WORKING GROUP ON ELECTRICAL TRAWLING (WGELECTRA)

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Contents

i Executive summary

The Working Group on Electrical Trawling (WGELECTRA), works on improving knowledge of the effects of electrical or pulse fishing on the marine environment. In this report the group provide details of ongoing work including preliminary results, upcoming research projects, and possibilities for international collaboration and scientific publications. A living document, overviewing the current published scientific knowledge on pulse trawling, was updated and attached as annex.

Highlights of ongoing research included presentations about laboratory and field experiments on the effects of electrical stimulation on fish, benthic invertebrates and biogeochemical processes. Results were presented of a monitoring project in which pulse trawl skippers record the catch and effort by tow. This information provides insight in the dynamics of pulse trawlers exploiting local aggregations of sole and can shed light on the effects of pulse fishing on local aggregations of fish and on possible competitive interactions between vessels. Further, pulse stimulation can also be used to increase selectivity in the net instead of a capture technique. This was shown by the studies of the Instituut Voor Landbouw-, Visserij-, en Voedingsonderzoek (ILVO) showing that a 200 mm benthos release panel equipped with an electrical stimulus (eBRP) has the potential to release up to 75% of the benthos and debris immediately after capture without significant losses of marketable Dover sole and other species. Other work focused on pulse trawling targeting brown shrimp. The preliminary results of an elaborate Dutch study including active pulse trawlers targeting shrimp confirmed that a pulse trawl with a straight bobbin rope and 12 bobbins can obtain similar or slightly higher catches of marketable shrimp, while showing drastic reductions in the bycatch of other invertebrates and fish. Finally, the group discussed a number of upcoming research projects including the study of the changes in catch rate of various fisheries in relation to emergence of pulse fishing.

ii Expert group information

Expert group name	The Working Group on Electrical Trawling (WGELECTRA)
Expert group cycle	Multi annual fixed-term
Year cycle started	2018
Reporting year in cycle	2/3
Chair(s)	Adriaan Rijnsdorp, The Netherlands
	Maarten Soetaert, Belgium
Meeting venue(s) and dates	17-19 April 2018, IJmuiden, The Netherlands (18 Participants)
	11-13 June, 2019, Ghent, Belgium, (12 Participants)

1 Terms of Reference

a) Produce a state-of-the-art review of all relevant studies on marine electrofishing. Yearly update it by evaluating and incorporating new research to it ;
b) Compare the ecological and environmental effects of using traditional beam trawls or pulse trawls when exploiting the TAC of North Sea sole, on (i) the sustainable exploitation of the target species (species and size selectivity); (ii) target and non-target species that are exposed to the gear but are not retained (injuries and mortality); (iii) the mechanical disturbance of the seabed; (iv) the structure and functioning of the benthic ecosystem; and to assess (v) the impact of repetitive exposure to the two gear types on marine organisms ;
c) Discuss and prioritize knowledge gaps, and discuss ongoing and upcoming research projects in the light of these knowledge gaps, including the experimental set up;
d) Create a platform for the application for supra-national joint research projects on electrotrawling and scientific publication of the obtained results.

2 Introduction

In 2018 the work of WGELECTRA was mainly focused on the request for advice to compare the ecological and environmental effects of using traditional beam trawls or pulse trawls when exploiting the TAC of North Sea sole (ICES, 2018b). Although the ICES evaluation of the scientific information available indicated that pulse trawling may contribute to reduce the ecological and environmental impacts of the beam trawl fishery for sole (ICES, 2018a), the EU has decided to maintain the ban on the use of electricity to capture fish in their renewed set Technical Measures (EU, 2019).

As for the 2019 meeting no request for advice was issued, the working group used the opportunity for an in depth discussion of the results of the ongoing research in Belgium, England, Germany and the Netherlands. The current report presents an overview of the ongoing research and some of the preliminary results. Preliminary results were shared in confidence and can only be used when formally published. All relevant published data are reviewed in the living document on principles and effects of pulse trawling, which can be found in the Annex of this report.

3 Sole pulse research: update on progress ongoing research

3.1 Effects on marine organisms: Pim Boute

Within the Impact Assessment Pulse Fisheries project, a PhD-project studies the effect of electrical pulse stimulation as used in sole fisheries, on marine fishes and invertebrates. This possible effect on marine organisms is studied at various levels:

- Study of the occurrence of internal injuries in fishes caught by pulse trawlers. To distinguish between injuries caused by electrical stimulation and injuries caused by mechanical stimulation, fishes were sampled on-board from commercial tows with the electrical pulse stimulus switched on and off and from conventional beam trawlers using tickler chains. Catches are analysed using X-ray photography followed by filleting to check for spinal injuries and haemorrhages along the spinal column respectively. Spinal abnormalities/injuries and haemorrhages are scored by taking into account the position on the anteroposterior axis of the fish and severity of the abnormality/injury;
- Study of the morphometry of a selection of fishes to better understand how the response of fishes to the muscle cramp inducing electrical pulse stimulus could result in a damaged spinal column;
- Study of the swimming behaviour of (non-)electro receptive fishes in response to the electrical stimulus to quantify sensitivity thresholds;
- Study of species-specific behavioural responses and survival of selected marine benthic invertebrates in response to a worst-case-electrical stimulus. The behavioural responses are quantified before and after exposure and a control group was included;
- Study of the fish muscle activation in response to electrical stimuli to quantify sensitivity thresholds of muscle activity;
- Study of the distribution of the electric field around a pulse gear using finite element modelling. In addition we model and measure the electric field in our experimental set-ups.

Above study parts will be integrated to construct a predictive framework on the effect of electrical pulse stimulation on fishes and benthic invertebrates.

3.2 Effects on marine ecosystems: Justin Tiano

Within the Impact Assessment Pulse Fisheries project, a PhD-project studies the effects of pulse trawls and beam trawls on the benthic ecosystem (Tiano et al., 2019). The work places an emphasis on biogeochemical functioning in order to assess benthic-pelagic coupling and benthic metabolizm. Changes to these dynamics hold implications for carbon cycling, primary production and benthic food availability.

For a field campaign in June 2017, commercial pulse and beam trawlers cooperated with scientists to create experimentally trawled areas in the Frisian Front area in the North Sea. Benthic chlorophyll-a and oxygen demand was significantly reduced after both tickler chain beam trawl and pulse trawl disturbance. Effects from pulse trawl disturbance was more variable and less severe compared with that of the beam trawl implying a greater biogeochemical impact associated with the heavier tickler chain gears.

Work being conducted to experimentally isolate the effects of electricity and mechanical disturbance has found little to no effect from electrical stimulation on biogeochemical measurements when using standard sole pulse settings. When switching the settings to a direct current and exposing samples for up to 2 minutes (as is sometimes seen in the Ensis electrofishery), however, significant declines in pH and phosphates were observed.

To upscale the effects of bottom trawl fisheries in the North Sea, a biogeochemical model will be used. This model estimates the recovery of nutrient and oxygen parameters in response to mechanical disturbance. Sediment type, levels of organic matter deposition, amount of trawling events and several other parameters can be modified in order to adapt this model to different areas in the North Sea.

The effect of electrical exposure on burrowing organisms is of particular interest as these animals may be able to escape the mechanical effects of bottom trawl gears but can still be stimulated electrically. These organisms also carry out important functions such as bio irrigation and bioturbation which affect sediment biogeochemistry. Preliminary results from laboratory experiments suggests that electrical pulses may increase burrowing behaviour as the animals try to escape the disturbance.

The research, so far, only shows biogeochemical impacts coming from mechanical disturbance as there is no evidence of electrical pulses (using sole pulse parameters) leading to a detectable impact on biogeochemistry. Given the larger mechanical impact and seabed penetration from tickler chain beam trawls, we have found a comparatively reduced effect from pulse trawls on sedimentary organic material, nutrient concentrations and benthic community metabolizm.

3.3 Research approach for assessing direct mortality among demersal fish and benthic organisms in the wake of pulse trawl: Pieke Molenaar

Various stakeholders expressed their concerns about the impacts of pulse fisheries. A major concern is the direct effect of a passing pulse trawl on benthic organisms. It has been claimed that a passing pulse trawl causes mass mortality among benthic organisms, resulting in a 'graveyard' in the wake of a pulse trawler. Direct scientific evidence of such claims is absent to the best of our knowledge. In fact, over 90% of undersized fish caught by pulse trawling is alive when landed on deck (Schram and Molenaar, 2018), suggesting that direct mortality among fish exposed to the electric field of a pulse trawl is at least very low.

Given this indirect evidence, direct mortality among benthic organisms caused by passing pulse trawls seems unlikely. Nevertheless, concerns about this effect are persistent among stakeholders. Indeed this direct effect of pulse trawling has never been investigated in situ. Therefore the current pilot study aimed to develop a method for in situ assessments of direct mortality and to perform a first assessment.

The specific the objectives of the method development included:

1. Investigate whether it is possible to detect the track of pulse trawls on the sea floor using side-scan sonar.
2. Test whether it is possible to deploy a shrimp trawl in the pulse trawl track and sample benthic organisms from the track.

3. To confirm the deployment of the shrimp trawl in the pulse trawl track by underwater video observations.
4. To assess the species composition of samples collection in pulse trawl tracks.
5. To test methods for assessment of the condition of sampled organisms.

The research approach and methodology is presented and discussed with the members of WGELECTRA during the meeting. The field experiments are planned shortly after the meeting when weather conditions are sufficient.

3.4 Optimization pulse trawl selectivity trough through modification of pulse settings: Pieke Molenaar

It has been investigated whether the selective nature of pulse fishing can be further enhanced by the optimization of pulse settings. In the context of the landing obligation, it is desirable to reduce the chance of catching undersized plaice and sole without affecting the marketable catch. To test the selective effect of different pulse settings (within the legal bandwidth), in May 2018, divided over three days, in the Fisheries Innovation Centre in Stellendam, 11 tests were carried out with sole and plaice. During the tests, only one setting was changed and the other two were placed on the commercial setting; 60 hertz, 350 µs, 60 volts. To study the selective effect, experiments were carried out with increasing levels of voltage (volts), frequency (hertz) and pulse duration (µs).

In the 32.8 meter long seawater basin five cages with fish stood in a row behind each other. For each test, the fish are grouped by species and length class and placed in a cage. For each setting, three increasing variations in the setting were tested in successive tests. This was done with the same group of fish and with a 60-minute rest period between repetitions. During the test, the pulse electrodes were dragged over the bottom along the cages at a speed of 4 miles per hour. The reactions of the fish were recorded with a camera from the side and top perspective. The videos were analysed for the intensity of the responses (e.g. none, vibrations, flights, etc.) during and after exposure to the pulse stimulation.

The effect of the mediating variables on the results is difficult to explain and therefore only the most obvious effects of the pulse settings on the reaction of the fish are discussed. During all experiments it was clear that sole reacts more intensively to pulse stimulation than plaice. Furthermore, the experiments showed that it was possible to selectively control the intensity with which different length classes of sole responded. Responses by plaice did not show a clear distinction between the different length classes. In general the pulse stimulation has a less clear effect on plaice. An increase in voltage (volts) amplified the response of small sole and all sizes of plaice. As a higher frequency (hertz) was applied, the response of sole got stronger. This effect was less clear in plaice. Pulse duration had the most selective effect, in particular on larger sole specimens, a more intense response was observed and with no clear effect visible in the other length classes and plaice specimens. From these experiments it seems possible to optimize the selectivity of the pulse gear with a combination of the optimal pulse duration, frequency and voltage, so that the catch of marketable fish is retained, but the catch of small (undersized) plaice and sole is limited. Follow-up research should focus on a greater number of repetitions of the tests to ensure that the effect of the pulse setting on the fish by the pulse stimulation can be better distinguished from the effect by the mediating factors (orientation and degree of burrowing).

3.5 Pulse exposure experiments on greater and smaller sandeel: Pieke Molenaar & Pim Boute

Stakeholders expressed questions about the impacts of pulse fisheries on key species in the North Sea foodweb as greater and smaller smelt. The major concern is the possible impact of a pulse trawl on those species that could cause a major effect on species in the foodweb that rely on those species. For cod it is known that exposure to a pulse stimulus can induce spinal injuries, bot for greater and smaller sandeels this has not been investigated. Given the slim morphology of the greater and smaller sandeels and the commonly used 80+ mm mesh openings in a commercial pulse trawl cod-end, it is not possible to collect representative samples from commercial catches as the fast majority of the sandeels escape from the pulse trawl. To address this question a laboratory study is designed where wild caught greater and smaller sandeels are exposed to pulse stimuli as used in the commercial fishery. Smaller sandeels were collected at sea with a small meshed otter trawl and after transferring and acclimatization exposed to pulse stimuli and compared with a not exposed group. After exposure fish were euthanized with and assessed for internal injuries with X-ray pictures and dissection. Preliminary results show no differences between the exposed and control groups for smaller sandeels. Catches of greater sandeels were low and additional animals will be collected in the third quarter of 2019.

3.6 Sediment resuspension and gear penetration: Adriaan Rijnsdorp, Jochen Depestele

Bottom trawls impact the seabed by disturbing the top layer of the sediment and the resuspension of the silt fraction (Depestele et al., 2016; O'Neill and Ivanović, 2016). In the FP7-project BENTHIS, an approach was developed to quantify the mechanical impact of bottom trawls by decomposing the fishing gear and estimating the impact of the different gear components (Eigaard et al., 2016). The sediment resuspension is determined by the hydrodynamic drag of the gear and the silt fraction of the sediment (O'Neill and Summerbell, 2016) and empirical relationships have been established to estimate the hydrodynamic drag of different gear components(O'Neill and Ivanović, 2016); O'Neill et al, in prep). With the dimensions of the relevant gear components, which are currently being collected, the towing speed of the commercial vessels and the trawling intensities of the different habitats, the amount of silt brought into suspension by the beam trawl fleet using conventional tickler chain gear will be compared to the resuspension caused by the pulse trawl fleet.

3.7 Comparative performance of pulse trawling vs. beam trawling: Marieke Desender

Cefas executed two practical field trials in 2019 to enhance the understanding regarding the impacts of pulse trawling for flatfish in the southern North Sea.

In the first trial, from 17 March till 29 March 2019, a pulse vessel equipped with its current commercial gear (two 12m PulsWings) was compared with a sister vessel rigged with two 12m SumWings and 2*258m tickler chains. Both vessels (>221kW) fished as close as possible mid-Southern North Sea. Shooting and hauling was synchronized for sampled hauls on the two vessels. A towing time of app. 2hours. was the same between the two vessels. Catch (Landings, discarded fish, benthos and inert material) was compared on 19 hauls. Additionally, on six separate hauls a vitality assessment (reflexes and injuries) on discarded plaice and sole was performed throughout the sorting process.

In Trial two, the PulsWing vessel continued normal fishing the week after from 24-29 March 2019 with the same gear but on different grounds located more south and closer to the UK coast. Catch performance was investigated on 18 hauls and an additional 6 hauls were observed for vitality assessment.

A report is being finalized illustrating the results of this research.

3.8 Implications of pulse trawling for UK conservation interests: Julie Bremner

Cefas is conducting two projects commissioned by the UK government in relation to pulse trawling.

One, funded under the UK Fisheries Science Partnership, "A study to investigate the potential ecological impacts of pulse trawling", aims to investigate whether there are differences in the fish and benthos communities in an offshore pulse trawling ground and an inshore area not subject to pulse fishing, off the UK East Anglian coast. The areas were surveyed over a period of 10 days in November 2018 using an otter trawl and Jennings beam trawl and the species richness, fish counts and lengths and benthic invertebrate species volumes were assessed. The report is being finalized.

The second project aims to assess:

e) The comparative performance and impact of pulse trawling vs. beam trawling
   1. Practical field trials with scientific observers aboard one pulse trawler and one beam trawler (update given by Marieke Desender)
   2. Comparative analyses of Cefas data with existing outputs from the Dutch pulse fishery. Discussions and work ongoing.

f) Ecosystem effects of pulse trawling through direct observation
   1. Design a study to assess ecosystem effects of pulse trawling. To design a large-scale ecosystem study that will enhance understanding on the ecosystem effects of pulse trawling and comparative effects of pulse trawling vs. beam trawling. This is a desk-based task to design a study and it does not include conducting the study itself. The focus of the study will be on the impacts on benthic communities, but it will also take account of other components of the marine ecosystem. Cefas will host a meeting with colleagues from the Netherlands and Belgium to discuss the focus and content of an ecosystem study immediately after WGELECTRA 2019.

g) Analyse spatio-temporal effort distribution across the fishing grounds, to support the design of an ecosystem study.
   1. Cefas will also focus on gaining a greater understanding of the patterns of effort offshore of the UK East Anglian coast and south-east England. Cefas are in discussion with colleagues in WUR and ILVO; work is ongoing.

h) Examine implications of pulse trawling for UK conservation interests.
   1. This work aims to complete an initial appraisal of the implications of pulse trawling for species and habitats in UK waters protected under conservation designations and marine features of national and international importance. JNCC has iden-

tified the key features and their distribution across the UK sector of the south-western North Sea and is conducting a risk assessment for these features. The report is being finalized.

i) Describe the socio-economic situation in other fisheries coexisting with pulse trawling.

1. Stakeholders have reported concerns that pulse trawling is impacting on small-scale fisheries. This task aims to examine available data on fisheries sectors operating in the vicinity of pulse trawling, including inshore vessels and the recreational sector. Cefas is currently gathering data on the UK sectors and in discussion with ILVO on their pulse fishing on the Belgian coast project with a view to aligning approaches.

3.9 Pulse fishing along the Belgian coast: analyses of available datasets: Lies Vansteenbrugge

Lies Vansteenbrugge from ILVO (Flanders Research Institute for Agriculture, Fisheries and Food, Belgium) presented a new Belgian project that started 1st of September 2018: "Pulse fishing along the Belgian coast: analyses of available datasets". The project runs for approximately 1 year (until 31 July 2019). It is financed by the national EMFF and FIVA (Flanders government). The project is a desk study, meaning available datasets are analysed. The focus lies on the southern North Sea and 5 commercial species: sole (*Solea solea*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*), European sea bass (*Dicentrarchus labrax*) and brown shrimp (*Crangon crangon*). A longer time series is analysed making sure that also time before the introduction of pulse fishing in 2009 is included in the analysis.

The first part of the project focuses on changes in biomass. Commercial landings and effort data are analysed and LPUE indices (landings per unit of effort) are calculated. Furthermore, biological data is explored to identify potential shifts in the age structure or the mean weight at age. Besides commercial data, also available recreational long term datasets are investigated. Alongside the fisheries dependent data, fisheries independent data from the IBTS (international bottom trawl survey), BTS (beam trawl survey) and DYFS (demersal young fish survey) surveys are used to calculate indices to identify potential changes over this long term period.

The second part of the project focuses on VMS analyses where logbooks and effort are linked. Here, we focus on sole and plaice and select only the TBB gears both pulse and regular. Unfortunately only data from the commercial fleet is available here. The analysis aims to identify spatio-temporal shifts related to the introduction of the pulse fleet.

With this project, ILVO aims to answers some of the questions raised by stakeholders, mostly fishermen who claim to have encountered changes in the southern North Sea at the same time pulse fishing was adopted.

3.10 Declining catch rates of small-scale fishers in the southern North Sea in relation to the pulse transition in the beam trawl fleet: Adriaan Rijnsdorp

Small-scale fishers have raised complaints about falling catch rates on their fishing grounds in the southern North Sea. In a desk study by Rijnsdorp et al (2018), complaints of gillnet and handline fishers working in the coastal waters of Belgium and the Netherlands were compared to (i) trends in the catch rate of sole, cod and sea bass estimated for the beam trawl fisheries in six different areas of the southern North Sea and (ii) trends in the spawning stock biomass of these species estimated by ICES. It is shown that the catch rate of sole in the beam trawl fishery increased between 2009 and 2016. Therefore it is unlikely that the decline in the catch of sole in gillnets is due to a decline in the biomass of sole in the southern North Sea. It is more likely that the decline is due to the competition with pulse trawlers which are more efficient at catching sole than traditional beam trawlers. The decline in cod catches in gillnet and handline fisheries matched the declining catch rate of beam trawlers between spring and autumn suggesting that the decline is related to a decline in stock size in the southern North Sea. For sea bass the decline in catch rates of the small-scale fishers is likely related to the decrease in stock size.

3.11 eBRP trials with cramp pulse: Maarten Soetaert

Benthos release panels (BRPs) are known for their capacity to release large amounts of unwanted benthos and debris. Additionally, they are also more selective hence catching less undersized fish. However, until now, unacceptable commercial losses of sole (*Solea solea* L.) was hampering a successful introduction in commercial beam trawl fisheries. To eliminate this drawbacks, two approaches were tested by ILVO. First, the BRP was rigged in a net with a straight footrope as being used by pulse trawlers to prevent slack. This eliminated the occurrence of slack in the panel and 'bag formation' which reduced the loss of sole (and benthos) by 10-20%.

Second, the minimal electrical stimulus to immobilize Dover sole was determined in the lab with the idea of preventing the fish to dive and escape through the panel. Exposures in a setup with a homogenous electric field showed that a minimum frequency of 28 pulses per second at 50 V m-1 was needed to completely immobilize all sole during exposure despite their orientation. None of the (repetitively) exposed animals showed external injuries or died during the month following exposure. To take into account possible losses at sea as well as a reduced reaction of fish when exposed in a heterogeneous electrode set-up, especially with thin electrodes, it was decided to use a pulse stimulus with 40 square 250 µs pulses per second (20 HZ PBC) for the sea trials, i.e. halve the duty cycle used in commercial pulse trawlers targeting sole.

The final part of the presentation showed the effect of the electrical immobilization stimulus on the selectivity and release capacity of BRP's by implementing it in 200 and 240 mm BRPs and doing catch comparisons comparing it to a reference net without BRP. The results of these sea trials confirm that electrifying a BRP prevents sole from escaping/diving through it. The best results were obtained with an electrified 200 mm electrified BRP (eBRP) in which the loss of commercial sized sole was completely eliminated while still allowing 20% of the undersized sole to escape. There are no indications that the release capacity of the (e)BRP for benthos and debris was affected by the electric field and were still in the 30-50% range. These results will be submitted for publication in ICES JMS in August 2019.

3.12 Small-scale dynamics of fishing patterns: Adriaan Rijnsdrop

In the Netherlands, a research project is carried out that collects detailed logbook information of the total pulse trawl fleet on the catch per tow of the main commercial species as well as the date, time and position where the trawl was shot and hauled. Data have been collected from 1 January 2017 onwards and is ongoing. The objective of the project is to gain insight in how pulse fishers exploit their resources and how the allocate their effort in space and time. Knowledge on how fishers exploit their fisheries resources is important for understanding how fishing affect the population dynamics of the exploited species and how the fishery may affect the ecosystem. The introduction of a new gear may affect the way fishers deploy their gear in space and time.

Results of a preliminary analysis of the data collected until 30 September 2018 have been reported in Rijnsdorp et al (2019). The behaviour of pulse trawl vessels is compared to the behaviour of traditional beam trawl vessels collected between 2000 and 2005. The study showed that pulse trawl (PT) and traditional beam trawl (BT) vessels had similar fishing patterns with alternating periods of searching, or sampling, for fishing grounds and exploitation of fishing grounds. The catch rate of sole during exploitation of a fishing ground was on average 22% (PT) and 23% (BT) higher than while searching for fishing grounds. PT deploy 73% of their tows while exploiting a fishing ground and 27% while searching or sampling, as compared to 69% and 31% in BT. The number of tows taken on a fishing ground by PT (large vessels: median = 16.4; small vessels: median = 18.8) was higher than by BT (median = 13.0). During an exploitation event – the period of successive tows made at a fishing ground – the sole catch rate declined over successive tows. Although the rate of decline varied substantially among the different fishing grounds, the statistical analysis showed that on average the rate of decline was faster for BT than for PT. Of the pulse fishing grounds distinguished during the study period 61% were exploited by a single vessel and 39% were exploited by two or more vessels. Vessels differ in the proportion of fishing grounds shared with other vessels. Fishing effort on shared fishing grounds is higher than on the fishing grounds exploited by a single vessel only.

The logbook data provide detailed information on what happens on the local fishing grounds which is fundamental to assess the impact of the pulse trawl fishery and beam trawl fishery on the fisheries resources and on the benthic ecosystem.

The study of the total pulse fleet provides a unique dataset to study not only the dynamics of the whole fleet, including the interactions among pulse vessels, but also provides a solid basis to study competitive interactions with other fisheries.

4 Shrimp pulse research

4.1 Ongoing work Netherlands: Jimmy van Rijn/Edward Schram

All Dutch pulse trawlers targeting shrimp (HA31, ST24 and WR40 all year-round + TH10 in late summer) are involved and being studied in a 2 year project (2018-2019). The first goal was to gather 'reference data' of this fisheries in every season (per quarter) and in each of the N2000 areas. Data is gathered in 3 ways: (i) catch volume estimate + commercial catch are recorded for every haul and compared with a conventional fishing 'buddy', (ii) self-sampling while fishing with 1 conventional and 1 pulse trawl simultaneously (direct left right catch comparison) and (iii) an observer trip doing the same but on board.

The first results indicate that in average the catches of commercial and small shrimp are ± 15% and 35% higher respectively, while the bycatch of round fish, flatfish, benthos and rubble was reduced with ±5%, ±40%, ±50% and ±40% respectively. The increased catch rates for shrimp seem highest in summer and more shallow fishing grounds like the Waddensee. This dataset is further being completed during 2019 and additionally some innovations such as a different bobbin rope design or shorter electrodes are being evaluated. The final results of this project should be available at the end of Q1 2020.

4.2 Ongoing work Belgium: Maarten Soetaert/Mattias van Opstal

Currently there is 1 Belgian vessel fishing electrically, i.e. the O81 which started early 2019. In contrast to all other pulse trawlers targeting shrimp equipped with a Marelec generator, this vessel was equipped with a newly developed gear of LFish. This manufacturer made a modular design which allows fishermen to modify the pulse settings between 1 and 7 Hz, 0.1 and 1 ms and 30-65 Vp, whereas the Marelec generators produce a fixed 0.5 ms and 5 Hz with variable amplitude between 30 and 80 Vp.

The vessel has only been fishing on the Dutch coast, although it has no access to the N2000 areas. There is no funding provided to monitor (the catches of) the O81 in 2019 and with the upcoming new technical measures it is also unlikely their pulse licence will be extended past 2019.

5 Varia

5.1 Guidelines for defining the use of electricity in marine electro trawling

Electricity can be used to facilitate fish and invertebrate capture in both marine and freshwater environments. In freshwaters, electrofishing is largely used for research or management purposes. In marine environments electrofishing is principally used in the form of electro trawling for the commercial capture of fishes and benthic invertebrates, in particular common sole (*Solea solea* L.), brown shrimp (*Crangon crangon* L.), and razor clams (*Ensis* spp.). The terminology and definitions used to describe the electrical stimulus characteristics and experimental set-ups have, so far, been diverse and incomplete, hampering constructive discussion and comparison of electrofishing studies. This paper aims to (i) harmonize existing terminology, abbreviations, and symbols, (ii) offer best practice recommendations for publishing results, and (iii) provide a concise and comprehensible reference work for people unfamiliar with this topic. By incorporating common practice in marine electric pulse trawling terminology and related freshwater electrofishing studies, based on existing terms where possible, we provide a framework for future studies. The suggested guideline is recommended by the ICES Working Group on Electrical Trawling as a constructive approach to improved communication standards in electrofishing and electrical pulse stimulation research and publications and published in July 2019 in the ICES Journal of Marine Sciences **(Soetaert et al., 2019).**

5.2 PhD-proposals Ghent University

Three PhD proposals were submitted by Ghent University in the second halve of 2019:

- Pulse trawl fishing: effects on the behaviour and food quality of the benthic infauna and implications for higher trophic levels (by Anouk Ollevier)
- Addressing the long-standing question on the impact of pulse trawling on young life stages of marine organisms in the North Sea (by Jan Francies Van Waes)
- Does a possible perturbation of marine microbes prevent pulse trawling from being widely commercialized in the North Sea? (by Laure Van den Bulcke)

Unfortunately, none of them was funded (VLAIO). Seen the recent EU decision to phase out pulse trawling by 2021, it is uncertain if these topics will be resubmitted in the future.

5.3 Questions JNCC

Question JNCC	Answer WGELECTRA
Update on how the concerns of the ecological effect of pulse trawling on the ecosystem and mitigation options have been explored further	An update can be found in the 2019 report of WG ELECTRA, the updated living document on side-effects of pulse trawling as well as the recent report of WMR reviewing all open research questions (Quirijns et al., 2018). There are some lack of evidence of the impact of pulse fisheries on to species (marine mammals). Discussion on how this information might help to understand pulse fishing impacts in the ecosystem will need to be explored Pim Boute is continuing his fleet sampling to assess side-effect in most of the (by)caught species. All animals of this large-scale sampling (including 15 000 + animals so far) are being examined and X-rayed to reveal a potential negative impact.
Linking from the above note, more information on the impact on the food chain and the trophic interactions. Can we use other gear as a proxy? It might be possible to develop some model which quantifies the loss of prey (like cod injuries, or repetitive exposure to fish) for marine mammals and birds	There are no known issue with marine mammals being bycaught in beam or pulse trawls, resulting in a very low likelihood of making contact with the electric field hence risk on adverse side effects as indicated in the 2015 WG ELECTRA meeting report.
Pulse fisheries is likely to be happening in softer sediments, some areas have sandeel, which is an important prey in the food chain. More studies under sandeels, rather than focus only in the marine commercial species such as cod and sole	The possible side-effect on sandeels are being studied based on sampling on board of commercial vessels as well as a laboratory experiment. The final results will be presented next year.
Limited knowledge on how the increased catch efficiency for sole may be impacting predators.	The higher catch efficiency of the pulse trawl for sole (see WGELECTRA Report 2018) and the lower catch efficiency for other fish species is expected to reduce the bycatch of predators.
Identify the optimal electrical settings and gear design which can balancing the negative impact to marine species most at risk of injury and behavioural changes with a worthwhile catch efficiency	So far, injuries have only been proven and confirmed in adult Atlantic cod. These species are only rarely been by-caught by pulse trawls and are landed or die from barotrauma. Literature suggests that different pulse frequencies result in a different injury rate, it remains unclear how these affect the catch efficiency for the target species, although it can be expected that the pulse used nowadays is optimal in terms of catch efficiency for sole. This means a trade-off, which is difficult since there is no objective common denominator to compare the catch increase for sole + reduced by-catch, bottom contact and fuel consumption rates with the unclear net-effect of electric pulse on the (small) bycatches of Atlantic cod.

6 Reference

Depestele, J., Ivanović, A., Degrendele, K., Esmaeili, M., Polet, H., Roche, M., Summerbell, K., et al. 2016. Measuring and assessing the physical impact of beam trawling. ICES Journal of Marine Science: i15-i26.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., et al. 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science 73: i27-i43.

Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures, amending Council Regulations (EC) No 1967/2006, (EC) No 1224/2009 and Regulations (EU) No 1380/2013, (EU) 2016/1139, (EU) 2018/973, (EU) 2019/472 and (EU) 2019/1022 of the European Parliament and of the Council, and repealing Council Regulations (EC) No 894/97, (EC) No 850/98, (EC) No 2549/2000, (EC) No 254/2002, (EC) No 812/2004 and (EC) No 2187/2005. *25.7.2019*. Official Journal of the European Union, 198: p105-201.

ICES. 2018a. ICES Special Request Advice, Greater North Sea Ecoregion, Published 30 May 2018, sr.2018.08.

ICES. 2018b. Report of the Working Group on Electric Trawling (WGELECTRA). 17-19 April 2018. IJmuiden, The Netherlands. ICES Document ICES CM 2018/EOSG:10.

O'Neill, F. G., and Ivanović, A. 2016. The physical impact of towed demersal fishing gears on soft sediments. ICES Journal of Marine Science: 73: i5-i14.

O'Neill, F. G., and Summerbell, K. J. 2016. The hydrodynamic drag and the mobilisation of sediment into the water column of towed fishing gear components. Journal of Marine Systems, 164: 76-84.

Quirijns, F. J., Steins, N. A., Steenbergen, J., and Rijnsdorp, A. D. 2018. Recommendations for additional research into pulse-trawl fisheries. Wageningen Marine Research report C106/18. 56 pp.

Rijnsdorp, A.D., van Rijssel J., Hintzen, NH. 2018. Declining catch rates of small-scale fishers in the southern North Sea in relation to the pulse transition in the beam trawl fleet. Wageningen Marine Research report C051/18

Rijnsdorp A., Aarts G., Gerla D, van Rijssel J., Poos JJ. 2019. Spatial dynamics of pulse vessels: a preliminary analysis of the pulse logbook data collected in 2017 and 2018. Wageningen University & Research report C030/19

Schram, E., and Molenaar, P. 2018. Discards survival probabilities of flatfish and rays in North Sea pulse-trawl fisheries. Wageningen Marine Research report C037/18. 39 pp.

Soetaert, M., Boute, P. G., and Beaumont, W. R. C. 2019. Guidelines for defining the use of electricity in marine electrotrawling. ICES Journal of Marine Science. doi.org/10.1093/icesjms/fsz122

Tiano, J. C., Witbaard, R., Bergman, M. J. N., van Rijswijk, P., Tramper, A., van Oevelen, D., and Soetaert, K. 2019. Acute impacts of bottom trawl gears on benthic metabolizm and nutrient cycling. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsz060.

Annex 1: List of participants

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Annex 2: Resolutions

WGELECTRA - Working Group on Electrical Trawling

2016/2/SSGIEOM22 A **Working Group on Electrical Trawling** (WGELECTRA), chaired by Maarten Soetaert, Belgium, and Adriaan Rijnsdorp, the Netherlands, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2018	17-19 April	WMR Ijmuiden, the Netherlands	Interim report by 31 of May 2018 to ACOM-SCICOM	
Year 2019	11-13 June	Ghent, Belgium	Interim report by 11 of July 2019 to ACOM-SCICOM	
Year 2020	TBD	TBD	Final report by end of June 2020 to ACOM-SCICOM	

ToR descriptors

ToR	Description	Background	Science plan codes	Duration	Expected Deliverables
a	Produce a state-of-the-art review of all relevant studies on marine electrofishing. Yearly update it by evaluating and incorporating new research to it.	a) Science Requirements b) Advisory Requirements	2.1, 6.1, 6.4	Yearly update	Review report to SCICOM
b	Compare the ecological and environmental effects of using traditional beam trawls or pulse trawls when exploiting the TAC of North Sea sole, on (i) the sustainable exploitation of the target species (species and size selectivity); (ii) target and non-target species that are exposed to the gear but are not retained (injuries and mortality); (iii) the mechanical disturbance of the seabed; (iv) the structure and functioning of the benthic ecosystem; and to assess (v) the impact of repetitive exposure to the two gear types on marine organisms..	b) Advisory Requirement as part of a response to request from the Dutch Ministry of Agriculture, Nature and Food Quality. s WGECO will provide some considerations for WGELECTRA to take account of when responding to this request.	2.1, 2.7, 6.4	Year 1	Relevant section of the WGELECTRA report must be made available for independent external review by 30 April 2018.
c	Discuss and prioritize knowledge gaps, and discuss ongoing and upcoming research projects in the light of these knowledge gaps, including the experimental set up	a) Science Requirements b) Advisory Requirements	2.1, 2.7, 6.4, 6.6	Year 1, 2 & 3	Scientific research adressing knowledge gaps or questions from management

d	Create a platform for the application for supra-national joint research projects on electrotrawling and scientific publication of the obtained results	a) Science Requirements b) Advisory Requirements	3.1, 6.6	Year 1, 2 & 3	Joint projects and publications among participants and others Collaboration with other related WG's such as WGNSSK, WGCRAN

Summary of the Work Plan

Year 1	- Initiating the review document - Discussing & evaluating ongoing & recently completed research - Brainstorm & application of a joint research project - Answering special request from The Netherlands-Dutch Ministry of Agriculture, Nature and Food Quality.
Year 2	- Updating the review document - Discussing & evaluating ongoing& recently completed research - Evaluating and presenting results from joint research projects - Answering possible requests
Year 3	- Finalizing the review document - Discussing & evaluating performed research - Presentation achievements and further goals joint research projects - Answering possible requests - Writing the final 3year report

Supporting information

Priority	The current activities of this Group will allow ICES to respond to advice requests from member countries. Consequently these activities are considered to have a very high priority. It will also lead ICES into issues related to the ecosystem effects of pulse fisheries, especially with regard to the application of the Precautionary Approach. Current pulse derogations in the sole fishery will expire in 2019. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 10–15 members and guests. In 2016 two PhD students started working on the ecosystem effects of pulse trawling in the Netherlands.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There is a close working relationship with the Assessment Working groups (WGNSSK) dealing with the target species of the pulse fisheries (sole, plaice) and WGCRAN. It is also very relevant to the Working Group on Ecosystem Effects of Fishing.
Linkages to other committees or groups	
Linkages to other organizations	/

Annex 3: Living document on principles and effects of pulse trawling

Please find WGELECTRA living document on principles and effects of pulse trawling below

Pulse fishing in marine fisheries

Review of the technology, research and research agenda

Last revised and updated by WG Electra **July 27th** 2019.

Previous versions published in: June 27th 2018

This overview was initially merged and completed by Maarten Soetaert (2017) based on:

(1) Verschueren, B. and Polet, H. September 2016. Pulse fishing in marine fisheries – Review of the technology, research and research agenda. Institute of Agricultural and Fisheries Research (ILVO) internal document: 70 p.

(2) Rijnsdorp, A., De Haan, D., Smith, S. and Strietman, W. J.. December 2016. Pulse fishing and its effects on the marine ecosystem and fisheries. Wageningen Marine Research (WMR) confidential report C117/16: 32p.

(3) WG Electra, 2017. Final report of the working group on electric trawling. ICES CM 2017/SSGIEOM:20; 40 p.

Contents

1 Introduction

The North Sea flatfish fishery is mainly carried out with vessels that tow double beam trawls over the sea bed to target sole and plaice (Rijnsdorp et al., 2008). This beam trawl fishery, in particular the one targeting sole, is characterised by a substantial bycatch of undersized fish, benthic invertebrates and debris. In addition, beam trawls have an adverse impact on the structure of sea bed habitats and impose an additional mortality on invertebrate animals in the path of the trawl (Lindeboom and de Groot, 1998; Bergman and Santbrink, 2000; Kaiser et al., 2006). In terms of benthic impacts, flatfish beam trawls together with shellfish dredges are considered to be the most detrimental fishing gears in the North Sea (Polet and Depestele, 2010). These benthic impacts are related to tickler chains that are used to chase sole out of the sea bed. These tickler chains dig into the sea bed to a depth of 8cm or more (Paschen et al., 2000).

Research into alternative methods to catch sole has been conducted since the 1970s to increase the selectivity for sole. This research focussed on the use of electrical pulses that led to a contraction of the body muscles (cramp response) during exposure which prevented the sole to dig into the sediment. The U-shaped form of a cramped sole makes it easier to catch in a bottom trawl. After successful commercial trials since 2005, an increasing number of vessels has switched from the traditional tickler chain beam trawls to pulse trawls. These vessels operate under a temporary licence, because use of electricity in catching marine fish is not allowed in EU waters (EC nr 850/98, article 31: non-conventional fishery techniques).

In addition to the deployment of pulse trawls in the flatfish fishery, pulse trawls have adopted in the fishery for brown shrimps in the Netherlands although the number of vessels is small (4) and the vessels are not allowed to use the gear in the Natura2000 areas. The shrimp pulse invokes a startle response in shrimps which allows the fishers to reduce the weight of the gear and subsequent bottom contact. Experiments have shown that the application of electrical stimulation in the fishery for brown shrimp may reduce the bycatch of other species (Polet et al., 2005a, 2005b.

The introduction of pulse fishing in the North Sea has raised serious concerns among stakeholders (fishing industry, NGO's) and EU member states. Fishing trials and laboratory experiments reported spinal fractures in cod (van Marlen et al., 2007; de Haan et al., 2008). Kraan et al. (2015) made an inventory of the concerns which were discussed at a pulse dialogue meeting organised in July 2015. The concerns are related to the lack of knowledge about (i) the ecological effects of electrical pulses on the marine ecosystem and (ii) the risk of an increase in catch efficiency and the consequences for other fisheries. The concerns were aggravated by the increasing number of temporary licences to 84 in 2014, as part of a Dutch pilot project in preparation of the introduction of the landing obligation under the reformed European Common Fisheries Policy[1].

The objective of the current report is to provide a synthesis of the studies on pulse fishing that have been conducted so far in the light of the major concerns raised. This report describes the electrical characteristics of the flatfish and brown shrimp pulse system and reviews the catch efficiency and selectivity of the gear , the effects of pulse stimulation on

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1380

marine organisms, the effect on the marine ecosystem and the effects on viability and survival.

2 Electrotrawl technology

2.1 Basic working principle

Electrical fishing works by using electrical currents to induce a desired response in the target species, which either compromises the target's ability to evade capture or makes it available for capture by stimulating it to move into the net opening of the fishing gear (Breen et al., 2011). A less obvious, but nonetheless promising application is to enhance escape behaviour of unwanted species in selective devices.

The form and dimensions of the electric field generated in the water and the underlying substrate and its effect on the target will be dependent upon many factors, i.e. the characteristics of the electrical power source and the electrodes, the properties of target species and habitats in the fished area. In the context of electrofishing, 'electrodes' are the conductive parts of the electric circuit in contact with the water. The electrodes may be mounted on, or separated by, non-conducting elements (insulators) which together can be termed the electrode array (Figure 2-1). These descriptions will be applied throughout the manuscript and are strongly advised to be adopted in future research.

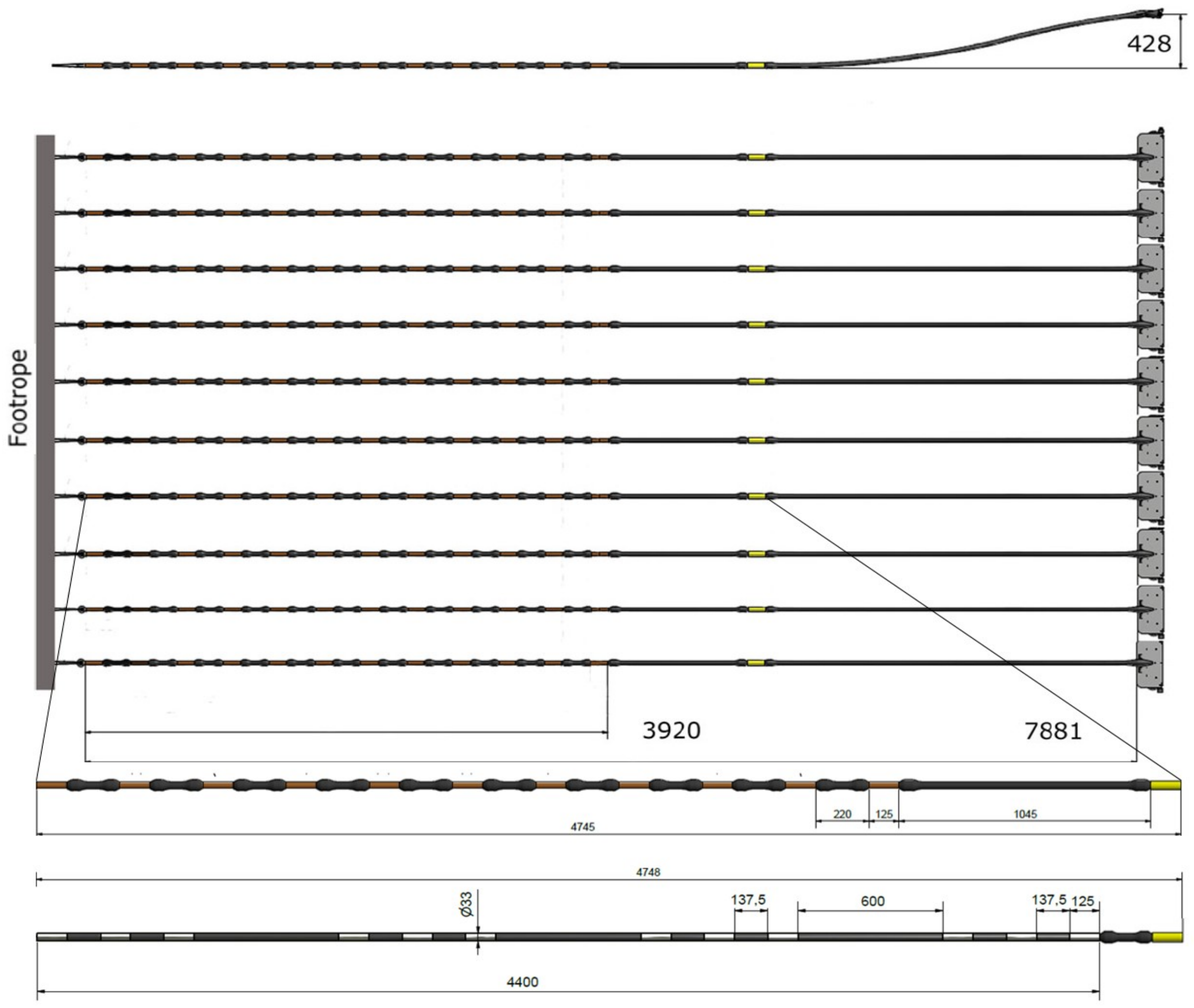


Fig. 2-1: Schematic representation (in mm) of the ten 7.881 m long electrode arrays of a 4 m beam pulse wing used in electrotrawls targeting common sole with a close-up of two possible electrode array types (from HFK Engineering B.V.). The white or grey conductive parts are made of stainless steel or copper respectively and are called electrodes, whereas the longer black parts are non-conductive and called insulators or insulated parts. The entire structure consisting of electrodes and insulators through which the pulse generator releases its electrical current is called an

'electrode array'. Note that 'electrode array', 'electrode' and 'insulator' were often referred to as 'electrode', 'conductor' and 'isolator' respectively in older electrotrawling manuscripts. It is strongly advised to no longer use the older terminology in future research.

2.2 Some explanatory physics

A good understanding of the operation of electric fields in water is essential to fully comprehend the working principles and the effects of electrotrawling. An electric field is generated by an electrical power supply that charges one electrode positive (anode) and one electrode negative (cathode). This creates a potential difference (voltage [V]) over the 2 electrodes, spaced at a certain distance. Charged ions in the water will be attracted to the oppositely charged electrode and induce a flow of charge in the water between the electrodes that is called the current (I, [A]). It is analogous with the flow of water down a river or through a pipe and is a measure of the amount of electrical charge moving through a point over a period of time. One ampere is equivalent to $6{,}2 \times 10^{18}$ electrons passing a given point in one second.

The more ions in the water, the higher its conductivity and the better its capacity to conduct electric current. Conductivity varies considerably, depending on the temperature, the salinity and the organic matter content of the water (Soetaert et al., 2013). The capacity of the power source to create a potential difference over 2 electrodes (power, [W]) is limited and depends on the conductivity, because it is in permanent competition with the ion flow in the water, which will continuously neutralize the charge on the electrodes. Therefore, the potential difference over the 2 electrodes will be inversely proportional to the conductivity of the water, which is illustrated by the formula of electrical power: $P = V^2/R$, with P the power, V the potential difference and R the resistance, which is the inverse of conductivity. Indeed, when the conductivity is high as in sea water, the charge on the electrodes supplied by the power source will be easily neutralized and the potential difference will be small. Each potential difference over 2 electrodes induces an electric field in the water. This field is characterized by the field strength ([V/m]) which indicates the voltage gradient at a certain location in the medium between the electrodes.

In most natural situations, the lines of force/flux within an electric field radiate out from the electrode and thus do not run parallel to each other (Polet, 2010). These heterogeneous electrical fields differ from homogeneous electrical fields, where the force/flux lines run in parallel to each other. An (almost) homogeneous electrical field can easily be created by placing two plate-shaped electrodes parallel, providing a constant voltage gradient, current density, and power density. A homogeneous field simplifies experimental conditions and is ideal for lab experiments, but it may be difficult to extrapolate to commercial electrofishing operations, during which the electric fields will always be heterogeneous.

The distribution and strength of an electrical field is strongly influenced by a complex relationship between the shape and size of the electrodes (anodes and cathodes), as well as the mutual distance (Novotny, 1990).

Power sources can produce different types of current as is illustrated in Soetaert et al. (2019). Basically these can be divided into two types: Direct Current (DC) which is the movement of electric charges in one direction and Alternating Current (AC), which is a bipolar current flow. Both types can be applied with intervals and hence will generate pulses. In case of DC this results in Pulsed Direct Current (PDC). In case of AC this results in either Pulsed Alternating

Current (PAC) if 1 pulse consist of a positive and negative part, or in Pulsed Bipolar Current (PBC) if 1 pulse is successively positive or negative.

Pulsed currents are characterized by the number of pulse cycles per second (Hz), pulse duration (ms), pulse shape and amplitude (V). The higher the potential difference on the electrode, the higher the amplitude and the field strength will be. In highly conductive seawater, the preferred use of pulsed current instead of continuous current is obvious. It allows to reach acceptable, i.e. sufficiently low, electrical power demand, while maintaining desired electrical field intensity. The pulses can be generated by producing large bursts of peak power that are short in duration and intercalated with recovery periods in which the transformer and capacitor components store the energy required for the next burst (Novotny, 1990).

A more detailed description of electrofishing principles and an overview of the variables affecting the electric field is given in Soetaert et al. (2019).

2.3 Pulse definitions

A guideline for defining the use of electricity in marine electrotrawling was published by Soetaert et al. (2019), covering the physiological responses of animals to electric fields, the electric principles of electrofishing, variables affecting the electric field distribution, the electrical waveform parameters and a chapter on standardising study design descriptions. The overview of pulse parameters and their definition is given in Table 2.1, although we refer to the original publication for more details, explanation and illustrations. Note that most papers prior to 2019 use f when referring to f_a for PBC pulses (except for those of de Haan *et al.*) and used a variable terminology for electrodes and electrode arrays.

Table 2.1: Overview of electrical pulse parameters with their symbol, unit and definition. (taken from Soetaert et al., 2019)

	Pulse parameter	Symbol	Unit	Definition
Key parameters	Amplitude	*V*	volt, V	Maximum potential difference or field strength of a pulse. This can be circuit or location specific and be expressed as peak voltage, peak-to-peak voltage, median voltage or root mean square voltage.
	Frequency	*f*	hertz, Hz	Number of cycles per second.
	Pulse width	*PW*	millisecond, ms	Time duration that the pulse is on.
	Pulse shape	PS	-	Shape of a single pulse which can be, e.g. exponential decay, sinusoidal, or rectangular (examples see Snyder, 2003).
Amplitude parameters	Peak voltage	V_{pk}	volt, V	Magnitude of the zero to maximum (or minimum) instantaneous voltage appearing between the electrodes. If a poorly formed waveform is used with an initial voltage overshoot (e.g. Figure 4) then V_{pk} will reflect this value. If using bipolar pulses, which have positive and negative peaks with different amplitudes, the highest absolute value should be given.
	Peak-to-peak voltage	$V_{pk\text{-}pk}$	volt, V	Potential difference between the maximum and minimum instantaneous voltage appearing between the electrodes. For PDC (with no negative component), $V_{pk\text{-}pk}$ will equal V_{pk} since all peaks have the same polarity and are measured against the baseline. For alternating/bipolar pulses, $V_{pk\text{-}pk}$ is the potential difference between the positive and negative peak voltage: $V_{pk\text{-}pk} = V_{pk}^{+} - V_{pk}^{-}$.
	Median voltage	V_{med}	volt, V	Voltage measured in the middle of a pulse, i.e. at half the pulse width. Although this value does not properly represent the energy content, it is easy and straight forward to interpret and determine for rectangular pulse shapes.

				It also diminishes the impact of voltage overshoot at the onset or end of the pulse and gives a measure of pulse stability or decay.
	Root mean square voltage	V_{rms}	volt, V	Equal to the value of DC voltage that would produce the same power dissipation in a resistive load.
Time related parameters	Duty cycle	*dc*	percentage, %	Calculated as $dc = ((PW \times f)/1000) \times 100$ for PDC or $dc = (((PW_1 + PW_2) \times f)/1000) \times 100$ for PAC and PBC with the pulse width (*PW*) in milliseconds and frequency (*f*) in Hz.
	(Inter pulse) interval time or pulse break time	*PB*	millisecond, ms	Time span between two pulses, measured from the end of the fall time to the onset of the rise time of the next pulse.
	Period	*T*	millisecond, ms	Time from the start of one cycle to the start of the next cycle, i.e. 1 s/*f*.
	Pulse period	*PT*	millisecond, ms	Time from the start of one pulse to the start of the next pulse, i.e. $PW + PB$. Note that for PDC, $PT = T$.
	Rise time	δt_{rise}	millisecond, ms	Time it takes the pulse to rise from 10 to 90% of V_{med}.
	Fall time	δt_{fall}	millisecond, ms	Time it takes the pulse to fall from 90% to 10% of V_{med}.
Other parameters	Total pulse width	PW_t	millisecond, ms	Time interval in PAC covering both pulses $PW_t = PW_1 + PB_1 + PW_2 = T - PB_2$.
	Apparent frequency	f_a	hertz, Hz	Number of PBC pulses per second.
	Burst width	*BW*	millisecond, ms	Time duration that a gated burst pulse is present starting from the onset of the first pulse until the offset of the last pulse of the burst.
	Burst interval/break time	*BB*	millisecond, ms	Time interval between two bursts of a gated burst.

2.3.1 Animal responses

A wide range of responses of aquatic animals to electric fields, ranging from initial startle reactions to death, has been observed (Snyder, 2003). However, for the practical purposes of marine electrofishing these can be broadly summarised into four main responses (Polet, 2010): 1) Fright, minimum response which may include undirected movement; 2) Electro-taxis, induced directed movement; 3) Electro-narcosis, immobilisation of the target specimen through an induced narcosis and 4) Electro-tetanus, paralysis of the target specimen through an induced muscle contraction.

Given a fixed field strength, the level of response from an exposed specimen will be determined primarily the specimen's orientation in the field and its relative size, by its distance from the electrode and by the form of the electrical signal. Distance from the electrode will determine the current and/or power density that the specimen is exposed to, while its orientation in the field and its relative size will determine the potential voltage difference that it experiences across its body. Therefore, it is generally accepted that larger fish, with a larger potential difference over its body as illustrated in Fig. 2-2, will show greater reaction. However, the sensitivity varies greatly between different species.

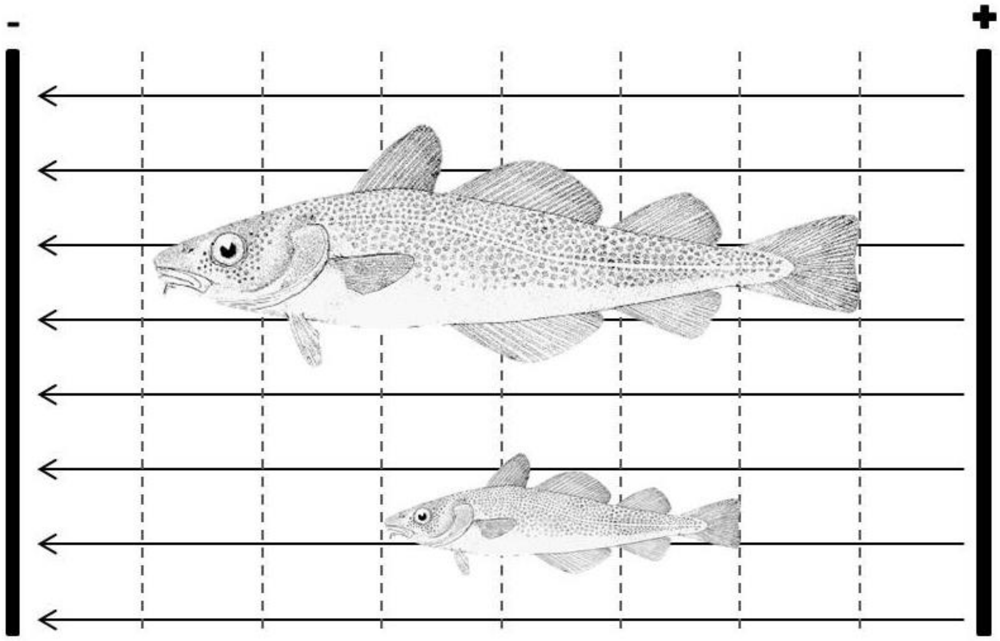


Fig. 2-1 - illustration of cod in a homogenous electrical field between 2 parallel electrodes. The horizontal lines are the electrical field lines, representing the current flow between the electrodes. The dashed vertical lines are equipotentials, zones with the same potential. The larger the difference between 2 extremities of a fish, in this case head and tail, the higher the potential difference over its body and the stronger it is experiencing the electrical field. E.g.: Suppose an applied potential difference over the electrodes of 80 V which results in a potential difference between each equipotential of 10 V. In this case the large fish will experience 60 V, whereas the small fish only 30 V. Consequently, the orientation of the fish has a marked influence on the potential difference over his body. Reproduced from Soetaert et al., 2015.

At low frequencies, a PDC field will frighten the fish, which as a consequence will try to swim away (startle reaction). Once the frequency exceeds a certain threshold value, usually around 20 pulses per second, the jerking movements of the muscle, induced by the electrical pulses, are succeeding so fast that the muscles are continuously stimulated and remain contracted. This summation of many individual contractions may lead to a cramp and immobility (Snyder, 2003).

Due to the electro-chemical nature of nerve impulse and muscle stimulation, the presence of a sufficiently intense electric field can stimulate both nerves (neurones) and muscle cells to induce a range of behavioural responses including: inhibition of movement, enforced directional movement towards electrodes (electro-taxis) and uncoordinated and severe muscular contractions (electro-tetanus). However, the precise role of varying electric field strength on the central nervous system and the many different manifestations in observed responses is less clear. In the scientific literature, most work on this topic has focused on teleost fish and this was comprehensively reviewed by Snyder (2003).

2.3.2 Differences with freshwater electrofishing

Electrofishing has been used frequently since the 1950's as sampling technique for fish in freshwater whereby electric energy is passed into the water. In case direct current (DC) is used, fish intercepting this energy will show forced swimming toward the source of electricity, which is called galvano-taxis. As reviewed by Snyder (2003a), freshwater electrofishing is a very effective sampling method but it has the disadvantage that it may inflict harm to fish. Salmoninae are known to be susceptible to spinal injuries, associated haemorrhages, whereas it can be lethal for burbot and sculpins under some conditions. Freshwater electrofishing is also reported to result in cardiac arrests, long behavioural and physiological recovery times and doubtful effects on early life stages. Unfortunately, many questions remain unanswered, the interpretation of some results is often difficult to understand or questionable and a lot of variation and contradictions are reported.

This is not surprising since application of electric pulses comprises many different factors: electrode shape and set-up, different pulse parameters used, differences in conductivity, temperature and surrounding medium, size of the animal, species-dependent reactions and side-effects,… Freshwater electrotrawling differs from pulse trawling electrofishing in almost every characteristic, as overviewed in Table 2.2. Note that this table does not include marine electrofishing on *Ensis* spp. because it is poorly documented and the pulse settings (continues current, not pulsed) are more similar to freshwater electrofishing because it aims for a similar slow behavioural response in *Ensis* spp. and subsequently requires exposure times around 1 minutes.

Table 2.2: Overview of major differences between freshwater and marine electrofishing. (taken from Soetaert et al., 2015)

	Freshwater electrofishing	Marine pulse fishing
Application	sampling of river or lakes	commercial trawling
Goal	sampling all fish species of all size	increase marketable catch
Working principle	inducing galvano-taxis to anode	upwards startle reaction
	or immobilization on the seafloor	or immobilization on the seafloor
Gear	static	dynamic/moving
Electrodes	2 (hemi)sphere, ring or cylinder	multiple wire-shaped electrodes
Electrode distance	> 1 m	0,3 - 0,6 m
Water conductivity	0,01-0,1 S m^{-1}	4,2 S m^{-1} (North Sea, 15°C)
Electric dispersion	current = or > in fish than in water	current < in water than in fish
Exposure duration	0,5-3 minutes	0,5-3 seconds
Duty cycle	always >10%, often 60-100%	<3%
Frequency	15-120 Hz (and up to 500 Hz)	5-80 Hz
Potential difference	100-400 V	60-100 V
Pulse type	DC, PDC or PAC	always pulsed
Pulse shape	exponential, sinus, quartersinus, square, triangular,…	rounded shape caused by impedance of long electrodes

How electric current interferes with the fish physiology is not yet elucidated. Fish can be considered to be an electrical network composed of resistors and capacitors. The membrane and tissues act as the dielectric of a capacitor with the ability to by-pass frequencies as well as frequency attributes expressed in the leading and trailing edges of the pulse (Sternin *et al.*, 1976; Sharber *et al.*, 1999). Given the differences in the anatomy of fish species, the response to an electric stimulus will differ across species (Halsband, 1967; Emery, 1984). The interaction with the electric field is also affected by the pulse settings and the environment. In addition, other pulse parameters can affect the impedance of tissues (Finlay *et al.*, 1978), resulting in different electric doses and effects. The conductivity of the surrounding medium is also decisive. Whereas in fresh water high amounts of current may flow through the fish' body as it conduct current better than the surrounding water, this will not occur in fish surrounded by seawater with a much higher conductivity (Lines and Kestin, 2004). On the other hand, much higher field strengths will be found in the immediate surrounding of a fish in seawater, which might indirectly affect the flow of ions in the fish' body, the charge on neurons, the polarity of membranes and tissues,…. The long list of differences and poorly understood phenomena stress that prudence is warranted when extrapolating freshwater results.

2.4 History of pulse trawling

Interest in marine electrofishing was stimulated by the successful introduction of electrofishing techniques in freshwater and experiments carried out in Germany, as reported by Houston (1949). Attracting fish to an anode, as is the case in freshwater, was the main focus back then. This gradually changed when Bary (1956) stipulated that the theories used for freshwater could not be extrapolated to seawater. Inducing a startle reaction in the target species, to make it leave the seafloor and enter the trawl, became the primary objective. This would possibly allow the replacement of traditional tickler chain or bobbin rope stimulation with electrodes, without loss in efficiency (De Groot and Boonstra, 1970). Successful experiments with electric fields in otter trawls targeting demersal fish (Mc Rae and French, 1965) and shrimp (Pease and Seider, 1967) showed increased catch efficiency. In 1970, experiments were set up in the Netherlands with lightweight electrotrawls intended to target brown shrimp. Besides higher catch rates at daytime, another advantage became apparent, as for example, the reduction in trawl induced injury of juvenile flatfish (Boonstra and de Groot, 1970). In Belgium, Vanden Broucke (1973) obtained good indicative results with increased shrimp and Dover sole catches. In search of alternative stimulation mechanisms for other species, Stewart also investigated the effect on Norway lobster (Stewart, 1972, 1974). He found that electric pulses could stimulate emergence of these animals from their burrows in less than 5 seconds.

In those years '70-80 European fisheries institutes in The Netherlands, UK, Belgium, France and Germany carried out research and development in the use of electrofishing in marine fisheries, in some cases in collaboration with private companies. The main motivation for this work was to develop gears which saved fuel, particularly during the post 1974 'oil shock' period when the price of oil rose rapidly and electrofishing, which was perceived as being more energy efficient than conventional towed gears, offered the opportunity to save fuel. Despite the good progress that was made, the challenge, especially on the technical side, was still enormous (Stewart, 1971). It was very difficult to reproduce the results made with the small beam trawls in larger commercial trawls, as more electrodes and thus more power was required. The increased power demand, the drag resistance of the voluminous pulse generators, the electrode connections in the water, the electrode material and the electrical efficiency were all leading to an accumulation of technical difficulties, safety issues and frequent malfunctioning (Boonstra, 1979). This hurdle was difficult to overcome at that time and hence markedly slowed down the further study and development of marine electrofishing. This vulnerability, combined with the large investment and maintenance costs of an electrofishing device, hampered a successful introduction.

Half a decade later, a new generation of pulse generators enabled sufficiently high voltage peaks (Agricola, 1985). From then on various experiments proved very successful in increasing catch efficiency (Horn, 1982, 1985; Delanghe and Vanden Broucke, 1983). The first commercial pulse beam trawls were already commercially available, when the method was banned in 1988 in the Netherlands. Development in the other European nations also ceased around that time.

Later the European Commission prohibited the use of electricity to catch marine organisms (EC nr 850/98, article 31: non-conventional fishery techniques). The main reason for these bans were likely the fear of further increasing catch efficiency in the beam trawling fleet, which was under severe international criticism back then (Van Marlen, 1997).

Since then all legal electric fishing in European waters has taken place under an agreed derogation from these regulations. Since the 1990s there has been an increased focus on reducing the environmental impact of trawling, particularly beam trawling. Electrofishing techniques have the potential to reduce this impact because of the reduced gear weight, lower towing speed and higher selectivity. This led to a revival of interest in electrofishing and a high level of collaboration between public and private sectors. In the Netherlands this has lead to the redevelopment of the flatfish pulse trawl and in Belgium the brown shrimp (*Crangon crangon*) pulse beam trawl was optimised. In a separate development in the early 2000s, it was discovered that razor clams (*Ensis sp.*) could be induced to emerge from the seabed through electrical stimulation.

2.5 Electrotrawls and pulse trawls today

2.5.1 The *Crangon* pulse trawl

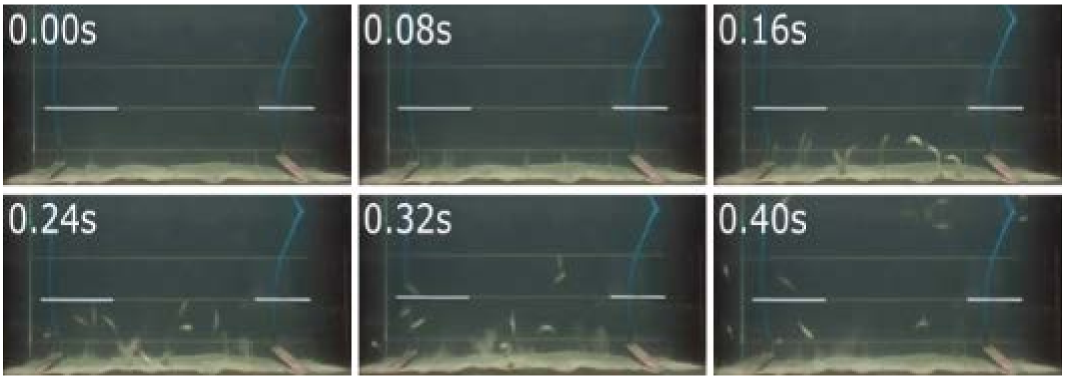


Fig. 2-2 – Pulse stimulation of brown shrimp (Crangon crangon). The shrimp are buried in the sand (top left), when the electrical pulse field is switched on. After only 0,16 s all shrimp have left their buried position in a vertically upward direction.

Based on successful application of shrimp electrotrawls in China, the Belgian Institute for Agricultural and Fisheries Research (ILVO) started investigating the potential of pulse trawling for brown shrimp in the late 1990s. The research of Polet et al. (2005a,b) revealed that a half-sine square pulse (PDC) with a frequency of 5 Hz, a pulse duration of 0,5 ms and an electric field strength of approximately 30 V/m gave the best result to startle brown shrimp successfully. By stimulating the body musculature involuntary, these shrimp are forced to leave there buried position in the seabed in a vertically upward direction, as is illustrated in Fig. 2-3.

Based on these findings, a commercial pulse beam trawl system for *Crangon* (Fig. 2-4), was first developed and tested by ILVO in 2008 in cooperation with the Belgian company Marelec and the University of Ghent (Verschueren and Polet, 2009). The pulse beam trawl is equipped with a pulse generator on top of the beam. The pulse generator connects to 12 stainless steel electrodes (6 cathodes + 6 anodes) that are rigged in the net opening of the trawl. They form 11 electrode pairs that are fired alternatively by the pulse generator. The gear is connected to the vessel via an electrical supply cable, which is hauled along with the fishing line. The low frequency and short pulse duration of the applied electrical field allows the system to operate with a very low energy input of about 1 kWh per trawl (Table 2.3).

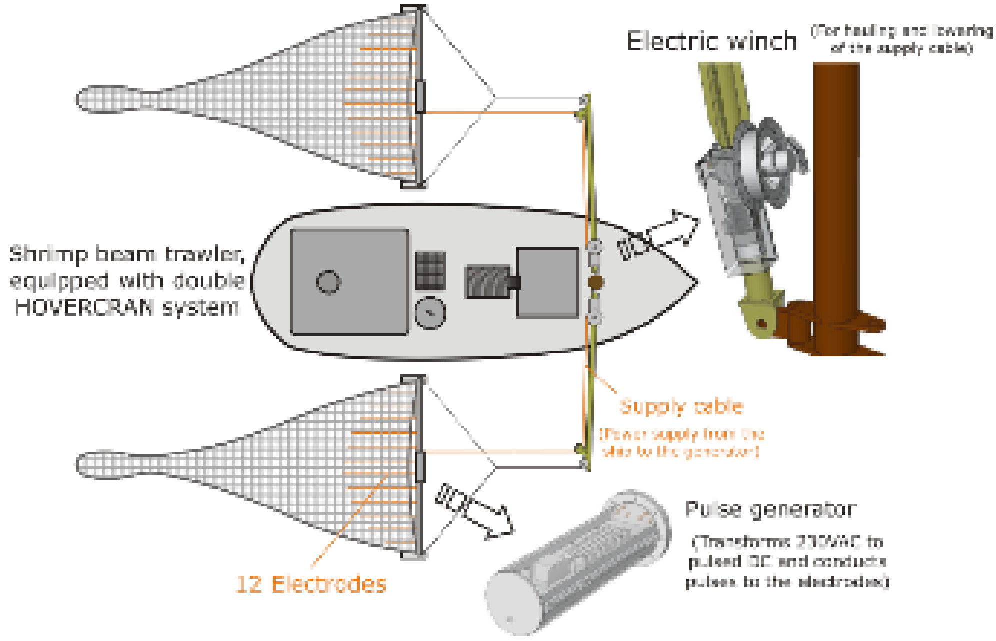


Fig. 2-3 – Illustration of the pulse trawl system for brown shrimp as it was developed in Belgium by Marelec, ILVO and UGent in 2008.

In the original ILVO concept the pulse trawl was meant to hover above the seafloor, in order to minimise seafloor contact. Therefore, the entire bobbin rope was removed and replaced by electrodes. Combined with a raised footrope this allowed non-target species to escape underneath the trawl (Fig. 2-5). Stimulated shrimp are forced to leave the seafloor high enough, so they can be caught by the hovering trawl. This setup was called the Hovercran configuration (= the HOVERing pulse trawl for a selective CRANgon fishery) and it was rewarded with the runner-up prize of the WWF International Smart Gear Competition in 2009. The gear (without a sieve net) was successfully tested on the Belgian coast. Normal catch rates were preserved, seafloor contact was reduced by 75% and an overall by-catch reduction of 35% resulted in cleaner catches. Moreover, the catch efficiency seemed less dependent on light and turbidity conditions. This contrasts with traditional shrimp beam trawling, where catch quantity varies strongly with light intensity and turbidity of the seawater (Verschueren and Polet, 2009).

Table 2.3 – Overview of pulse characteristics applied in the brown shrimp pulse fishery. Modified from Verschueren et al. (2014).

Pulse characteristics	
Pulse type	DC, between square and half-sine
Average power supplied per m beam width	0,125 kW
Maximum conductor voltage*	65 V
Pulse frequency	5 Hz
Pulse width**	500 µs
Electrode characteristics	
Number of electrodes	12
Distance between electrodes	600 – 700 mm
Total electrode array length (isolator + conductor)	2750 – 3200 mm
Number and dimensions (length and diameter) of conductor elements	1 (1500 mm x 12 mm)

* Voltage ratings refer to the peak voltage measured (zero to peak).
** The pulse duration refers to a single pulse period.

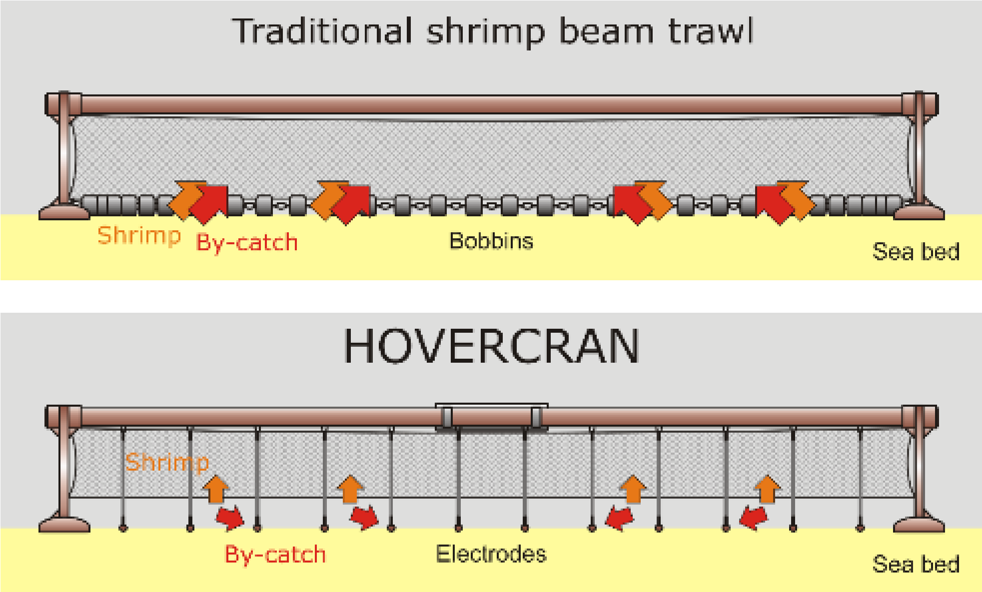


Fig. 2-4 - Illustration (frontview) of the original HOVERCRAN concept (how it was conceived by ILVO in 2008). The traditional bobbin rope is removed in order to reduce seafloor contact and create opening for non-target species to escape. In its place, the electrodes stimulate the shrimp to leave their buried positions.

In 2007, the Foundation for the Sustainability of the Crangon Fishery was established by the Dutch producers organisations with the aim of promoting new research that focuses on improving the sustainability of the brown shrimp fishery. The positive Hovercran results were picked up by this foundation and new study trials with the Hovercran on the Dutch Wadden Sea with commercial shrimp cutters were setup. These tests were carried out with the vessels TX 25 and HA 31, and in first instance focused on the technical improvement of the technique. It soon became clear that the risk of trawl damage, during fishing on rougher and more uneven fishing grounds, increased in absence of the bobbin rope. For such fishing grounds, like the Wadden Sea with its many tidal trenches, a solution had to be found in the form of a straight bobbin- and footrope (Verschueren et al., 2012 and Verschueren et al., 2014). However, the gain in better selectivity and reduced seafloor contact with the Hovercran design is counteracted by adding bobbins to the ground gear. On the other hand, the shrimp capture efficiency increases with the number of bobbins.

Fig. 2-6 - Image of a pulse trawl design that is being used today on the Dutch Wadden Sea by HA 31. The gear is characterised by the use of a straight, lightweight bobbin rope with 11 ellipsoidal bobbins (instead of 36 bobbins in the previous traditional *beam trawls). The pulse generator (central) and the 12 electrodes are attached to the beam.*

In order to avoid abuses, the Dutch ministry of economic affairs has implemented limiting technical measures where the *Crangon* pulse fishermen have to adapt to, if they want to continue pulse trawling. Herein, among other things, the number of bobbins was reduced in a way that a minimum mutual distance of 60 cm between two adjacent bobbins has to be ensured. In current practice this has led to a shrimp pulse trawl design that is illustrated below.

Meanwhile research and development on shrimp pulse trawling continues. ILVO is currently testing a complete new modular pulse system with all electronics (11 pulse modules) built-in a hydrodynamic efficient wing (figure 2-7). During 2016 and 2017 new trials on RV's and commercial shrimp cutters will be carried out. Another Dutch novelty is the cable-less 'Jack Wing' pulse gear. The idea is to partly generate the electrical energy underwater on the gear during towing. The energy is stored in battery packs inside the gear. This would make the use of an electrical supply cable and its necessary winch redundant.

Fig. 2-7 - ILVO's modular pulse fishing system with all electronics built-in a wing

2.5.2 The flatfish pulse trawl

In the pulse trawling technique targeting flatfish, a cramp inducing electrical field is applied. At least a ten times higher frequency is used compared to *Crangon* pulse trawling, stimulating the fish musculature in a cramp (Figure 2.6). As a consequence the fish are immobilised on the seafloor during the exposure, making it easy to scoop them with the ground gear of the pulse trawl.

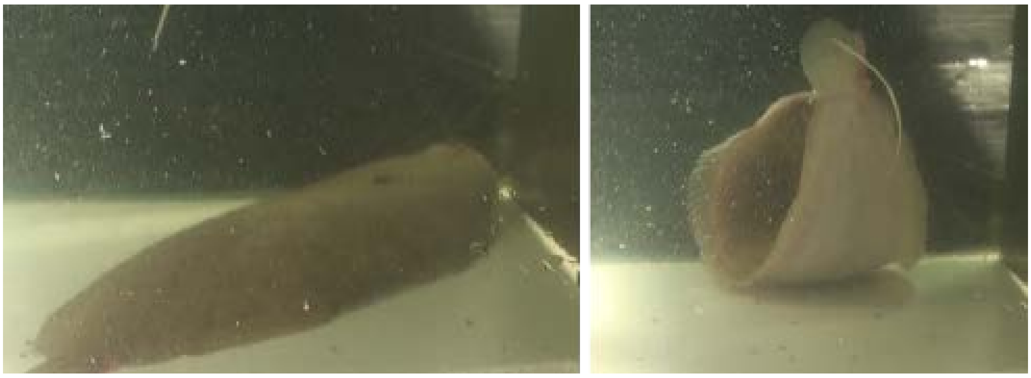


Fig. 2-8 – Dover sole (Solea solea) exposed in an aquarium to a pulsed electrical field. As long as the exposure lasts, the muscles are stimulated resulting in continuous spasms. Pulses are bipolar and the pulse frequency can vary between 30 and 80 Hz with a duty cycle around 2%.

In 1992 Verburg Holland, taken over by the Delmeco Group in 2010, started with the development of a pulse beam trawl for flatfish (Van Stralen, 2005). This fishing gear can be considered as the first in a series of prototypes that has led to 30% of the currently used electrotrawls (Figure 2.9, on the right). From 2007 on, another Dutch company, HFK engineering, had started its own developments in parallel. HFK applied the pulse system on a new type of beam trawl, the so-called SumWing trawl. In this gear, the cylindrical beam with trawl shoes is replaced by a wing-shaped foil with a runner at the centre. The SumWing itself reduces fuel consumption by some 10% (van Marlen et al., 2009). The integration of the pulse system into the SumWing has a larger potential in reducing gear drag, seafloor impact and fuel consumption (van Marlen et al., 2011), as a consequence it soon became the most popular pulse trawl in the Netherlands. Meanwhile also other combinations are in use, in which HFK pulse modules are incorporated into other beam trawl alternatives, such as the SeeWing and the Aquaplanning gear. The number of vessels using HFK pulse modules is about 5 times that using the Delmeco design (Turenhout et al., 2016).

Fig. 2-9 - Pulse SumWing by HFK Engineering (left) and Delmeco Multiwing (right). Both gears are used today in the Dutch flatfish pulse fishery. Around 90 vessels are equipped by either Delmeco or HFK according to a ratio of approximately 1 to 5 respectively.

Pulse trawls receive electric power from the vessel by an additional cable that also provides communication between the wheelhouse and the fishing gear. In both Delmeco and HFK systems the electrodes are connected to pulse modules, i.e. small ceiled units with electronics, built-in the beam or wing. The number and the configuration of the electrodes may vary according to the gear width and the manufacturer, although physical boundaries of the gear are described in a directive issued by the Dutch Ministry of Economic Affairs on 18 November 2016 (01. 20161111 "Nieuwe Voorschriften Pulstoestemming Platvis version 1.3") and refers to the conditions of electric gear application as described in article 31bis, lid 2 of the European reference for Technical Measures (EU 850/98). The main derogations for flatfish gears are:

- A maximum power consumption of 1 kW per meter beam length;
- A pulse amplitude of 60 V 0 to peak maximum;
- An electrode length of max 4.75 m, (the section that has bottom contact);
- Conductor length 125 to 200 mm with a maximum of 12 per electrode;
- Electrode distance not smaller than 0.4 m;

- Number of electrodes adapted to the width of the licenced gear (4 or 12 m);
- Operational conditions of the Delmeco system are registered on a computer as part of the pulse equipment. The HFK system does not record the electrode voltage and current real-time but operates with a pulse hardware certificate which assures the equipment will operate within the licensed bands. The Delmeco system stores information of:
  - the electric power discharged over the electrodes;
  - over at least 100 fishing hauls;
  - any access to the data storage;
  - the date, times and positions of pulse operation;
- Groundrope rigging will not contain additional tickler chains

The basic characteristics of the pulse systems as used in practice are listed in Table 2.4. An electrode array itself measures around 6 m and consists of an alternating series of isolated parts (isolators) and conductive parts (electrodes). A detailed construction design of both systems can be found in van Marlen et al. (2014) and de Haan et al. (2016). The pulse characteristics are similar for both systems. The electric parameter settings can also be adapted to the environmental conditions such as seawater temperature and salinity. These conditions may influence the conductivity or flatfish behaviour and thus the response to the electrical pulse field (de Haan et al., 2016).

Table 2.4 – Pulse and electrode characteristics applied in the Dutch flatfish fishery. Modified from de Haan et al. (2016).

Pulse characteristics	
Pulse type	Bipolar
Average power supplied per m beam width	0,6 – 0,7 kW
Electrode voltage*	45 – 50 V
Pulse frequency	30 – 80 Hz
Pulse width	100 – 330 μs
Duty cycle	0,9 – 2,2%
Electrode characteristics	
Number of electrodes	10 (≤221 kW) or 25 – 28 (>221 kW)
Distance between electrodes	415 – 425 mm
Number and dimensions (length and diameter) of conductor elements	Delmeco: 6 (180 mm x 26 mm) HFK: 2 (125 mm x 27 mm) + 10 (125 mm x 33 mm)
* Voltage ratings refer to the peak voltage measured over the positive part of the pulse (zero to peak).	

In the first place, the large-scale conversion to pulse trawling in the Dutch beam trawl fishery, was based on economic motives. According to the comparison experiment of van Marlen et al. (2014), the net earnings (gross earnings – fuel costs), increased with 155 to 186% compared to conventional beam trawling with tickler chains. However, the rather large investment and relatively high maintenance costs related to pulse trawling, were not taken into account. This profit increase is mainly due to the large savings in fuel consumption. The relatively light design of the pulse trawls also allows operation on a wider range of sediments (Rasenberg et al., 2013). Additionally, the catch efficiency of Dover sole is clearly higher in pulse trawling (Rasenberg et al., 2013). As a result, the introduction of the commercial Dutch pulse trawler fleet caused a reallocation of fishing effort (Batsleer et al., 2016). Sys et al. (2016) studied the competitive interactions between the Dutch and the Belgian beam trawl fleets in the North Sea. The study showed that sole landings of traditional Belgian beam trawlers (>221 kW) from 2006 to 2013 were lower during weekdays than during weekends, when the Dutch fleet is in harbour. After pulse trawling was introduced in 2011, the negative weekday effect in the sole landing rates was much more pronounced in 2012 and 2013. This increased loss of efficiency during weekdays, as a result of increased competition with the Dutch trawler fleet, coincided with a reallocation of fishing effort by the Belgian beam trawler fleet.

2.5.3 The *Ensis* electrotrawl

According to Breen et al. (2011) electrical fishing techniques are certainly being used in the Scottish razor clam (*Ensis sp.*) fishery since 2004. Small inshore vessels fly-drag up to three pairs of electrodes slowly across the seabed, followed either by divers who collect emerging razor clams or less commonly by some kind of dredge that's drawn across the surface of the seabed. Because these practices are illegal, little detailed description of the gears is available. Murray et al. (2016) report that within the fishing community electrofishing is believed to be preferred over dredging, despite the risk of financial penalties if caught. This is due to the reduced fuel consumption required to drag the rig and to the lower incidence of damaged clams in the catch. Woolmer et al. (2011) experimentally designed and trialled methods to harvest razor clam using electrical stimuli. Three mild steel flat bar electrodes (30 x 8 x 3000 mm) were used on a separation distance of 0,6 m to produce maximal DC field strength of approximately 50 V/m. The study demonstrated that electrofishing gear generating relatively low DC can be effectively used to stimulate the emergence of razor clams from their burrows. Since no electrical pulses are used, it is recommended to use the more general name 'electrotrawl' instead of 'pulse trawl' for this fishing gear.

Fig. 2-10 - Two different prototypes of pulse dredges that were developed and tested in Irish (left) and Dutch (right) razor clam fisheries. Right picture modified from Breen et al. (2011) and left picture from Visserijnieuws (2015).

In Breen et al. (2011) it is mentioned that the development of a novel *Ensis* dredge employing electrical stimulus was being carried out in Ireland around 2010. Herein a skimming blade is used to pick up the razor clams (Figure 2.10 on the left). Preliminary results showed landings comparable to those achieved by hydraulic dredges and crucially, the condition of the razor clams seemed better with lower breakages and long survival. Similar prototypes were tested in the Netherlands (Figure 2.10 on the right). In general this technique is considered potentially more environmentally benign compared to existing hydraulic and toothed dredges (Breen et al. 2011; Woolmer et al. 2011).

2.5.4 Other applications in trawling

A less obvious, but nonetheless promising application of pulsed electrical fields is to enhance escape behaviour of unwanted species in selective devices. Soetaert et al. (2016d) studied the combination of a benthos release panel (BRP) provided with an electrical field. BRPs are known for their capacity to release large amounts of unwanted benthos, debris and to a lesser extent undersized fish. However, unacceptable commercial loss of Dover sole, due to escape through the BRP, is hampering a successful introduction in commercial beam trawl fisheries. To eliminate this drawback, the effect of electric stimulation at the height of the BRP to eliminate the loss of commercial sole was examined. This allowed for the release of 35-50% of the benthos and debris and significant parts of the undersized commercial fish without the loss of commercial fish in particular marketable sole. The results showing the promising potential of electrified BRPs (eBRPs) will be submitted in the summer of 2018.

3 Catch composition & effort of pulse trawls

3.1 General overview

When evaluating a new fishing method, gear selectivity with regard to target species and (unwanted) bycatch species is of major importance next to preservation of commercial catch rates. Comparative analysis between pulse and conventional trawling is therefore an essential approach. In recent years several experiments have been carried out at sea to determine catch compositions of *Crangon* and flatfish electrotrawls. Ideally both trawls, pulse and conventional, are simultaneously tested on the same vessel (port and starboard side), leading to paired observations. However, sometimes practical limitations, such as different optimal towing speeds, preclude direct catch comparison. Differences and variability between studies may also result from varying catch conditions (most importantly spatial or temporal variation), or by differences between the tested gears (e.g. arrangement of the ground gear, trawl design, dimensions, etc.).

So far, the data indicates that electrical stimulation offers a promising innovation to reduce the bycatch of fish and benthic invertebrates in **brown shrimp** fisheries, while maintaining the catch rate of marketable sized shrimps. However, this is only the case when a light bobbinrope with only 12 bobbins was used. When more bobbins and/or a more heave gear is used, the catch rates of marketable shrimp are up to 30% higher compared to a traditional trawl and the improvements in by-catch reductions are largely undone.

The available evidence for the **sole pulse** shows that it has a higher catch efficiency for sole and the lower catch efficiency for plaice and other fish and invertebrate species when expressed in catch rate per hour. The comparative fishing experiment in 2015 suggests that the catch efficiency of the pulse trawl may have improved. The better size selectivity of the pulse trawl indicated by the 2011 comparative fishing experiment (van Marlen et al., 2014), is not corroborated in later experiments. However, compared to the catch of marketable sized sole, the bycatch of undersized fish in the pulse trawl is lower than in the conventional beam trawl. All experiments carried out show that the bycatch of benthic invertebrates is substantially reduced. Therefore, the comparative fishing experiments suggest that the catch efficiency of the pulse trawl may have increased, but the available evidence, however, is too thin to draw a firm conclusion. It is well known that the catch efficiency of a fishing gear may increase over time due to technological developments and improved skills of the fishermen, in particular when new techniques are introduced (Eigaard et al., 2014). Additional comparative studies may shed light on this question. We expect that knowledge on the effect of fish size on the dose-effect relationship between pulse stimulation and the cramp response in sole and other flatfish species will allow us to give a mechanistic interpretation of the size selectivity of the pulse gears used in the commercial fishery.

When it comes to the catch rates of the ensis pulse trawl and selective innovations such as the electrified benthos release panel (eBRP), more data is required to draw reliable conclusions.

3.2 Catch composition of *Crangon* pulse trawls

Representative catch comparison experiments were executed recently on 6 commercial *Crangon* trawlers in Belgium, the Netherlands and Germany. An experiment was carried out by Verschueren et al. 2014 on the vessel HA 31. During four commercial trips on the Dutch Wadden Sea, a normal shrimp beam trawl, fitted with conventional ground gear with 36 bobbins and a sieve net, was directly compared with a lightweight pulse trawl (Figure 3.1). The pulse trawl was a combination of a classic beam with trawl shoes and a new 'square' net design with sieve net inside. In order to stimulate the shrimp to leave the sediment, an electrical pulse field (12 electrodes) was combined with a reduced bobbin rope (11 bobbins). The experimental setup is illustrated below.

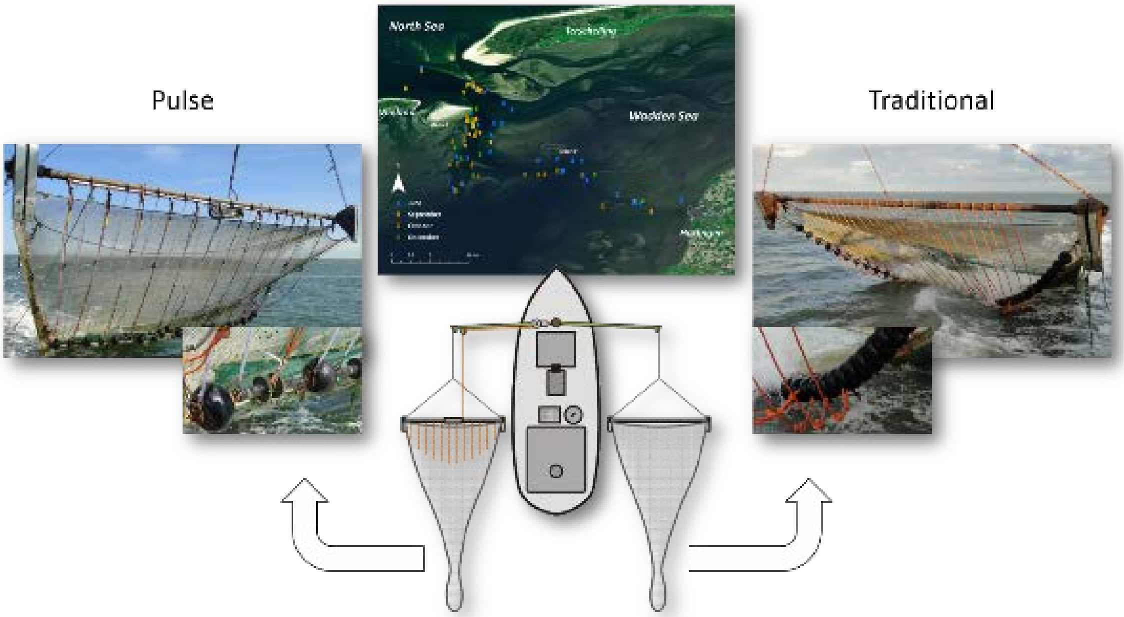


Figure 3.1: Schematic illustration of the paired catch comparison experiment carried out in the Dutch Wadden Sea. On the left (portside of the vessel) the pulse trawl with 12 electrodes and a lightweight bobbin rope (155kg) with 11 bobbins is shown. The conventional shrimp trawl (on the right – starboard side) was fitted with 36 bobbins (400kg). Modified from Verschueren et al. (2014).

Marketable shrimp catches were higher with the pulse trawl (16% in June and 9% in September). In October and December, no significant differences were observed in commercial shrimp. Bycatch of discarded, undersized shrimp was significantly lower with the pulse gear (-19 to -33%) during three of the four trips. Bycatch of benthic fish and invertebrates was significantly lower in volume (-50 to -76%) in the pulse gear for each trip. This reduction was particularly striking when looking at juvenile plaice (Figure 3.2) and to a lesser extent when considering juvenile dab, flounder, cod and whiting. Sieve nets are satisfactory effective in avoiding the bycatch of relatively large individuals of all species, but less so at reducing 0-group plaice and sole. The pulse trawl with the configuration described above, appeared to be very complementary with the sieve net.

Less mobile benthic invertebrates such as razor clams, winkles, anemones and starfish were less abundant in the pulse trawl catches. The bycatch of many mobile demersal organisms like armed bullhead, goby, shore crab, starfish and pipefish was also significantly lower with the pulse gear. The improved selectivity of the HA 31 pulse gear can be attributed to the use of the lightweight ground gear. With only 11 bobbins distributed over the full width of the gear, considerable escape opening is created between the footrope and the seabed.

Another catch comparison between a commercial beam trawl and a shrimp pulse trawl with a straight foot- and ground rope with 11 bobbins as well as a sieve net was carried out between the summer of 2012 and the summer of 2013 in the German Wadden Sea. Results of the first project phase between June and August 2012 are reported in Kratzer (2012). On average, total shrimp catches in pulse trawls were 10% higher than in conventional beam trawls. Catches of large marketable A-shrimp were 8% higher in the pulse trawl and catches of small non-marketable shrimp 14% higher. In some of the trials the pulse trawl caught smaller shrimp, in other trials there were no significant differences between the gears. Variations of towing speed between 2,5 and 3,5 kts had no marked effect on the catch rates of the pulse and the standard trawl. The same study demonstrated that a smaller number of bobbins in the modified ground rope allows fish to escape underneath the footrope and leads to lower bycatch. Bycatch rates were on average 15% lower in the pulse trawl. The median of the fish bycatch was 6% in the conventional trawl and 4% in the pulse trawl (maximum values 30% and 20% respectively). On species level, the pulse trawl primarily caught fewer juvenile flatfish: plaice (5–12 cm: -28%); sole (5.5–10 cm: -43%); dab (4–6 cm: -50%), but also bycatch of sand goby (4.5–8.5 cm: -75%) and hooknose (4–10 cm: -44%) was considerably reduced compared to conventional beam trawling.

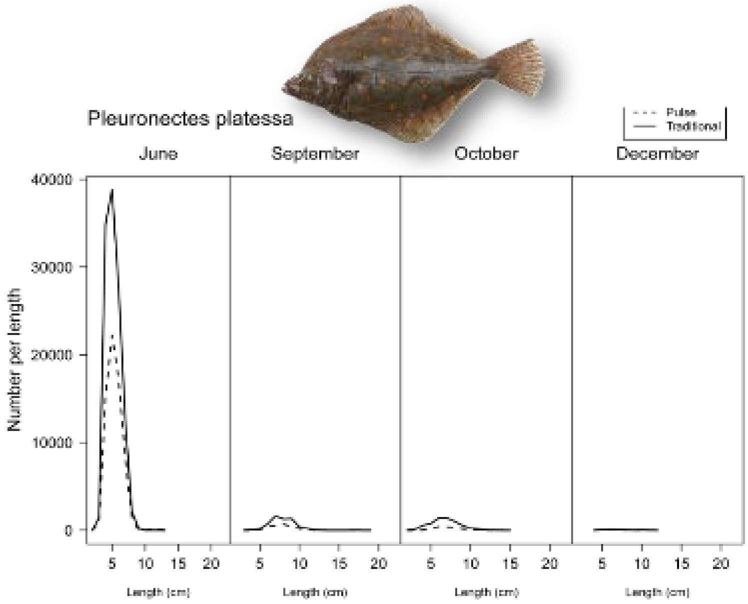


Figure 3.2: Length-frequency distribution of discarded plaice, one of the main by-catch species in Crangon fisheries. Separated in pulse (dotted) and traditional catch (solid) during seasonal sampling. In summer months the shortcomings of the sieve net as a selectivity-improving device are illustrated. Pulse stimulation and sieve net are clearly complementary. Modified from Verschueren et al. (2014).

The full project report by Stepputtis et al. (2014) extended these results. Total catch (+23%), discarded shrimp (+8%) and cooked shrimps (+9%) were significantly higher and bycatch (-9%) was significantly lower with the pulse beam trawl compared to the standard trawl. Further, there was a pronounced variability for all catch fractions over the course over the whole year and over the course of daytimes, indicating a clear seasonal effect and a clear daytime-effect on the catch composition. On average, the amount of bycatch per litre of cooked shrimp was reduced by 14% with the pulse beam trawl. Flatfish and benthic fish were significantly reduced in numbers of individuals with the pulse beam trawl (-13%, -29%, respectively) and in weight of individuals (-15%, -23%, respectively). To verify the effect of the electric field itself, the pulses of the pulse beam were switched off. Despite very small sample sizes, all catch fractions were significantly lower with in the pulse beam trawl without pulses, compared to the standard trawl. Taking into account results from the main experiment, high efficiency of the electric field was indicated.

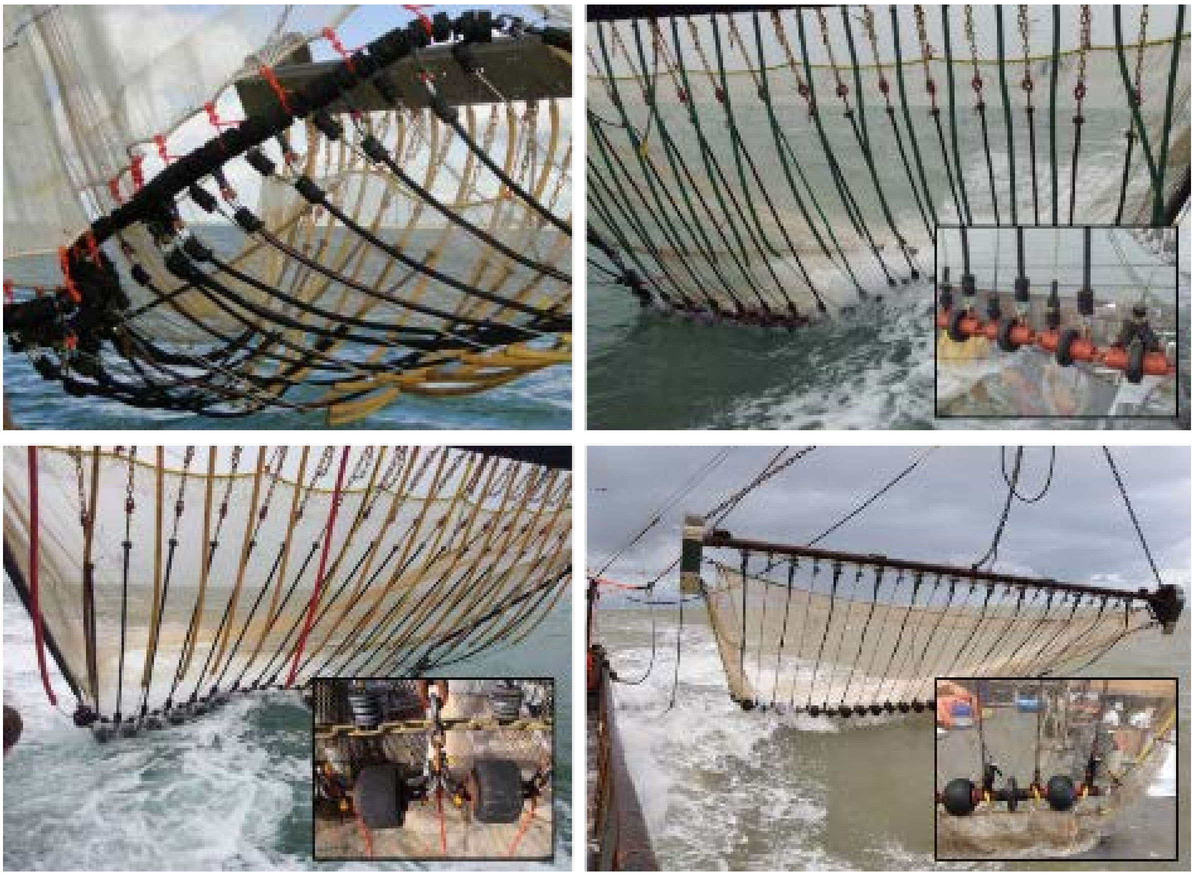


Figure 3.3: Four different ground gear designs tested in a pulse trawl on the Dutch eurocutter TH 10. Each design resulted in different bycatch rates when compared to a standard trawl. Bycatch reduction increased with the size of the escape opening between the seabed and the footrope. Modified from Verschueren et al. (2013).

A third series of experiments was conducted on the Dutch eurocutter TH 10 (Verschueren et al. 2013 & Verschueren et al. 2016). Various types of straight bobbin ropes and a ground rope design with rubber discs, illustrated below, were compared mutually and with a conventional bobbin rope (Figure 3.3). Strongly varying results were demonstrated. Catch efficiency (commercial shrimp catches) and bycatch levels were different for each design.

As shown in most studies, the bobbin rope design has a large effect on the outcome in pulse trawling, as is confirmed by most studies. In all experiments it was found that bycatch reduction increases with the size of the escape opening between the seabed and the footrope. Consequently a lightweight bobbin rope design with significant spacing between adjacent bobbins delivers the best results in terms of bycatch reduction. Regulators and managers should consider gear specifications, i.e. number of bobbins and/or set-up of bobbins, when assessing the practical implementation of pulse fishing gear in the shrimp fishery.

3.3 Catch composition of flatfish pulse trawls

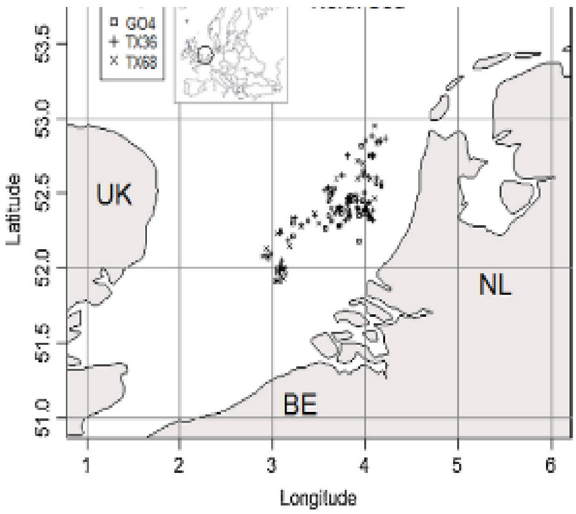
Development of pulse trawling systems for flatfish has proceeded without interruption in the Netherlands from 1998 to present. In 2007 a total of 5% of each European beam trawl fleet was allowed to use pulse beam trawls by derogation (Soetaert et al., 2013). All research and evaluations carried out before 2011 were based on the specifications of the pulse trawls developed by Verburg Holland (ICES, 2010). In 2011, the permits were doubled under the condition that information on the effects of the pulse trawl fishery on the ecosystem would be collected. As a consequence new manufacturers entered the market. Verburg Holland was acquired by the Delmeco Group and HFK Engineering introduced the 'PulseWing' in the Dutch beam trawler fleet. From then on broadly two different types of the flatfish pulse trawl are being used on more than 90 beam trawlers in the Southern North Sea. As far as we know, only two studies on the catch composition of these gears were executed, since this large-scale implementation took place.

Van Marlen et al. (2014) reports on a one-time, comparative fishing experiment in May 2011 between one commercial fishing vessel using traditional flatfish tickler chain beam trawls and two boats using either the Delmeco or the HFK flatfish pulse trawls. The three vessels fished 'side-by-side' as much as possible given the differences in optimal towing speeds. In total 93 hauls were sampled, sometimes partly, for sole, plaice and discards. The study area is shown on the map in Figure 3.4. The authors were particularly interested in finding out what the difference was between catches and bycatches of both gears, the fate of cod in the pulse trawl catches, and the fuel saving potential. In addition to this, (length-related) differences in landings and discards of the target species, plaice and sole, were studied.

The net earnings (gross earnings – fuel costs) showed a large increase for both pulse trawlers TX 36 (186%) and TX 68 (155%). However, the large investment and high maintenance costs of the pulse gears are hereby not taken into account. This increase is mainly due to their lower fuel consumption (on average 43%), as the catches of the target species were lower (plaice: 71% and sole: 86%), compared with conventional beam trawls with tickler chains (figure 6-5). The total catch in the pulse trawls was considerably lower, only 37% of the conventional trawl. Fewer discarded fish (57%) and benthic discards (80%) were caught by hectare fished, compared to the vessel fishing with conventional beam trawls during the experiment. The discards of the main target species were also lower, for plaice the ratio by hectare was 62%, and for sole 46%, which was confirmed by the analysis of the length effect (Figure 3.5).

Spinal damage in cod occurred in about 10% of the cod catches on-board the pulse trawlers, and mainly in larger individuals, that are usually landed. However, it should be noted that the average catch of cod was lower than with the traditional beam gear (31% in kg/h)

Figure 3.4: Fishing positions of the three vessels in the North Sea during the catch comparison of 2011. GO 4: Conventional beam trawler; TX 36: HFK SumWing with pulse and TX 68: Delmeco Multiwing with pulse. Modified from van Marlen et al. (2014).



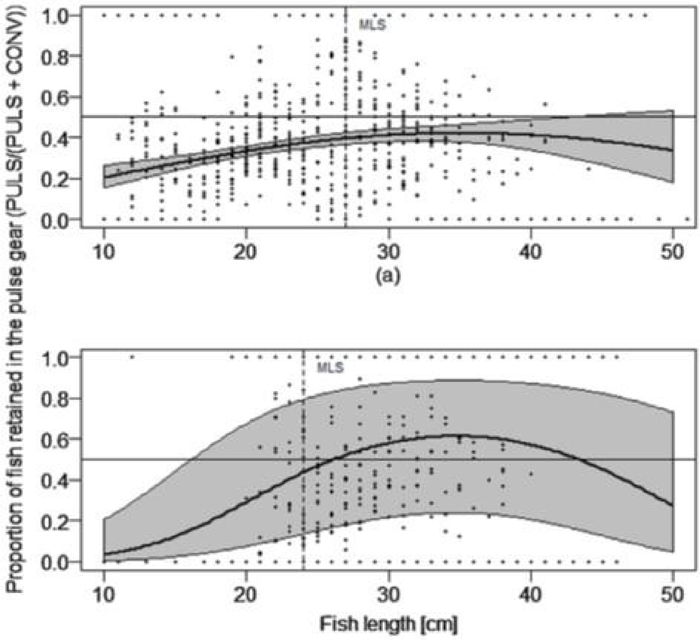


Figure 3.5: *Size selection of the pulse trawl relative to the conventional tickler chain beam trawl for plaice (a) and sole (b). The heavy line shows the proportion of fish retained caught per hour fishing in pulse gear vs. length The value of 0.5 means both gears catch equal numbers (> 0.5 means pulse gear catches higher numbers; < 0.5 means pulse catches lower numbers). The grey band gives the 95% confidence limit. Data points are given in black dots. MLS is Minimum Landing Size (plaice: 27 cm, sole: 24 cm) (van Marlen et al., 2014)*

In 2015 another comparative fishing experiment was conducted in conjunction with the fishing industry survey (van der Reijden et al., in prep). A total of 38 parallel hauls were carried out. The results showed that the pulse trawl caught significantly more marketable sole per hectare and slightly less marketable plaice than the conventional beam trawl, but did not corroborate the results of van Marlen et al (2014) of a lower bycatch of undersized sole and plaice. Because of differences in the cod-end mesh size of the pulse and tickler chain vessel, results should be interpreted with caution.

In order to meet the required conditions set by the EU, the Dutch Cooperative Fisheries Organisation (CFO) decided to set up a monitoring program in December 2011 that consisted of a combination of self-sampling and observer trips on 25 vessels. The outcome of this program is written down by Rasenberg et al. (2013). In what follows the main conclusions are highlighted.

First of all, the results from the two methods (self-sampling and observer trips) were compared to check the consistency of the self-sampling method. Three significant differences were observed: Both the bycatch of benthos & debris, sole discards and cod landings were significantly higher in the self-sampling program. This may be due to spatial and temporal differences.

Overall, more than 40% of the average pulse catches consisted of benthos and debris. In addition, the results show that there is variation in discards between quarters and between the five fishing areas that were defined in the analysis. However, no clear seasonal or spatial patterns were distinguished. The benthos catches of the observer program were compared with the benthos catches of the beam trawl fishery from the Data Collection Framework (DCF) program. The numbers of starfish and crab caught in the pulse trawl trips were lower than in the conventional beam trawl trips. The number of individuals caught by the pulse vessels was

84% lower for starfish and 58% lower for crabs compared conventional beam trawls. The amount of starfish and crabs in the bycatch is a good indicator of the benthos bycatch quantities in these fisheries. This is consistent with earlier research done in 2011 by Van Marlen et al. (2014).

Cod catches were very low as compared to the total catch in both the self-sampling and the observer program. The self-sampling program showed an average landing rate of 3 kg/hour and an average discard percentage of 7%. The observer program showed an average landing rate of 1 kg/hour and an average discard percentage of 12%. Cod catches are too low to make a reliable comparison with the DCF beam trawl data.

On average around 30% of the total pulse trawl catch consisted of marketable fish. The percentage of discarded commercial fish species varied between the self-sampling (17%) and the observer program (29%). Plaice and sole catches (landings and discards), both of the pulse self-sampling and the observer program, were compared with the beam trawl fishery samples from the DCF program, as is given in Table 3-1. The average amount of plaice caught in the pulse trawl fishery appeared to be lower than in the beam trawl fishery during the sampling period. The actual amount of plaice discards caught during the self-sampling (27 kg/hour) and the observer trips (66 kg/hour) was lower compared to the beam trawl fishery (87 kg/hour). This is consistent with the research done by van Marlen et al. (2014).

Table 3.1: Observed plaice and sole landings and discards (kg/hour), including standard deviation, and discard % for the self-sampling trips (>300hp), monitored observer trips (>300hp) and DCF beam trawl trips (>300hp) in 2012. Modified from Rasenberg et al. (2013).

Type of fishery and sampling method	Plaice			Sole		
	L	DC	%DC	L	DC	%DC
Pulse trawl, self-sampling	37 ±43	27 ±45	42%	35 ±19	6 ±26	15%
Pulse trawl, observers	61 ±44	66 ±66	52%	32 ±14	4 ±4	10%
Beam trawl, (DCF - observers)	90 ±86	87 ±71	49%	29 ±14	6 ±10	17%

The average sole discard percentage during the observer program (10%) seemed to be lower than the average calculated from the self-sampling trips (15%) and the DCR beam trawl trips (17%). The actual amount of sole discards was respectively 6 kg/hour, 4 kg/hour and 6 kg/hour for the three sampling methods and thus lie in the same range. Sole landings were clearly higher in the pulse fishery, according to the monitoring program. This is in contrast with the catch comparison by van Marlen et al. (2014), were both sole landings and discards were lower in the pulse fishery. This could be explained by the fact that in recent years, at the time of the CVO monitoring program, the fishermen got more experienced with the pulse trawl and learned to catch sole more efficiently. Apart from this van Marlen et al. (2014) only covered a small time period and a relatively small fishing area. However, since the difference in standard deviations in these results are relatively large, absolute correct comparison with the beam trawl fishery cannot be given.

3.4 Catch composition of *Ensis* electrotrawls

If the emerging razor clams are hand-picked by divers, it can be assumed that the selectivity is substantially 100%. This may not be the case when dredge-like devices are used. However, very little is known about (by)catch rates in these gears. In Breen et al. (2011) it is mentioned that the development of a novel *Ensis* dredge employing electrical stimulus was being carried out in Ireland around 2010. Preliminary results showed landings comparable to those achieved by hydraulic dredges and crucially, the condition of the razor clams seemed better with lower breakages and long survival. Similar prototypes were tested in the Netherlands. Nevertheless, we could find no documented studies that report catch comparisons between conventional *Ensis* dredges and pulse dredges.

3.5 Redistributing fishing effort

The transition from the conventional beam trawl to the pulse trawl, coinciding with an overall decrease in fishing effort, has resulted in a shift in the effort distribution. Relative fishing effort increased in areas off the Thames estuary, Norfolk banks and off the Belgian coast (Turenhout et al., 2016). Shifts in distribution of fishing effort of pulse trawlers may give rise to local competition between pulse vessels and traditional fishers. Sys et al. (2016) showed that the landing rates of sole by the Belgian beam trawlers (>=221 kW) from 2006 to 2013 were lower during weekdays than during weekends when the Dutch trawler fleet is in harbour, while no such an effect was found for plaice. After the development of a pulse trawler fleet, the negative weekday effect in the sole landing rates was much more pronounced in 2012 and 2013. This increased loss of efficiency during weekdays, as a result of increased competition with the Dutch pulse trawler fleet, coincided with a reallocation of fishing effort by the Belgian beam trawler fleet.

4 Effects of exposure to pulse fields

4.1 General overview

Introducing electrotrawling on a large scale without a sound knowledge of the interactions between electrical fields and the marine ecosystem would be against the principles of the precautionary approach and responsible fishing. Until recently, the effects of low frequency (<100Hz) pulses on marine organisms were largely unknown (Soetaert et al., 2013). The vast majority of studies on the harmful effects of electrofishing focuses on its use in freshwater, widely adopted as a sampling technique for fishery ecology and management purposes (Snyder, 2003; Polet, 2010). Snyder (2003) reported that, although often not externally obvious or fatal, spinal injuries and associated haemorrhages may be regularly present as a result of exposure to electricity, warranting the need for radiological and histological examination.

The principal cause of spinal injuries appears to be powerful convulsions of the body musculature induced by sudden changes in the electric potential. These sudden changes occur when the current is switched on and off or pulsed. In PDC, longer exposures subject the fish to more pulses and thereby increase the risk for spinal injury, with the incidence of injuries being lowest for low frequency (≤30Hz) PDC (Snyder, 2003). Besides minimizing frequency, results from several studies suggest that the field strengths should also be kept to a minimum to limit injuries (Schreer and Cooke, 2004).

An overview of all experimental studies in which marine organisms were exposed to a pulse trawl stimulus is given in Table 4.1. Thereafter, the specific effects of exposure to the 3 types of pulse stimulation that are applied today, are separately overviewed in detail per chapter.

Table 4.1. Overview of experimental studies in which marine organisms were exposed to a flatfish or shrimp pulse stimulus. N refers to the number of exposed animals. Vpeak refers to the potential difference over the pair of electrodes.

Species	Results	Pulse stimulus	Field strength (V/m)	Frequen-cy (Hz)	Duration (sec)	Source
Cod (35-60cm) N=320	Maximal exposure close to conductor resulted in spinal fractures upto 70% of the cod. Fracture incidence increase with field strength and decrease with frequency	Sole pulse	4-103	30-180	1	De Haan et al (2016)[1]
Cod (<20cm) N=140	No injuries.	Sole pulse	76-370	30-180	1	
Cod (30-80 cm) N=180	Exposure of 180 cod close to conductor resulted in spinal fractures in 0-5% of the cod.	Sole pulse	60-120 (Vpeak)	40-80	1-2	Soetaert et al (2016a,b) Marine Coastal Fisheries

[1] This publication includes earlier IMARES reports

Species	Results	Pulse stimulus	Field strength (V/m)	Frequen-cy (Hz)	Duration (sec)	Source
Cod (40- 70 cm) N=26	Exposure to a homogeneous field did not cause lesions except for a spinal fracture in 1 animal.	Square PDC, PBC	100-200	40-200	2	Soetaert et al (2016a) Fish. Res.
Sole (25-30cm) N=146	Exposure of 146 soles to a homogeneous field did not cause lesions. One sole died 13d after exposure but without any injuries. One sole showed minor gill haemorrhage during exposure.	Square PDC, various pulse types	150-200	5-200	2-5	Soetaert et al (2016a) Fish. Res.
Dab N=100	Cramp response. No lesions detected. No mortality observed related to exposure.	Sole pulse				De Haan, D. et al. (2015) IMARES Report number
Catshark N=23	No effect on the success rate and timing of artificial prey electric field detection was observed after exposure to the pulse trawl electrical fields	Sole pulse & Shrimp pulse heterogeneous field	60 V_{peak}	80 5	5	Desender et al., (2017a) Experimental Marine Biology and Ecology
Catshark N=48	No mortality and no visible injuries observed. Fish in all tested groups started feeding normally directly after the exposures. Fish of all pulse-exposed groups produced eggs in numbers varying between 5-39 per group during 9 month post exposure	Delmeco sole pulse	8, 48, 162	40	4 x 1 second	De Haan, D., et al. (2009) IMARES Report C105/09

Species	Results	Pulse stimulus	Field strength (V/m)	Frequency (Hz)	Duration (sec)	Source
Plaice (n=25) Sole (n=30) Cod (n=20) Bull-rout (n=19) Armed bullhead (n=20)	Flatfish: minor reactions in flatfish, 15% sole swam upwards. Roundfish: active swimming during exposure. No fractures detected. Histological examination showed small haemorrhage in 2 exposed plaice. Number of melanomacrophage centres in spleen of exposed cod was higher.	Shrimp pulse heterogeneous field	60 V_{peak}	5	5	Desender et al., (2016) Fish Res
Cod 3 egg stages 4 larval stages 1 juvenile stage	Hatching/developmental rate delayed in 1/3 egg stage. Mortality increased in 2/4 larval stages No altered development or deformities	Shrimp pulse homogeneous field	150	5	5	Desender et al., (2017b) Marine and Coastal Fisheries
Sole 1 egg stage 1 larval stage	No adverse effects or deformities recorded	Shrimp pulse homogeneous field	150	5	5	Desender et al., (2018) North American Journal of Fisheries Management

Helmet crab, Swimming crab	Freeze during stimulation and show escape reaction immediately afterwards	Delmeco sole pulse	Due to confidentiality, no details on the pulse characteristics were provided by the company. The potential difference over the electrodes was twice the potential difference of the Delmeco prototype of 2004.	1st group exposed 10 s; 2nd group exposed 10 s for 3 days in a row.	Smaal and Brummelhuis (2005) RIVO Report: C089b/05	
Decapode: brown shrimp, steurgarnaal	Tail flips and/or freeze. After 1 s resume to normal					

Species	Results	Pulse stimulus	Field strength (V/m)	Frequency (Hz)	Duration (sec)	Source
	movements. When mechanically stimulated directly after exposure the animal moves					
Hermit crab	Freeze or withdraw in shell upon stimulation.					
Echinodermata: Common sea star, Echino- cardium, Ophiuroidea	No visible response.					
Polychaetes: Ragworm, sea mouse	No visible response.					
Bivalves: razor clam, cockle, *Acanthocardia echinata*	Closes shell, Ensis slightly extends its foot. No effect on filtration activity					
Whelk	(partly) withdraws in shell.					
Brown shrimp N=30-60 per group (tot=1730)	Tail flip response at 5 HZ. Cramp response at >=60 Hz. No increase in mortality or injuries. Increase in virus infection at highest exposure	Sole & shrimp pulse; homo-geneous field	150-200	5-200	1-5	Soetaert et al. (2014) ICES JMS
Ragworm N= 23-50 per group (tot=616)	Squirming response. No increase in mortality or					
Brown shrimp N=479 (pulse) N=178 (mechanical)	Sole pulse reduced survival. Mechanical stimulation gave reduced moulting rate. No increase in IBV infection.	Sole and shrimp pulse	60 V (Vpeak)	5 & 80	20 times 1 sec exposure during 4 days	Soetaert et al (2016c) Marine Coastal Fisheries

4.2 Effects of the *Crangon* pulse field

4.2.1 Effect of pulse parameters and temperature on pulse's efficacy

The masterthesis of Stappenpenbeck (2017) investigated the effect of pulse parameter settings and environment on the reaction of brown shrimp by using a high-speed camera and tracking the escape path of each shrimp. The parameters varied were:

- Number of pulses: 1 to 7
- Pulse duration: 0.1 ms, 0.3 ms and 0.5 ms
- The electrode shape: plate or wire
- Water temperature: 8°C or 16°C.

The results indicated that the pulse duration used in commercial trawls can be reduced from 0.5 ms to 0.3 ms. Additionally, shrimp showed much stronger responses when exposed to the threadlike wire electrodes compared to plate electrodes. Finally, it was shown that the shrimp achieved their highest position after 5 to 6 pulses in 16°C and after 8 pulses in water of 8°C. This illustrated that low water temperatures result in weaker responses of shrimp, which explains why the catches of a pulse trawl outperform that of a conventional trawl mainly during summer and autumn when the water is warmer (Verschueren et al., 2014). These results imply that it might be necessary to design more flexible systems, which can be easily adapted to actual water conditions in order to always get the minimal environmental impact for optimal catch rates and gradually decrease by-catch rates.

4.2.2 Effect on invertebrates

When conducting exploratory laboratory trials, Polet et al. (2005a,b) also assessed effects 9 invertebrate species after a single 15 second exposure to low frequency DC pulses including swimming crab (*Liocarcinus holsatus*), shore crab (*carcinus maenas*), hermit crabs (*Bernhardus pagurus*), starfish (*Asterias rubens*), *Spisula subtruncata*, brittle star (*Ophiurra* spp.) *Pandalus montagui* and brown shrimp. No adverse effect on survival was found. Similarly, ragworm (*Alitta virens*) and brown shrimp exposed up to 4 times to the shrimp pulse did not show a reduced 14 day survival (Soetaert et al. 2014). This result was confirmed in a follow up study in which brown shrimp was exposed 20 times to the shrimp pulse in a commercial setting without showing adverse effects on survival, moulting or the number of egg carrying females 14 days after the start of the experiment (Soetaert et al. 2016a).

4.2.3 Effect on adult fish

After the preliminary studies of Polet et al. (2005a) investigating survival and external injuries in sole, plaice, armed bullhead, cod, pogge, dab, turbot, dragonet, five-beard rockling and gobies, Desender et al. (2016) evaluated short-term effects on adult fish after exposure to the pulse stimulus which is used today in the *Crangon* electrotrawls. European plaice *(Pleuronectes platessa)*, Dover sole *(Solea solea)*, Atlantic cod *(Gadus morhua)*, Bull-rout (*Myoxocephalus scorpius*) and Armed bullhead (*Agonus cataphractus*) were once exposed during 5 seconds. Following characteristics were evaluated:

- behavioural reactions, observed 10' before and 20' after exposure

- short term mortality
- presence of macroscopic lesions by visual inspection
- presence of microscopic lesions in the dorsal muscle, gills, heart, liver, spleen, intestines and kidney, determined by means of histological examination
- Inspection of spinal damage by X-ray.

Roundfish species, Atlantic cod in particular, were displaying more active and agitated fast swimming activity during exposure. The majority of flatfish showed only minor reactions and remained close to the bottom throughout the observation period. During exposure,15% of sole swam upwards. There was no difference in number of movements before and after exposure between control and exposed organisms within the same species.

No mortality was observed, which corresponds to the findings of Polet et al. (2005a). No spinal damage was observed and macroscopic lesions did not differ significantly between control and exposed groups, Upon histological examination, in two exposed plaice, a small focal haemorrhage between muscle fibres was found, which was not encountered in control animals. In addition, the number of melanomacrophage centres (MMCs) in the spleen of exposed cod was significantly higher than in the non-exposed animals. No haemorrhages, MMCs or other lesions were observed in sole and cod 14 days after a 2 s exposure to the crangon pulse as well as other much stronger pulse stimuli between plate electrodes (Soetaert et al., 2016a). This indicates these histological deviations were reversible and healed after 14 days. The authors concluded the applied electrical field seemed to have only limited immediate impact on the exposed animals and no electric-induced irreversible injuries or mortality was observed.

Finally, possible impact of pulse trawling on electro-receptor organs, the Ampullae of Lorenzini, of elasmobranchs has been questioned by Desender et al. (2017a). This study aimed to examine the role of pulsed direct current (PDC) on the electro-detection ability of the small-spotted catshark, *Scyliorhinus canicula*. The response of the sharks to an artificially created prey-simulating electrical field was tested before and after exposure to the pulses used to catch flatfish and shrimp. No statistically significant differences were noted between control and exposed animals, both in terms of the number of sharks exhibiting an electroresponse prior to and following exposure as well as regarding the timing between onset of searching behaviour and biting at the prey simulating dipole. These results indicate that, under the laboratory circumstances as adopted in this study, the small-spotted catshark are still able to detect the bioelectrical field of a prey following exposure to PDC used in pulse trawls.

4.2.4 Effects on early life stages of Atlantic cod and Dover sole

Recently, concern was expressed about electrofishing over active spawning grounds and hereby affecting survival of sensitive embryos or juveniles that are present on or in the substrate (Polet, 2010). Brown shrimps are specifically caught in shallow coastal zones and estuaries, important nurseries or spawning areas for a wide range of marine species. Exposure of recently hatched larvae might reduce growth rates, induce malformations or cause mortality. The exposure of near-ripe or ripe broodstock fish to electric fields may also hamper natural reproduction (Snyder, 2003), an aspect that has not been investigated yet for pulse trawls.

In order to address this matter, experiments were carried out with different developmental stages of Atlantic cod (*Gadus morhua*) by Desender et al. (2017b). Three embryonic, four larval and one juvenile stage were exposed to a homogeneous electrical field of approximately 150 V/m during 5 seconds, mimicking a worst case scenario. In all embryos, no significant differences in mortality rate were found. However, in the embryonic stage exposed at 18 days post fertilization (DPF), the initial hatching/developmental rate was delayed. Larvae exposed at 2 and 26 days post hatching (DPH), exhibited a higher mortality rate. In the other larval and juvenile stages, no short-term impact of exposure on the survival was observed. Morphometric analysis of larvae and juveniles revealed no differences in yolk resorption, possible deformations and measurements of length, eye, head, and muscle height of the notochord. Although exposure to a worst case electrical field did not impact the survival or development of six out of eight young life stages of cod the observed delayed hatching/developmental rate and decreased survival for larvae are indicting an impact of electric pulses and warrant further research.

An analogous experiment was carried out by Desender et al. (2018) to investigate the effect on the development of Sole (*Solea solea*). Exposure of sole embryos at 2 days post fertilisation (DPF) and larvae at 11 days post hatching (DPH) did not result in lower survival eight days post exposure. Additionally, no differences in yolk resorption and morphometric length measurements of the notochord, muscle, eye, and head, were observed in the developing larvae at respectively 6 and 19 DPH. However, this study only included short term effects and was stopped before larvae metamorphosis.

4.3 Effects of the flatfish pulse field

4.3.1 On invertebrate species

Two exploratory studies evaluated the behaviour and survival of invertebrates exposed to the flatfish cramp pulse. Smaal and Brummelhuis (2005) exposed on average 10 individuals of 19 species of molluscs, echinoderms, crustaceans and polychaetes to pulse amplitudes and exposure times respectively two times higher and eight times longer than the settings used in the field. Reactions during exposure were minor or negligible and the survival after three weeks did not differ from control groups. Van Marlen et al. (2009) exposed six benthic invertebrate species to three subsequent 1 second bursts. For each species 20 animals were exposed at three different distances, ranging from 10 to 400 cm from the electrode. Compared to the control groups, they observed a significant reduction in the survival rate of exposed Ragworm (*Allita virens*) and European green crab (*Carcinus maenas*) of 3% and 5%, respectively. Atlantic razor clam (*Ensis directus*) displayed a significant 7% reduction in survival rate after exposure at 10 cm from the electrode, but higher survival rate at 20 cm from the electrode. Furthermore, food intake was significantly reduced by 10 to 13% in the European green crab. No significant effects were found for Common prawn (*Palaemon serratus*), Surf clam (*Spisula solidissima*) and Common starfish (*Asterias rubens*). Authors concluded that electrical stimulation in electrotrawls is less invasive than conventional beam trawling with mechanical stimulation. Both reports only examined the effect of the cramp stimulus and the variable results suggest that insufficient animals were included to exclude the variability due to natural mortality.

As an extension Soetaert et al. (2014) evaluated the survival, gross lesions and microscopic lesions of large numbers of Ragworm and Brown shrimp 14 days after exposure to various electrical pulses in a homogeneous electrical field. A series of single exposures to various pulses did not result in increased mortality, nor in the abundance of lesions (Soetaert et al. 2014). A fourfold exposure of Ragworm to a stimulus with maximal potential and duty cycle resulted in intense squirming during and especially after exposure, but none of the animals died or showed lesions in the 14 d after exposure. However, single exposure on brown shrimp to the highest electrical field strength showed an increase in the number and size of intranuclear bacilliform virus (IBV) infection in the hepatopancreas. In addition, no discernible negative effects were found in *Crangon*, 14 days after four repetitive exposures (Soetaert et al. 2014). However, indirect effects of pulse were not studied and cannot be completely dismissed. Therefore it was argued that additional experiments were warranted, evaluating the impact of repetitive exposure to commercial wire-shaped electrodes and pulses, as may occur in fishing practice.

To evaluate the effect of repetitive exposure to electrical fields, Brown shrimp were exposed 20 times in 4 days to commercial electrodes and shrimp or flatfish pulse settings and monitored up to 14 days post first exposure (Soetaert et al., 2016c). Survival, egg loss, moulting and the degree of intranuclear bacilliform virus (IBV) infection were evaluated and compared to stressed but not-electrically-exposed (procedural control) and non-stressed non-exposed (control) shrimp as well as to shrimp, exposed to mechanical stimuli. The lowest survival at 14 days post first exposure was observed for the sole cramp pulse treatment (57%), which was significantly lower than the procedural control group with the highest survival (70%). However, no significant difference was found between the non-stressed control group (66%) or the shrimp exposed to mechanical stimulation (60%) or the shrimp pulse (65%). No effect of electrical stimulation on the severity of IBV infection was found this time, which illustrates that the observation in the previous study was most probably an anomaly. The lowest percentage of moults was observed for the repetitive mechanical stimulation treatment (14%), which was significantly lower than the procedural control group with the highest percentage of moults (21%). Additionally, the mechanically stimulated shrimp that died had a significantly larger size compared to the surviving individuals. Finally, no effect of the shrimp pulse was found. Therefore, it can be concluded that repetitive exposure to a cramp stimulus and mechanical stimulation may both have a negative effect on the growth and/or survival of *Crangon crangon*. However, there is no evidence that electrotrawl stimulation would have a more adverse impact on *Crangon* stocks than mechanical stimulation in conventional beam trawling.

Finally, the impact of a bottom trawl on the benthos depends also on the footprint of the gear used and the sensitivity of the benthic community. The mechanical effects of the pulse trawl are probably lower because of the reduced mechanical disturbance and by-catch rates which result in lower mortality rates. The replacement of tickler chains running across the net opening by electrodes running in longitudinal direction, has decreased by 50% the bycatch of benthic invertebrates. In addition, the trawling footprint, defined as the sea floor area swept per hour trawling, is 23% lower than the footprint of the conventional beam trawl due to the reduction in towing speed from about 6.5 to 5 knots. In ecological terms these two factors are important to decrease the impact of trawling on the North Sea benthic ecosystem. Because the pulse trawl vessels showed a change in their spatial distribution, differences in habitat sensitivity need to be taken into account on top of the additional impact of electrical stimulation to assess the changes in impact on the seafloor.

4.3.2 On adult fish species

4.3.2.1 Dover sole (Solea solea)

Soetaert et al. (2016a) exposed over 100 sole in a homogeneous electric field to a wide range of different electric pulses, including those of the commercial pulse trawlers targeting sole but also several 'worst case' exposures with much higher pulse durations, frequencies. No mortality was found in fish and neither macroscopic or histological lesions nor other abnormalities were observed.

4.3.2.2 Common dab (Limand limanda)

Recently concern has been raised about injuries and skin deformation observed in Common dab (*Limanda limanda*). Since the start of electrotrawling, the appearance of ulcers in fish was suggested in the media as a negative side-effect of pulse gears and became a debate in European fishing communities. De Haan et al. (2015) investigated whether electric stimuli could cause injuries in dab, and enhance the development of diseases, such as ulceration. The pulse treatment was given in the closest range of a conductor with a dose extending the commercially applied practice. The fish were kept in observation for five days after the treatment, after they were analysed for external and internal lesions, possibly attributable to pulse exposure. In case of lesions attributable to infections, bacteriological tests were conducted. It was concluded that lesions primarily related to pulse exposure were neither observed in the fish analysed directly after the treatment, nor in the fish that were kept in observation for a period of five days after the treatment.

4.3.2.3 Whiting (Merlangius merlangus)

van Marlen et al (2014) reported that 4 out of 45 cod (9%) caught in the comparative fishing experiment in 2011 showed a spinal fracture. In whiting, only 1 out of 57 fish examined showed a spinal fracture (2%). A similar result was obtained by Rost in her MSc thesis (2015) reporting a pulse related fracture in 5 out of 226 whiting collected on board of 4 pulse trawl vessels. No laboratory experiments have been performed yet because of the difficulty to get and keep whiting in captivity.

4.3.2.4 Atlantic cod (Gadus morhua)

Spinal injury in Atlantic cod induced by electrical pulses was first observed in catches from UK 153, the first commercial ship rigged with a pulse beam trawl, and in field research on board the TX 68 and TX 36 (van Marlen et al., 2014) and other pulse trawlers (Rasenberg et al., 2013), amongst which also undersized individuals (van Marlen et al., 2011).

An initial laboratory experiment performed by De Haan et al. (2008) with farmed cod in Norway revealed that the cod's position in relation to the electrode is critical: When a fish positioned next to a pair of electrodes at a distance of 40 cm was subjected to electrical pulses (i.e. with the fish next to the fishing gear), no reaction was observed. When a cod positioned above a pair of electrodes at a distance of 20 cm (half the height of the opening of the net) was subjected to the pulses, it would show strong spasms. Cod exposed in either of these positions exhibited normal behavior again immediately following the test. However, cod found closer to the conductors, in the hot-spots of the electric field located in the immediate 5-10 cm surrounding of the electrodes, exhibited spinal injuries as a result of the spasms in 50% of the cases. This initial trial showed that only those cod subjected to electric pulses close to an electrode are at risk of being injured. The answer to the question of what happens to the small cod that escape through the mesh in the fishing gear, was addressed by De Haan et al. in a follow-up study in 2010 published as a report in 2011 and a A1 paper in 2016. Two different groups of farmed cod were tested: small cod, on average 14 cm long, and mature cod, on average 47 cm long. The small cod was be exposed closer to the electrodes (at a distance of 1 to 3 cm) and were therefore subjected to pulses that were 3 to 5 times stronger, yet none of the 140 small cod showed injuries. This contrasts to the field trial of van Marlen et al. (2014) where the harmed fish were between 20 and 27 cm. The larger cod were exposed as close to the electrodes as possible (at a distance of some 6 cm). This time, 50 to 70% of the large fish incurred injuries, even after reducing the electrode charge by half. Injuries in the large fish decreased once the pulse frequency was increased to 100Hz; and at 180Hz, no injuries were observed. Increasing the pulse frequency may prove effective in reducing the incidence of injury, but then it is yet to be seen if sole can still be fished efficiently. Moreover, the strength of the electric field at sea has been reduced in comparison with the test conditions. The charge at sea is 17% lower, while the electrode distance is 30% greater, at 41 to 43 cm instead of 32.5 cm (UK153). Field strength measurements carried out by IMARES in 2010 on board the TH10 and OD17 with the fishing gear on the seabed, show that the cod were exposed in 2008 and 2010 under realistic conditions.

In 2013, ILVO also carried out tests on farmed cod in Norway, in partnership with Ghent University. The fish – 100 large fish (64-82 cm) and 50 smaller ones (42-49 cm) – were subjected to various pulses, including the same ones used by IMARES in 2008 and 2010. In addition, the same electrodes and configuration were used as those previously applied by IMARES. But this time, no injuries were observed (Soetaert et al., 2016a). There was also no mortality during the first two weeks following exposure, and no other injuries could be detected. The ILVO's results therefore deviated sharply from those of earlier experiments carried out by IMARES. In order to eliminate any effects which might be due to equipment, season, location, or treatment, a joint experiment was set up by the ILVO, IMARES, and Ghent University. The experiments were then recreated in late 2013 under identical conditions. A total of 80 cod (36-45 cm) were subjected to electric pulses, whereby only 2.5% effectively showed any such injuries. Even when the electric charge was doubled to 120V, only 13% of the fish were injured (Soetaert et al., 2016b). The comparative experiment demonstrated that differences in equipment could be eliminated as a cause of these results and that the cod themselves must hold the key to the variations in results. Possible parameters include body structure, muscle mass, response patterns, subtle differences in body position, genetic variation, and variation in skeletal strength.

In conclusion, it can be summarized that pulse trawl catches at sea exhibit signs of spinal injury in cod, and this is confirmed by the tank experiments. This research demonstrates that the size of the cod and its position with respect to the electrodes play a major role. Large cod positioned above or next to the field remained unharmed. Large cod exposed to electric pulses at the shortest possible distance from an electrode sustained an injury in 50 to 70% of the cases. Unlike the large fish, which were all caught, juvenile cod up to 16 cm were not harmed in laboratory studies. This however contrasts to the injuries observed in larger undersized cod of 20-27 cm in the field trials of van Marlen. Besides, the laboratory studies showed that cod's susceptibility to electric pulses can vary widely and would seem to depend on subtle differences in fish health. One of the recommendations is therefore to sample cod landings and/or discards so that the condition of round fish that have sustained injuries can be compared from one season to the next, in the hope of ultimately identifying the parameter responsible.

4.3.2.5 European Seabass (Dicentrarchus labrax)

Despite the spinal injuries observed in gadoid fish, especially cod, in previous studies (van Marlen et al., 2014; de Haan et al., 2016; Soetaert et al., 2016a&b) no spinal injuries were observed in two length groups of seabass (31.3 ± 2.2 cm and 42.1 ± 2.5 cm) after exposure to the same pulse stimulus and set-up as used in the experiments with cod. This difference in vulnerability may be due to natural variation as seen in cod by Soetaert et al. (2016b) but it seems more likely that it is linked to differences in vertebral morphology as was also seen in freshwater research (Soetaert et al. 2018).

4.3.2.6 Lesser spotted dogfish (Scyliorhinus canicula L.)

De Haan et al. (2009) exposed 3 groups of 16 dogfish with similar length (0.3-0.65 m) to the electric stimulus used in pulse trawling for sole, each on a different distance. One group was exposed in the 'far field' 0.4 m side ways of the conductor, another in the 'above field' or 0.1-0.3 m above the center of a conductor pair and the last one in the 'near field' which was closer than 0.1 m from the conductor element. A 4th control group was also included. Each fish was exposed four times in a row and feeding and behavioural responses were monitored during the stimulus and in the 14 days period following the stimulation. Afterwards, the fish were kept in husbandry for another 9 months.

Regarding other behavioural responses (mainly reflexes and muscle contractions, and post-reactions, such as a rapid body reverse, short-curled body rotations and acceleration towards the water surface), there were some clear differences between exposure groups. The responses of the fish exposed in the "far field" range, representing the fish just aside the fished area of the trawl, were minor and ignorable. However, the responses of the fish exposed in the "above field" range were more pronounced with contractions, rapid body reverses, short- curled body rotations and acceleration towards the water surface occurring.

No evidence was found on differences in feeding response or likelihood of injury or death between the exposure groups. There was no evidence that fish sustained injuries as a result of the exposures. Respectively 8 and 9 months after the experiment a single specimen of the "above field" category and "near field" category died. In the 14 days observation period after the exposures no aberrant feeding behaviour could be distinguished. Fish in all tested groups started feeding normally the same day directly after the exposures. In a period of 7 months after the exposures all exposed groups produced eggs in numbers varying between 5539 per group. Surprisingly the control group did not produce eggs.

4.3.2.7 On prey detection of electrosensitive cartilaginous fish (Scyliorhinus canicula L.)

Possible impact of electrotrawling on electro-receptor organs, the Ampullae of Lorenzini, of elasmobranchs has been questioned by Desender et al. (2017a) and investigated as described previously. Besides the effect of the 5 Hz startle pulse for shrimp, small-spotted catshark, *Scyliorhinus canicula*, was also exposed to a 30 Hz PBC cramp pulse for flatfish. Again, no statistically significant differences were noted between control and exposed animals, indicating that, under the laboratory circumstances as adopted in this study, the small-spotted catshark are still able to detect the bioelectrical field of a prey following exposure to cramp pulse used in pulse trawls targeting flatfish.

4.3.2.8 Skin ulcerations

After one year of preliminary studies, Vercauteren started a PhD investigating the possible correlation between pulse fishing and (the rise) in skin ulceration in fish in 2016. A detailed project description can be found in Appendix 2 'ongoing and future research'.

The first workpackage of her PhD consists of sampling of wild dab and the construction of the monitoring database which will continue until the end of 2018. So far, an association of skin ulceration with temperature and salinity was found. This corresponds to different previously conducted studies. Furthermore, two bacterial species, *V. tapetis* and *A. salmonicida*, were isolated in virtually pure cultures from skin ulcers in dab. These findings indicate a potential involvement of these microorganisms in the development of skin ulcerations. The results of this campaign are already accepted for publication in a peer-reviewed journal (Vercauteren et al. 2017, Journal of Fish Diseases). Data of three years of monitoring will be thoroughly analysed at the end of 2018, when the planned monitoring campaigns are completed.

The goal of the 2nd workpackage was the development of a skin ulceration model and study the importance of previous trauma to the skin. Therefore these two previously discovered bacteria were used to set up an infection model to induce skin ulceration(s) under controlled laboratory circumstances. Two experiments in the laboratory using *V. tapetis* and *A. salmonicida,* were successfully completed. The first results indicate that ulcerations appeared to be worse in the area where scales were removed and this both on the pigmented and non-pigmented side, implying the facilitating role of previous skin damage in skin ulceration development. Furthermore, these descaled areas showed significantly more severe lesions in the group inoculated with one of the bacteria under study compared to the control group, pointing towards a contributing role of the inoculated microorganisms. Various confounding factors including sex, age, condition, length were analysed and proven to have no significant impact on the results. The manuscripts discussing the final results of these experiments will be submitted soon. Bacteriological examination of the ulcerations is ongoing to verify that the isolates retrieved from the skin ulcers belong to *V. tapetis* or *A. salmonicida*, including histological and immunohistochemical examination of the lesion to confirm that ulcerations are similar to those naturally occurring. The submission of the A1 publication reporting the final results is due this year. Futhermore, a study to evaluate the possibly contributing role of various environmental and anthropogenic factors in the development of skin ulcerations in dab and a final study of the impact of skin ulcerations on the general health status of dab are planned in the next year using the previously pinpointed experimental infection model.

4.4 Effects of the *Ensis* pulse field

4.4.1 Before-after-control impact study

An extensive study by Woolmer et al. (2011) summarises the results of experimental work carried out as part of "Design and Trials of Electrofishing System for Razorclams – FIFG 57437". The aim of the project was to design and trial methods of harvesting Ensis spp. using electrical stimulus with the intention of providing a more environmentally benign alternative to existing hydraulic and toothed dredges. The simple electrofishing gear used in this project (Figure 6.6) employed a voltage of 30 v DC with a current of 140 A. This produced a maximum electrical field strength of 50 vm-1 between the electrodes; a voltage at which guidelines consider it is safe for divers to come into direct contact with the electrodes.

A field experiment was developed and implemented to determine negative effects on non-target invertebrate macrofauna, and epifauna including fish species. A modified BACI (before-after-control-impact) design established a series of four 200 m x 100 m experimental areas containing 50 m x 100 m fished (treatment) or control sectors in Carmarthen Bay south Wales (Figure 6.7). The electrofising gear was used in the in the „treatment" areas by fly dragging in order to simulate a commercial fishing operation. In order to determine whether the electrofishing gear had negative effects on non-target macrofauna a series of macrofaunal grab samples were collected from each sample sub-sector before fishing, and then variously at intervals up to 28 days post-fishing. Epifaunal species were sampled by divers surveying transects before and after electrofishing treatments. Throughout the experimental work observations and video footage was reviewed for visual effects on species and changes in behaviour. The results of this study demonstrate that the effects of electrofishing gear employing relatively low DC voltage and amperage can be effectively used in the harvest of Ensis spp. without serious negative effects on the epifaunal and macrofaunal benthic community. Given the commonly reported negative effects of alternative approaches such as hydraulic and toothed dredges the results of this study suggest that further development work is warranted in order to develop less disturbing fishing gears, both for Ensis spp. and for other species.

4.4.2 Behaviour and survival.

In addition to this study, Murray et al. (2016) conducted a series of tank and in situ experiments with Ensis pulse fields. The authors state that species affected by the Ensis fishery will be exposed to an electric field for far longer than previous electrofishing studies have considered: continuously for over a minute, compared to several one second pulses in the Crangon fishery and 2 s exposures to the pulses used in sole fishery.

The experiments consisted of tank trials to determine the properties of the electric field generated by electrofishing equipment and to monitor the survival of individuals of the target species, *E. siliqua*, and three non-target species: the common starfish *Asterias rubens*, the hermit crab *Pagurus bernhardus* and the surf clam *Spisula solida*. Further direct observations were conducted using inshore fishing vessels to monitor recovery rates in situ of target species, non-target invertebrates and the sandeel, *Ammodytes marinus*. These were carried out using two commercial fishing vessels at two sites in Scotland: the FV Nicola Jane in Loch Nevis (Westcoast) and the FV Ensis in East Fife (East coast). An electrical stimulus was applied to the seabed, replicating commercial electrofishing practice. Video transects were also recorded to examine physical impacts of the electric rig on the seabed.

Electrofishing for Ensis spp. elicited a strong behavioural response from the target species and several non-target species, notably fish and crustaceans. The rapid and consistent emergent responses of razor clams both in tank and sea trials indicate that electrofishing is extremely efficient with little opportunity for marketable razor clams to escape capture once the track of a pair of electrodes passes them. Recovery time in the non-target species was shorter than for Ensis spp. in both sea trials and tanks trials, with individuals resuming apparently normal behavioural patterns after a maximum of 8 min8 s.

Overall, by-catch mortality was low, with only two incidences of mortality in the tank experiments. Tank trials involving *Ensis* and three other non-target species (Atlantic surf clam, *Spisula solida*; Sea star, *Asterias rubens* and Hermit crab, *Pagurus bernhardus*) were unable to reveal a significant difference in survival when comparing control against electrically fished individuals.

Whilst no direct observations of non-target species being predated were made, Ensis which were slow to recover and were observed being predated upon by fish (gobies) and crabs and in East Fife eider ducks (*Somateria mollissima*) have been observed following fishing vessels and diving between the electrodes to catch emerging Ensis. Predation will, however, be offset the by lack of by-catch, in comparison to the traditional alternative dredge methods with can result in 32 kg of by-catch, and 10 kg of displaced benthic invertebrates, to land 10 kg of razor clams.

Finally, there was no evidence of chemicals being released into the seawater, as chloride compounds were not found to evolve from the AC electrodes during the tank trials, nor was there any indication of erosion of the electrodes as has been reported in DC systems.

4.5 Conclusion

4.5.1 Direct mortality imposed by electrical stimulation

None of the experimental studies conducted showed that organisms exposed to pulse stimuli died from the exposure. The few incidences of mortality observed did not seem to be directly related to the electrical stimulation. The most severe effects observed are the spinal fractures and the internal bleeding through the rupture of the blood vessels. It seems likely that these lesions will impair their normal behaviour and will increase the risk of mortality for fish that are exposed to the pulse stimulus but escape from being caught. The experiment of de Haan et al (2016) showed that cod that are small enough to escape through the mesh did not develop vertebral fractures. The field strength generated outside of the path of a sole pulse trawl quickly reduces to values below 17 V/m, which is well below the critical field strength (37 V/m) above which fractures occur (de Haan et al., 2016). Although cod in the discard size range (17–35 cm) may develop vertebral injuries - spinal fractures were observed in cod of 20, 23, 27, and 55 cm in the catch of commercial pulse trawlers (van Marlen et al., 2014) - we do not expect that pulse trawling leads to additional mortality in discarded cod because the survival rate of cod discards in bottom trawl fisheries is low (Lindeboom and de Groot, 1998; Depestele et al., 2014). The fractures invoked by electrical stimulation do not contribute to the fishing mortality rate as they are restricted to the cod that are killed by any fisheries activity . The fractures invoked by electrical stimulation, however, will affect the economic revenue as the fractured cod will fetch a lower price, and may be relevant in terms of animal welfare.

In young life stages of cod exposed to the *Crangon* pulse, reduced survival was observed in two larval stages exposed 2 and 26 days post hatching. One embryonic stage exposed 3 days before hatching (18 days post fertilization) showed a slightly delayed developmental rate during the hatching process. This reduced survival was absent in sole larvae exposed at the same developmental stages (Desender et al., 2017b; 2018).

4.5.2 Electric-induced injuries

The only conclusively proven electrically-induced injuries so far are the spinal injuries observed (in gadoid species) after exposure to the cramp pulse for sole. No fractures or other major injuries have been observed in fish exposed to the shrimp pulse. The sensitivity to develop fractures in response to a pulse stimulus differ between fish species. Samples taken from the commercial fishery indicates that cod shows the highest incidence rate (about 10%), followed by whiting (about 2%). Sea bass and several flatfish species appear to be non-sensitive and do not developed vertebral fractures. These results are only indicative and needs further study as the number of observations is too low to draw any firm conclusion.

The experiments indicate that cod exposed to a field strength of less than 37 V/m, typical for the maximum field strength that is measured outside the array of electrodes, will unlikely develop a vertebral fracture. The experiments also indicate that small cod, that are small enough to escape through the 80 mm meshes of the codend, do not develop fractures. This indicates that only cod that are located within the trawl track run the risk of being exposed to a field strength that may invoke a vertebral fracture. In particular the cod that are located in close range to the electrodes are prone to develop a vertebral fracture. The size effect as well as the inter-stock variability on the fracture probability needs further investigation. It should be noted however that fewer cod are captured captured by pulse trawls compared to beam trawl (van Marlen et al., 2014) which can be attributed to the lower fishing speed, which will result in a lower total bycatch mortality for this species.

4.5.3 Sublethal effects

How the exposure of organisms to low field strength will affect their functioning is unknown and further research on the critical field strength at which the functioning is affected is required. We expect that the threshold levels for the sub-lethal effects will be species specific. The sub-lethal effects will further be affected by the frequency of exposure which can be estimated from the analysis of VMS and logbook information. A recent analysis of the trawling intensity at a resolution of 1x1 minute grid cells (about 2 km^2) showed trawling intensities between 0.1 and 5 times per year with a modal trawling intensity close to 1. Less than 5% of the surface area of the North Sea was trawled more than 5 times per year (Eigaard et al. 2017). These values refer to all bottom trawling fleet and are given as an upper level. The number of times that an organism will be exposed to an electrical stimulation per year is determined by the ratio of the width of the electric field exceeding the critical threshold level and the width of the pulse trawl and the annual trawling frequency. If low threshold levels apply, the exposure frequency will be higher.

5 Physical impact of pulse trawls

5.1 General

It is widely acknowledged that beam trawlers contribute extensively to the physical impact on the seabed in the southern North Sea (Jennings et al., 2012; ICES, 2014) and that beam trawling can affect benthic invertebrate and demersal fish communities (Lindeboom and de Groot, 1998; Kaiser et al., 2006; Polet and Depestele, 2010; van Denderen et al., 2014). The penetration into the seabed can be up to 8 cm, depending on beam trawl weight, towing speed, and sediment type (Paschen et al., 2000).

In recent years, some 80 Dutch flatfish directed beam trawlers have replaced tickler chains and their mechanical stimulus to raise fish into the path of the gear with electrodes and their electrical stimulus (Soetaert et al., 2013; van Marlen et al., 2014). These gears have greatly reduced fuel costs (van Marlen et al., 2014) and, it is claimed that, have also reduced benthic impacts (Soetaert et al., 2014).

Extensive studies have addressed the concern of seafloor disturbance by towed fishing gears, specifically of beam trawling. However, a few studies, have addressed the difference of seafloor disturbance between traditional trawls, such as beam trawls and dredges, and commercially used pulse gear targeting shrimps, sole and Ensis. An overview of the latter is given in the chapters below. Most of this work is still on-going or planned.

5.2 Physical impact of the shrimp pulse trawl

The opinions on the nature and consequences of the effects of shrimp trawls on the habitat are often very diverse and contradictory. Some studies indicate clear effects, while others regard this trawl as a relatively light gear with a limited impact (Rumohr et al. 1994; Vorberg 1997).

Disturbance of the seabed becomes important when it affects the habitat of the benthic population that supports it. Changes in epibenthic communities are usually most apparent when sessile epibenthic species decline or disappear (Riesen and Reise 1982). Also for the Wadden Sea, the shrimp fishing area par excellence, this is illustrated by the relatively sudden decline in a number of key species and habitats they form. The main species are the oyster (*Ostrea edulis*), seagrass beds (*Zostera marina*), the Sabellaria reefs (*Sabellaria spinulosa*) and the sea cypress fields (*Sertularia cupressina*). The effect of the shrimp fishery in the decline of these organisms in the Wadden Sea is under discussion.

The coastal zone where most of the shrimp fisheries in the North Sea is carried out, is characterized by a relatively dynamic environment. In addition to the fisheries there are also other processes that cause disturbance of the seafloor. The question is whether the fishing pressure causes effects that are distinguishable from other disturbance. As an analysis of the relationship between beam trawling and benthic fauna in the North Sea revealed (van Denderen et al. 2014), there was only a negative relationship with fishing effort in the relatively deeper areas further away from the coast with finer sediment and not in the shallower, closer to the coastal areas with coarser sediment. Even in the wind farm Egmond no effect could be demonstrated on the soil fauna after an absence of trawling for 5 years (Bergman et al. 2014).

Only one recent study has focused on the physical disturbance of the habitat by the shrimp beam trawl together with the shrimp pulse trawl. This study was carried out in the Benthis project by ILVO and IMARES in 2015. No report is available yet. However, studies have shown that the bottom impact of pulse trawlers targeting shrimp is smaller than using traditional beam trawl gear. Indeed, pulse trawls use a straight bobbin rope to enable a good rigging of the electrodes. On one hand this bobbin rope is much shorter and contains less bobbins (for example 12 for a pulse trawl vs 36 for a traditional trawl in the Netherlands) and on the other hand this guarantees a better orientation of the bobbins to allow them to roll properly over the seafloor instead of shearing over it as most bobbins close to the trawl shoes of a traditional gear do. This differences are illustrated below and will reduce the impact on both the amount of area touched by the fishing gear as well as the penetration depth.

Figure 5.1: Front view (top) and details of the bobbin rope (bottom) of a traditional trawl with 36 bobbins in a u-shaped bobbin rope (400 kg, left) and a pulse trawl with 11 bobbins in a straight configuration (150 kg inclusive of electrodes, right) illustrating the difference in mechanical stimulation and the size and orientation of escape opportunities between the bobbins for by-catch species

5.3 Physical impact of the flatfish pulse trawl

The physical effects of beam trawls rigged with tickler chains are expected to be high due the close contact with the seabed (Suuronen et al., 2012) and the infaunal benthic impact they cause (e.g. Lindeboom and de Groot, 1998; Kaiser et al., 2006). Surprisingly, only a few (grey literature) studies have quantified the *physical* effects of beam trawling. These studies focused on (i) changes in seabed bathymetry estimated from boxcore sampling or physical modelling of individual gear components (Paschen et al., 2000), and they also investigated (ii) compaction and (iii) changes in sediment composition by RoxAnn surveys, sidescan sonar imagery, and by estimating the pressure of individual gear components on the seabed (Fonteyne, 1994; Leth and Kuijpers, 1996; Lindeboom and de Groot, 1998; Fonteyne, 2000).

Depestele et al., (2015) and Depestele et al., (2018) present a direct comparison in seafloor disturbance between the beam trawl fishing for flatfish and the pulse trawl fishing for flatfish in sandy and muddy areas. Sea trials were conducted in the FP7-BENTHIS project in 2013 on a nearshore fishing ground in the southern North Sea. A second series of sea trials were carried out in the Frisian Front area in the Central North Sea in 2014.

The first trials are described in Depestele et al. (2015) and investigated the geotechnical and hydrodynamic impact of a traditional tickler-chain beam trawl (hereafter called "tickler-chain trawl") and a "Delmeco" electrical pulse beam trawl (hereafter called "pulse trawl"). The geotechnical investigations focus on measuring the alteration to the seabed bathymetry using a Kongsberg EM2040 Multi-Beam EchoSounder (MBES) in conjunction with the fishing vessels' global positioning system (GPS). Not only does this approach permit the detection of trawl marks in a similar way to the study of Malik and Mayer (2007) but it also allows the quantification of vertical changes in sediment bathymetry before and after trawling. In particular, the alteration to seabed bathymetry is investigated for (i) a single pass of a tickler-chain beam trawl, (ii) multiple passages of a tickler-chain beam trawl, and (iii) pulse beam trawl.

The hydrodynamic investigations focus on the quantity and particle size distribution of sediment mobilized into the water column behind (i) a tickler-chain trawl and (ii) a pulse trawl. An optical particle size analyser (Sequoia LISST 100X) was mounted on a sledge which was positioned behind the trawl and towed directly from the beam of each beam trawl. This approach has been used by O'Neill et al., (2013a, b) to measure the sediment mobilized behind different gear components, scallop dredges, trawl doors, and roller clumps.

The experimental results were compared with the predictions of the numerical models of Ivanovic´ et al., (2011) and Esmaeili and Ivanovic´ (2014) predicting the penetration depth of gear elements into soft sediments and with the empirical model of O'Neill and Summerbell (2011) which relates the hydrodynamic drag of a gear element to the sediment mobilized in its wake. It was demonstrated how these methods can be used to quantify and assess the physical impacts on soft sediments and highlight the need to distinguish between alteration of seabed bathymetry and depth of penetration.

Detailed materials, methods and results are given in Depestele et al. (2015). A view of the groundgear of both trawls is given in Figure 5.2.

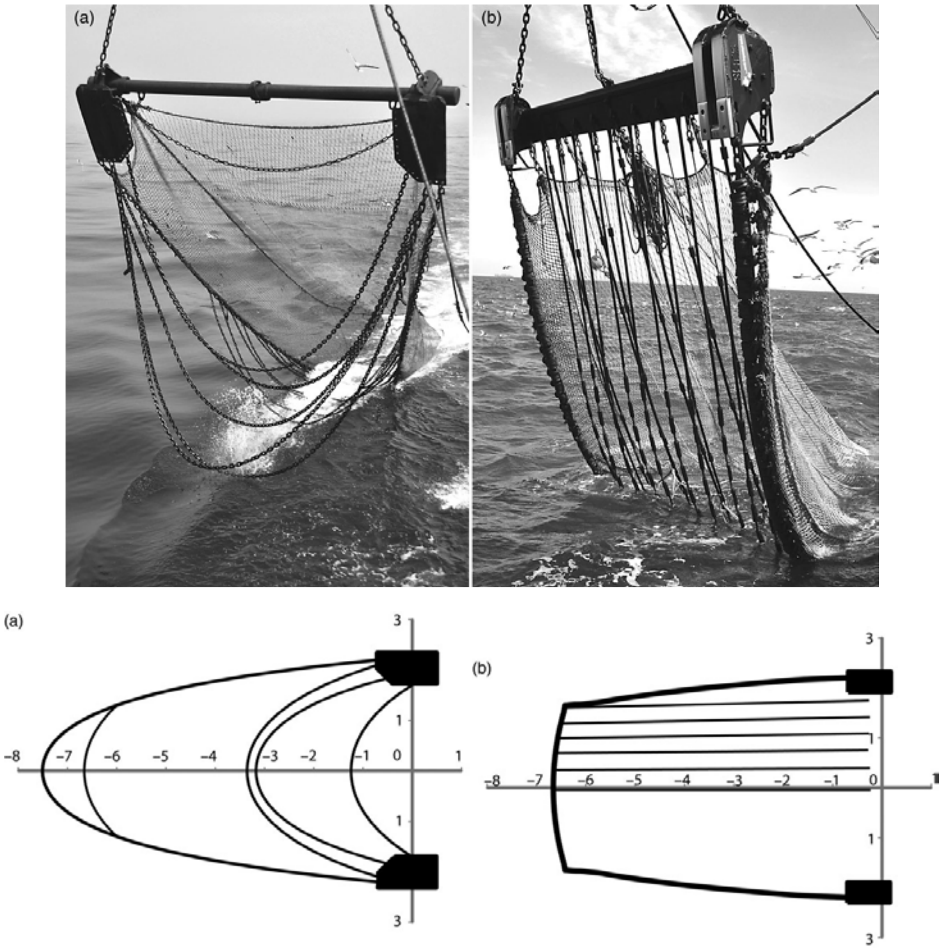


Figure 5.2: Gear components in contact with the seabed for the tickler-chain (a) and pulse (b) trawl. Tickler chains with a chain link diameter of 28 mmare attached to the trawl shoes, whereas the tickler chains of 11–16 mm are attached to the groundgear (only one is shown).

The results indicate that the seabed bathymetry changes between 1 and 2 cm after one passage of the trawl and that it is further increased by higher trawling frequencies. Furthermore, the results suggest that the alteration following the passage of the conventional trawl is greater than that following the pulse trawl passage. Both gears penetrate the seabed to some extent, but the range of penetration depths of the tickler chain is larger, and deeper penetrations depths are more likely to occur than with the pulse. There was no difference in the quantity of sediment mobilized in the wake of these two gears; however, the numerical model introduced in this study predicted that the tickler-chain trawl penetrates the seabed more deeply than the pulse gear. Hence, greater alteration to the seabed bathymetry by the tickler-chain beam trawl is likely to be a result of its greater penetration.

It has to be noted that the difference in seabed disturbance between the tickler and pulse gear is quite conservative. This is because the experimental tickler gear was a 'light type' (1.065 kg) in the group of tickler chain beam trawls and the experimental pulse gear was a 'heavy type' (2.500 kg) in the group of flatfish pulse trawls.

The second fishing experiment took place in the offshore Frisian Front location which exhibited less dynamic and muddier conditions compared to the location described in

Depestele et al. (2016). This second set of trials also used 'SumWing' gears rigged with tickler chains to be compared HFK 'PulseWing' gears.

The differences in physical effect between a sumwing with tickler chains and electrodes (pulsewing) is illustrated in Figure X1 and X2 below on the basis of backscatter values, which reflect the intensity (strength) of the reflection of the acoustic signals on the seabed. The discrepancies in values inside and outside the trawl track are more pronounced for the trawl with tickler chains than those for the pulse trawl, but for both gears the discrepancies disappear within 3 days in muddy habitats.

Bathymetrical measurements using MBES showed that the traditional beam trawl tracks were consistently and uniformly deepened to 1.5 cm depth in contrast to the 0.7 cm deepening that followed pulse trawling. While the overall impact of the tickler chain trawl was greater, due to the heterogenous impact of the pulse trawl (some parts of the pulse gear creates deeper furrows in the seafloor surface), a minority (20%) of the MBES measurements resulted in a deeper level of bathymetrical alteration than that of the tickler chain trawl. MBES backscatter strength analysis suggested that tickler chian trawls (3.11 dB) also flattened seabed roughness significantly more than the PulseWing trawls (2.37 dB). The reduced pulse trawling impacts allowed a faster re-establishment of the oxygenated layer (based on SPI) and micro-topography in contrast to traditional beam trawling (based on MBES backscatter).

The penetration depth was estimated by measuring the depth of the disturbance layer (SPI) and by modelling the erosion of the surficial sediments due to sediment mobilisation in the wake of the gear (traditional beam = 0.6 cm; pulse trawl = 0.8 cm). The traditional beam trawl showed a deeper penetration depth (mean = 4 cm, SD= 0.9 cm) than the pulse trawls mean = 1.8 cm, SD = 0.8). Traditional beam trawls homogenized the sediment at a greater depth (3.4 cm, 0.9 cm) and removed a higher proportion of the oxygenated layer than pulse trawls (1 cm, 0.8 cm) (Figure 9.1). Particle size analysis suggested that pulse trawling caused a coarsening trend towards the top layers (winnowing effect), while traditional beam trawls exhibited this and additionally injected finer particles into the deeper sediment layers (~4 cm depth).

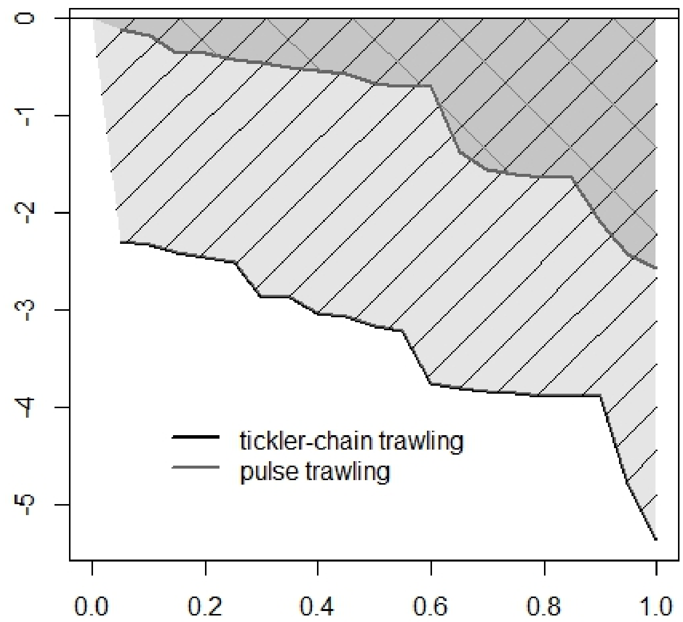


Figure 5.3. Depth of disturbance (cm) following traditional beam (tickler-chain) and pulse trawling based on the assessment SPI images. (/// = tickler chain; \ \ \ \=pulse trawl). Depestele et al (2018).

The experimental study of the mechanical disturbance of the seafloor by the tickler chian trawl and the pulse trawls showed that the replacement of tickler chains by electrodes reduce the average depth of mechanical disturbance (penetration) by more than 50% in sandy mud.

5.4 Physical impact of the Ensis pulse trawl

The study by Woolmer et al. (2011) does not address the issue of physical disturbance of the habitat but does state that the intense physical disturbance by the conventional harvesting gear for Ensis such as the hydraulic and toothed dredges makes further investigations in the less intrusive Ensis pulse gear worthwhile investigating. Murray et al. (2016) reported the physical impact of the fishing gear on the seabed was well within the range expected by natural disturbance and presented a visibly lower impact on the environment than current dredge methods.

5.5 Conclusion

Although the different types of pulse- and electrotrawls differ greatly in electric stimulation and rigging used, they all replace some part to almost all of the mechanical stimulation by electric stimulation which results each time in a reduction of the physical impact of the fishing gear. The pulse trawl targeting shrimp have less bobbins compared to traditional beam trawls reducing the area touched by the fishing gear. The pulse trawl targeting flatfish still has a ground rope covering the entire width of the trawl to scope up fish, however it was shown that the penetration depth of this ground rope and subsequent sediment resuspension are smaller than theconventional beam trawl with tickler chains. Moreover, these trawls fish slower which will also account for a ±10-30% decrease in the area swept by these trawls. Finally, the electrotrawls targeting *ensis* sp. with only flat steel bars touching the seafloor replace dredges which are considered to be amongst the fishing gears with the highest physical impact. Therefore, it can concluded that the physical impact of vessels using electric stimulation will be smaller than that of conventional fishing gears targeting the same species.

6 Impact of pulsetrawls on biogeochemistry

In order to fully assess the impact of pulse fishing on the benthic ecosystem, the potential consequences to biogeochemistry and to the functioning of benthic organisms need to be analysed. As changes to biogeochemical dynamics may affect benthic pelagic coupling and primary production in the water column, these effects may extend beyond the benthic region (Nedwell et al., 1993). In addition to the general release and consumption of nutrients and oxygen, the ability for organisms to facilitate changes to these processes through activities such as bioturbation can have a substantial effect on biogeochemical characteristics (Braeckman et al., 2010). Therefore, the possible sub-lethal impacts of electrical stimulation on the functioning of benthic organisms is of particular importance. Possible chemical changes due to electrolysis is also a subject of concern due to the potentially harmful substances which may be released into marine habitats (Soetaert et al., 2015).

6.1 Field experiments

In June 2017, a field experiment assessing the biogeochemical effects of electric pulse fishing took place in the Frisian Front area of the North Sea (Tiano *et al*., 2019). The study compared the impact of both electric pulse fishing and traditional beam trawl methods with tickler chains. Benthic landers were deployed and box core sediment samples were collected to measure rates of oxygen consumption and nutrient fluxes in fished and unfished areas. Traditional beam trawling produced a larger and more consistent impact on sediment oxygen consumption, oxygen micro-profiles and sediment surface chlorophyll levels. Pulse trawling, on average, had lower yet more variable effects for these measurements.

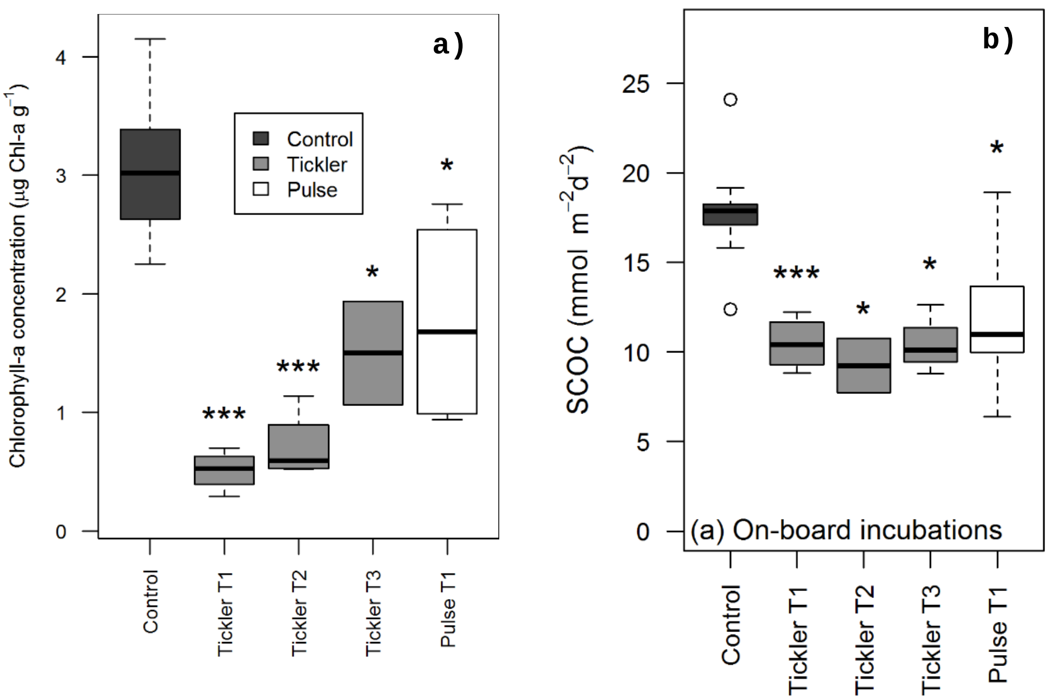


*Figure 6.1. Comparison for a) chlorophyll a concentrations and b) sediment oxygen consumption (SCOC) in control, tickler chain trawled (tickler T1 - T3), and pulse trawled (Pulse T1) sediments. *p < 0.05; ***p < 0.001 significant differences compared to control samples. Tiano et al (2019).*

6.2 Discussion

Research on biological fuel cells and 'cable bacteria' show that electrical currents in the sediment have the ability to create a significant impact on sediment biogeochemistry (Nielsen *et al*., 2010). A unidirectional current can cause the mobilization of porewater ions and can facilitate the consumption of oxygen in marine sediments (Risgaard-Petersen *et al*., 2012). There is currently no evidence, however, linking electrical pulses used in the flatfish fishery to changes in biogeochemical characteristics. This may be due to the bi-directional flow of electrons limiting impacts from chemical reactions or electrolysis. Moreover, the current research suggests that the mechanical impact from both pulse trawling and traditional beam trawling has a much greater influence on biogeochemical dynamics than effects from electricity (Tiano *et al*. in prep).

6.3 Conclusion

The transition from the traditional beam trawl to the pulse trawl resulted in a reduced mechanical impact on the seafloor which will have reduced the impact on the benthic ecosystem due to the smaller footprint (surface are trawled), lower trawling intensity, and lower penetration depth (depth of disturbance). According to a population dynamic model PD2, this will reduce the impact on the equilibrium benthic biomass by 50%. Relatively little is known about the potential adverse effect of electrical stimulation on the benthos and functioning of the benthic ecosystem. The preliminary results of the laboratory and field experiments do not reveal any consistent impact of electrical stimulation on benthic biogeochemical functioning in contrast to the mechanical disturbance related to sediment mixing and sediment resuspension.

7 Viability and survival of the catch

7.1 Mechanical impact of pulse trawls

Although the primary stimulator are electric pulses, fish caught with pulse trawls still endure several mechanical impacts in a pulse trawl which, apart from the electric stimulus, will affect their viability and survival chances when escaping the net or after discarding. These mechanical impacts can be encountered in different stages of the process. It starts upon first contact with the fishing gear, where animals may be hit by those parts of the trawl making contact with the sediment such as the trawl shoes, the tickler chains, chain matrices or bobbin rope, the electrodes or the footrope (1). Afterwards, fish pass through the net and eventually end in the codend, where they will not only make direct and long lasting contact with the net material but also with fish, hard bodied invertebrates such as sea urchins and crabs, stones, litter and passing clouds of suspended sediment (2), all of which may cause external (scale loss, open wounds, loss of mucus layer, …) or internal (bruisings, bleedings…) lesions. Note that also fish escaping through the meshes may be exposed to these kinds of damage. Finally, the net is hauled to the surface, the catch will be emptied on deck and sorted by the crew (3) which exposes the fish to stressors such as barotrauma, thermotrauma and possible suffocation but also to additional mechanical impact before and during the sorting process causing more external and internal lesions. When comparing pulse trawling and conventional beam trawling, a lower physical impact on the animal is suggested in every stage of the process (excluding any electrical effect).

During the initial stimulation in front of the ground rope, the mechanical damage inflicted on animals will most likely be lower in a pulse trawl because the tickler chains are removed and the fishing speed is reduced up to 30% from 6-7 kn to 4-5 kn. Although this may result in less incidents of external damage, it is unclear how this relates to the potential impact of the additional electrical stimulus in a pulse trawl. When comparing the mechanical damage encountered in the net during the fishing process, it can be concluded that this will be lower for the pulse trawl. Firstly, the lower fishing speed as well as the reduced sediment re-suspension (Depestele et al., 2016) will favour selectivity and reduce the pressure on and possible sandblasting of the catch. Secondly, less organisms will be impacted since the smaller surface area fished and higher selectivity will reduce the bycatch. Thirdly, the lower volumes of benthos and stones (up to 80% according to van Marlen et al., 2014) will reduce external damage and crushing of the animals in the cod-end. For the same reason, the mechanical impact experienced in the last stage, the catch processing on deck, will also be smaller. Due to the smaller catch volumes, the catch in the hoppers will be less compacted and the processing will be faster resulting in a shorter air exposure which is also beneficial for the survival of the discards (Uhlmann et al., 2016; van der Reijden et al., 2017). Therefore, it may be concluded that it is most likely that the overall mechanical impact on the animal as caused by the fishing gear will be smaller when caught by a pulse trawl, which is confirmed by the higher reflex-impairment response in flatfish discards caught by beam trawls (Uhlman et al., 2016).

7.2 Discard survival in pulse trawls targeting sole

The EU landing obligation (LO)[2] requires fishers to land all marketable and undersized fish that are subjected to landing restrictions (quota). With scientific evidence for high survival after discarding fishers are allowed to discard those species, while other species under quota restrictions obligatory to land. This LO exemption chances of survival after discarding of several species were studied for multiple fisheries.

The aim of an elaborate survival study for pulse trawls (van Marlen et al., 2016) was to determine the average survival rate of sole, plaice and dab discards in commercial pulse trawl fishery of the Dutch fleet. This was executed by monitoring fish collected from catches for a certain period of time (21 days on average) to observe fisheries induced mortality. A second goal of this study was to investigate whether a vitality score can be used as a proxy of the survival chance. The vitality of each fish was assessed individually by scoring external damages and the impairment of reflexes, and related to the observed survival time. A third goal was to study the variation in discard survival estimates by looking into correlations between survival estimates and environmental or other potential factors.

In total eight experimental trips were carried out on board two pulse vessels in the North Sea in the period between November 2014 and October 2015, three of which were primarily dedicated to comparing techniques for improving survival. Live fish from the catch were collected from different locations in the processing line and at different times. All sampled fish were scored for external damages and reflex impairment, then tagged to enable individual monitoring over time. To observe and record the survival times, these fish were stored in a specially developed system of tanks filled with continuously refreshed sea water. Except for the first trip, all experimental trips were done with three of such tank systems. The tank systems were designed with restrictions in dimensions and weight to enable transport from the vessels to the IMARES laboratory in Yerseke, the Netherlands and monitor survival over an extended period of time. During storage on board fresh sea water was continuously supplied. During transportation the circulation of sea water was maintained and air supplied. Fish status was checked and dead fishes were removed daily during the monitoring period of some three weeks. To distinguish between fisheries induced mortality and handling induced mortality, control fish were used. These control fish were caught using a small vessel operating a shrimp trawl in short tows at low speed previous to the survival experiments and were treated in exactly the same way as fish from the catch.

[2] https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en

The result of the project showed that the average survival rates of discard sole (as determined after a monitoring period of 21 days on average) on the vessels fishing with a pulsewing (12 m width) and a commercial towing duration (~125 minutes) varied between 8% and 48% over 6 trips (n=226), with an average of 29% [95 CI: 11 - 19%] over all trips. For short hauls (~60 minutes) the overall survival rate was higher (24% - 59%) with an average of 41%. The overall survival rates of discard plaice on the pulse vessel taken from commercial hauls of ~2 hours was assessed 7 trips (n=349) and varied between 4% and 28% per trip with an average of 15% [95% CI: 11-19%]. Using a short tow duration (~60 minutes) increased this percentage, with an average of 39%. Dab was sampled during one trip on board a pulse vessel with an average survival of 15% (n=226).

Sole control fish showed good survival rates (~85%) in our experiment. Plaice controls suffered mortality a couple of days after arrival at the laboratory in Yerseke, around day 12. Mortality of control fish is undesirable and may lead to discussions about the accuracy and reliability of the observed survival rates. After trip eight, a Vibrio infection in the tank system affected mortality in the control and experimental fish. However, by right censuring these data, possible infection effects are excluded.

The results indicate that the overall discard survival rates are correlated with fish vitality. Vitality was measured in two distinct ways; by using a damage classification of A, B, C, and D, comparable with earlier survival research and as a summation of present damage scores and reflex impairment scores, divided by the total number scored damages and reflexes. Both showed a relation with the survival rate of discard plaice. Too few data were available for the species dab and sole to find a good correlation. However, the data suggests that a similar relation exists for sole discard survival. To confirm this a relation, more data should be collected, in which external factors are taken into account.

It was concluded (van Marlen et al., 2016) that the overall discard survival rate varied considerably between the trips, however, the conditions also varied to a great extent between trips. It should be noted that a full factorial design, in which all (potential) factors are tested individually was not made for this study. Such a design was practically not feasible, as multiple factors could not be controlled (such as weather), while other factors are very coherent (such as fishing location, and fishing depth), and because of limitations in resources only a relatively small number of trips could be carried out. As a result only a first explorative analysis was done to identify potential, influential factors. From this explorative analysis, it seems that water temperature, towing duration, fishing depth and vessel are factors that are highly correlated with discard survival rates, but a full predictive model was not tested so far. Such a model could lead to better knowledge of the various factors causing the mortality of the fish, and hence, give insight in adjustments that will increase discard survival rates.

Next to the study described above, a plaice discard survival study was performed in Belgium in 2015. Both the Dutch and Belgian datasets were merged and analyzed together. In total six different fishing vessels were included in the data, but for comparison with pulse trawls only three vessels were selected: two pulsewings (NL) and one sumwing using tickler chains (B). The width of the gear for those vessels was 12 m and engine power was around 1470kW (GO31, GO23, Z483). In comparison with survival estimates for plaice discards from pulse trawls, the merged dataset showed relatively lower survival estimates for comparable (in towing duration, fishing depth, vessel and gear size) conventional beam trawl fishing gear with thickler chains. Both damage class and vitality score appeared to be good proxies for survival. Haul duration was an important factor affecting survival rate, with shorter hauls having higher survival rates in general.

8 Overview Updates

Table 9.1: Updates made in 2018 version.

Topic	Description	Old section	New section

9 References

Agricola, J.B. 1985. Experiments on electrical stimulation of flatfish in beam trawling during 1984. ICES CM 1985/B:36.21 pp.

Anon., 2016. De Belgische visserij 2015 – Aanvoer en besomming. Departement Landbouw en Visserij, Belgium. Depot no. D/2016/3241/140.

Bary, B.M. 1956. The effect of electric fields on marine fishes. Scotland Home Department 1, 32.

Batsleer, J., Rijnsdorp, A. D., Hamon, K. G., van Overzee, H. M. J. and Poos, J. J. 2016. Mixed fisheries management: is the ban on discarding likely to promote more selective and fuel efficient fishing in the Dutch flatfish fishery? Fisheries Research, 174: 118–128.

Blancheteau, M. 1967. Contribution to the study of taxis in interrupted and alternating currents. In Fishing with electricity, its application to biology and management, pp. 93-99. Ed. by R. Vibert. Fishing News London.

Breen, M., Howell, T. and Copland, P. 2011. A report on electrical fishing for razor clams (Ensis sp.) and its likely effects on the marine environment. Marine Scotland Science Report Volume 2 No 03. 120 pp.

Boonstra, G.P. 1979. Onderzoek naar de mogelijkheden van toepassing van elektrische visserij op garnalen en platvis 1968–1978. Visserijblad 32, 107–121.

Degrendele, K., De Mol, L., Roche, M., Depestele, J.. 2015. The use of high resolution multibeam surveys in the monitoring of the physical impact of sand extraction and beam trawling. Poster presented at the Shallow survey symposium (Plymouth, UK).

De Groot, S.J. and Boonstra, G.P. 1970. Preliminary notes on the development of an electrical tickler chain for sole (Solea solea L.). ICES report for the Gear and Behaviour Committee.

De Haan, D., van Marlen, B., Velzenboer, I., van der Heul, J. and van der Vis, H. 2009. The effect of pulse stimulation on biota - Research in relation to ICES advice - Effects on dogfish. ICES Document C105/09. 32 pp.

de Haan, D., Haenen, O., Chen, C., Hofman, H., van Es, Y., Burggraaf, D. and Blom, E. 2015. Pulse trawl fishing: The effects on dab (Limanda limanda). IMARES C171/14. 43 pp.

de Haan, D., Fosseidengen, J. E., Fjelldal, P. G., Burggraaf, D. and Rijnsdorp, A. D. 2016. Pulse trawl fishing: characteristics of the electrical stimulation and the effect on behaviour and injuries of Atlantic cod (Gadus morhua). ICES Journal of Marine Science. doi: 10.1093/icesjms/fsw018.

Delanghe, F. and Vanden Broucke, G. 1983. Electrische visserij op garnaal uitgevoerd met bordennet. Mededelingen van het Rijksstation voor Zeevisserij, Rijksstation voor Zeevisserij nr. 199-TZ/106. 22 pp.

Depestele, J., Ivanovic, A., Degrendele, K., Esmaeili, M., Polet, H., Roche, M., Summerbell, K., Teal, L., Vanelslander, B., and O'Neill, F., 2015. Measuring and assessing the physical impact of beam trawling. ICES Journal of Marine Science; doi:10.1093/icesjms/fsv056

Desender, M., Chiers, K., Polet, H., Verschueren, B., Saunders, J., Ampe, B., Mortensen, A., Puvanendran, V. and Decostere, A. 2016. Short-term effect of pulsed direct current on various species of adult fish and its implication in pulse trawling for brown shrimp in the North Sea. Fisheries Research. 179: 90-97.

Desender, M. Kaijura, S., Ampe, B., Dumoulin, L., Polet, H., Chiers, K. and A. Decostere. 2017a. Pulse trawling: Evaluating its impact on prey detection by small-spotted catshark (*Scyliorhinus canicula*). Journal of Experimental Marine Biology and Ecology 486: 336-343.

Desender, M., Decostere, A., Adriaens, D., Duchateau, L., Mortensen, A., Polet, H., Puvanendran, V., Verschueren, B. and Chiers, K. 2017b. Impact of pulsed direct current on embryonated eggs, larvae and young juveniles of Atlantic cod (Gadus morhua L.) and its implication in electrotrawling for Brown shrimp. Marine and Coastal Fisheries 9: 330-340 DOI: 10.1080/19425120.2017.1321592.

Desender, M., Dumoulin, L., Duchateau, L., Adriaens, D., Delbare, D., Polet, H., Chiers, K. and A. Decostere. 2018. Electrotrawling: The impact of pulsed direct current on early life stages of Sole (*Solea solea*). North American Journal of Fisheries Management. **https://doi.org/10.1002/nafm.10039**

Esmaeili, M., and Ivanovic´, A. 2014. Numerical modeling of fishing ground gear component on the seabed. Ocean Engineering, 91:316–328.

Fonteyne, R. 1994. Physical impact of a 4 m beam trawl. In Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea, pp. 21–58. Ed. by S. J. De Groot, and H. J. Lindeboom. NIOZ Rapport 1994–11, RIVO-DLO report CO26/94, 257 pp.

Eigaard, O. R., Marchal, P., Gislason, H., and Rijnsdorp, A. D. 2014. Technological Development and Fisheries Management. Reviews in Fisheries Science & Aquaculture, 22: 156-174.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., et al. 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science, 73: i27-i43.

Eigaard, O. R., Bastardie, F., Hintzen, N. T., Buhl-Mortensen, L., Buhl-Mortensen., P., Catarino, R., Dinesen,

G. E., et al. 2017 The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsw194.

Fonteyne, R. 2000. Physical impact of beam trawls on seabed sediments. In The Effects of Fishing on Non-Target Species and Habitats: Biological, Conservation and Socio-Economic Issues, pp. 15–36. Ed. by M. J. Kaiser, and S. J. de Groot. Fishing News Books, 399 pp.

Glorius, S., Craeymeersch, J., van der Hammen, T., Rippen, A., Cuperus, J., van der Weide, B., Steenbergen, J. and Tulp, I., 2015. Effecten van garnalenvisserij in Natura 2000 gebieden. IMARES report C013/15.

Horn, W. 1982. Fortschritte bei der Elektrifizierung von Baumkurren für den Plattfischfang. Informationen for die Fischwirtschaft 29, 76–77.

Horn, W. 1985. Fortsetzung der Versuche mit elektrifizierten Baumkurren. Fischerblatt 33, 40.

Houston, R.B. 1949. German commercial electrical fishing device. Special Scientific Report: Fish. US Fish and Wildlife Service 34, 1–4.

ICES. 2010. Report of the Workshop to Assess the Ecosystem Effects of Electric Pulse Trawls (WKPULSE), 24–26 February 2010. IJmuiden, the Netherlands. ICES CM 2010/SSGESST:01. 36 pp.

ICES (2012) Request from France to review the work of SGELECTRA and to provide an updated advice on electric pulse trawl. Special request, November 2012. Book 1.5.6.1.

ICES. 2014. Second Interim Report of the Working Group on Spatial Fisheries Data (WGSFD), 10–13 June 2014, ICES Headquarters, Copenhagen, Denmark. ICES CM 2014/SSGSUE:05. 102 pp.

ICES. 2016. Second Interim Report of the Working Group on Electrical Trawling (WGELECTRA), 10-12 November 2015, IJmuiden, the Netherlands. ICES CM 2015/SSGIEOM:29. 44 pp.

Ivanovic´, A., Neilson, R.D., and O'Neill, F. G. 2011. Modelling the physical impact of trawl components on the seabed and comparison with sea trials. Ocean Engineering, 38: 925–933.

Jennings, S., Lee, J., and Hiddink, J. G. 2012. Assessing fishery footprints and the trade-offs between landings value, habitat sensitivity, and fishing impacts to inform marine spatial planning and an ecosystem approach. ICES Journal of Marine Science, 69: 1053–1063.

Kaiser, M. J., Clarke, K. R., Hinz, H., Austen, M. C. V., Somerfield, P. J., and Karakassis, I. 2006. Global analysis and prediction of the response of benthic biota and habitats to fishing. Marine Ecology Progress Series, 311: 1–14.

Kratzer I. 2012. Pulse beam trawling vs. traditional beam trawling in German shrimp fishery: a comparative study. Master thesis, Universität Rostock, Germany.

Leth, J. O., and Kuijpers, A. 1996. Effects on the seabed sediment from beam trawling in the North Sea. ICES Annual Science Conference. ICES C.M.1996/Mini 3.

Lindeboom, H. J., and de Groot, S. J. 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. RIVO-DLO Report C003/98. 404 pp.

Mc Rae, E.D. and French, L.E. 1965. An experiment in electrical fishing with an electric field used as an adjunct to an otter trawl net. Commercial Fisheries Review 27, 1–11.

Murray, F., Copland, P., Boulcott, P., Robertson, M. and Bailey, N. 2016. Impacts of electrofishing for razor clams *(Ensis spp.*) on benthic fauna. Fisheries Research 174 (2016) 40–46.

Novotny, D.W. 1990. Electric fishing apparatus and electric fields. In: Fishing with Electricity, Applications in Fresh Water Fisheries Management. pp. 34-88. Cowx, I.G. and Lamarque, P. (eds.). Oxford, England: Fishing News Books.

O'Neill, F. G., and Summerbell, K. 2011. The mobilisation of sediment by demersal otter trawls. Marine Pollution Bulletin, 62: 1088–1097.

O'Neill, F. G., Simmons, S. M., Parsons, D. R., Best, J. L., Copland, P. J., Armstrong, F., Breen, M., et al. 2013a. Monitoring the generation and evolution of the sediment plume behind towed fishing gears using a multibeam echosounder. ICES Journal of Marine Science, 70: 892–903.

O'Neill, F. G., Robertson, M., Summerbell, K., Breen, M., and Robinson, L. A. 2013b. The mobilisation of sediment and benthic infauna by scallop dredges. Marine Environmental Research, 90: 104–112.

Paschen, M., Richter, U., and Ko¨pnick, W. 2000. Trawl Penetration in the Seabed (TRAPESE). Final report Contract No. 96–006. University of Rostock, Rostock, Germany. 150 pp.

Pease, N.L. and Seider, W.R. 1967. Development of the Electro-shrimp trawl system. Commercial Fisheries Review 29, 8–9.

Polet H., Delanghe F. and Verschoore R. 2005a. On electrical fishing for brown shrimp (Crangon crangon): I. Laboratory experiments. Fisheries Research 72: 1–12.

Polet H., Delanghe F. & Verschoore, R. 2005b. On electrical fishing for brown shrimp (Crangon crangon): II. Sea trials. Fisheries Research, 72: 13–27.

Polet, H. 2010. Electric Senses of Fish and Its Application in Marine Fisheries. In: He, P. 2010. Behavior of Marine Fish, Capture Process and Conservation Challenges. 1st Edition, May 2010. ISBN-10: 0-8138-1536-3; ISBN-13: 978-0-8138-1536-7 - John Wiley and Sons.

Polet, H., and Depestele, J. 2010. Impact assessment of the effects of a selected range of fishing gears in the North Sea. ILVO-report. Oostende, Belgium. 120 pp.

Rabaut, M., Guilini, K., Van Hoey, G., Vincx, M., Degraer, S., 2007. A bio-engineered soft-bottom environment: The impact of Lanice conchilega on the benthic species-specific densities and community structure. Est. , coast. and shelf sci. 75, 525-536.

Rasenberg, M., van Overzee, H., Quirijns, F., Warmerdam, M., van Os, B. and Rink, G. 2013. Monitoring catches in the pulse fishery Wageningen, IMARES: 59p.

Ribeiro, M., 2016. Fishing for a feeding frenzy: effect of shimp eam trawlin on the diet of Dab and Plaice in Lanice conchilega habitats. Master of Science in Marine Biodiversity and Conservation EMBC+ (Promotor: A. Vanreusel, Supervisors: J. Depestele; J. Derweduwen), Gent (Belgium).

Riesen W. & Reise K., 1982. Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgolander Meeresunters 35: 409-423

Rumohr H., Schomann H. & Kujawksi T. 1994. Environmental impact of bottom gears on benthic fauna in the German Bight. In: Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea. S. J. de Groot and H. J. Lindeboom (eds.). NIOZ-Rapport 1994-11, RIVO-DLO Report CO26/94,75–86

Schreer, J.F., Cooke, S.J. and Connors, K.B. 2004. Electrofishing-induced cardiac disturbance and injury in rainbow trout. Journal of Fish Biology 64, 996–1014.

Smaal, A.C. and Brummelhuis, E. 2005. Onderzoek naar mogelijke effecten van de pulskor op bodemdieren, RIVO C089/05, 15.

Snyder, D.E. 2003. Invited overview: conclusions from a review of electrofishing and its harmful effects on fish. Reviews in Fish Biology and Fisheries 13, 445–453.

Soetaert, M., Chiers, K., Duchateau, L., Polet, H., Verschueren, B., and Decostere, A. 2014. Determining the safety range of electrical pulses for two benthic invertebrates: brown shrimp (Crangon crangon L.) and ragworm (Alitta virens S.). ICES Journal of Marine Science 72(3): 973-980.

Soetaert, M., Decostere, A., Polet, H., Verschueren, B., and Chiers, K. 2015. "Electrotrawling: a promising alternative fishing technique warranting further exploration." Fish and Fisheries 16(1): 104-124.

Soetaert, M., Decostere, A., Verschueren, B., Saunders, J., Van Caelenberge, A., Puvanendran, V., Mortensen, A., Duchateau, L., Polet, H. and Chiers, K. 2016a. Side-effects of electrotrawling: Exploring the safe operating space for Dover sole (Solea solea L.) and Antlantic cod (Gadus morhua L.). Fisheries Research. 177: 95-103.

Soetaert, M., de Haan, D., Verschueren, B., Decostere, A., Puvanendran, V., Mortensen, A., Saunders, J., Van Caelenberge, A., Polet, H., Chiers, K., 2016b. Host determined variability in occurrence of electric-induced effects in Atlantic cod (*Gadus morhua* L.). Marine and Coastal Fisheries 8: 412-424.

Soetaert, M., Verschueren, B., Chiers, K. Duchateau, L., Polet, H., and Decostere, A. 2016c. Impact of repetitive electric exposures on brown shrimp (*Crangon crangon* L.). Marine and Coastal Fisheries 8: 404-411.

Soetaert, M., Lenoir, H. and Verschueren, B. 2016d. Reducing bycatch in beam trawls and electrotrawls with (electrified) benthos release panels. ICES Journal of Marine Science 73: 2370-2379.

Soetaert, M., Verschueren, B., Decostere, A., Saunders, J., Polet, H. and Chiers, K. 2018. No injuries in European Seabass tetanized by pulse stimulation used in electrotrawling. North American Journal of Fisheries Management 38:247–252.

Soetaert, M., Boute, P. G. and Beaumont, W. R. C. 2019. Guidelines for defining the use of electricity in marine electrotrawling. ICES Journal of Marine Science doi:10.1093/icesjms/fsz122.

Stappenbeck, F. 2017. Investigation of the reaction of brown shrimp on pulsed electric fields in order to optimise Crangon pulse trawls. Master thesis at Rostock University, 68 p.

STECF (2012) 39th Plenary report meeting report of the Scientific, Technical and Economic Commit-tee for Fisheries (STECF-PLEN-12-01). (eds. Casey, J. & Doerner, H.). Publications Office of the Eu-ropean Union, Luxembourg, EUR 25303 EN, JRC 70759. ISBN 978-92-79-24753-8. p. 112.

Stepputtis, D., Zajicek, P., Vorberg, R., Berkenhagen, J., and Kratzer, I. 2014. Ökologische und ökonomische Untersuchungen zum Nutzen einer Pulsbaumkurre in der deutschen Garnelenfischerei (Projektbericht); 231 pp.

Stewart, P.A.M. 1971. A review of Marine Electrical Fishing. IF Meeting, Bergen, 9 pp.

Stewart, P.A.M. 1972. An Exploratory Investigation into the Effects of Electric Fields on Burrowed Nephrops. SOAFD Marine Lab, Aberdeen, 15 pp.

Stewart, P.A.M. 1974. An investigation into the effect of electric field on Nephrops norvegicus. Journal du Conseil / Conseil International pour l'Exploration de la Mer 35, 249–257.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., and Rihan, D. 2012. Low impact and fuel efficient fishing – looking beyond the horizon. Fisheries Research, 119–20: 135–145.

Sys, K., Poos, J. J., Van Meensel, J., Polet, H. and Buysse, J. 2016. Competitive interactions between two fishing fleets in the North Sea. ICES Journal of Marine Science. doi: 10.1093/icesjms/fsw008.

Teal, L., Depestele, J., O'Neill, F., Craeymaersch, J., van Denderen, D., Parker, R., Perdon, J., Polet, H., Rasenberg,, M., Vanelslander, B. and Rijnsdorp, A., 2014. Effects of beam and pulse trawling on the benthic ecosystem. IMARES report number C098/14.

Turenhout, M.N.J., B.W. Zaalmink, W.J. Strietman, K.G. Hamon. 2016. Pulse fisheries in the Netherlands; Economic and spatial impact study. Wageningen, Wageningen Economic Research, Report 2016- 104. 32 pp.

Vanden Broucke, G. 1973. Further investigations on electrical fishing. ICES C.M. 1973/B:14. 5pp.

van Denderen, P. D., Hintzen, N., Rijnsdorp, A., Ruardij, P., and Van Kooten, T. 2014. Habitat-specific effects of fishing disturbance on benthic species richness in marine soft sediments. Ecosystems, 17: 1216–1226.

van Denderen, P.D., Bolam, S.G., Hiddink, J.G., Jennings, S., Kenny, A., Rijnsdorp, A.D., van, K.T., 2015. Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. Mar Ecol Prog Ser 541, 31-43.

van Marlen, B. 1997. Alternative stimulation in fisheries. Final Report EU-project AIR3-CT94-1850, June 1997. 190 pp.

van Marlen, B., de Haan, D., Van Gool, A. and Burggraaf, D. 2009. The effect of pulse stimulation on marine biota – Research in relation to ICES advice – Progress report on the effects on benthic invertebrates. IMARES C103/09. 53 pp.

van Marlen, B., Wiegerinck, J.A.M., Van Os-Koomen, E., van Barneveld, E., Bol, R.A., Groeneveld, K., Nijman, R.R., Buyvoets, E., Vanden Berghe, C. and Vanhalst, K. 2011. Vangstvergelijking tussen pulskorschepen en een conventioneel boomkor-vaartuig. IMARES C122b/11. 65 pp.

van Marlen, B., Wiegerinck, J. A. M., van Os-Koomen, E., and van Barneveld, E. 2014. Catch comparison of flatfish pulse trawls and a tickler chain beam trawl. Fisheries Research, 151: 57–69.

van Marlen, B., Molenaar, P., van der Reijden, K. J., Goudswaard, P.C., Bol, R. A., Glorius, S. T., Theunynck, R. and S. S. Uhlmann. 2016. Overleving van discard platvis: vaststellen en verhogen. IMARES report C180/15: 116 p.

van Stralen, M.R. 2005. De Pulskor, Samenvatting van het onderzoek naar de ontwikkeling van een alternatief vistuig voor de vangst van platvis gebaseerd op het gebruik van elektrische stimuli. MarinX-rapport 2005.26. 26 pp.

Vercauteren, G., Chiers, K., Verschueren, B., Decostere, A. and Polet, H. 2010. Effects of Low-frequency Pulsed Direct Current on Captive-housed Sea Fish. Journal of Comparative Pathology. 143(4): 354 (p18).

Verschueren, B. and Polet, H. 2009. Research Summary on HOVERCRAN, the Hovering Pulse Trawl for a Selective Crangon Fishery. Unpublished ILVO manuscript. 30pp.

Verschueren, B., Vanelslander, B. and Polet, H. 2012. Verduurzaming van de garnalenvisserij met de garnalenpuls. ILVO mededelingen, nr. 116. Instituut voor Landbouw- en Visserijonderzoek – ILVO D/2012/10.970/116.

Verschueren, B. and Vanelslander, B. 2013. Project Combipuls: Pulsvisserij op tong en garnaal. Projectrapport - Instituut voor Landbouw- en Visserijonderzoek. 48pp.

Verschueren, B., Lenoir, H., Vandamme, L. and Vanelslander, B. 2014. Evaluatie van een seizoen pulsvisserij op garnaal met HA 31. ILVO mededelingen, nr. 157. Instituut voor Landbouw- en Visserijonderzoek - ILVO D/2014/10.970/157.

Verschueren, B., Lenoir, H., Vandamme, L. and Vanelslander, B. 2016. De pulsvisserij op garnalen: Vergelijking met een klassiek vistuig. ILVO Mededelingen, nr. 211. Instituut voor Landbouw- en Visserijonderzoek - ILVO D/2016/10.970/211.

Vibert, R. 1963. Neurophysiology of electric fishing. Transactions of the American Fisheries Society, 92.

Visserijnieuws. 2015. Special: Schaal- en schelpdieren & Aquacultuur. Nr. 35: 32-33.

Vorberg R. 1997. Auswirkungen der Garnelenfischerei auf den Meeresboden und die Bodenfauna des Wattenmeeres. Verlag Kovac, Hamburg.

Woolmer, A., Maxwell, E. and Lart, W. (2011). SIPF C0083-Effects of electrofishing for Ensis spp. On benthic macrofauna, epifauna and fish species. Seafish Report SR652.