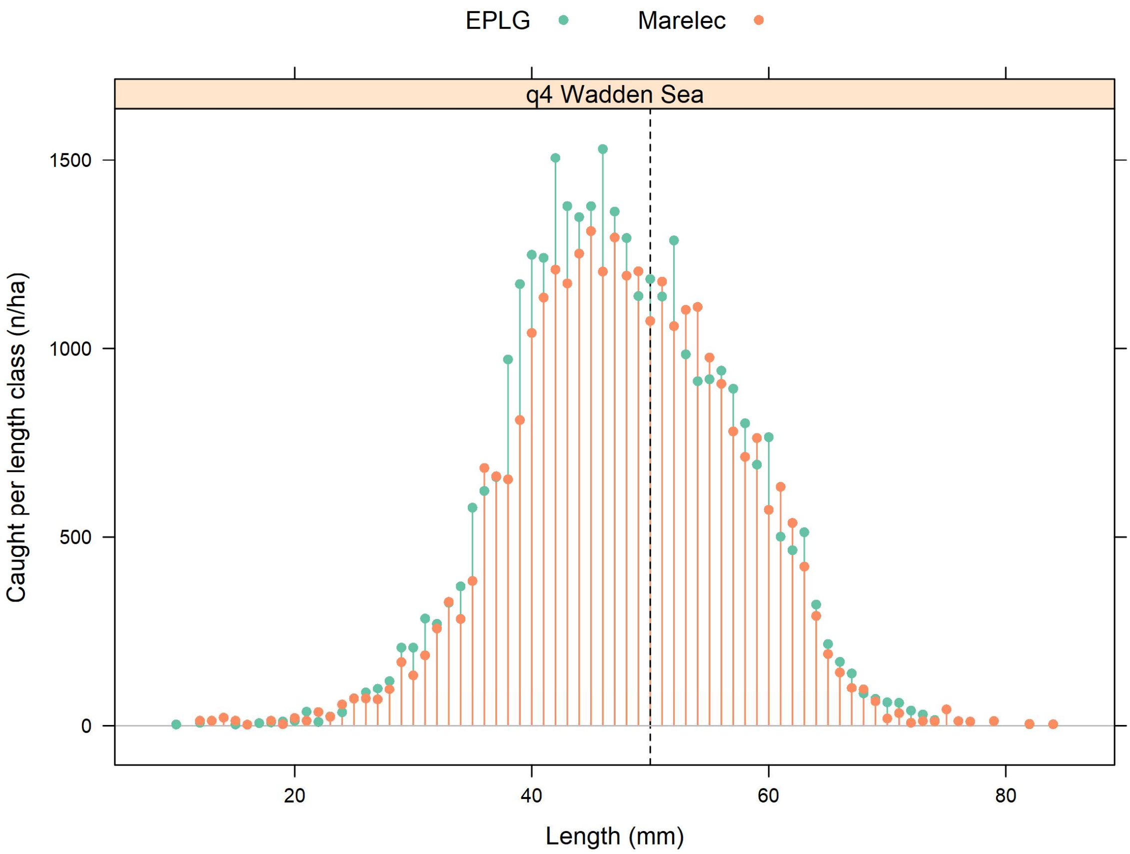

Figure 16: The number of shrimp per length class caught per hectare (n/ha) by the EPLG (green) and Marelec gear (orange) for the combined configuration ("Configuration 1 + 2"). The vertical dotted line at 50 mm represents the threshold between small and discarded shrimp (left) and shrimp of commercial size (right).

Bycatch variance for different fish species is represented in Table 26 for all three configurations combined. It is important that the results of the following tables on bycatch of fish with the configurations separated and combined is interpreted with care as the sampling rates are very low. The bycatch species with the highest sampling rate was plaice, for this species 1057 specimens were sampled on a total of 20 hauls (40 samples).

Table 26: Bycatches of fish in the pulse trawl with Marelec (PS) and EPLG (SB) gear for the 20 sampled hauls (all 3 configurations combined), expressed as number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage. Species caught in amounts lower than 1/ha at both PS and SB are excluded from the table

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)
European plaice	Schol	103,98	84,43	-19%
Gobies nei	Grondels	26,10	50,39	93%
European smelt	Spiering	16,92	17,45	3%
European flounder	Bot	6,89	9,71	41%
European sprat and herring	Sprot haring	5,09	6,36	25%
Fivebeard rockling	Vijfdradige meun	2,93	2,41	-18%
viviparous blenny (eelpout)	Puitaal	0,96	1,35	41%
Black goby	Zwarte grondel	0,85	1,30	52%
Seaweed pipefishes nei	Zeenaaldachtigen spp	0,64	1,09	70%
Common dab	Schar	0,49	1,80	270%

In Table 27, 28, and 29, the bycatch rates are shown per configuration. When comparing the overall results of the three configurations, it is configuration 1 that achieved lower bycatch rates for most species (as shown in Table 27). Configuration 2 and 3 show strong increases in the amount of bycatch for most species and are thus not favourable over configuration 1 (Table 28 and 29). It is important to notice that due to the very low catch rates, no LFDs of bycatch species are shown for this innovation.

Table 27: Bycatches of fish in the pulse trawl with Marelec (PS) and EPLG – configuration 1 (SB) gear, expressed as number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage. Species caught in amounts lower than 1/ha at both PS and SB are excluded from the table.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)
European plaice	Schol	69,4176	49,7303	-28%
Gobies nei	Grondels	39,8598	24,25099	-39%
European smelt	Spiering	16,7255	9,146643	-45%
European sprat and herring	Sprot en haring	9,0181	5,086236	-34%
Fivebeard rockling	Vijfdradige meun	5,66901	4,032515	-29%
European flounder	Bot	2,47884	3,176249	28%
Seaweed pipefishes nei	Zeenaaldachtigen spp	1,24249	2,461039	98%
Shorthorn sculpin	Gewone zeedonderpad	1,00497	-	-

Table 28: Bycatches of fish in the pulse trawl with Marelec (PS) and EPLG – configuration 2 (SB), expressed as number of animals caught per hectare trawled (n/ha). The difference in catch rates between both gears expressed as percentage. Species caught in amounts lower than 1/ha at both PS and SB are excluded from the table.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)
European plaice	Schol	136,748	108,4055	-21%
Gobies nei	Grondels	18,7433	77,90888	316%
European smelt	Spiering	17,2845	24,5039	42%
European flounder	Bot	9,31019	13,46366	45%
European sprat and herring	Sprot en haring	3,09823	6,642562	114%
Fivebeard rockling	Vijfdradige meun	2,00709	1,037998	-48%
Black goby	Zwarte grondel	1,44054	2,040976	42%
viviparous blenny (eelpout)	Puitaal	1,27146	1,298483	2%
Common dab	Schar	0,64301	2,504187	289%
Atlantic horse mackerel	Horsmakreel	-	0,45612	-

Table 29: Bycatches of fish in the pulse trawl with Marelec (PS) and EPLG – configuration 3 (SB), expressed as number of animals caught per hectare trawled (n/ha). The difference in catch rates between both gears expressed as percentage. Species caught in amounts lower than 1/ha at both PS and SB are excluded from the table.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)
European plaice	Schol	79,5709	85,98064	8%
Gobies nei	Grondels	19,207	23,94021	25%
European smelt	Spiering	16,2603	14,0027	-14%
European flounder	Bot	8,93416	12,23468	37%
European sprat and herring	Sprot en haring	7,53575	9,504239	26%
viviparous blenny (eelpout)	Puitaal	0,97818	1,800729	84%
Common dab	Schar	-	2,433156	-
Fivebeard rockling	Vijfdradige meun	-	3,065582	-

The catch rates for invertebrates are compared in Table 30. Also here, very low sampling rates makes it difficult to formulate conclusions on the effect of the EPLG gear and the different pulse settings. The bycatch species with the highest sampling rate was green shore crab, for this species only 66 specimens were sampled on a total of 20 hauls (40 samples). As the catch rates were so low, chances of skewing the results by having the net hitting coincidental aggregations of benthos on only one side of the ship is very plausible. Overall, a decrease in benthos bycatch is visible although configuration 1 (Table 30) shows an increase in bycatch of benthos while the other two configurations show a decrease (Table 31 and 32).

Table 30: Bycatches of invertebrates in the EPLG – configurations combined (SB) and Marelec (PS) gear expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant values are indicated in bold.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)	P-value
Green shore crab	Strandkrab	7,34	2,51	-193	0,04
Edible crab	Noordzeekrab	4,54	-	-	-
Baltic macoma	Nonnetje	3,72	0,59	-530	0,28
Yellow sea squirt	Doorschijnende zakpijp	3,52	0,90	-291	0,16
Blue mussel	Mossel	1,94	0,76	-157	0,46
Common starfish	Gewone Zeester	1,73	0,91	-90	0,48
Humpback prawns	Steurgarnaal	1,02	2,37	57	0,41
Total (in numbers)	**Totaal (aantal)**	**25,16**	**9,90**	**-61**	

Table 31: Bycatches of invertebrates in the EPLG - configuration 1 (SB) and Marelec (PS) gear expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant values are indicated in bold.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)	P-value
Blue mussel	Mossel	8,24	4,37	-89	0,56
Baltic macoma	Nonnetje	7,69	-	-	-
Green shore crab	Strandkrab	6,67	6,34	-5	-
Yellow sea squirt	Doorschijnende zakpijp	4,61	1,66	-178	0,28
Common starfish	Gewone Zeester	2,91	2,16	-35	0,50
Humpback prawns	Steurgarnaal	2,22	15,45	86	0,50
Trough shells	Strandschelpen	2,17	-	-	-
Common swimming crab	Gewone zwemkrab	1,10	4,41	75	0,50
Sea anemones	Anemoon	-	2,11	-	-
Serpent star	Gewone Slangster	-	6,62	-	-
Total (in numbers)	**Totaal (aantal)**	**35,60**	**43,12**	**21**	

Table 32: Bycatches of invertebrates in the EPLG- configuration 2 (SB) and Marelec (PS) gear expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant values are indicated in bold.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)	P-value
Green shore crab	Strandkrab	7,25	1,69	-328	0,09
Yellow sea squirt	Doorschijnende zakpijp	4,07	-	-	0,14
Common starfish	Gewone Zeester	1,58	1,04	-53	0,54
Sea anemones	Anemoon	0,83	-	-	0,20
Baltic macoma	Nonnetje	0,72	1,38	48	0,42
Total (in numbers)	**Totaal (aantal)**	**15,17**	**5,65**	**-63**	

Table 33: Bycatches of invertebrates in the EPLG - configuration 3 (SB) and Marelec (PS) gear expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant values are indicated in bold.

Species	Dutch name	PS = Marelec	SB = EPLG	Difference (%)	P-value
Green shore crab	Strandkrab	8,74	3,38	-158	0,48
Edible crab	Noordzeekrab	4,54	-	-	-
Baltic macoma	Nonnetje	3,50	-	-	0,02
Humpback prawns	Steurgarnaal	0,77	-	-	0,39
Yellow sea squirt	Doorschijnende zakpijp	0,63	2,36	73	0,34
Total (in numbers)	**Totaal (aantal)**	**18,17**	**5,74**	**-68**	

3.2.3 Conclusion

The results obtained with the different pulse settings must be interpreted with care. Due to small differences and overall extremely clean catches, it is hard to pinpoint the optimal settings or the best suited gear. From the ten set-ups tested during the data recording, not a single one managed to notably reduce bycatch without losing a large amount of shrimp. From the data obtained from the three configurations of the observer trip, configuration 1 seems to be the best option, with a reduction in fish bycatch and a small (but again, hard to prove due to the small numbers) increase in benthos bycatch. They also caught more small (<50 mm) shrimps. Despite the small differences in performance, the skipper of the HA31 preferred to fish with EPLG gear, as he felt it was more robust than the Marelec gear. This can also mean that some of the differences in the catch and bycatch are not only acquired by altering the setting but perhaps also due to some structural differences between the two pulse gears.

3.3 Additional discs between bobbins (WR40)

3.3.1 Introduction

The current Dutch legislation has clear limitations for fishermen targeting shrimp with electrical pulses. The most important may be that the number of bobbins is limited to 14 in a straight bobbin rope configuration. Fishermen argue that this works well enough in summer and fall when the water temperature is high, but that this gear lacks the ability to catch sufficient shrimp during wintertime. One reason may be the decreased reactiveness of shrimp at colder temperatures, and the fact that they have to move to deeper and rougher fishing grounds requiring more robust gear. As a result, fishermen tend to switch back to a traditional gear with a higher environmental impact during the coldest months of the year.

The goal of the WR40 was to optimize the fishing gear for these colder and deeper conditions in such a way that the catch efficiency for shrimp would be elevated towards similar levels as a traditional shrimp trawl without losing the pulse trawl advantage of reduced bycatch rates. Therefore, he added two additional discs (3 cm width) between the 14 bobbins (see Figure 17) and compared this innovative gear with a traditional beam trawl with 36 bobbins in a round bobbin rope from mid November 2018 until the end of February 2019.

Figure 17: Close up of two bobbins in the standard straight bobbin rope configuration as obliged for pulse trawlers in the Netherlands (front) and the new bobbin rope with two additional rubber discs between the bobbins (back).

3.3.2 Results & discussion

3.3.2.1 Fishing grounds

During the data recording, the WR40 was active in both the Waddenzee and the North Sea Coastal Zone, during the observer trip, WR40 only fished in the North Sea Coastal Zone, as indicated in Figure 18.

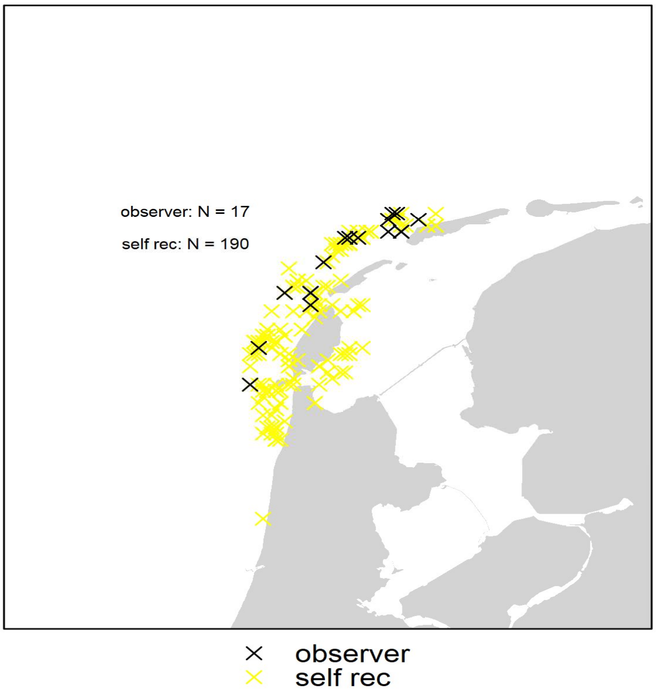

Figure 18: The locations where the WR40 fished during the period she tested the experimental gear. Each yellow cross indicates a haul during which data recording took place (week 46 of 2018 until week 7 of 2019), whereas the black crosses indicate the hauls that were sampled, sorted and analysed for a detailed direct catch comparison during the observer trip (week 4 of 2019).

3.3.2.2 Data recording

The results of the data recording are summarized in Table 34. The discs had a positive effect on the catch of commercial shrimp as there was an overall increase of 3% but with quite a large variation as the catch varied between a - 9% and + 23%, whereas the bycatch levels showed an overall 9% decrease with a total catch volume varying between –15% and 4% (the only increase noted). The overall discard volume was lowered by 21% with the decrease varying between 10% and 37%.

Table 34: The number of hauls, the total amount of cooked commercial shrimp caught ('S'), the total pooled catch volume ('V') and the total volume discarded ('D') per fishing week.

Week	# hauls	Reference (SB)			Experimental (PS)			Experimental vs Reference		
		S (kg)	V (L)	D (L)	S (kg)	V (L)	D (L)	S	V	D
46 - 2018	22	2795	7521	3907	2905	7274	3517	4%	-3%	-10%
47 - 2018	11	1370	3740	1969	1295	3186	1512	-5%	-15%	-23%
48 - 2018	18	2810	7725	4092	3100	7422	3413	10%	-4%	-17%
49 - 2018	20	2365	7641	4583	2425	6479	3344	3%	-15%	-27%
50 - 2018	19	3150	7597	3524	3335	6925	2613	6%	-9%	-26%
51 - 2018	16	2585	4929	1586	2785	4842	1241	8%	-2%	-22%
02 - 2019	21	2780	6518	2923	2530	5821	2550	-9%	-11%	-13%
04 - 2019	43	3730	10078	5255	4580	10455	4533	23%	4%	-14%
05 - 2019	17	1385	3067	1276	1565	2839	816	13%	-7%	-36%
06 - 2019	18	1345	3640	1900	1325	3108	1394	-1%	-15%	-27%
07 - 2019	18	1475	2443	535	1485	2256	336	1%	-8%	-37%
Total	223	22060	54818	26295	22750	50150	20735	3%	-9%	-21%

3.3.2.3 Observer trip

The observer trip took place the week of 21 January 2019. In total 17 hauls were sampled. The experimental pulse gear was rigged on portside and the traditional gear on starboard, both equipped with a sieve net. The skipper noted that the catch efficiency for shrimp was clearly higher than the weeks prior to the observer trip, which is confirmed by the data recording.

The difference in catch rate for each fraction is illustrated in Figure 19. The results show a significant increase in the catches of commercial shrimp and round fish. No significant effect on the catches of small discard shrimp were noted while a significant reduction in the bycatch of flatfish, invertebrates, and rubble (trash, vegetal materials, debris, and empty shells) was observed.

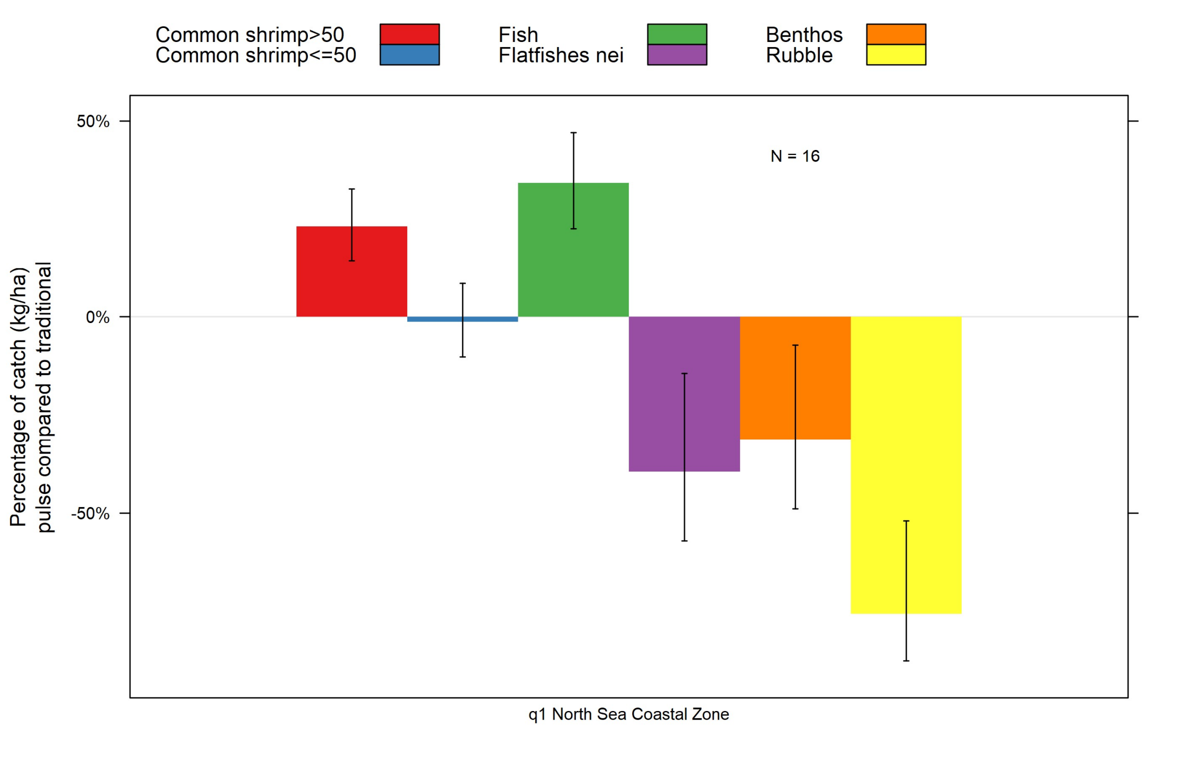

Figure 19: Differences in catch rate (kg/ha) for each fraction sampled during the observer trip.

The different catch efficiencies for shrimp can also be observed in their length-frequency distributions (LFD's) showing that the pulse gear with additional discs caught systematically more shrimp larger than 50 mm whereas the catch rates of smaller individuals are variable and do not show a clear pattern (Figure 20).

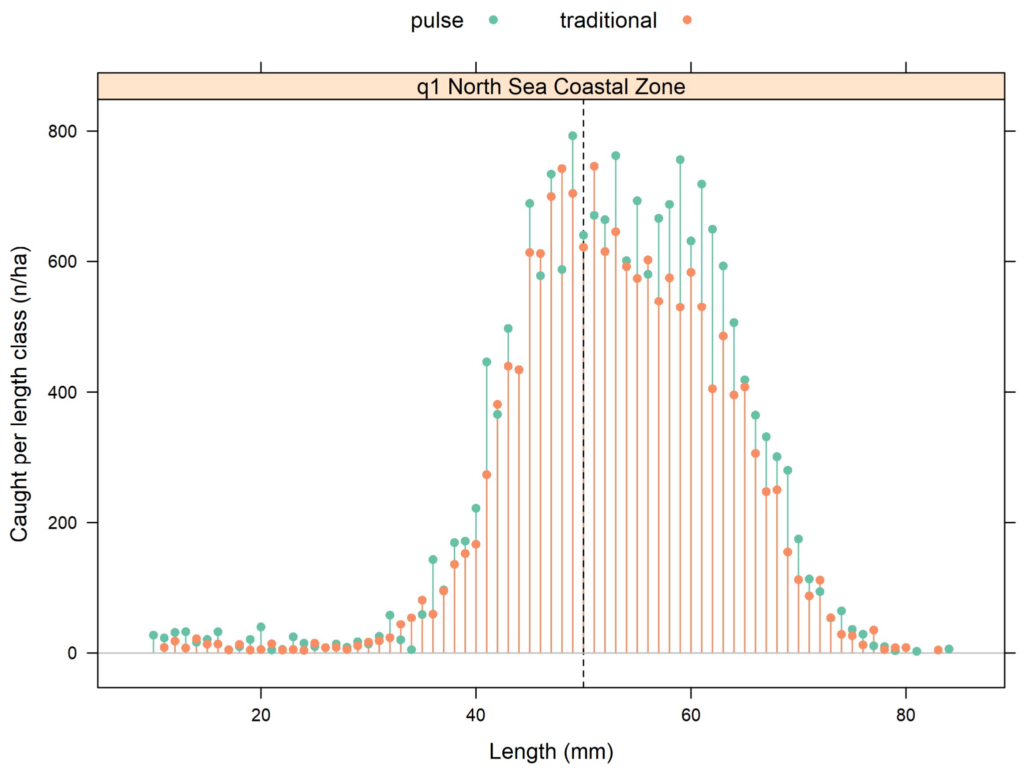

Figure 20: The number of shrimp per length class caught per hectare (n/ha) by the reference (orange) and experimental (green) gear. The vertical dotted line at 50 mm represents the threshold between small and discarded shrimp (left) and shrimp of commercial size (right).

When analysing the bycatch of fish in detail (Table 35), the first thing that stands out is the large variability between the percentage difference in catch rates between both gears, going from large reductions (dab, sole, hooknose) to large additional catches (sprat, herring, whiting, plaice). This may partially be caused the small sampling rate (only 17 hauls sampled by small subsamples) which makes the estimates less accurate. Therefore, the results of fish caught in numbers lower than 1/ha at both SB and PS are excluded from the table. The results of species with 50 individuals or more per hectare give an impression on the overall trend for that species and are therefore further examined in the length-frequency distributions in Figure 21. These show that catch reduction for dab and catch increases for sprat and herring is not length-dependent and observed in every length class. The large catch increases for herring and sprat are remarkable although these results should be handled with care. Indeed, these species strictly live in schools increasing variability by catching ‘all or none’. This was also observed in the data of the reference measurements in year 1, showing catches varying strongly between hauls and sides, which can easily lead to skewed results and wrong interpretations.

Table 35: Bycatch of fish in the traditional shrimp trawl (SB) and modified pulse trawl (PS) expressed as number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage.

Species	Dutch name	SB = ref.	PS = exp.	Difference (%)
Gobies nei	Grondels	147,1	124,5	-15%
Common dab	Schar	142,6	96,0	-33%
European sprat and herring	Haring	85,7	222,1	159%
Seaweed pipefishes nei	Zeenaald	46,9	53,8	15%
Dragonet	Pitvis	6,7	7,0	4%
Hooknose	Harnasmannetje	6,8	2,6	-61%
European plaice	Schol	3,5	4,8	37%
Whiting	wijting	2,8	4,9	78%
Common sole	Tong	2,8	0,7	-77%
Mediterranean scaldfish	Schurftvis	0,4	1,9	404%
Small sandeel	Zandspiering	0,6	2,2	286%
European flounder	Bot	1,2	0,6	-50%

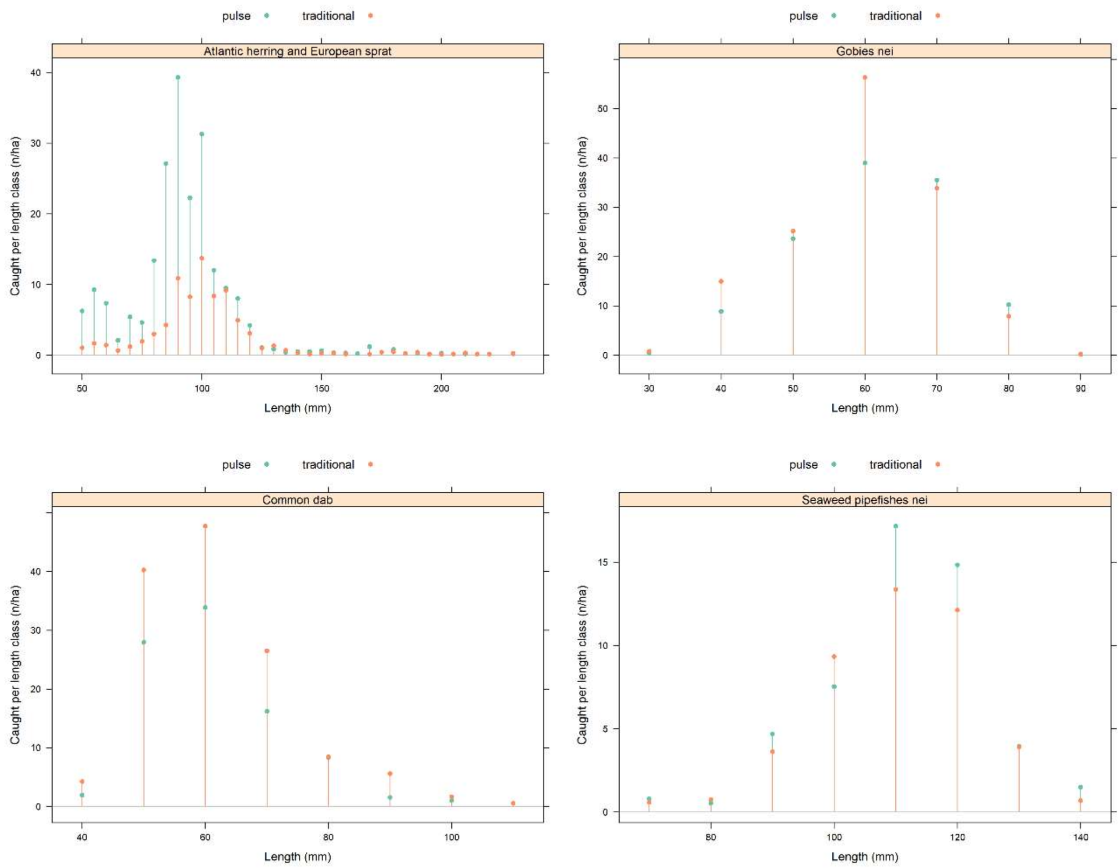

Figure 21: The number of fish per length class caught per hectare (n/ha) by the reference (orange) and experimental (green) gear.

The catch rates for invertebrates are compared in Table 36. In general, bycatch in the experimental pulse trawl nets was lower for 8 out of the 10 invertebrate species caught, resulting in an overall bycatch reduction of 18% based on the total number of animals. The two exceptions are the common necklace shell and the humpback prawn. The latter shows a similar 20% catch increase similar to commercial brown shrimp catches, which is expected, as this species probably reacts with a similar startle response as brown shrimp when exposed to the 5 Hz electrical stimulus of the pulse trawl.

Table 36: Bycatches of invertebrates in the traditional shrimp trawl (SB) and modified pulse trawl (PS) expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant values are indicated in bold italics.

Species	Dutch name	SB = ref.	PS = exp.	Difference (%)	P-value
Liocarcinus swimcrabs nei	Zwemkrab	318,8	308,7	3	0,85
Solen razor clams nei	Mesheft	46,7	8,4	82	0,10
Serpent star	Slangster	33,2	16,5	50	0,01
Sea anemones	Anemonen	15,2	2,0	87	0,13
Common necklace shell	Tepelhoorn	7,8	18,7	-141	0,38
Common starfish	Zeester	6,9	4,7	32	0,15
Right-handed hermit crabs nei	Heremietkreeft	4,9	2,5	49	0,21
Humpback prawns	Steurgarnaal	1,8	2,2	-19	0,66
Total (in numbers)	**Totaal (aantal)**	**435,3**	**363,7**	**-16**	

3.3.3 Conclusion

The efficiency for commercial brown shrimp during the observer trip was higher than the average observed during the data recording period, whereas the bycatch reductions are in the same order of magnitude. Although the results of this study were variable, a clear reduction in the amount of bycatch of invertebrates and rubble was observed. This indicates that having additional discs between the bobbins may keep the pulse trawl economically competitive during winter months by maintaining the catches of commercial shrimp at a similar level compared to traditional shrimp trawls with ± 36 bobbins in a round bobbin rope, while obtaining an ecological benefit of reduced bycatches of benthos and rubble.

Pulse trawls targeting shrimp tended to switch back to their traditional trawl gear in winter when the water was cold as they could no longer keep pace with their colleagues using the mechanical stimulation of ± 36 bobbins on a round bobbin rope. The reason for this reduced efficiency lies in the fact that brown shrimp show a weaker electric-induced startle response in cold water. Also, pulse trawls targeting shrimp in deeper waters (f.e. Voordelta) experienced smaller catch efficiencies for shrimp than their colleagues fishing in shallow water (f.e. Waddenzee). The fishermen argued that the pulse trawl with 14 bobbins as prescribed in the technical measures in the Netherlands is too light for the fishing conditions in the deeper waters. The present innovations with additional mechanical stimulation of discs between the bobbins showed the potential to overcome this issue by catching similar quantities of commercial shrimp as traditional fisherman while still significantly reducing the bycatch rates and environmental impacts on other invertebrates and therefore definitely warrants future attention.

3.4 Sieve mat in square pulse trawl net (ST24)

3.4.1 Introduction

Shrimp fishermen in the Wadden Sea are obliged to use a funnel shaped sieve net in order to stop larger animals from entering the cod-end. However, this 60 mm sieve net tends to clog, especially in periods with lots of seaweed or algae, resulting in substantial parts of the shrimp catch being funnelled out of the trawl. To minimize this drawback, fishers often need to clean them, losing valuable fishing time. A possible alternative could be the sieve mat, a rectangular panel attached between the head rope and the bobbin rope, covering the entire cross section of the trawl opening (Figure 22) making it much easier for the fishermen to inspect, repair or clean. This sieve mat was tested several years ago in traditional shrimp trawls, but the rigging of the rectangular panel in a trawl with a round bobbin rope was too unpractical and inefficient. Pulse trawls do not have this round bobbin rope as they are equipped with straight bobbin ropes and have a more rectangular net design. This makes them more suitable to test a sieve mat. The goal of this study was to optimize the selectivity of a 60 mm sieve mat to make it as efficient as the standard sieve net by testing different positions and inclinations.

Figure 22: Sieve mat in the nets of the ST24.

3.4.2 Results

3.4.2.1 Fishing grounds

During the data recording, ST24 was active in or just outside the Wadden Sea on the fishing grounds shown in Figure 23. All hauls were done in Q2 2019.

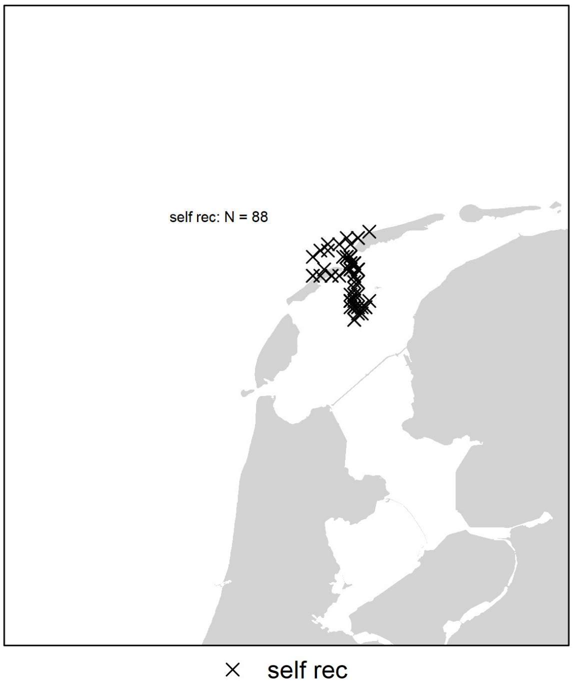

Figure 23: The locations where ST24 fished during the period the sieve mat was tested. Each black cross indicates a haul during which data recording took place (week 14 until 26 of 2019).

3.4.2.2 Data recording

The skipper of the ST24, Peke Wouda, tried different ways to hang the netting in the trawl mouth, testing different angles and tensions on the panel, but never achieved similar catch rates as the pulse trawl with standard sieve net. This can clearly be observed in Table 37.

With a decrease of almost 15% of commercial shrimp, an increase of over 3% of total catch volume and only a decrease of just under 7% of discard volume, the sieve mat did not prove to be effective.

Table 37: Comparison of cooked commercial shrimp catch (S), total catch volume (V), and total discard volume (D) between a standard sieve net (reference) and a sieve mat (experimental).

Week	# hauls	Reference			Experimental			Exp vs Ref		
		S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D
14 - 2019	6	530	1017	336	530	980	294	0%	-4%	-12%
18 - 2019	21	920	1816	636	840	1665	583	-9%	-8%	-8%
24 – 2019	24	2110	4165	1499	1672	3901	1755	-21%	-6%	17%
25 – 2019	14	1450	2967	1068	1264	3080	1047	-13%	4%	-2%
26 – 2019	17	1080	2414	990	900	2359	1180	-17%	-2%	19%
Total	82	6090	11987	4860	5206	12379	4528	-14,52%	3,27%	-6,82%

3.4.2.3 Observer trip

Due to the unsatisfactory and negative results and the bad overall performance of the innovative gear, this project was not continued further and no observer trip was added to gather data.

3.4.3 Conclusion

Despite the fact that the sieve mat was optimized and tested for several weeks, the skipper could not eliminate the unacceptable high losses of commercial shrimp. As a result, he decided to stop investing time and money in it and focussed on fishing with discs instead of bobbins.

3.5 Pulse with 24 discs instead of bobbins (ST24)

3.5.1 Introduction

The goal of this innovation was similar to the one tested by WR40 mentioned earlier (Additional discs between bobbins, section 3.3) except for the fact that the bobbins were completely replaced by discs. Fishermen argued that during winter months, pulse trawls catch less shrimp than the traditional gear, also when fishing in deeper and colder waters, the traditional trawl outperforms the pulse trawl. ST24 adjusted the pulse trawl, trying to improve the catch efficiency for shrimp in cold and deep waters to a similar level as the traditional trawl, without losing the pulse trawl advantage of reduced bycatch rates. The traditional pulse gear bobbin rope with ten bobbins, was replaced by a bobbin rope with 24 discs (see Figure 24) increasing the number of contact points with the sediment without increasing the area impacted by the trawl. During the final weeks of data recording, the reference gear was replaced by traditional gear (a round bobbin rope without pulse) and then compared to the pulse gear as was the case for the WR40 section 3.3 (except now only discs).

Figure 24: Discs on straight bobbin rope (ST24).

3.5.2 Results & discussion

3.5.2.1 Fishing grounds

During the data recording, the ST24 was active in both the Wadden Sea and the North Sea Coastal Zone, during the self-sampling trip, ST24 only fished in the Wadden Sea, as indicated in Figure 25.

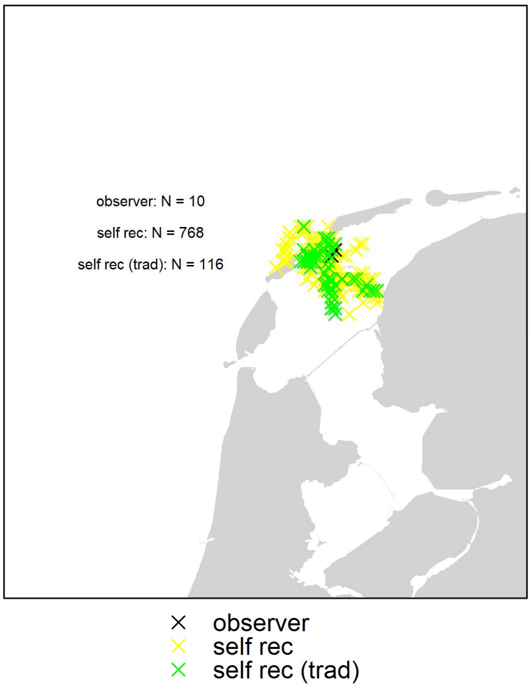

Figure 25: The locations where the ST24 fished during the period the experimental gear was tested. Each yellow cross indicates a haul during which data recording took place (week 34 of 2019 until week 51 of 2020), the black crosses indicate the hauls that were sampled, sorted and analysed for a detailed direct catch comparison during 2 weeks of self-sampling (week 28 and 29 of 2020)

3.5.2.2 Data recording

For the data recording of the pulse with discs, two sets were gathered by ST24. A comparison was made from 33 weeks combining a total of 747 hauls between a reference pulse with bobbins and a pulse with discs instead of bobbin (Table 38). Another comparison was made over 5 weeks with 116 hauls between the traditional gear with a round bobbin rope without pulse and a pulse with discs (Table 39).

Table 38 shows an overall reduction in the catch of shrimp by 5%. Although this is not ideal it was accompanied by a decrease of over 11% in the total catch volume and by almost 24% in the total discard volume. The shrimp catch was consistently lower varying between a loss of 12% and a gain of 1%. The total volume caught varied between a decrease of 25% and an increase of 10% although there were only two weeks during which the total catch volume was higher on the experimental side than on the reference side. The discard volumes varied between a decrease of 44% and 3% with only one week showing an increase of 10%.

Table 38: Comparison of shrimp catch (S), catch volume (V), and discard volume (D) between a pulse net with bobbins (reference) and a pulse net with 24 discs (experimental).

Week	# hauls	Reference			Experimental			Exp vs Ref		
		S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D
34 - 2019	15	1245	3087	1482	1175	2382	834	-6%	-23%	-44%
35 - 2019	14	1245	3055	1405	1155	2403	889	-7%	-21%	-37%
36 - 2019	12	1080	3071	1505	1030	2385	906	-5%	-22%	-40%
37 - 2019	16	1270	3163	1487	1150	2387	859	-9%	-25%	-42%
38 - 2019	12	1055	2476	1090	970	2124	828	-8%	-14%	-24%
39 - 2019	16	1270	3163	1487	1150	2387	859	-9%	-25%	-42%
46 - 2019	27	2895	5449	1689	2560	4705	1364	-12%	-14%	-19%
47 - 2019	23	2230	4173	1252	2100	3683	958	-6%	-12%	-24%
48 - 2019	33	2100	4218	1434	2040	3653	986	-3%	-13%	-31%
49 - 2019	34	1375	2304	737	1260	2486	820	-8%	8%	11%
50 - 2019	30	1620	2391	885	1545	2632	658	-5%	10%	-26%
05 - 2020	18	760	1596	606	725	1515	576	-5%	-5%	-5%
06 - 2020	19	410	733	205	385	648	149	-6%	-12%	-27%
09 - 2020	25	625	1767	972	615	1740	939	-2%	-2%	-3%
10 - 2020	25	795	1703	647	765	1529	535	-4%	-10%	-17%
12 - 2020	22	1085	2177	762	1050	1910	535	-3%	-12%	-30%
15 - 2020	20	985	2051	799	955	1802	577	-3%	-12%	-28%
16 - 2020	25	920	1881	677	855	1601	512	-7%	-15%	-24%
17 - 2020	23	975	1892	624	960	1753	508	-2%	-7%	-19%
18 - 2020	26	990	1870	561	975	1688	405	-2%	-10%	-28%

Table 38 continued

Week	# hauls	Reference			Experimental			Exp vs Ref		
		S (kg)	V (l)	D (l)	S (kg)	V (l)	D (l)	S	V	D
19 - 2020	26	715	1526	580	695	1363	450	-3%	-11%	-22%
22 - 2020	22	1195	2235	715	1140	2037	611	-5%	-9%	-15%
23 - 2020	28	1500	2835	879	1395	2442	635	-7%	-14%	-28%
24 - 2020	22	1495	2786	864	1400	2445	611	-6%	-12%	-29%
25 - 2020	28	1850	3594	1186	1865	3349	938	1%	-7%	-21%
27 - 2020	29	2100	3980	1194	1980	3703	1000	-6%	-7%	-16%
34 - 2020	26	1480	3222	1257	1460	3023	1058	-1%	-6%	-16%
35 - 2020	14	765	1956	958	740	1753	771	-3%	-10%	-20%
36 - 2020	20	1215	3566	1961	1165	3182	1623	-4%	-11%	-17%
37 - 2020	25	1615	3837	1727	1525	3431	1441	-6%	-11%	-17%
38 - 2020	22	1515	3273	1342	1495	3130	1221	-1%	-4%	-9%
39 - 2020	23	1550	3677	1618	1520	3370	1348	-2%	-8%	-17%
40 - 2020	27	2130	4563	1825	2040	3943	1341	-4%	-14%	-27%
Total	747	44055	93270	36412	41840	82580	27745	-5,03%	-11,46%	-23,80%

Table 39 shows an overall increase of the catch of shrimp of 8%. The increase in catch was not subjected to large variations. Furthermore, this increase is accompanied by a decrease of 11% in catch volume which was consistently negative and variating between -4% and -17%. This reduction led to an average decrease of just under 40% in the discarded volume with strong variation but again consistently a decrease of the discard volume between -21% and up to 50%.

Table 39: Comparison of shrimp catch (S), catch volume (V), and discard volume (D) between traditional net (without pulse) with bobbins (reference) and a pulse net with 24 discs (experimental).

		Reference			Experimental			Exp vs Ref		
Week	# hauls	**S (kg)**	**V (l)**	**D (l)**	**S (kg)**	**V (l)**	**D (l)**	**S**	**V**	**D**
44 - 2020	20	1695	4018	1768	1825	3866	1392	8%	-4%	-21%
46 - 2020	23	1845	4898	2449	1975	4066	1220	7%	-17%	-50%
47 - 2020	30	1400	3693	1884	1520	3080	1078	9%	-17%	-43%
48 - 2020	19	1510	3640	1602	1635	3492	1222	8%	-4%	-24%
49 - 2020	24	1665	4078	1917	1800	3555	1102	8%	-13%	-43%
Total	116	8115	20329	9619	8755	18059	6014	7,89%	-11,17%	-37,48%

3.5.2.3 Self-sampling

The self-sampling took place during weeks 28 and 29 of 2020 (no observer trip because of covid-19 regulations). Each week, 5 hauls were sampled (10 in total). The experimental gear (with discs) was rigged on starboard, both sides equipped with pulse and a sievenet. Samples were transferred to ILVO at the end of the week for detailed analysis.

On average, the analysed samples contained 71% shrimp (all sizes) in the reference gear and 75% shrimp in the experimental. The difference in catch rate for each fraction is illustrated in Figure 26. The results show a significant increase in the catches of fish and a significant decrease in catches of benthos (weights excluding swimming crab) with the experimental gear. No significant effect on the catches of shrimp (discard and commercial), flatfish or rubble (trash, vegetal materials, debris and empty shells) was found.

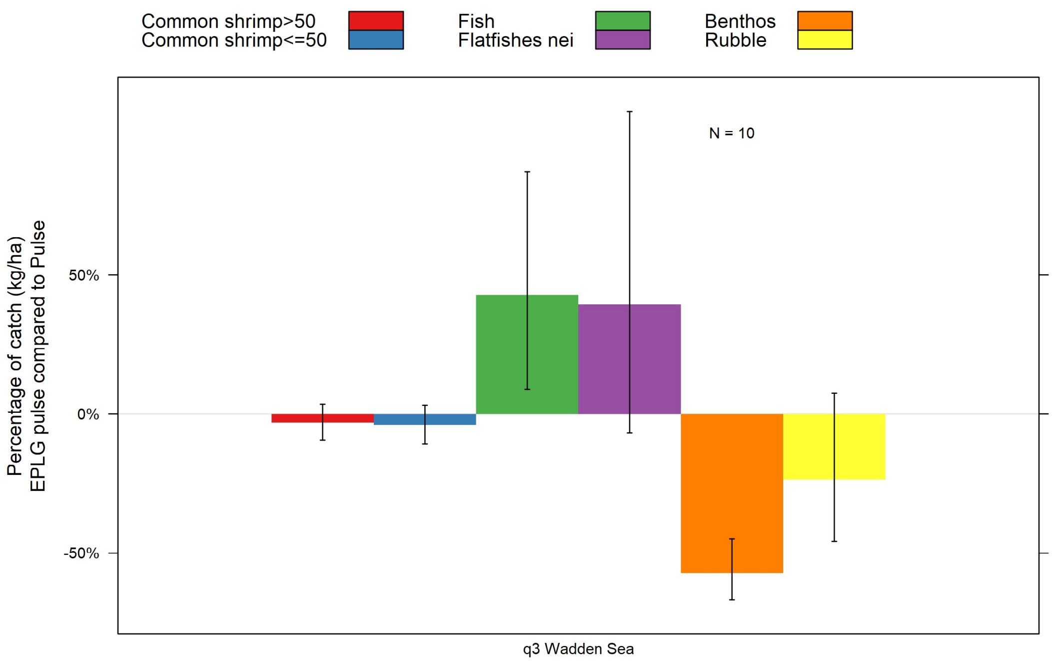

Figure 26: Differences in catch rate (kg/ha) for each fraction sampled during the observer trip.

Although not significant, lower catch efficiencies for shrimp can also be observed in the length-frequency distributions (LFD's) showing that the pulse gear with discs caught little less shrimp (both smaller and larger than 50 mm) (Figure 27).

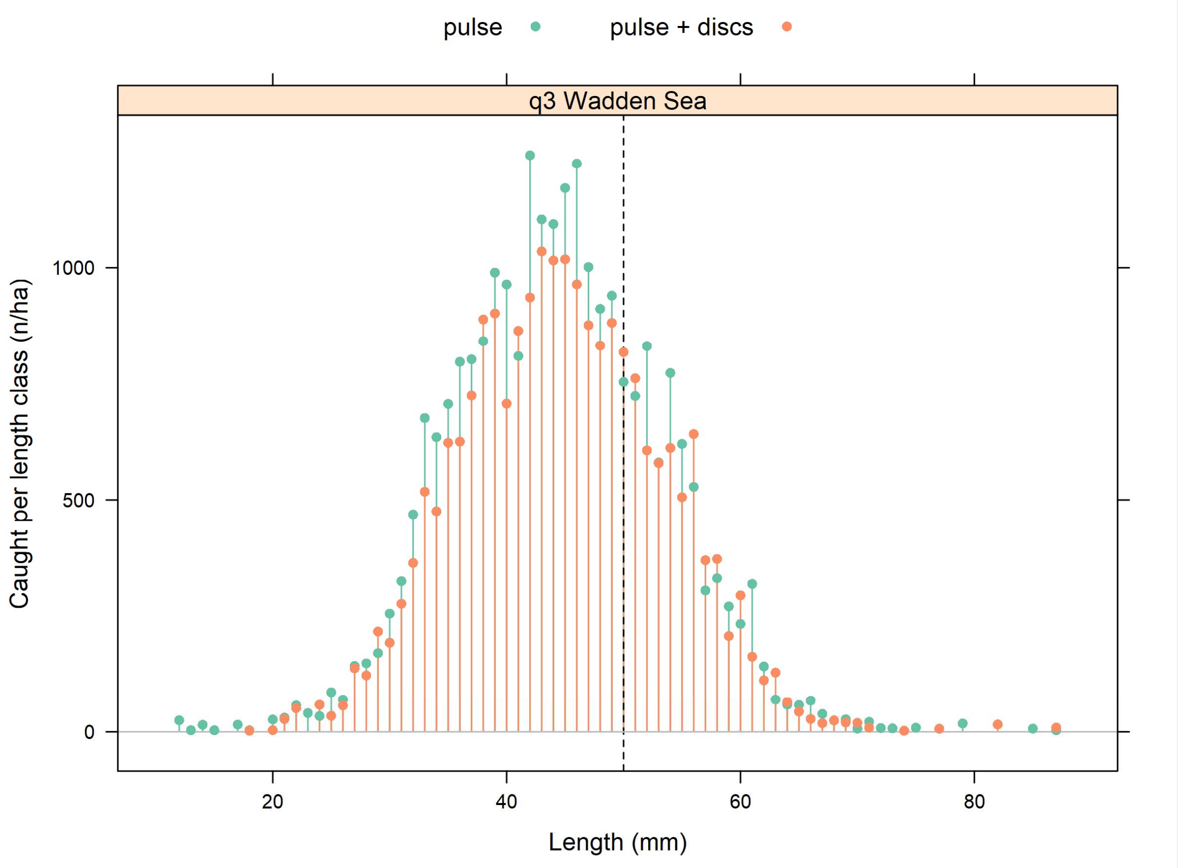

Figure 27: The number of shrimp per length class caught per hectare (n/ha) by the reference net (green) and experimental net with discs (orange). The vertical dotted line at 50 mm represents the threshold between small and discarded shrimp (left) and shrimp of commercial size (right).

Bycatches of fish are represented in Table 40. The difference in catch rates between the traditional bobbin rope and the rope with discs show high variability. The gear with discs caught more bycatch for some species (ex.) sprat, herring and plaice, but less for others ex. whiting and gobies. It is important to notice that these results should be interpreted with care. Because of the clean catches (>70% shrimp), sampling rate of bycatch species was very low. Length-frequency distributions (LDF) of species with the highest catch rates are shown in Figure 28. None of these LFDs indicate length-dependent differences in catch rates.

Table 40: Bycatches of fish in the pulse trawl with discs (SB) and reference pulse trawl (PS) expressed as number of animals caught per hectare trawled (n/ha) and the difference in catch rates between both gears expressed as percentage. Species caught in amounts lower than 1/ha at both PS and SB are excluded from the table.

Species	Dutch name	PS = ref.	SB = discs	Difference (%)
European sprat and herring	Sprot en Haring	105,13	164,25	56%
European plaice	Schol	50,95	86,84	70%
Whiting	Wijting	39,04	32,71	-16%
Common dab	Schar	16,40	22,75	39%
Gobies nei	Grondels	5,44	3,08	-43%
Seaweed pipefishes nei	Zeenaald	3,58	2,72	-24%
Pouting	Steenbolk	3,57	2,91	-19%
Shorthorn sculpin	Gewone zeedonderpad	3,25	0,88	-73%
Common seasnail	Slakdolf	2,66	1,26	-52%
Hooknose	Harnasmannetje	2,49	3,54	42%
viviparous blenny (eelpout)	Puitaal	2,06	0,20	-90%
Common sole	Tong	1,28	3,77	195%
Rock gunnel	Botervis	1,t24	2,71	118%

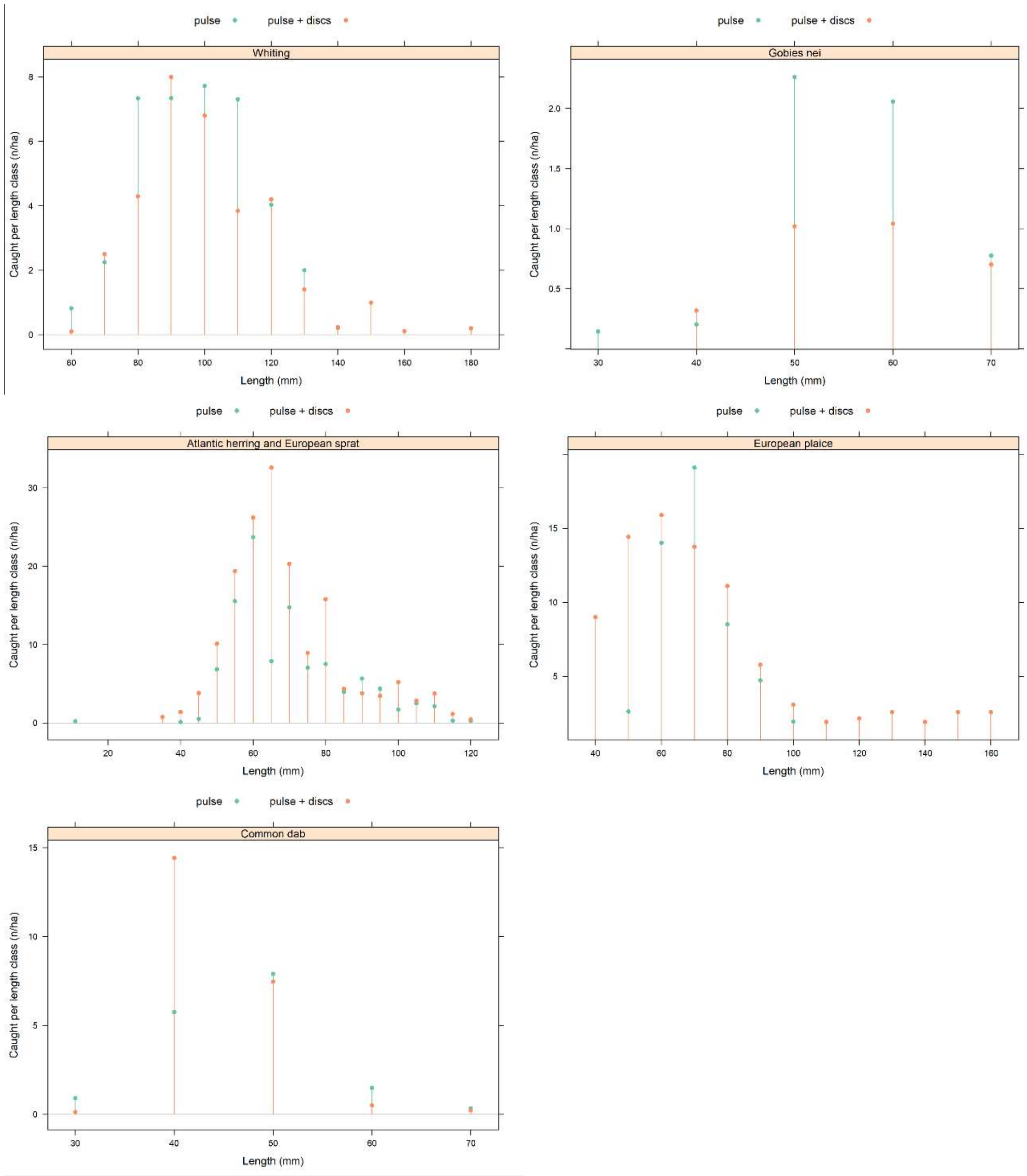

Figure 28: The number of most caught fish species per length class per hectare (n/ha) by the reference pulse gear (green) and experimental gear with discs (orange).

The catch rates for invertebrates are compared in table 41. Swimming crab was the benthos bycatch with the highest sampling rate, here the experimental gear showed slightly higher catch rates +12%. Rates for other benthos species with catch rates of less than 10/ha were lower for the experimental gear ex. serpent star (-103%), common starfish (-238%).

Table 41: Bycatches of invertebrates in the traditional shrimp trawl (SB) and modified pulse trawl (PS) expressed as number of animals caught per hectare trawled (n/ha), the difference in catch rates in percentage and the P-value. Significant differences are indicated in bold.

Species	Dutch name	PS = ref.	SB = discs	Difference (%)	P-value
Swimming crab	Zwemkrab	843,72	957,97	12	0,46
Serpent star	Gewone Slangster	53,03	26,18	-103	0,22
Common starfish	Gewone Zeester	48,69	14,41	-238	0,14
Green shore crab	Strandkrab	35,60	27,56	-29	0,51
Sea anemones	Anemoon	6,77	7,90	14	0,58
Solen razor clams nei	Mesheft /Ensis	1,37	1,52	10	0,83
Right-handed hermit crabs nei	Heremietkreeften	0,87	1,52	43	0,42
Total (in numbers)	**Totaal (aantal)**	**990,0**	**1037,1**	**5%**	

3.5.3 Conclusion

As the goal of this experimental setup was to increase catch rates of shrimp with pulse gear in colder and deeper waters. The ST24 replaced the bobbins at the front of the net by discs which have a reduced contact area with the seafloor. The results showed a slight reduction in the number of shrimps caught with the pulse gear with discs compared to the traditional pulse gear with bobbins while the reduction in bycatch was almost a quarter of the total bycatch volume. The amount of shrimp per size class remained the same. When looking specifically at the bycatch, a strong reduction in the serpent star and common starfish was noticed while the other bycatch species slightly increased. For bycatch of fish, the results were less easy to interpret as some species show a decrease and others an increase in the amount caught. The comparison between the traditional non-pulse gear with bobbins and the pulse gear with discs shows the efficiency of the pulse gear as it caught slightly higher amounts of shrimp while greatly reducing the amount of bycatch and discard rates. This proves the efficiency and usefulness of the pulse gear for shrimp trawl fishing.
Important to note from these two experimental setups, is that the discs can work on a commercial level as they have almost similar catches of shrimp as the bobbins (with pulse) but with reduced impact on the bottom. Furthermore, it has the possibility to greatly reduce some bycatch, although only for certain species, others remained the same or slightly increased. On the other hand, the pulse gear with discs was not able to increase the catch of shrimp above that of a pulse gear with bobbins and even less so for that of the traditional gear. Further research into the discs should be done as they might prove useful when used in the warmer months and when fishing in shallower waters.

4 Conclusions & recommendations

Pulse trawling seems to be a good alternative to traditional trawling when fishing for shrimp, with overall similar or higher catch rates, reduced bycatch rates, and a lower mechanical impact on bottom and benthic life. This project fine-tuned certain aspects of the pulse trawl gear that were later taken over by the involved stakeholders. Improvements were made regarding the loss of catch efficiency during the colder winter months and deeper waters. Alternative adaptations were proposed and further investigated. These alternatives were tested in five different experiments carried out by three fishing vessels: the electrode setup by the HA31, the EPLG pulse settings by the HA31, adding discs between bobbins by the WR40, a sieve mat in the net by the ST24, and discs instead of bobbins by the ST24.
When looking at the results obtained from the electrode setup experiments performed by the HA31, which consisted in a reduction of the electrode length from 110 cm to 80 cm or an increase of the distance from the electrodes to the bobbins from 55 cm to 80 cm, neither of the experimental setups proved to be a better than the reference setup. Due to this result no observer trip was undertaken.
For the EPLG experiment by the HA31, the settings of the pulse were altered in the EPLG and compared to the reference settings of the Marelec pulse gear. The settings that were altered were: the voltage of the pulse (the peak), the pulse duration, and the pulse frequency. Out of the ten different combinations, none was significantly better than the reference gear, and some even gave negative results. The fishermen did deem the EPLG a more robust gear than the Marelec.
The WR40 replaced several bobbins by 14 discs on the bobbin rope instead of a 36 bobbin rope to make the pulse perform better in colder water in winter or on deeper fishing grounds. Normally the fishermen would switch from the pulse gear back to the tradition trawl gear in winter. The innovation of the discs gave very promising results as the amount of commercial shrimp increased slightly while the discard rates went down drastically by almost 25%. As it is a fairly cheap and simple technique it is an economically viable option for the fishermen to introduce it in their gear on the future. The ST24 tried replacing the standard sieve net, which needs a lot of maintenance and reduces the catch, by a sieve mat that would be easier to clean and would not clog as fast. After five weeks, the experiment was stopped due to the large losses in commercial shrimp and so no observer trip was done.

The ST24 also performed an experimental setup with discs, but unlike the WR40, all the bobbins were replaced by 24 discs, further reducing the impact on the bottom and reducing the drag. This was then compared to a pulse setup with bobbins and a traditional beam trawl. The first experiment saw a very slight reduction of the amount of shrimp caught but this was accompanied by large reductions in the bycatch. When comparing the discs to a traditional beam trawl, there was a strong increase in the amount of shrimp paired with a substantial reduction in the amount of bycatch.
Overall, the reductions in bycatch do not give a clear picture as for some species catches decreased while for others catches increased. Furthermore, due to the low sampling size of certain species, caution must be taken when interpreting the results. Out of all the tested innovations and setups, changing the bobbins by discs has most potential for the future.

Nawoord

Wij willen de schippers en hun bemanning die hebben meegewerkt aan dit onderzoek heel erg hartelijk danken voor hun deelname aan het project en de prettige samenwerking.
Daarnaast willen wij de collega's van zowel het ILVO als WMR danken voor hun zeer waardevolle werk aan boord van de schepen en/of het uitvoeren van de metingen in het lab: Eddy Buyvoets, Christian Vanden Berghe, Tom Bangma, Maarten van Hoppe, Caroline Weber, Steven van der Stelt (student bij WMR) en de mensen van FishNed die zijn ingehuurd voor dit project.
De volgende collega's en ex-collega's van het ILVO en WMR hebben een bijdrage geleverd aan het onderzoek: Maarten Soetaert, Jimmy van Rijn, Edward Schram, Pepijn de Vries. Wij willen Ingeborg de Boois en Eugene Rurawanga danken voor de controle van de data en de invoer van deze complexe set in de WMR database. Tot slot willen wij de collega's van het Thünen instituut danken voor hun bijdrage aan de opzet van het programma en hun deelname aan de workshop.

Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2021. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

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Justification

Report C105/21
Project Number: 4311100054

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: Allard van Mens
Scientist fisheries innovations

Signature:

Date: 22–12-2021

Approved: Dr. Ir. T.P. Bult
Director

Signature:

Date: 22–12-2021

Annex 1 Technical specifications of the fishing gear (in Dutch)

Voorschriften voor het gebruik van het vistuig
Type klossenpees: rechte klossenpees
Nettype: vierkant net (geen V-net)
Max. afstand tussen korrestok en klossenpees: 4 meter
Diameter klossen: tussen 170mm en 270mm
Breedte klossen: tussen 80mm en 180mm
Vorm klossen: vierkant of ellipsvormig
Afstand tussen klossen onderling: minimaal 60 cm
Gewicht klossenpees: maximaal 250 kilo inclusief elektroden

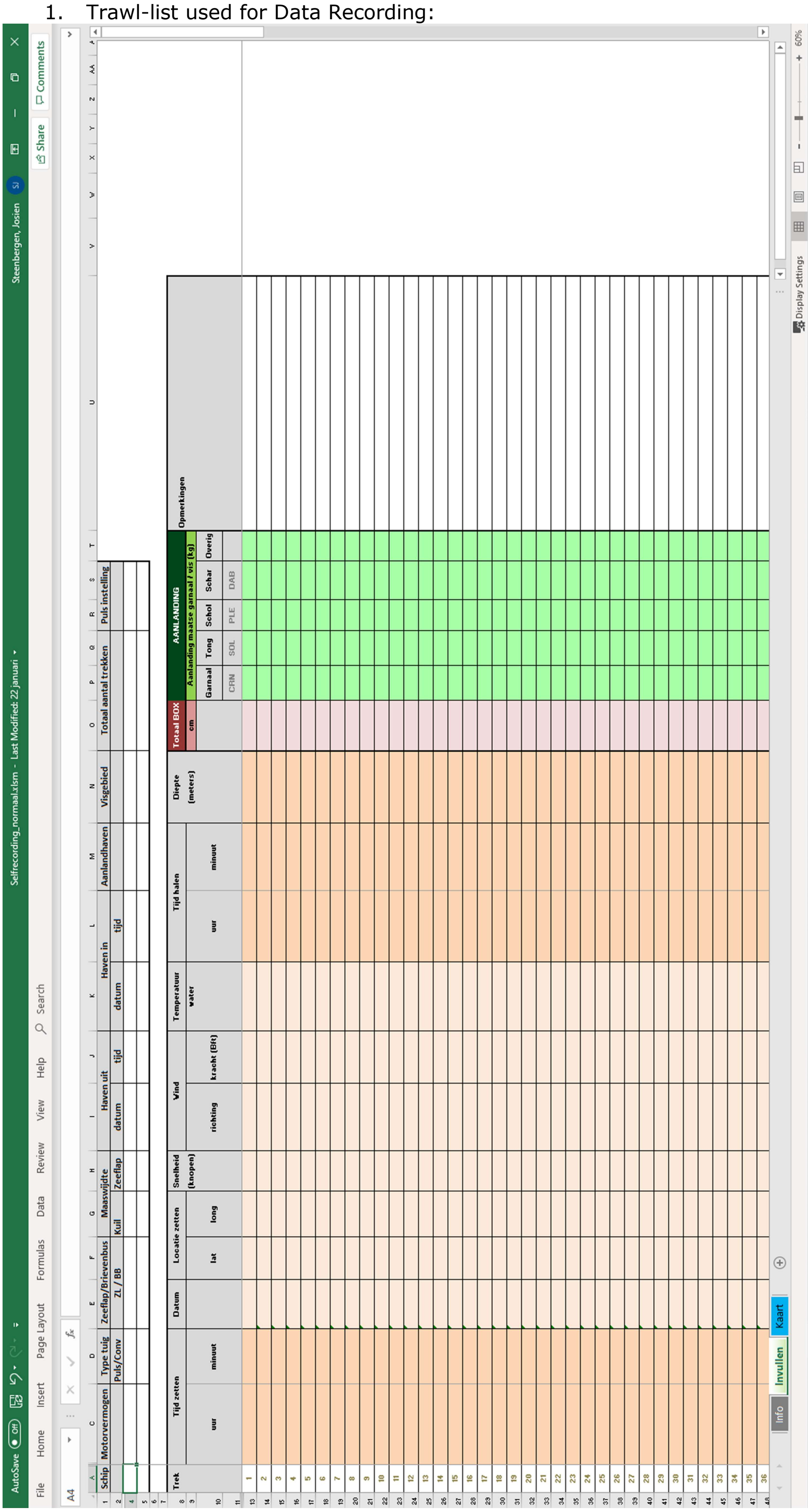
Onverminderd de van toepassing zijnde Europese en nationale voorschriften, geldt:
- Alle klossen moeten vrij kunnen rollen over een stalen as. Toepassingen die het vrij kunnen rollen van de klossen kunnen verhinderen, zoals rubberen onderpezen etc. zijn verboden.
- De afstand van minimaal 60 centimeter tussen de klossen onderling wordt gemeten vanuit het middelpunt van de ene klos naar het middelpunt van de eerstvolgende klos etc.
- Het Is niet toegestaan voor de klossenpees kietelaar(s) aan te brengen.

Technische aspecten garnalen puls apparatuur
Soort puls : unipolaire puls (stroom volgt één richting)
Pulsvorm : DC tussen halve sinus en blokvorm
Maximale spanning (Vpeak): 65
Maximale spanning RMS (Max.rms): 3.25
Pulsduur (ms): maximaal 0,5
Herhalingsfrequentie (Hz): 5 - 8
Ingangsvermogen: maximaal 0.2 kW per meter boomlengte of wekveldbreedte
Uitgangsvermogen: maximum Is lager dan ingangsvermogen
Polariteit eerste en laatste elektroden: Vast (-1- of -)
Polariteit tussenliggende elektroden: Wisselend (-1- of -)
Maximale veldsterkte tussen 2 elektroden: 50 V/m (maximale afwijking = **10%)**
Tussenafstand elektroden: min. 0.65 meter
Aantal pulsstrengen: max. 12 (elk met 1 conductor)
Lengte pulsstrengen (pulsdragers): max. 2.75 meter
Lengte conductoren: max. 1.50 meter
Diameter conductoren: max. 12 mm
Tussenafstand elektroden: min. 0.65 meter

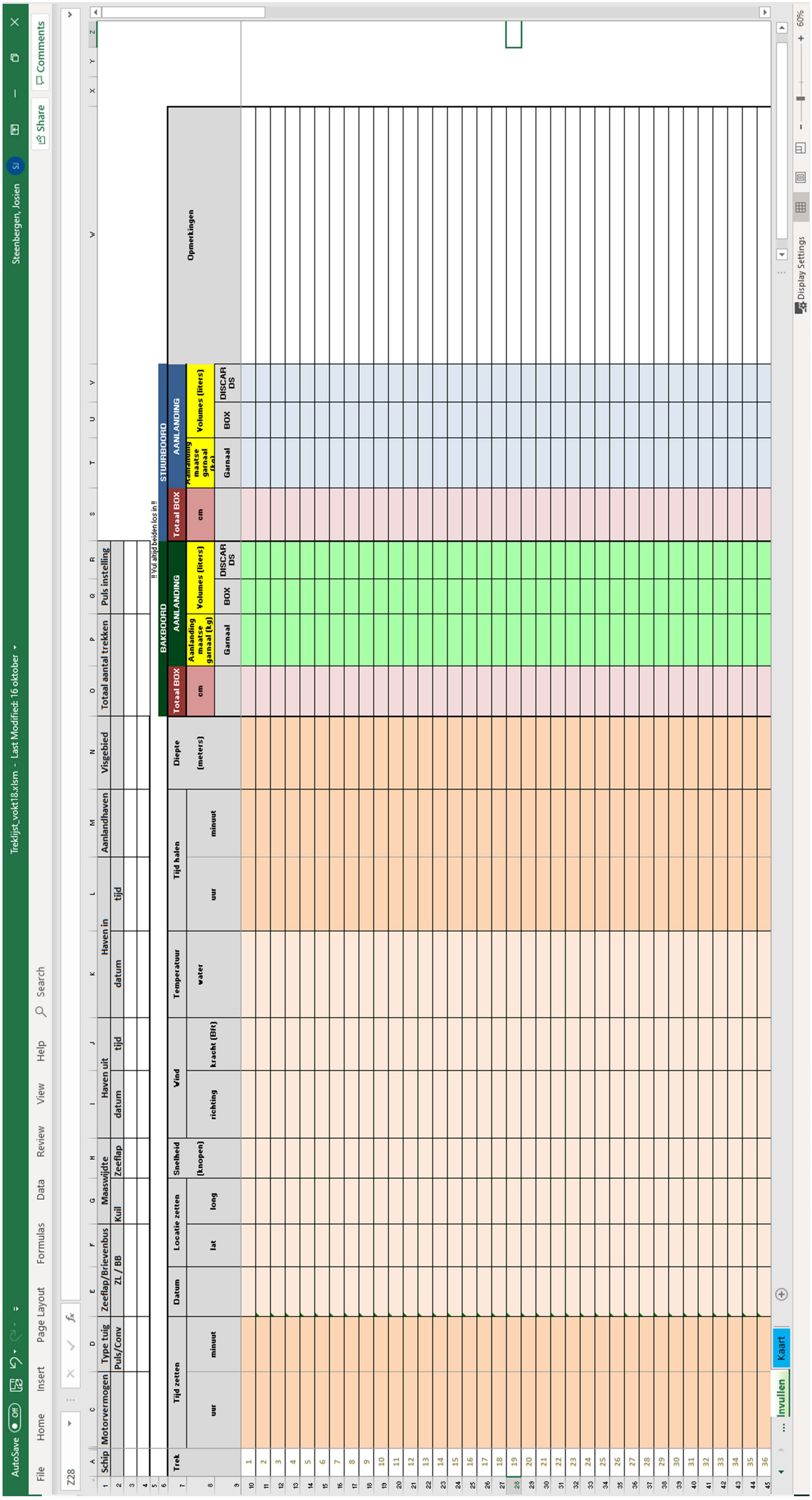
Overige voorschriften met betrekking tot de technische aspecten:
- Ingangsvermogen = elektrisch vermogen achter de scheepsgenerator en voor de voedingskabels. Advies = veiligheidsklasse CE gekeurd.
- De isolatie van de elektrodes is afdoende en bestaat uit één geheel en niet uit bijvoorbeeld rubberschijfjes.
- Het vaartuig is uitgerust met een computergestuurd beheersysteem dat de maximale stroom per boom en het werkelijke voltage tussen de elektroden van tenminste de laatste 100 trekken volledig automatisch registreert. Niet bevoegde personen hebben geen toegang tot het computergestuurde beheerssysteem en het is niet mogelijk om wijzigingen aan te brengen in de door het computergestuurde beheerssysteem gegenereerde gegevens.

Annex 2 Trawl lists

1. Trawl-list used for Data Recording:



2. Trawl-list used for gear trials



Annex 3 Pulse vessels and gear

1. ST24

	Traditional	Pulse
Beam width (m)	8.5	8.5
# Bobbins	32	12
# electrodes	-	12
Shape of "grondpees"	U-shape	Square

Traditional

Pulse

Vessel	TH10	23.95 m
	Traditional	**Pulse**
Beam width (m)	9	9
# Bobbins	40	12
# electrodes		12
Shape of "grondpees"	U-shape	Square

Vessel	WR40	23 m
	Traditional	**Pulse**
Beam width (m)	9	9
# Bobbins	37	12
# electrodes	13	12
Shape of "grondpees"	U-shape	Square

Vessel	HA31	23.27 m
	Traditional	**Pulse**
Beam width (m)	9	9
# Bobbins	34	13
# electrodes		12
Shape of "grondpees"	U-shape	Square

ANNEX 4 Species overview

Note that in some cases it was (on board) not possible to identify until species level. This was the case with herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). The juveniles of these species look very much alike and when they are caught they are often caught in high numbers. At the same time on board of the vessels is limited and therefor it was decided to only provide the genus level of these species; Clupea. Shows the names of the animals at the level of classification provided in the baseline study (species, genus or family) in English and scientific and Dutch names of the species that are included in the “higher levels” are also provided.

ENGLISH_NAME	*SCIENTIFIC_NAME*	DUTCH_NAME
Abra sp.	*Abra sp.*	Dunschalen indet.
Abra sp.	*Abra alba*	Dunschalen indet.
Allis shad	*Alosa alosa*	Elft
American piddock	*Petricolaria pholadiformis*	Amerikaanse boormossel
Anchovy	*Engraulis encrasicolus*	Ansjovis
Baillon's wrasse	*Symphodus bailloni*	Baillon's lipvis
Baltic macoma	*Limecola balthica*	Nonnetje
banded wedge shell	*Donax vittatus*	Zaagje
Bib	*Trisopterus luscus*	Steenbolk
Blunt gaper	*Mya truncata*	Afgeknotte gaper
Bobtail indet.	*Sepiola sp.*	Dwerginktvissen indet.
Brill	*Scophthalmus rhombus*	Griet
Bull-rout	*Myoxocephalus scorpius*	Zeedonderpad
Butterfish	*Pholis gunnellus*	Botervis
Callionymus sp.	*Callionymus maculatus*	Gevlekte pitvis
Callionymus sp.	*Callionymus lyra*	Pitvis
Callionymus sp.	*Callionymus sp.*	Pitvissen indet.
Callionymus sp.	*Callionymus reticulatus*	Rasterpitvis
Clupea	*Clupea*	Clupea
Clupea	*Sprattus sprattus*	Sprot
Clupea	*Clupea harengus*	Haring
Cod	*Gadus morhua*	Kabeljauw
Common cockle	*Cerastoderma edule*	Kokkel
Common mussel	*Mytilus edulis*	Mossel
Common slipper shell	*Crepidula fornicata*	Muiltje
Common spider crab	*Macropodia rostrata*	Hooiwagenkrab
Common squids nei	*Loliginidae*	Loliginidae
Common squids nei	*Loligo sp.*	Langvinpijlinktvissen indet.
Common squids nei	*Theutida*	Pijlinktvissen indet.
Common whelk	*Buccinum undatum*	Wulk
Dab	*Limanda limanda*	Schar
Demosponges	*Demospongiae*	Sponzen indet.
Edible crab	*Cancer pagurus*	Noordzeekrab
European common squid	*Alloteuthis subulata*	Dwergpijlinktvis
Five-bearded rockling	*Ciliata mustela*	Vijfdradige meun
Flounder	*Platichthys flesus*	Bot
Goby	*Neogobius melanostomus*	Zwartbekgrondel
Goby	*Pomatoschistus lozanoi/minutus*	P. lozanoi/minutus
Goby	*Aphia minuta*	Glasgrondel
Goby	*Gobius niger*	Zwarte grondel

ENGLISH_NAME	*SCIENTIFIC_NAME*	DUTCH_NAME
Goby	*Pomatoschistus minutus*	Dikkopje
Goby	*Pomatoschistus sp.*	Grondels indet.
Greater sand-eel	*Hyperoplus lanceolatus*	Smelt
Green crab	*Carcinus maenas*	Strandkrab
Grey gurnard	*Eutrigla gurnardus*	Grauwe poon
Helmet crab	*Corystes cassivelaunus*	Helmkrab
Hermit crab indet.	*Pagurus sp.*	Heremietkreeften indet.
Hermit crab indet.	*Diogenes pugilator*	Kleine heremietkreeft
Hermit crab indet.	*Pagurus bernhardus*	Gewone heremietkreeft
Hermit crab indet.	*Pagurus prideaux*	Adamsiaheremiet
Hippocampus guttulatus	*Hippocampus guttulatus*	Zeepaardje
Hooknose	*Agonus cataphractus*	Harnasmannetje
Horse mackerel	*Trachurus trachurus*	Horsmakreel
Horse mackerel	*Carangidae*	Horsmakrelen
Idotea sp.	*Idotea sp.*	Zeepissebedden
Jellyfish	*Scyphozoa*	Kwallen
Lamprey	*Lampetra fluviatilis*	Rivierprik
Lemon sole	*Microstomus kitt*	Tongschar
Lesser weever	*Echiichthys vipera*	Kleine pieterman
Mackerel	*Scomber scombrus*	Makreel
Macoma Balthica	*Mergellus albellus*	Nonnetje
Nassarius sp.	*Nassarius reticulatus*	Gevlochten fuikhoorn
Nassarius sp.	*Nassarius sp.*	Fuikhoorns indet.
Natica sp.	*Euspira nitida*	Glanzende tepelhoorn
Natica sp.	*Natica sp.*	Tepelhoorns indet.
Nereis sp.	*Nereis sp.*	Zagers unident.
Norwegian egg cockle	*Laevicardium crassum*	Noorse hartschelp
Nudibranchs	*Nudibranchia*	Naaktslakken
Palaemonidae	*Palaemonidae*	Steurgarnalen indet.
Palaemonidae	*Palaemon sp.*	Steurgarnaal
Pipefish indet.	*Syngnathus sp.*	Zeenaalden indet.
Pipefish indet.	*Syngnathus acus*	Grote zeenaald
Pipefish indet.	*Syngnathus rostellatus*	Kleine zeenaald
Pipefish indet.	*Entelurus aequoreus*	Adderzeenaald
Plaice	*Pleuronectes platessa*	Schol
Poor cod	*Trisopterus minutus*	Dwergbolk
Razor clams	*Ensis sp.*	Zwaardschedes indet.
Sand-eel indet.	*Ammodytes sp.*	Zandspieringen indet.
Sand-eel indet.	*Ammodytes tobianus*	Kleine zandspiering
Sand-smelt	*Atherina presbyter*	Koornaarvis
Sand mason worm	*Lanice conchilega*	Zandkokerworm
Sardinella sp.	*Sardinella sp.*	Sardinella
Scaldfish	*Arnoglossus laterna*	Schurftvis
Sea-snail	*Liparis liparis liparis*	Slakdolf
Sea anemones	*Metridium dianthus*	Zeeanjelier
Sea anemones	*Urticina felina*	Zeedahlia
Sea anemones	*Anthozoa*	Zeeanemonen
Sea bass	*Dicentrarchus labrax*	Zeebaars
Sea lamprey	*Petromyzon marinus*	Zeeprik
Sea mouse	*Aphrodita aculeata*	Fluwelen zeemuis

ENGLISH_NAME	*SCIENTIFIC_NAME*	DUTCH_NAME
Sea scorpion	*Taurulus bubalis*	Groene zeedonderpad
Sea squirts	*Ascidiacea*	Zakpijp
Sepia	*Sepia sp.*	Sepia
Serpent star indet.	*Ophiura ophiura*	Slangster
Serpent star indet.	*Ophiura sp.*	Slangsterren indet.
Slender swimcrab	*Portumnus latipes*	Breedpootkrab
Smelt	*Osmerus eperlanus*	Spiering
Sole	*Solea solea*	Tong
Sole	*Solea sp.*	Solea
Solenette	*Buglossidium luteum*	Dwergtong
Spatangus purpureus	*Spatangus purpureus*	Purperen zeeklit
Spisula sp.	*Spisula subtruncata*	Halfgeknotte strandschelp
Spisula sp.	*Spisula solida*	Stevige strandschelp
Spisula sp.	*Spisula sp.*	Strandschelpen indet.
Starfish	*Asterias rubens*	Zeester
Striped red mullet	*Mullus surmuletus*	Mul
Swimming crab indet.	*Callinectes sapidus*	Blauwe zwemkrab
Swimming crab indet.	*Liocarcinus holsatus*	Gewone zwemkrab
Swimming crab indet.	*Liocarcinus depurator*	Blauwpootzwemkrab
Swimming crab indet.	*Liocarcinus navigator*	Gewimperde zwemkrab
Swimming crab indet.	*Liocarcinus sp.*	Zwemkrabben indet.
Swimming crab indet.	*Liocarcinus marmoreus*	Gemarmerde zwemkrab
Thornback ray	*Raja clavata*	Stekelrog
Three-spined stickleback	*Gasterosteus aculeatus*	Driedoornige stekelbaars
Trumpet worm	*Lagis koreni*	Goudkammetje
Tub gurnard	*Chelidonichthys lucerna*	Rode poon
Tube-eye	*Stylephorus chordatus*	S. chordatus
Turbot	*Scophthalmus maximus*	Tarbot
Viviparous blenny	*Zoarces viviparus*	Puitaal
Whiting	*Merlangius merlangus*	Wijting

ANNEX 5 Innovations as a result from the workshop (in Dutch);

Er zal in het 2e innovatie jaar worden gewerkt volgens het zogenaamde WMR innovatiemodel (zie hieronder). In Nederland hebben we reeds ruime ervaring met het zogenaamde " bottum-up" innoveren in de visserij. In het innovatie traject komen de ideeën voor innovatie uit de sector en trekken Wetenschap en sector gezamenlijk op. Het Wetenschappelijke instituut heeft de technische expertise en internationale netwerken om de sector te voorzien van input bij de innovaties die door de sector worden voorgesteld. Daarnaast begeleiden ze de veldtesten en worden gegevens verzameld volgens vaste protocollen. M.b.v. deze gegevens kan worden beoordeeld of de innovaties de beoogde doelen behalen bij toepassing in het veld. In het WMR innovatiemodel worden de volgende fases onderscheiden (voor het eerst beschreven in Molenaar et al, 2016):

1. Ontwikkelfase
2. Testfase
3. Onderzoeksfase
4. Uitrolfase

Het huidige project voorziet in de eerste drie fasen. De innovaties die in dit project zijn voorgesteld zijn tijdens de innovatieworkshop op 12 oktober 2018 ingebracht door de deelnemers aan de workshop en gezamenlijk beoordeeld. Aan de workshop namen deel Wetenschappers van het Belgische ILVO, het Duitse Thünen instituut, de deelnemende vissers, vertegenwoordigers van de sector en het beleid, een NGO en fabrikanten van pulstuigen.

4.1 Aanpassingen aan het vistuig

In tegenstelling tot het traditionele vistuig met een ronde klossenpees met 36-40 klossen is de pulskor voor garnaal voorzien van een rechte klossenpees waarop de elektroden eindigen. Deze kan in theorie maximaal 20-22 klossen bevatten maar werd binnen de huidige technische maatregelen in Nederland gelimiteerd op 12 klossen. Deze klossen zorgen er enerzijds voor om het net mooi boven de grond te houden, maar zorgen ook voor een mechanische stimulus die garnaal opschrikt en in het net doet belanden. Op basis van eerdere onderzoeken aan boord van TX25 en later de HA31 is het echter ook aannemelijk dat meer klossen ook voor meer bijvangst zorgen (Verschueren et al, 2014). De elektrische prikkel die gebruikt wordt stimuleert echter vooral garnaal. In een pulskor wordt de mechanische stimulatie door klossen dus grotendeels vervangen door elektrische stimulatie met pulsen waardoor er minder bijvangst plaatsvindt. Het effect van de elektrische pulsen is echter het beste in warm water en veel minder effectief tijdens de wintermaanden; een pulstuig vangt in kouder water aantoonbaar minder dan het traditionele net (Verschueren et al, 2019), waardoor de meeste deelnemende pulsvissers zouden gaan terugschakelen naar een traditioneel net. In de zomer daarentegen is er een meervangst van garnaal met het pulstuig, wat nog ruimte laat om ingrepen te doen om de hoeveelheid bijvangst nog extra te reduceren.

De volgende aanpassingen aan het vistuig zullen getest worden:

- **Schijven tussen de klossen**: het doel van deze innovatie is om te testen of het verlies van garnaal tussen de klossen kan worden beperkt in de wintermaanden. Door de toepassing van de schijven wordt tevens verwacht dat de klossenpees beter aan de grond te houden is op diepere en ruigere visgronden buiten het wad doordat de afstand tussen de klossen minder groot is. Het doel is om het verlies aan garnaal in de koudere wintermaanden te verminderen zonder de bijvangst te verhogen. Deze aanpassingen zou pulsvissers bovendien toelaten om 's winters gelijkaardige vangsten te behalen als collega's met een traditioneel net maar met veel minder bijvangst van andere dieren. De schijven hebben gelijke diameter als de klossen.

Figuur 1: voorbeeld van de huidige klossenpees van WR40 (onderaan) en de experimentele met extra schijven (bovenaan).

- **Verhoogde schijven i.p.v. klossen**: Alternatieve grondpees waar de 12 klossen met een breedte van 15-18 cm en een diameter van 22 cm vervangen worden door 24 of 48 schijven van 3 cm breed en 30 cm hoog. Hierdoor verandert het bodemcontact van de klossenpees in termen van hoeveelheid contact niet maar worden de afstanden tussen 2 opeenvolgende klossen/-schijven verkleind. De diameter van de schijven kan ook makkelijker aangepast worden waardoor de grondpees hoger van de grond zou komen. De hypothese is dat de platvis door de verhoogde grondpees meer kans heeft om te ontsnappen. Daarnaast wordt verwacht dat er minder werveling is dan bij de klossen waardoor de ontsnappingskans wordt verhoogd. Het doel is dan ook om minder kleine platvis bij te vangen. Wel dient in een later stadium onderzocht te worden wat het verschil in bodemperforatie is bij toepassing van deze dunnere schijven.

Figuur 2: voorbeeld van een alternatieve grondpees met 24 schijven van 30 cm hoog i.p.v. 12 klossen van 22 cm hoog.

- **Zeefmat**: In tegenstelling tot het traditioneel vistuig heeft de pulskor een rechte klossenpees, wat bepaalde aanpassingen in het net veel makkelijker te implementeren maakt. Een voorbeeld hiervan is de zeefmat, de welke dient als alternatief voor het zeefnet. Het zeefnet is een trechtervormig stuk net met een maasgrootte van 60 mm dat in het grotere net met maasgrootte van 22-24 mm gestoken wordt en dat alle grotere vis en bijvangst afleidt naar het uiteinde van de trechter die buiten het net uitmondt. Hierdoor wordt alle grotere bijvangst onmiddellijk geloosd en komt die niet in de vangst terecht. Het nadeel van dit zeefnet is echter dat het makkelijk gaat verstoppen als er veel kleine platvis gevangen wordt (voorjaar) of er veel wier in het water zit (zomer) waardoor ook veel commerciële garnaal gaat ontsnappen via het zeefnet en de visserman veel tijd verliest met het spoelen van de netten. De zeefmat zou gemaakt worden uit hetzelfde 60mm netmateriaal als het zeefnet, maar zou als een rechthoekige zeef tussen de boom en de rechte klossenpees gehangen worden (iets wat bij de traditionele garnaalkor niet kan). Hierdoor zou alle grotere vis en bijvangst niet de kans krijgen om in het net te komen maar zou de visser het wel veel makkelijker schoon kunnen houden.

Figuur 3: Traditionele garnaalkor met zeefnet (links) en zeefmat (rechts).

4.2 Aanpassingen aan de pulsinstellingen

Recent labo-onderzoek (Stappenbeck et al., 2017) observeerde o.a. een even goede schrikreactie van garnaal indien de pulsduur verkort werd van 0.5 ms naar 0.3 ms. Indien dit bevestigt kan worden in de praktijk betekent dit dat het vermogen van de pulstuigen met 40% verlaagd zou kunnen worden. Dit kan mogelijk de reactie van andere soorten en de hoeveelheid bijvangst verder verkleinen. Daarnaast zagen ze dat sommige garnalen beter reageerden bij een frequentie van 6 of 7 Hz i.p.v. de frequentie van 5 Hz zoals die nu gebruikt is. Deze laboresultaten tonen aan dat de huidige pulsinstellingen mogelijk nog verder verbeterd kunnen worden. Daarom zouden we de HA31 aan 1 zijde willen uitrusten met een pulsvistuig van LFish en vergelijkend te vissen met het standaard Marelec pulsvistuig als referentie. Het vistuig van LFish is modulair en werd ontwikkeld in samenwerking met ILVO en de software laat de schipper binnen een beperkte range toe om zijn de 3 belangrijkste pulsparameters aan te passen binnen een beperkte range: frequentie tussen 1-10 Hz, pulsduur tussen 0.1 en 1 ms en spanning tussen 30 en 80V (pulskarakteristieken van het huidige pulstuig zijn 5 Hz, 0.5 ms en 30-80 V). Het doel is om te kijken of de pulsparameters zo geoptimaliseerd kunnen worden dat de hoeveelheid bijvangst van kleine garnaal, andere ongewervelden en vis per hoeveelheid gevangen commerciële garnaal verder kan verlaagd en dus verbeterd worden.

4.3 Aanpassingen aan de electroden

Tot slot zou de HA31 ook willen experimenteren met een andere elektroden configuratie. Enerzijds zou er gevarieerd worden met de afstand tussen het einde van de elektrodes en de klossenpees. Deze laatste bedraagt nu ongeveer 10-15 cm maar laboratoriumstudies doen vermoeden dat de garnaal zijn hoogste positie pas bereikt tijdens zijn vluchtreactie onmiddellijk na de blootstelling. Dit zou betekenen dat er meer tijd nodig is tussen de blootstelling en de start (= nadien op dezelfde locatie aanwezig zijn) van het net, waarvoor dus de afstand tussen beide moet vergroot worden. Anderzijds is het idee om de lengte van de elektrodes te verkorten waardoor de garnalen minder lang blootgesteld zouden worden. Dit klinkt contra-intuïtief, maar recente laboratorium experimenten hebben laten zien dat de eerste sprong van de garnaal recht omhoog is, maar de daaropvolgende sprongen random zijn. Dit betekent dat de garnalen in veel gevallen niet langer hoger in de waterkolom gaan tijdens de blootstellingen (en pas erna tijdens hun gecontroleerde vluchtreactie). Een kortere blootstelling gevolgd door een vluchtreactie leidt dus mogelijks tot een beter vangstmechanisme waarbij ook de impact op de andere organismen verkleint zou worden.

Bronnen

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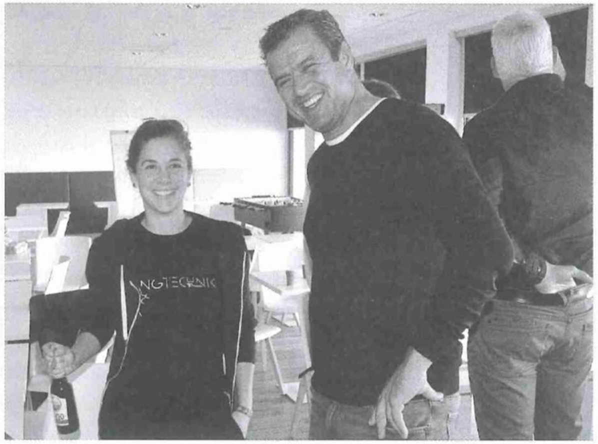
Onderzoeksplan in de maak voor tweede onderzoeksjaar

Brainstormen over garnalenpuls

IJMUIDEN – Nog selectiever en ook inzetbaar in de wintermaanden. Enkele innovatie-ideeën over de garnalenpuls die verder uitgewerkt moeten worden in een nieuw onderzoeksplan. Dat onderzoeksplan is een belangrijke voorwaarde om ook in 2019 garnalenpulsonderzoek te kunnen blijven doen.



★ *Gerrit Boerdijk (WR 40) praat na met wetenschappelijk medewerker Isabelle Kratzer van het Thünen-Institut, vestiging Rostock, die met haar collega Juan Santos in IJmuiden was. Vanwege de garnalenvisserij voor de Hollandse kust lag de WR 40 van Boerdijk (met de WR 20 en de WR 212) die dag toevallig afgemeerd aan de Trawlerkade in IJmuiden.*

Dit jaar is het jaar van de zogenoemde 0-meting. De vier nog deelnemende garnalenpulskotters, WR 40 (Boerdijk), ST 24 (Wouda), HA 31 (Nagel) en TH 10 (Baaij), en vier conventionele garnalenvissers (hun 'buddy's') meten en noteren voor elke trek in Natura 2000-gebied de totale vangsthoeveelheden en de vangsten van maatse garnalen. Daarnaast doen de garnalenpulsvissers drie weken per kwartaal een bakboord-stuurboord vergelijking. Dit alles moet informatie geven over vangsten en vangstsamenstelling van het garnalenpulstuig ten opzichte van het traditionele tuig met de klossenpees. In 2019 is er ruimte voor verdere innovaties van het garnalenpulstuig.

Over dat tweede jaar van het garnalenpulsonderzoek, dat ook wordt gefinancierd vanuit het EFMZV via het ministerie van LNV, werd vorige week vrijdag een bijeenkomst georganiseerd bij Wageningen Marine Research (WMR) in IJmuiden. Aan die bijeenkomst namen naast de deelnemende garnalenvissers en belangenorganisaties ook de uitvoerende onderzoekspartners WMR, ILVO en het Duitse Thünen-instituut deel, het ministerie van LNV en een vertegenwoordiger van Natuurmonumenten.

In groepjes werden ideeën geopperd en daarna bediscussieerd met de hele groep. De vissers willen het garnalenpulstuig ook in de winter kunnen gebruiken. Het lijkt er nu op dat de garnaal in kouder water niet voldoende reageert op de puls, waardoor de vangsten met de puls in de winter achterblijven ten opzichte van de traditionele methode. Wanneer de puls ook in de winter beter operabel gemaakt kan worden, kan worden gekeken of ook in deze periode de puls een oplossing kan bieden in het verhogen van de selectiviteit van de garnalenvisserij. Andere innovatie-ideeën zijn erop gericht om in de warmere maanden nog selectiever te kunnen vissen dan is gebleken uit voorgaande studies door het ILVO en Thünen-instituut.

Onder leiding van Josien Steenbergen van WMR worden de ideeën verder uitgewerkt in een onderzoeksplan, dat eerst zal moeten worden goedgekeurd door het ministerie voordat in 2019 het garnalenpulsonderzoek kan worden voortgezet.

★ *Vissers, visserijorganisaties, onderzoekers en andere 'stakeholders' aanwezig op de garnalenpulsworkshop bij Wageningen Marine Research in IJmuiden.*

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