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The impacts of flatfish pulse trawling: evidence review, data gaps and future research

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Executive Summary

Until recently, the North Sea flatfish fishery mainly involved beam trawl vessels, but there has been a rapid transition to an alternative method of fishing known as pulse trawling. While the switch has been commercially successful, the rapid introduction has raised concerns about knowledge on the ecological impacts of pulse trawling and its consequences for other fisheries. The aim of the present study is to review knowledge of pulse trawling as currently used in the North Sea flatfish directed commercial fisheries. Specific objectives of the report are to conduct a systematic search of the literature to identify relevant publications, describe the identified impacts of the pulse trawling in the context of UK North Sea fisheries, identify the main knowledge gaps and propose practical research to address those gaps.

The systematic search returned twenty-eight records, an equal mixture of published journal articles and technical reports. The results were reviewed according to a confidence assessment designed to indicate whether sufficient evidence existed at the time of the review to resolve each topic; this was based on a combination of the number of studies on each topic and the consistency of the evidence presented within them. Most of the research originates from The Netherlands, but Belgian researchers have also made a significant contribution. From the sources identified, 17 species or species groups have been investigated, using a combination of lab experiments and vessel-based studies; sole, plaice and cod are the best-studied, with the others often featuring in only one or two studies.

While there is a growing body of evidence on the impacts of pulse trawling, this evidence addresses many aspects of a complex subject. The main limitations with the evidence base are the insufficient numbers of studies comparing pulse to conventional beam trawling, inconsistency in the application and reporting of the fifteen different pulse parameters that have been listed across the studies, a lack of clarity on which are the key parameters that must be included in studies and differences in methodological approach. It is recognised that pulse research is evolving and so our conclusions represent the body of evidence available at the time of the review (late 2017) and do not account for any work since published.

The studies considered four main topics: catches (landings and discards), ecological effects on non-target species and those exposed to the pulse but not captured in nets, impacts on the physical environment and socio-economic effects. Large-scale effects on the ecosystem are not known. Statements that can be made with higher degrees of confidence are:

Catches, landings and discards: Total catch per haul is much less than in conventional beam trawling. There is a reduction in overall catch per fished area and per hour, mostly in non-target species. There is no substantial difference in discard rates for plaice and sole when using the pulse trawl. Discard survival estimates for plaice and sole are similar for beam trawl and pulse trawls (15-30%) and benthos discards are lower than beam trawling.

Non-target and uncaptured species: Exposure to the electrical pulse under laboratory conditions does not affect survival in cod, dogfish or common starfish, though nothing is known about discard survival for these species. Cod can be injured by pulse trawling, most commonly haemorrhages or spinal damage, though in what proportion is not clear, nor is whether these injuries could result in mortality in the longer term. Dogfish are not injured by exposure to the pulse. Pulse trawling induces up to day-long behavioural change in cod (from muscle contractions up to, in some cases, paralysis or seizures), but the prevalence of these injuries is uncertain. There may be some form of behavioural effect on dogfish, though the extent is unclear and there is no behavioural effect on common starfish. There is very

little information and, of that which is available, a lack of consistency in results, on the effects of pulse trawling on reproduction or the occurrence of illness or disease.

The physical environment: Spatial distribution of fishing effort has evolved with the move from beam to pulse trawlers, with pulse trawling more concentrated around the Dutch, Belgian and eastern/south-eastern English coasts. It is predicted to continue on this trajectory, though the recent voluntary pulse trawling exclusion zone should ameliorate this if complied with. Pulse trawling causes less sediment mobilisation and seabed penetration overall than conventional trawling.

Socio-economic impacts: Fishing trips for the pulse fleet have shortened compared to some of the beam trawlers. There is a clear economic benefit in pulse trawling compared to beam trawling due to significantly reduced fuel consumption and the whole Dutch North Sea sole fleet has transitioned to pulse trawling. The economic implications of pulse trawling for other commercial and recreational fisheries is unknown.

The following programme of work is recommended, based on applied field studies, desk-based assessments and support (e.g. advice and reviewing) for other research programmes.

Field studies

1. Comparative studies of pulse and beam trawling, including both pulse systems and accounting for a range of fishing intensities and conditions (to include the 'new' grounds not accessible to conventional beam trawlers). Methods would include expansion of existing observer and self-sampling programmes and/or dedicated sea trials.
2. Experiments to determine the ecosystem effects of pulse trawling: A statistically designed experiment that would enable pulse trawlers to operate in some fishing areas but exclude them from others, in which only conventional beam trawlers can operate (and to include reference areas where feasible).

Desk-based studies

3. Re-examination of existing data on survival and sub-lethal effects, to ascertain which are relevant to the pulse characteristics used in the fishery.
4. Initial assessment of implications of pulse trawling for species and habitats in UK waters protected under conservation designations, including food-web or other indirect effects for key species.
5. Analysis of fisheries data to gain a greater understanding of effort distribution across the fishing grounds, including any areas accessible to pulse but not beam trawls.
6. An economic assessment of the expansion of the pulse fishery from the perspective of potential impacts on small vessel inshore fisheries and recreational angling.

Independent reviewer

7. Support for the research conducted in European countries in the form of contributing to research plans, reviewing documents and potentially providing staff for practical research.

This programme of work would provide objective scientific evidence for Defra to understand whether the catches, landings and discards from pulse trawling out-perform conventional beam trawling; whether the ecosystem effects of pulse trawling are better, worse or the same as beam trawling; where and when the flatfish pulse fishery is operating and whether the fishing grounds are expanding and, lastly, how the catches and environmental effects of flatfish pulse trawling are impacting inshore fisheries and recreational angling.

Introduction

Background

Until recently, the North Sea flatfish fishery mainly involved beam trawl vessels. A beam trawl is a net which is held open by a steel beam, and vessels typically use two nets, one towed either side of the vessel. Attached to the beam are steel chains, that are pulled across and through the sediment up to a depth of 8 cm to stimulate flatfish to ascend from the seafloor and be overtaken by the net (Paschen *et al*. 2000). The beam trawl fishery, in particular, the one targeting sole, is characterised as having substantial unwanted catches of undersized fish, in particular plaice and benthic invertebrates. This fishing method is known to 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).

This method of fishing has a relatively high fuel demand, required to pull the trawls at sufficient speed to catch the target species. Due to the known ecological impacts, but catalysed by historical high fuel prices, there has been a rapid transition from beam trawls to an alternative method of fishing known as pulse trawling (*electro-fishing*). Research into alternative methods to catch sole have mostly focussed on the use of electrical pulses that produce a contraction of the body muscles (cramp response) during exposure making them available to the approaching net. Since commercial trials commenced in 2005, pulse trawling has expanded in the commercial fishery and the transition from beam trawl to pulse trawl is now complete for the North Sea sole fishery. Due to the low towing speeds and subsequent fuel savings, the transition has been a substantial commercial success. In 2014, for example, the net profits of pulse trawlers was ~17 million Euros; compared with the beam trawlers, which broke even in the same year (Turenhout *et al*. 2016).

While the switch to pulse trawls has been commercially successful, the rapid introduction of this novel method of fishing in the North Sea has raised concerns among the fishing industry, eNGOs, scientists and EU Member States. These concerns relate to the level of knowledge concerning the impacts of pulse trawling, both in terms of the ecological effects and the consequences to other commercial fisheries. There have been several anecdotal reports from fishers and anglers, who describe catching damaged and decomposing fish and subsequent reduced commercial catches in areas where pulse trawlers have recently been active. These concerns have motivated an independent review of the research conducted on pulse trawls now being used in the North Sea sole fishery.

EU Regulations

Technical measures are a broad set of rules which govern how, where and when fishers may fish. Fishing by means of electricity has been prohibited in the EU Technical Measures Regulation since 1998 (EU, 1998; EC 850/98, Article 31: non-conventional fishery techniques). However, a derogation for the use of pulse trawls, applied for by The Netherlands, has been awarded since 2005 to allow pulse trawling in 5% of the total number of vessels of each Member State within the EU. Following this, there was an unsuccessful attempt to increase the level of permitted pulse use to 10%, which did not receive sufficient

EU Member State support. However, following a Dutch proposal, pulse trawls were defined by the EU as an innovative gear that could be used in a pilot project, under Article 14 of the CFP Regulation 1380/2013. There are currently around 84 vessels using pulse trawls in the North Sea flatfish fishery and there is no time limit for the pilot project under current legislation. The majority of vessels currently using pulse gear are Dutch, but there are also UK, German and Danish flagged vessels, although these vessels are operated by Dutch companies. At the time of writing, there is a process underway to replace the current EU framework of rules on technical measures on the basis of a Commission proposal. This proposal has co-legislator positions currently outlined in a General Approach (GA) reflecting the Council position, and a European Parliament 1st reading position, and work continues towards a compromise to agree the final outcome. The aim of the review is to optimise the contribution of technical measures to achieving the key objectives of the latest reformed Common Fisheries Policy (CFP). As part of this process the regulatory status of pulse trawling will need to be addressed.

Research

Scientific research into the ecological impacts of pulse trawling has been ongoing for several years. This has been focussed in those countries with a commercial interest from the fishing industry in pulse trawling, The Netherlands and Belgium, who have both published reports and scientific peer-reviewed papers. Further to national research programmes, there have been international initiatives and collaborations including the founding of new ICES groups (International Council for the Exploration of the Sea). Since 2010, an ICES Workshop to Assess the Ecosystem Effects of Electric Pulse Trawls (WKPULSE), followed by a Study Group on Electrical Trawling (SGELECTRA), and most recently a Working Group on Electrical Trawling (WGELECTRA) - delivering the following terms of reference (ToRs): a) Produce a state-of-the-art review of all relevant studies on marine electrofishing; b) Supply required information to answer on request of member states concerning electro-trawling; c) Discuss and prioritise knowledge gaps, and discuss ongoing and upcoming research projects in the light of these knowledge gaps, including the experimental setup. There have also been reviews and summaries of the research (e.g. Quijrijns *et al*., 2015; Rijnsdorp *et al*., 2016; ICES, 2016). There is substantial research ongoing and planned into the effects of pulse trawling, mostly from The Netherlands and Belgium.

Aims

Given the number of licenses now awarded, pulse trawling has effectively become a mainstream commercial fishing method, thereby increasing the risks associated with any negative effect of this fishing method. Its widespread adoption raises questions about its impacts on target and non-target species, and the sustainability of impacted fisheries. These impacts on catches, discards and marine ecosystems need to be studied to inform fisheries management decisions. The aim of the present work is to review knowledge of pulse trawling as currently used in North Sea flatfish directed commercial fisheries. Specific objectives of the project are to:

1) conduct a systematic search of the literature to identify relevant publications and report on the use and impact of pulse trawling in the North Sea;

2) visit and learn from lead pulse trawl researchers to ascertain latest knowledge;
3) draft a review of the identified material;
4) deliver findings to inshore North Sea UK fishing interests;
5) describe the identified impacts of the pulse trawling method in the context of UK North Sea fisheries, and
6) based on (1) and (2), identify the main knowledge gaps and propose and plan specific practical research tasks to address those gaps.

Flatfish pulse trawling

There are currently two producers of flatfish pulse trawling equipment; Delmeco Group Ltd. and HFK Engineering. A third pulse system is marketed by Marelec. The Marelec system is used only in the shrimp fishery and, while it is similar in principle to the flatfish pulse gear, some of the characteristics differ (e.g. it employs a much lower pulse frequency) so it will not be considered further. The history of the two systems is described in de Haan *et al*. (2011) and the specifications of the gears are given in Table 1.

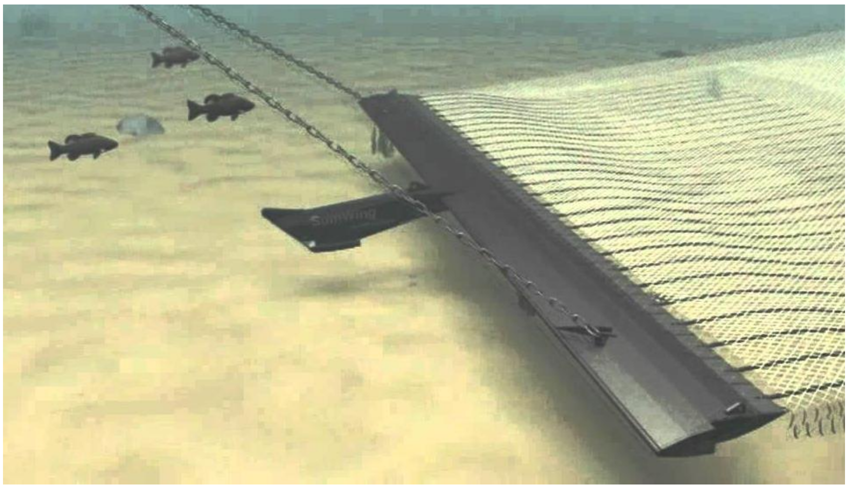
The Delmeco pulse systems

The original pulse trawl design was developed by Verburg-Holland Ltd. The company was purchased by Delmeco Group Ltd. in 2010, with subsequent re-development and wider marketing of the system. Developments in the technology have included reductions in voltage across the conductors (60 to 50 V $^{0\ \text{to peak}}$), increased distances between the electrodes (0.325 to 0.425 m) and a reduction in the number of electrodes (giving a reduction in power). Delmeco have three separate pulse system designs, with two in active use - Delmeco TX68 and TX19, with UK153 no longer in service). Cefas observed initial technical trials of the Delmeco gear in 2004 during a fact-finding mission under the 'Fishing gears with mitigating ecological impacts' project MF0706 (Cefas, 2005).

Figure 1 Example of the Delmeco pulse trawl (this is UK153, which is no longer in use). From van Marlen *et al*. (2006)

The HFK PulseWing

The HFK Engineering pulse trawl system was developed in 2009 (Figure 2). The system differs from the Delmeco design both in the pulse characteristics and in the method of deployment. The HFK pulse system is deployed on the company's proprietary SumWing trawl. This is a hydrodynamic wing-shaped beam for which only the nose-cone makes seabed contact (it is *shoeless*). The SumWing combined with HFK's pulse system is marketed as the PulseWing. The prototype commercial application was on the Dutch-flagged fishing vessel TX36.



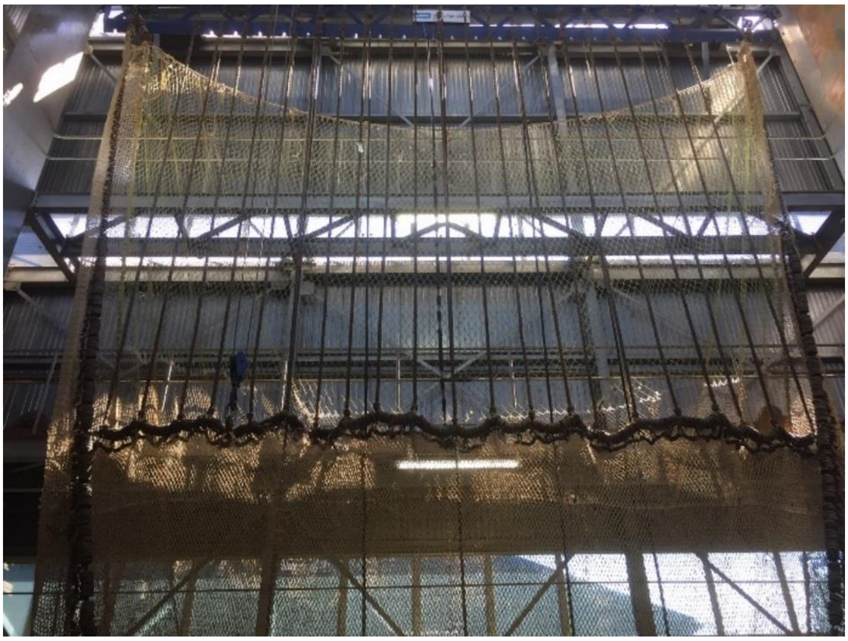


Figure 2 The HFK PulseWing (top) in situ visualisation and (bottom) net with electrode array.

Table 1 The characteristics of the Delmeco and HFK pulse gears (from de Haan *et al.*, 2011)

Pulse concept	Power single gear (kW)	Electrode voltage (V 0 to peak)	Pulse frequency (Hz)	Pulse width (µs)	Electrode: Number	Electrode: Distance	Electrode: No. of conductors	Electrode: Conductor length x diameter (mm)
Delmeco UK153	8.5	60	40	220*	32	0.325	6	180 x 26
Delmeco TX68	5.5	50	40	220*	25	0.425	6	180 x 26
Delmeco TX19	5.5	50	80	130	25	0.425	6	180 x 26
HFK TX36	7	45	45	170/50	28	0.415	2 10	125 x 27 125 x 33

*Refers to a single pulse period

As part of this study (objective 2), the authors undertook a fact-finding trip to the Netherlands on the 31st of May 2017. The purpose of the visit was to meet with the pulse trawling researchers to gain a better understanding of the technology and the research conducted to date. In the event, the authors were also able to meet with the PulseWing designer, the fisheries co-operative of Urk (VCU) and the Dutch Fisherman's Association, as well as undertake a site visit to pulse vessel UK176. The trip notes were reported to Defra in June 2017; a summary is provided in Appendix 1.

Pulse trawling literature review

Search and sifting

The systematic search used Web of Science, Google and Google Scholar searches, which were conducted during May 2017 and the www.pulsefishing.eu website document list, the contents of which were searched in August 2017.

The sift criteria and search outcomes are summarised in Table 2. Three hundred and eighty-nine records were returned. These records were then systematically searched to identify those containing information relevant to this review.

Some evidence was reported in more than one medium; for example, the same study reported in a technical report, journal article and, in many cases, also in review documents. To prevent duplication skewing the evidence base, review documents were excluded and technical reports were only retained where results were not also reported in peer-reviewed journal articles. Five of the records returned were ICES study group reports, which are considered to contain summaries of research that has been either reported elsewhere in technical documents or is not yet complete. These were also excluded from the review.

Some of the records on the www.pulsefishing.eu website were Dutch-language reports. A preliminary check was conducted by a native-speaker to ascertain if they contained potentially useful information. Of the 19 records, four are technical reports that may have contained original data (concerning skin ulcers, catches from pulse *versus* beam trawlers and sole and plaice survival). The programme leader for the Dutch pulse research programme, Adriaan Rijnsdorp, has confirmed that two of the reports contain information included in later English-language reports and so these were discarded. The other two, one regarding incidence of fish lesions in Belgian coastal waters and their possible link to the advent of pulse trawling (i.e. not a specific pulse trawling study) and the other on the results of the first commercial trials of the pulse gear in 2004-2005, are only included in English in ICES WGELECTRA reports.

As noted above, review documents such as the WGELECTRA reports were not included in the review. Thus, we engaged a Dutch-speaking colleague, Marieke Desender[1], to investigate the information. The report on fish lesions does not formally assess pulse effects and so has not been included in our review. The report on the initial commercial trials is itself a summary report of a number of studies. Most of these used prototype gears that differed from those used in the commercial fishery (either in size, some being 7 m trawls, or in electrode and power characteristics) and so they were rejected. Two of the studies tested gear more akin to the contemporary pulse trawls (these were termed "pulskor") and so these were retained for the review and the results translated into English.

Summary of literature reviewed

Twenty-eight records were retained for review. Having extracted the key information from the data sources, each of the records were allocated to main research evidence areas. All the identified references provided evidence against one or more of these topics:

1. Total catch
2. Landings
3. Discards
4. Survival
5. Injury
6. Reproduction
7. Disease
8. Behaviour
9. The physical environment
10. Socio-economics

[1] Marieke recently started work at Cefas. Some of Marieke's research is featured in the review, so she did not take part in the other components of the review such as the systematic search, assimilation of the evidence or formulation of conclusions.

Table 2: Literature review search summary

Search engine	Search terms	No. records*	No. records retained	Reasons for exclusion of records
Google	North Sea AND "Pulse trawl" AND Flatfish OR sole OR plaice OR Solea solea OR Pleuronectes platessa North Sea AND "Electric fishing" AND Flatfish OR sole OR plaice OR Solea solea OR Pleuronectes platessa North Sea AND "Electro fishing" AND Flatfish OR sole OR plaice OR Solea solea OR Pleuronectes platessa	150	8	Not a primary study (e.g. is a presentation or summary report); subject of the study is a different fishery or gear type; duplicated records; duplicated data (published in a report and journal article); subject matter not directly relevant; information not sufficiently detailed (e.g. catch data agglomerated in bottom trawl métier).
Google Scholar		113	10	
Web of Science	"North Sea" AND Pulse AND trawl* AND Flatfish OR sole OR plaice OR Solea solea OR Pleuronectes platessa OR "North Sea" AND Electr* fishing AND Flatfish OR sole OR plaice OR Solea solea OR Pleuronectes platessa	57	2	
www.pulsefishing.eu	All links searched	69	5 (plus 3 additional Dutch language reports)	

*The first 50 references returned from each search string were retained for sifting.

An evidence matrix illustrating the type of evidence generated by each of the references is given in Table 3. Provided in the Evidence Summaries are the topics addressed by each of the references and the species (or species group) for which that evidence was presented.

Total fish or benthic invertebrate biomass (catches or discards) have been assessed in four records each. Seventeen taxa have been included in the reviewed studies, three flatfish, three roundfish and eleven benthic invertebrates[2]. Sole, plaice and cod are the best-researched, featuring in 10, 8 and 7 records, respectively. Most of the others are limited to one or two records.

[2] Two of the studies included a fairly large number of benthic invertebrate taxa - Teal et al.'s (2014) study used seabed samples containing 23 invertebrate taxa and Small and Brammelhuis' (2005) experimented on 18. Teal et al.'s study showed no clear patterns of response to pulse trawling and Small and Brummelhuis' returned no significant effects from their experiments so, for simplicity, the data from their studies, with the exception of taxa also included in other studies (common starfish, prawns, ragworms, razor clams, prickly cockles and swimming, hermit and helmet crabs) were aggregated to 'benthos' for the purposes of the review.

• Total fish	4 records
• Total benthos	5 records
• Sole *Solea solea*	10 records
• Plaice *Pleuronectes platessa*	*8* records
• Dab *Limanda limanda*	2 records
• Cod *Gadus morhua*	7 records
• Whiting *Merlangius merlangus*	1 record
• Dogfish *Scyliorhinus canicula*	3 records
• Brown shrimp *Crangon crangon*	2 records
• Common prawn *Palaemon serratus*	*2* records
• Green crab *Carcinus meanas*	1 record
• Swimming crab *Liocarcinus*	2 records
• Helmet crab *Corystes*	2 records
• Hermit crab *Pagurus*	2 records
• Ragworms *Hediste diversicolor*, *Allita virens*	*3* records
• Razor clam *Ensis directus*	*2* records
• Surf clam *Spisula subtruncata*	1 record
• Prickly cockle *Acanthocardia echinata*	2 records
• Common starfish *Asterias rubens*	4 records

Most of the research has been conducted by Wageningen Marine Research (formerly IMARES) in the Netherlands, though research centres in Belgium (ILVO and the University of Ghent) have also made significant contributions to the body of evidence and in several cases the two countries have collaborated. Several of the experimental studies included a partner institute in Norway (either IMR or NOFIMA). The UK has contributed to three of the records; two resulting from an investigation into seabed disturbance and ecological effects of pulse trawling compared to beam trawling (Aberdeen University, Marine Scotland Science and Cefas) and an assessment of potential effects of pulse trawling on the seabed in the North Norfolk Sandbanks and Saturn Reef SCI (Marine Scotland Science, ABPmer and Ichthys Marine). The body of work has been generated through a combination of state-funded projects, EU projects (DEGREE and BENTHIS) and PhD studentships (Maarten Soetaert and Marieke Desender).

The evidence is equally split between peer-reviewed journal papers (14 records; 2 vessel-based studies, 7 laboratory experiments, 2 combined vessel and laboratory studies and 3 data analysis, modelling or combined vessel and modelling papers) and technical reports (14 records; 6 vessel-based studies, 5 laboratory experiments, 1 combined vessel and laboratory study and 2 data analysis or modelling reports). Laboratory studies are better represented than vessel-based studies such as catch comparisons.

Given the derogation limitations for use of the fishing method, the vessel-based studies took place in the southern North Sea. Some gave details of the locales, which included the Dutch (6 records), English (4 records) and Belgian (1 record) coasts, while a few did not detail where in the region they took place. Study or data collection dates were provided for all but four of the records. These dates are important for determining whether studies are duplicated in multiple records and for providing context to help understand where the results fall within the evolution of the evidence base.

Of prime importance is the reporting of the pulse characteristics used in different studies. Fifteen different pulse parameters have been reported across the review records (current legal limits are given in square parentheses):

- Max power consumption per m beam length (kW) [legal max 1 kW]
- Pulse amplitude (volts) [legal max. 60 V 0 to peak]
- Electrode length (m); the section that has bottom contact [legal max 4.75 m]
- Conductor length (mm) [legal 125 to 200 mm]
- Number of conductors [legal max 12 per electrode]
- Electrode distance (m) [legal not less than 0.4 m]
- Pulse frequency (Hz; cycles per second)
- Duty cycle (%)
- Pulse duration (µs)
- Pulse shape
- Pulse type
- Exposure length (s)
- Field strength (V/m)
- Conductance δ (siemens)
- Electrode diameter (mm)

Some of these parameters will be relevant for vessel studies only (e.g. maximum power consumption per metre beam length) and they may not all be of equal importance in determining pulse effects. However, as a rough approximation of how comprehensively each record reported the pulse characteristics employed in the studies, the percentage of parameters reported has been calculated. There is significant variability across the studies in reporting of pulse characteristics, from none of the above listed parameters (sometimes due to commercial confidentiality or because records referred to the entire pulse fishery) to up to 80% of the parameters. In some cases, these discrepancies in reporting may be a result of an evolution in the understanding of the key parameters involved in pulse impacts (e.g. the work of de Haan and colleagues from 2009 to 2016). Otherwise, it is not clear why pulse parameters have not been consistently reported.

Finally, there is variability across studies in whether statistical analysis was used as a data interpretation tool. Twelve records reported statistical analysis of the data, six reported partial statistical analyses (some of the variables assessed) and 28% (equating to 7) of the records included no form of statistical analysis.

Table 3 Summary of records retained for review (pulse parameters reported = the number of parameters reported per record as a proportion of the total number reported across all records)

	Reference	Origin of the study	Topic	Species	Type of study	Location	Date (mm/yr)	Pulse parameters	Statistical analysis?
1	van Marlen *et al*. (2014)	Netherlands[1]	Catches, landings, discards	Total fish, sole, plaice, cod, whiting	P: vessel	SNS: Dutch	May '11	53%	Yes
2	Soetart *et al*. (2015)	Belgium[5,4]	Survival, injury, behaviour	Brown shrimp, ragworm	P: lab	N/A	Not given	80%	Yes
3	Soetart *et al*. (2016a)	Belgium[5,4]	Survival, behaviour, injury, disease, reproduction	Brown shrimp	P: lab	N/A	Not given	53%	Yes
4	Steenbergen & van Marlen (2009)	Netherlands[1]	Landings, discards	Sole, plaice	R: vessel	SNS: English	Jun-Sep 09	0*	No
5	Rasenberg *et al*. (2013)	Netherlands[1]	Discards	Sole, plaice benthos	R: vessel	SNS	Dec 11-Feb 13	0[#]	No
6	van Marlen *et al*. (2006)	Netherlands[1]	Catches, landings, survival	Total fish, sole, plaice	R: vessel	SNS: Dutch	Oct 05-Mar 06	0*	Yes
7	de Haan *et al*. (2016)	Netherlands[1], Norway[7]	Behaviour, injury	Cod	P: lab	N/A	Oct-Nov 08, Nov-Dec 10	40%	Yes
8	de Haan *et al*. (2015)	Netherlands[1]	Behaviour, injury	Dab	R: lab	N/A	Apr 14	66%	Yes
9	Soetart *et al*. (2016b)	Belgium[5,4], Norway[8]	Survival, behaviour, injury	Sole, cod	P: lab	N/A	Not given	53%	Yes (some)
10	de Haan *et al*. (2009a)	Netherlands[1]	Survival, behaviour, injury	Cod	R: lab	N/A	Sep 08, Nov 08	33%	Yes (some)
11	van Marlen *et al*. (2007)	Netherlands[1]	Injury, survival, behaviour	Cod, dogfish	R: vessel/lab	SNS (?)	Jul-Aug 07, Feb-Oct 07	27%	No
12	van Marlen *et al*. (2009)	Netherlands[1]	Survival, behaviour	Ragworm, prawn, green crab, razor clam, surf clam, common starfish	R: lab	N/A	Jul 09	0*	Yes (some)
13	de Haan *et al*. (2009b)	Netherlands[1]	Survival, injury, behaviour, reproduction	Dogfish	R: lab	N/A	Nov-Dec 08	27%	No
14	Soetart *et al*. (2016c)	Belgium[5,4]	Injury	Sole, benthos	P: vessel	SNS: England/Belgium	Apr, Nov, Dec 14, Feb 15	33%	Yes (some)

	Reference	Origin of the study	Topic	Species	Type of study	Location	Date (mm/yr)	Pulse parameters	Statistical analysis?
15	Sys *et al*. (2016)	Belgium[5,4], Netherlands[1]	Socio-economics	N/A	P: data analysis	SNS	2006-2013	0#	Yes
16	Batsleer *et al*. (2016)	Netherlands[1,2,3]	Socio-economics	N/A	P: modelling	SNS	Data from 1970s, 2005-2011	0#	Yes
17	ABPmer & Ichthys Marine (2015)	UK[10,11,13]	Physical disturbance	N/A	R: modelling	SNS: England	N/A (no data collection)	0#	No (model estimates)
18	Desender *et al*. (2017)	Belgium[5,4], USA[14]	Mortality, injury, behaviour	Dogfish	P: lab	N/A	Not given	60%	Yes
19	Uhlmann *et al*. (2016)	Belgium[4,5]	Catches, survival	Total fish, sole, plaice	P: vessel/lab	SNS (?)	Jun 14	27%	Yes
20	van der Reijden *et al*. (2017)	Netherlands[1], Belgium[4]	Survival	Sole, plaice, dab	P: vessel/lab	SNS: Dutch/English	Nov 14, Mar-Sep 15	60%	Yes
21	Turenhout *et al*. (2016)	Netherlands[1]	Socio-economics	N/A	R: data analysis	SNS	2008 - 2015	0#	No
22	Depestele *et al*. (2015)	Belgium[4,5,6], Netherlands[1], UK[12,10]	Physical disturbance	N/A	P: vessel/ modelling	SNS: Dutch	Jun 13	0*	Yes (some)
23	Soetart *et al*. (2016d)	Belgium[5,4], Netherlands[1], Norway[8]	Behaviour, injury	Cod	P: lab	N/A	Apr, May, Jun, Oct, Dec 13	67%	Yes (some)
24	Teal *et al*. (2014)	Netherlands[1], Belgium[4], UK[9]	Survival	Benthos (22 taxa agglomerated), plus common starfish	R: vessel	SNS: Dutch	Jun 13	0*	Yes
25	de Haan *et al*. (2013)	Netherlands[1], Belgium[4,5]	Behaviour, injury	Cod	R: lab	N/A	Oct 13	40%	No
26	Van Marlen *et al*. (2005a)	Netherlands[1]	Catches, landings, discards	Sole plaice Benthos, plus quahog, prickly cockle, swimming, hermit and helmet crabs	R: vessel	SNS	Nov 04-Jan 05	0%	Yes

	Reference	Origin of the study	Topic	Species	Type of study	Location	Date (mm/yr)	Pulse parameters	Statistical analysis?
27	Van Marlen *et al.* (2005b)	Netherlands[1]	Discard survival, injury, illness (blood parameters)	Sole, plaice	R: vessel	SNS	Nov 04-Jan 05	0%	Yes
28	Small and Brummelhuis (2005)	Netherlands[1]	Behaviour, exposure survival	Benthos (11 taxa agglomerated), plus razor clam, prickly cockle, common starfish, prawn, helmet crab, hermit crab, ragworm.	R: lab	Netherlands, Yrseke	Oct-Nov 04	0%	No

[1]IMARES [2]U. Wageningen [3]LEI [4]ILVO [5]U. Ghent [6]Federal Public Service [7]IMR [8]NOFIMA [9]Cefas [10]Marine Scotland [11]ABPmer [12]U. Aberdeen [13]Ichtys Marine [14]Florida Atlantic U. *parameters inferred, #whole fishery assessed, P = paper, R = report.

Evidence summaries

In this section, for each of the evidence topics, the data extracted from the references are summarised. The data are presented in Appendix 2. For each of the topics, the aims of the research are summarised, the evidence base described and the main findings, results and comments from the work summarised. After each topic the evidence is assessed in terms of its comprehensiveness, consistency and limitations against each evidence topic.

A crude measure of confidence in the sufficiency of the evidence base for providing a comprehensive answer to the issues within each topic is calculated using a combination of the number of studies on each topic and the consistency of the evidence presented within them. The consistency of the evidence is defined here as whether the results presented across the records were similar or diverged - evidence on a particular topic is consistent when each of the records presents similar findings, but inconsistent when the records describe divergent findings (e.g. when one record describes an effect but another finds no effect). This confidence measure is intended as an overall indicator of whether each topic had been sufficiently resolved at the time of the review, not as an indication of the scientific quality of the studies themselves. The confidence measures are given at the end of each topic.

Catches, landings and discards

Total Catch

Three references provided information on the effect of using pulse trawls on total catch, compared with conventional beam trawls (van Marlen *et al.,* 2005a; van Marlen *et al*., 2014; Uhlmann *et al*., 2016). A fourth reference supplied information on pulse total catches from a sampling programme (Rasenberg *et al*., 2013).

The studies illustrate that the total catch per haul when operating a pulse trawl is much less than when using a conventional beam trawl. There is a reduction, both in terms of the overall catch taken per fished area and the catch taken per hour. In one study there was observed a 69% reduction in **cod** and fewer undersized **plaice** and **sole**, in the second in terms of the overall catch the mean length of plaice and sole was smaller from the pulse trawls than the beam (25 cm *versus* 28 cm for both species[3]), although sample sizes were small. In the third there was no difference in catches of undersized sole, but undersized plaice reduced by 18%. Therefore, while the evidence for pulse trawls catching fewer fish is consistent, the evidence for reducing catches of small and undersized fish is less clear. The fourth study indicated that landings comprise less than a third of the total catch, with two thirds of unwanted fish and benthos caught.

Landings

[3] This is shorter than the minimum conservation reference size (MCRS) of 27 cm for plaice and 24 cm for sole.

Four references gave information on the effect of using pulse trawls on landings when compared with conventional beam trawls (van Marlen *et al.*, 2005a; van Marlen *et al.*, 2006; Rasenberg *et al*., 2013; van Marlen *et al*., 2014).

All four studies addressed landings per hour for **sole**; one study reported 22% less landings, two reported an increase of 10-22% and one provided evidence of both a decrease (from skipper and auction records, landings totalling 79% and 86% of beam landings, respectively) but a tendency to catch more marketable sole (modelling outputs).Of the two studies examining landings by area, one described a very small increase for sole, while the other found no differences in landings per area fished.

All four studies showed that between 17% and 58% fewer **plaice** were landed per hour from pulse trawling than beam trawling. Two studies presented landings per area fished; one found a 17% reduction for plaice but the other showed no difference from beam trawling.

Discards

Four references provide information on the effect of using pulse trawls on discards when compared with conventional beam trawls (van Marlen *et al.*, 2005a; van Marlen *et al*., 2006; van Marlen *et al*., 2014; Rasenberg *et al*., 2013). In three studies, the number of **plaice** discarded per hour fished reduced substantially when using pulse (18-69% reductions), while in the other there was no change. In two studies, the catch per hour of undersized **sole** was reduced when using pulse trawls (around 25%), but in the other two the mean discard rate for sole did not differ from beam trawls. In two studies, there were reductions of between 25% and 76% in **benthic invertebrate** discards. There was also reported a reduction in plaice discards per area fished. In terms of the discards rates, the proportion of the catch discarded, there was no substantial difference in discard rate reported for plaice or sole when using the pulse trawl. Therefore, the same proportion of the catch is thrown back as with conventional beam trawls.

Overall comments: catches, landings and discards

Making comparisons between pulse trawls and beam trawls is not straightforward, as simultaneous direct comparisons cannot be done. This is because, to use these fishing methods optimally, the two gears are fished at different speeds. Often reported are comparative catches per area and catches per hour. However, it is difficult to assess the overall difference in impact with these data. It would be useful to describe the comparative impacts using the quantity of sole landed as a metric; for example, the quantity of plaice discards generated per tonne of sole landed. Differences in the fish per area or hour need to be viewed in the context of the total amount of fishing delivered by the fleet. For example, catches per hour are reduced when using the pulse but, overall, catches will be reduced only if there is no increase in fishing time.

The available evidence shows that the total catches per haul are less with a pulse trawl and the discard rate appears constant. What is not clear is whether the proportion of the different species in the catch has changed, which would modify the overall catch composition of the fleet. Most catches of the North Sea plaice stock are generated by the Dutch fleet; the discard rate for the stock has not changed during the period 2010-2016 (mean 38% by

weight)[4]. A noticeable change in plaice discards with the introduction of pulse would be likely to have reduced the overall discard rate for the stock, but this has not been observed. Similarly, the discard rate for sole has remained constant at around 12%[5].

	No. of studies	Effect?	Consistent results?	Confidence
Total catches				
Fishes	4	Yes (reduction)	Yes	Highest
Sole	3	Yes (reduction)	No	Moderate
Plaice	3	Yes (reduction)	No	Moderate
Cod	1	Yes (reduction)	-	Lowest
Landings				
Sole and plaice	4	Yes (mixed)	No	Moderate
Discards				
Sole and plaice	4	Yes (reduction)	No[1]	Moderate
Benthic invertebrates	2	Yes (reduction)	Yes	Highest

[1]Reductions in amounts discarded (depending on the study), but no substantial differences in discard rates

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Survival

Two components of survival are relevant in the review of pulse trawling effects: the immediate and direct effects of exposure to the electrical pulse, to which both animals retained in the net and those escaping from capture are exposed (thus far, only assessed in laboratory experiments) and discard survival - that is, survival of invertebrates or fish discarded after capture (encompassing the timeline from initial pulse exposure to capture in the net, on-board sorting and survival post-discarding). The two components are considered separately; in the information below, immediate survival after the exposure, capture and sorting process is referred to as at-vessel survival, which is mainly indicated by measures of impairment. Research has shown that at-vessel mortality level is not a good indicator of longer-term discard survival.

Survival after electrical pulse exposure

Fishes: Five laboratory experiments addressed the direct effects on fishes of exposure to electrical pulses (van Marlen *et al*., 2007; de Haan *et al*., 2009a; de Haan *et al*., 2009b; Soetaert *et al*., 2016b; Desender *et al*., 2017).

Two studies assessed survival in **cod**; both indicate no direct effect of pulse exposure on survival. Three studies addressed **dogfish**; all showed no effects of pulse trawling on

[4] ICES Advice 2016, Book 6 1, Version 2: 11 November 2016; 6.3.36 Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 3.a.20 (Skagerrak). Greater North Sea and Celtic Seas ecoregions. Published 30 June 2016.

[5] ICES Advice 2016, Book 6 1, Version 2: 11 November 2016; 6.3.49 Sole (*Solea solea*) in Subarea 4 (North Sea), Greater North Sea and Celtic Seas ecoregions. Published 30 June 2016.

survival. One study assessed **sole**; it shows no mortality attributable to pulse exposure (one fish died, but had no abnormalities).

Invertebrates: Five studies assessed effects of pulse exposure on survival in invertebrates, four laboratory experiments (Smaal and Brummelhuis, 2005; van Marlen *et al*., 2009; Soetaert *et al*., 2015; Soetaert *et al*., 2016a) and one vessel-based field experiment (Teal *et al*., 2014). The studies assessed a range of species and included specific experiments on molluscs, crustaceans, polychaetes and echinoderms. There were generally no consistent responses of benthic invertebrates to pulse trawling, with, for example, species responding variably in different studies or circumstances, or changes in density (i.e. survival) in both fished and reference areas.

Of three laboratory studies considering **ragworm**, two showed a slight reduction in survival while the other reported no decrease in survival compared to controls. Of two studies considering **brown shrimp**, one indicated differences in survival while the other did not. **Green crab** was assessed in one laboratory study – survival was slightly lower in pulse-exposed crabs than controls. **Razor clam** was assessed in two studies – the results were inconsistent, with no differences reported in the first study and in the second a reduction in some circumstances but an increase in others. **Common starfish** was assessed in three studies and **prawn** and **surf clam** each in one study, with no effects of pulse exposure on survival.

Survival of pulse fishery discards

Discard survival encompasses the exposure to the electrical pulses but also the remainder of the capture and sorting process. It has been studied only in fishes.

Fishes: Four studies investigated discard survival of fishes, one by on-board assessment of impairment (Uhlmann *et al*., 2016) and three by on-board assessment combined with either 25-day laboratory-based observation of survival in captured fish (van der Reijden *et al*., 2017) 4-8 day observations of survival on board and at port, or 8-day survival estimation using published survival rates (van Marlen *et al*., 2006). Two of the on-board assessments of impairment did not differentiate between undersized and marketable sized fish (van Marlen *et al*., 2006 does not report whether they were marketable or discards and Uhlmann *et al*., 2016 reports aggregated results that include both marketable and discard fish).

Four studies address **plaice**. The data on impairment in fish at the point of discarding are not consistent; two of the studies report that plaice are lively on capture and no more or less impaired than in beam trawls, but one reports undersized plaice as mainly “lethargic” or “dead” (though does not include a beam trawl comparator). The three longer-term survival estimates differ depending on time, with one predicting a higher survival from pulse *versus* beam trawling over 8 days (28% *c.f.* 15%), one describing higher survival in all injury classes studied and the third recording a pulse trawling survival rate of 15% at 25 days.

Three studies contain data on **sole** discard survival, encompassing different sources of evidence (two on-board assessments, a 4- to 8-day observation and a 25-day laboratory observation). The on-board assessments indicate sole tolerate the full pulse trawl capture and sorting process reasonably well (low impairment; classed as “less lively”) and better than in the beam trawl fishery. One of the longer-term studies recorded a 25-day pulse

trawling survival rate of 29%, the other found no significant difference in survival between beam and pulse. One study assessed **dab**. This indicates an effect of pulse trawling on at-vessel survival, with pulse trawled dab lethargic or dead and a 16% survival rate at 25 days.

Overall comments: survival

Overall, the evidence for good survival in dogfish and cod after electrical pulse exposure is consistent, although there have been no assessments of discard survival. For sole, there appears to be no immediate effect of direct exposure to the electrical pulse and there is evidence that at-vessel survival is higher than in the beam trawl fishery. There is no evidence on the immediate effects of electrical pulse exposure in plaice.

Concerning discard survival, pulse-trawled fish are reported to, variously, look lively at the point of discarding and either survive better or no differently to fish caught using beam trawls, look lethargic or dead at the point of discarding, or have a higher survival rate than beam trawling after 8 days but a lower survival rate 25 days after capture. In general, discard survival estimates for plaice and sole are similar for beam trawl and pulse trawls (15-30%).

Invertebrates fare reasonably well with respect to formal pulse and beam trawling comparisons, with two of the four experiments specifically incorporating a beam trawl comparator. However, with the exception of the common starfish (on which two studies found no effects of pulse exposure), the results of the studies portray a reasonably large inconsistency in effects and, partly because there are few studies of each individual species and none on discard survival, it is difficult to form overall conclusions.

	No. of studies	Effect?	Consistent results?	Confidence
Sole	1,3	Pulse exposure: no Discard survival: no	No	Moderate
Plaice	4	Pulse exposure: no data Discard survival: no	No	Moderate
Dab	1	Pulse exposure: no data Discard survival: yes (reduction)	.	Lowest
Cod	2	Pulse exposure: no Discard survival: no data	Yes	Highest
Dogfish	3	Pulse exposure: no Discard survival: no data	Yes	Highest
Brown shrimp	2	Pulse exposure: yes (reduction) Discard survival: no data	No	Moderate
Ragworm	3	Pulse exposure: yes (reduction) Discard survival: no data	No	Moderate
Green crab	1	Pulse exposure: yes (reduction) Discard survival: no data	.	Lowest
Razor clam	2	Pulse exposure: yes (reduction/increase) Discard survival: no data	No[1]	Moderate
Common starfish	3	Pulse exposure: no Discard survival: no data	Yes	Highest
Prawn	1	Pulse exposure: no Discard survival: no data	.	Lowest
Surf clam	1	Pulse exposure: no Discard survival: no data	.	Lowest

[1]Consistency can be assessed because, although only one study was found, there were multiple tests.

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Injury

Fishes: Twelve studies assessed injury in fishes, eight laboratory experiments (de Haan *et al*., 2009a; de Haan *et al*., 2009b; de Haan *et al*., 2013; de Haan *et al*., 2015; de Haan *et al*., 2016; Soetaert *et al*., 2016d; Desender *et al*., 2017) and four vessel-based catch studies (van Marlen *et al.*, 2005b; van Marlen *et al*., 2007; van Marlen *et al*., 2014; Soetaert *et al*., 2016c). Damage, when it occurred, was mainly in the form of spinal fractures or haemorrhages and these were often associated.

Two studies considered **sole**; one found no injuries in fish exposed to the pulse (one fish with a bleeding gill) and the other found fewer dorsal injuries but evidence of more ventral damage. One study found fewer plaice were less damaged by the pulse trawl than the beam trawl. The one study including **dab** found no injuries associated with pulse exposure. **Cod** was the most-studied species, being included in three vessel-based catch studies and five references reporting laboratory experiments. Of the 12 pieces of evidence (individual tests) presented across the studies, 11 of those confirmed injuries (in 158 out of 935 cod tested, or 17% overall occurrence). However, the occurrence of the injuries varied among the tests, with eight tests indicating that occurrence of injury was comparatively low (2-13%) and three indicating injury occurred in significant proportions (39-45%). The one study assessing **whiting** indicates a very slight effect, with 2% of the whiting injured. Two studies investigated **dogfish**, with no evidence of injuries occurring as a result of pulse exposure.

Invertebrates: One laboratory experiment assessed injuries in invertebrates (Soetaert *et al*., 2015). This found no injuries associated with pulse exposure in **ragworm** or **brown shrimp**.

Overall comments: injury

The evidence of injuries in cod is compelling, though the extent of the problem is not clear; two studies provided evidence that injuries were size-related and occurred only in large cod and their prevalence and extent also seems to be related to the specifics of the pulse characteristics used in individual studies or in the two different gears. It is unclear whether these injuries could induce mortality in the longer term. That dogfish are not injured can also be stated with confidence. Otherwise, there have been insufficient studies on the other fishes to form firm conclusions and the invertebrates have seen little attention.

	No. of studies	Effect?	Consistent results?	Confidence
Sole	2	No	No	Moderate
Plaice	1	Yes (less damage)	·	Lowest
Dab	1	No	·	Lowest
Cod	8	Yes (injury)	Yes	Highest
Whiting	1	Yes (injury)	·	Lowest
Dogfish	2	No	Yes	Highest
Brown shrimp	1	No	·	Lowest
Ragworm	1	No	·	Lowest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Reproduction

Two laboratory studies assessed reproductive effects (de Haan *et al*., 2009; Soetaert *et al*., 2016a). One study each found no effect of pulse exposure on egg production in either **dogfish** or **brown shrimp**. There have been insufficient studies of any species to form conclusions on the effects of pulse trawling on reproductive capabilities of fishes or invertebrates.

	No. of studies	Effect?	Consistent results?	Confidence
Dogfish	1	No	·	Lowest
Brown shrimp	1	No	·	Lowest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Illness and disease

Three laboratory experiments investigated whether pulse trawling alters the presence or prevalence of disease (van Marlen *et al.,* 2005b; de Haan *et al*., 2015; Soetaert *et al*., 2015; Soetaert *et al*., 2016a) and one study assessed blood parameters in pulse trawled **sole** and **plaice,** finding no difference between beam and pulse trawled fish. One study assessed **dab**, finding no effects on parasites or bacterial infection. Two studies considered **brown shrimp**; of the three pieces of evidence presented, one showed an increased occurrence of viral infection (at a high field strength) while the other two indicated no effects. One study included **ragworm**; this found no increase in disease indicators.

As with reproduction, there is insufficient information on the occurrence of disease to form firm conclusions. Given the evidence of injuries in cod, it is unfortunate that no studies to date have addressed whether there are longer-term indirect effects on illness or disease.

	No. of studies	Effect?	Consistent results?	Confidence
Sole and plaice	1	No	·	Lowest
Dab	1	No	·	Lowest
Brown shrimp	2	Yes (infection)	No	Moderate
Ragworm	1	No	·	Lowest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Behaviour

Fishes: Nine laboratory studies assessed behavioural effects (van Marlen *et al*., 2007; de Haan *et al*., 2009a; de Haan *et al*., 2009b; de Haan *et al*., 2013; de Haan *et al*., 2015; de Haan *et al*., 2016; Soetart *et al*., 2016b; Soetaert *et al*., 2016d; Desender *et al*., 2017). Behaviour was assessed in terms of the physical responses to pulse stimulation and/or effects on feeding behaviour.

One study investigated **sole**, finding cramp responses and escape behaviour. The single study on **dab** found a clear physical response to pulse stimulation (cramping and escape behaviour) and no effect on feeding.

Five studies assessed **cod** behaviour. All reported physical responses to pulse exposure (ranging from reflexes and muscle contractions to paralysis, seizures and disorientation). Four of the studies followed physical responses post-exposure, all of which reported recovery after either minutes or over a period of a few hours to a day. Two studies specifically addressed feeding behaviour. Neither provided clear evidence to support or refute an effect on feeding; both reported changes in feeding behaviour (e.g. no response or less responsive to food, lack of normal searching behaviour), but in one study this was mirrored by concurrent changes in the control fish and the other study reported both reductions and increases in feeding response, which did not appear to obviously scale with pulse exposure.

Three studies considered **dogfish**. Two investigated physical reactions, one finding little reaction but the other reporting a significant response (up to 90% of fish experiencing body contractions). All three studies investigated feeding behaviour; one found a weak dampening of feeding response and two found no effects.

Invertebrates: Four laboratory studies assessed behaviour in invertebrates (Smaal and Brummelhuis, 2005; van Marlen *et al*., 2009; Soetaert *et al*., 2015; Soetart *et al*., 2016a). The studies assessed a variety of taxa, three reporting individual species but the last one considering 18 taxa and (with the exception of prawn) combining results at higher taxonomic levels.

Three studies examined **ragworm**. None provided conclusive evidence on effects, with one reporting variable responses that only weakly related to pulse exposure, the second reporting jerky movements or no effects on response or food intake and the third (discussing polychaetes) no effect.

Two studies assessed **brown shrimp**. Both recorded consistent effects of pulse exposure on immediate behaviour (cramping followed by an escape response); one of the studies examined moulting behaviour and found no effects. Two studies examined **prawns**, one described them jumping but with reductions in feeding levels and the other recorded prawns on the bottom for one minute (though responsive when touched). One study found behavioural responses in **green crab**, with stiffening in response to the pulse and reductions/increased variability in food intake).

Two studies assessed **razor clams**, with both finding strong physical responses but of a differing nature (foot and siphon responses, but often with propulsion in one and shell closure in the other (reported as bivalves)); one of the studies also found no effects on digging or filtration in bivalves. The one study assessing **surf clams** reported no effect of

pulse exposure on behaviour. Two studies examined **starfish**, both finding no behavioural effects (one report discussing echinoderms generally).

The study describing responses in higher taxonomic levels reported crustaceans freezing, molluscs retreating into their shells and no reaction at all from polychaetes or echinoderms. With the exception of starfish, these are not completely consistent with results of the species-specific studies.

Overall comments: behaviour

Cod and dogfish are the best-studied of the species. Neither the effects on cod nor dogfish are consistent; all studies reported some form of immediate physical response to pulse exposure - but with varying degrees of prevalence and severity - and feeding behaviour varied among the studies. There are either too few studies on the other species of fish and invertebrate to form firm conclusions or, in the specific case of the invertebrates, inconsistent responses in the different studies.

	No. of studies	Effect?	Consistent results?	Confidence
Sole	1	Yes (reaction)	·	Lowest
Dab	1	Yes (response)	·	Lowest
Cod	5	Yes (response)	No	Moderate
Dogfish	3	Yes (response)	No	Moderate
Brown shrimp	2	Yes (response)	No	Moderate
Ragworm	3	Yes (response)[6]	No	Moderate
Green crab	1	Yes (response)	·	Lowest
Razor clam	2	Yes (response)[6]	No	Moderate
Common starfish	21	No[6]	Yes	Highest
Prawn	2	Yes (response) [6]	No	Moderate
Surf clam	1	No	·	Lowest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

The physical environment

Four studies assessed physical seabed disturbance. Two investigated vessel effort distribution; one using VMS data from the Dutch flatfish fleet (Turenhout *et al*., 2016) and one using modelling to predict changes in effort distribution under future pulse trawling scenarios (Batsleer *et al*., 2016). The other two investigated effects of pulse trawling on seabed parameters, one using modelling (ABPmer & Ichthys Marine, 2015), the other a combination of modelling and field experiments (Depestele *et al*., 2015) - both studies addressed seabed penetration and sediment mobilisation, with one of them also considering seabed bathymetry.

[6] Results presented at the level of crustacea, mollusca, polychaeta and Echinodermata.

Comparisons of **seabed penetration** of bottom gears are complicated by differences in the configuration of components within and between the gear types. One study predicted the same or shallower penetration for all individual pulse gear components compared to beam components and so a shallower overall penetration depth. The other study predicted deeper penetration of pulse shoes than beam shoes and deeper penetration of pulse electrodes than the smallest beam trawl tickler chain, but shallower penetration for all other gear components and so a shallower overall penetration relative to beam trawling. The slight differences for individual gear components can be attributed to the gear used in the two studies, with the former considering the HFK PulseWing and the latter the older, heavier Delmeco pulse trawl.

In the one study assessing it, **seabed bathymetry** (connected to penetration of the gear) was less effected by pulse than beam trawling. Both studies described less **sediment mobilisation** with pulse than beam trawling.

Of the two studies assessing **effort distribution**, the first showed a divergence of beam and pulse trawling before and after the implementation of pulse trawling, with increased pulse effort off Belgian, Dutch and eastern/south-eastern English coasts compared to a shift of the remaining beam fleet into offshore waters of the central/eastern North Sea. The second predicted a change in effort under a future discard ban, with a heavier presence in the Southern Bight and a small expansion into the coastal eastern North Sea (compared to a concentration of effort in the offshore eastern and central North Sea for beam trawling), though no clear differences in effort under a scenario of continued discarding.

Overall comments: The physical environment

Overall, pulse trawling seems to mobilise less of the seabed than beam trawling, primarily because the mechanical components of pulse trawls penetrate less deeply into the bed when averaged across the gear as a whole (although some of the evidence is based on predictions rather than empirical measurements). Pulse trawling effort has shifted into waters off the Dutch, Belgian and eastern/south-eastern English coasts and is predicted to further diverge between the beam and pulse trawl fleet under a discard ban, with the pulse fleet concentrating within the southern Bight and moving slightly into the coastal zone off eastern England.

	No. of studies	Effect?	Consistent results?	Confidence
Seabed penetration	2	Yes (less overall)	Yes	Highest
Seabed bathymetry	1	Yes	-	Lowest
Sediment mobilisation	2	Yes (less)	Yes	Highest
Effort distribution	2	Yes (shifts)	Yes	Highest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Socio-economics

Three studies directly addressed socio-economics, two using data analysis (Sys *et al*., 2016; Turenhout *et al*., 2016) and one statistical modelling (Batsleer *et al*., 2016). One study found changes in **fleet behaviour**, with fishing trips for the pulse fleet shortening over the years compared to some beam trawlers. Two studies report **financial effects** in terms of increased net revenue for pulse trawling due to significantly lower fuel costs.

Overall comments: Socio-economics

The studies provide clear evidence of changes in behaviour over time in the pulse fleet, as well as financial benefits. The data on which the assertions are based were not always fully analysed, did not always include the most recent data and come from only a small number of studies. The Dutch beam trawl fleet has transitioned to a pulse fishery and no studies have investigated the effect of this transition on other fisheries (commercial or recreational).

	No. of studies	Effect?	Consistent results?	Confidence
Fleet behaviour	1	Yes (displacement)	·	Lowest
Financial effects	2	Yes (increased revenue)	Yes	Highest

Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Data gaps

Table 4 summarises the evidence base, indicating the relative level of confidence that the evidence base is sufficient to resolve the topic in question and highlighting gaps in the research. Gaps exist where topics have not been reported, where the number of studies for a given topic is small and/or where the evidence base is inconsistent.

The studies consider four main topics: catches (landings and discards), ecological effects on non-target species (invertebrates and undersized fish) and those exposed to the pulse but not captured in the nets (i.e. escaping animals), physical impacts on the environment and socio-economic effects. Effects on water chemistry and nutrients have not been addressed to-date, neither have indirect effects on marine species and there is, thus far, a lack of large-scale field experiments on the ecosystem effects of pulse trawling.

Table 4: Summary of the evidence base on the effects of pulse trawling

	Total catch	Landings	Discards	Survival	Injury	Reproduction	Illness/disease	Behaviour	Physical environment	Socio-economics
Fishes										
Benthos										
Sole										

	Total catch	Landings	Discards	Survival	Injury	Reproduction	Illness/disease	Behaviour	Physical environment	Socio-economics
Plaice	Moderate	Moderate	Moderate	Moderate	Lowest	No studies	Lowest	No studies	Not applicable	Not applicable
Dab	No studies	No studies	No studies	Lowest	Lowest	No studies	Lowest	Lowest	Not applicable	Not applicable
Cod	Lowest	No studies	No studies	Highest	Highest	No studies	No studies	Moderate	Not applicable	Not applicable
Whiting	No studies	No studies	No studies	No studies	Lowest	No studies	No studies	No studies	Not applicable	Not applicable
Dogfish	No studies	Not applicable	No studies	Highest	Highest	Lowest	No studies	Moderate	Not applicable	Not applicable
Brown shrimp	No studies	Not applicable	No studies	Moderate	Lowest	Lowest	Moderate	Moderate	Not applicable	Not applicable
Ragworm	No studies	Not applicable	No studies	Moderate	Lowest	No studies	Lowest	Moderate	Not applicable	Not applicable
Green crab	No studies	Not applicable	No studies	Lowest	No studies	No studies	No studies	Lowest	Not applicable	Not applicable
Razor clam	No studies	Not applicable	No studies	Moderate	No studies	No studies	No studies	Moderate	Not applicable	Not applicable
Common starfish	No studies	Not applicable	No studies	Highest	No studies	No studies	No studies	Highest	Not applicable	Not applicable
Prawn	No studies	Not applicable	No studies	Lowest	No studies	No studies	No studies	Moderate	Not applicable	Not applicable
Surf clam	No studies	Not applicable	No studies	Lowest	No studies	No studies	No studies	Lowest	Not applicable	Not applicable
Penetration	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Highest	Not applicable
Bathymetry	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Lowest	Not applicable
Sediment mobilisation	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Highest	Not applicable
Effort distribution	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Highest	Not applicable
Fleet behaviour	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Lowest
Financial parameters	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Highest

Not applicable	
No studies found during the review	
Relative confidence that evidence base resolves topic	
Highest (2 or more studies, consistent)	
Moderate (2 or more studies, inconsistent)	
Lowest (<2 studies)	

Catches, landings and discards

There are relatively few reported pulse trawl *versus* beam trawl comparisons of catches, landings and discards. The studies using only pulse trawling are useful for gaining understanding of the efficiency of the system, but comparative studies are still required to ascertain how catches compare with traditional beam trawling.

The results of catch comparisons depend on the metrics used; catches per area or hour are often reported in the studies but these are only useful in the context of total fishing by the fleet, not effects per vessel (e.g. pulse vessels have lower catches per hour, but may fish for longer). Reported differences in discards may be related to differences in catch composition, which has not always been fully addressed, and the comparisons of total discards could give a different picture than when comparing discarding rate. Pulse trawl catches must be set within the context of beam trawls in a systematic manner if the data are to be used to determine whether pulse trawling generates greater catches or landings of target species

and fewer discards of undersized and non-target fishes and benthic invertebrates. Research to fill these gaps could include:

- Comparative studies of pulse and beam trawling, including both the Delmeco and the HFK systems and accounting for a range of conditions over the year and on different grounds.
- Surveys of catches and discards in fishing grounds that are only accessible to pulse trawling and not conventional beam trawling (soft grounds). Clearly there can be no direct beam trawling comparator, but the data would provide understanding of catch composition and discard rates in these 'new' grounds and be compared with data from the wider pulse and beam fishery.
- Re-analysis of the existing data to include more targeted metrics such as discard rates and sole landings as a comparator (e.g. the quantity of plaice discards per weight of sole landed), as well as an assessment of full catch composition.

Non-target and uncaptured species

The evidence on effects of electrical pulse exposure originates from laboratory experiments. One of the clearest messages, perhaps predictably, from the laboratory experiments is that the effects of pulse exposure can vary quite significantly depending on the strength of the individual pulse parameters. This is true across a range of variables, including behaviour, injury and survival. The effect is difficult to define, because several of the early studies were prevented from listing pulse parameters due to commercial restrictions and because there has been inconsistency in the types of pulse parameters either utilised or reported – with 15 different pulse parameters listed across the records and a range of possible settings for many of the parameters, this is a significant limitation. Because the early studies served partly to determine the parameter ranges that could be employed in the environment, some studies also report effects that may not be seen in the fishery because they exceed the current permitted maxima for particular pulse parameters. Moreover, there are gaps in understanding on which pulse parameters are important for determining species' responses to pulse exposure, which means it is difficult to determine whether individual studies have addressed the correct parameters. This makes for a confusing picture and has generally reduced confidence in whether the evidence base is sufficient to confidently resolve some of the issues.

One can trace an increase in knowledge of the technicalities of the pulse gear as the evidence base has developed, which is manifested through more carefully planned experiments, the inclusion of a wider range of pulse parameters and better reporting of pulse characteristics. However, the lack of consistency in experimental approaches that has resulted from this learning process and in the associated reporting does make it difficult to piece together the evidence against a backdrop of complex effects of electrical shock on marine organisms (see Appendix 3 for notes on important methodological parameters).

Differences in the methodologies used in the experiments also present a problem, because some methodological choices will affect the outcome of the experiments. In a situation where a number of factors including the orientation of an animal in relation to the electrodes, its length or its weight, the strength of the electrical field, the length of the observation period, or

the value of any one of a range of technical parameters can all significantly influence how the animal is affected, it will be difficult to draw firm conclusions when studies do not hold these parameters constant. And with such a wide range of pulse characteristics being implicated in ecological effects on the species, it is a complex challenge for the researchers attempting to provide the evidence. Some of the studies have attempted to incorporate variations in a range of the parameters, but have been limited by small sample sizes in the various permutations.

There are overall gaps in particular topics; for example, the effects of pulse trawling on individuals and populations in the longer-term is not well-studied and reproduction and disease are particularly poorly covered. There is also a lack of understanding on the effects of multiple exposures to the electrical field: there are three circumstances in which individual animals can be subject to multiple exposures - individual animals exposed multiple times over the course of a few seconds as the trawl gear passes overhead, animals escaping forwards but not leaving the immediate vicinity may then be re-exposed later in the same haul and, finally, those that escape but do not leave the locale may be exposed within a reasonably short timeframe to further hauls by the same or other fishing vessels - and only the first has been specifically addressed in studies at the time of writing.

There would be considerable value in generating evidence on longer-term impacts of pulse trawling which is currently absent and opportunities to conduct large scale experiments have been missed with a wholesale change to pulse trawling. The lack of comparison to conventional beam trawling in many of the studies creates a notable gap in understanding. Fundamentally, given the transition of the Dutch sole industry from beam to pulse trawling and the potential for other EU member states to follow, the key question is not one of whether the pulse trawl effects the ecosystem, but whether it has a greater than, lesser, or equal effect to traditional beam trawling. Any future work will be most useful when it compares pulse to beam trawling. Research that could make a useful contribution to the evidence base on non-target and uncaptured species includes:

- Identification of any additional species that should be included in pulse trawling research, to consider migratory species that could be exposed to pulse trawling (e.g. eels and sea trout), other species of conservation or societal importance and those indirectly affected by pulse trawling through, for example, food-web effects.
- Assessment of the implications of pulse trawling for species and habitats protected under conservation designations, considering food-web or other indirect effects (acknowledging that the necessary information may not always be readily available).
- Further analysis of the existing data on survival, behaviour, injury, reproduction and disease, to ascertain which of the results already produced are relevant to the pulse characteristics used in the fishery. It may not be possible to undertake a full meta-analysis on some of these issues, as the evidence base is rather small. However, we consider there is merit in combining the data from individual studies in an overall statistical framework, where feasible.
- Systematic lab and/or field experiments to assess the impacts of multiple pulse exposures and longer-term survival and health for the key fish or invertebrate species. Could utilise tagging studies or other *in-situ* methods for larger species.

Physical effects

There is sufficient evidence to be relatively confident that pulse trawling does not disturb the seabed as much as beam trawling overall, though nothing was published at the time of writing on whether it may alter water chemistry. While these factors may be considered less of an immediate priority than effects on key species, the ecosystem is connected and the physical environment shapes the biological one so they are important in this respect (particularly porewater chemistry with respect to benthic invertebrates). Some further effort towards confirming whether pulse trawling generates less seabed sediment disturbance than traditional beam trawling across the range of conditions in which it is deployed (and on whether this is as true for the beam-mounted Delmeco system as well as the limited-contact HFK PulseWing) would also be useful - although this is a function of the weight and drag of the system, rather than the electrical characteristics *per se,* it is still a component of pulse trawling.

There is a lack of information on how the physical properties of the environment could affect the electrical shock experienced by the animals. Sea water salinity, temperature, turbidity and seabed type all affect conductivity (see Appendix 3). Considering that changes in pulse properties can increase or decrease the severity of pulse effects on animals and that fishers' may alter the parameters (adaptation of up to 20% of the nominal settings according to season; de Haan *et al*., 2009a), a better understanding of how variables such as seawater salinity or temperature and seabed type affect pulse transmission is also needed.

Effort has shifted with the onset of pulse trawling and is predicted to diverge further from beam trawling in future under a discard ban. This change, which brings pulse trawling closer to the English coast (though note the voluntary exclusion zone currently in place for the Dutch pulse fishery), is reported to be due to the reduced weight of the pulse gear *c.f.* conventional beam trawls allowing deployment on softer grounds (see Turenhout *et al*., 2016), though there is not much formal evidence from the review to indicate the extent to which the vessels are utilising previously unfished grounds nor on whether this is true of both the beam-based Delmeco pulse and the low-contact HFK PulseWing.

Information on changes in effort distribution, particularly in relation to shifts into 'new' fishing grounds not previously accessible to the flatfish fleet, is found in only one of the studies. Effort allocation will be important in understanding data on changing catches and this has not been sufficiently addressed to-date. It is an important issue, particularly given the lack of clarity on whether the pulse fishery continues to expand into new 'virgin' grounds.

Research to fill gaps on physical aspects of pulse trawling could include:

- Field studies to compare the effects of pulse trawling to beam trawling on seabed structure, including sediment mobilisation, compaction and changes in bathymetry.
- Lab and/or field trials to determine the effects of differing seawater salinity, temperature and seabed type on conductivity and the strength of the electrical field.

- Analysis of VMS and logbook data to gain a greater understanding of spatio-temporal effort distribution across the fishing grounds, including any areas accessible to pulse but not beam trawls (may require the adoption of new pulse trawling metier identifiers).

Socio-economic effects

The information on socio-economic factors has mainly been presented at the aggregate level; for example, the pulse fleet is reported to have generated revenue of ~17 million Euros in 2014 while the beam trawl fleet only broke even (Turenhout *et al*., 2016). While this illustrates the financial situation for the whole fleet, it does not provide comprehensive information on how the subtleties of the various factors contributing to profitability combine. That shifting to pulse trawling represents a clear financial gain for the fishery is evident, but there is benefit in a comprehensive review of the financial data to tease apart the relative contributions of the various factors to an increase in total profits including, for example, a simple increase in the number of vessels using the pulse gear *versus* traditional beam trawling, increases in the value of sole quotas, increased fuel efficiency and a suggested better quality of fish landed by pulse trawlers.

None of the records provided information on how increases in pulse fishing may be affecting the small inshore fisheries at the boundaries of the pulse grounds or how it may affect recreational sea angling returns. The evidence on the spatial overlaps between the activities of different fisheries and the catches taken of key species by those fisheries was not readily available for analysis. The collection and analysis of this data is identified as a gap that should be addressed.

Specifically, concerns have been reported by both stakeholder groups - increases in dead animals in the inshore grounds after pulse trawling (UK inshore fishermen, see section on stakeholder meetings) and reductions in cod and seabass takes in the angling industry (Sportvisserij Nederland, pers. comm.). Thus, further research from a socio-economic perspective could usefully include:

- A comprehensive and neutral assessment of the socio-economic factors associated with pulse trawling, to include data from the pre-pulse years (before 2008/2009) and the most up-to-date data, to consider year-on-year trends in aggregate variables but also on a sectoral and per vessel basis.

- Assessment of the expansion of the pulse fishery from the perspective of small inshore fisheries and angling, including engagement with international (e.g. Belgian, Dutch, British) stakeholders. Consideration of whether increased catches and revenue in the pulse fishery has affected inshore fisheries and angling.

Stakeholder meetings

Two UK stakeholder meetings were undertaken to fulfil objective 4 of this project (deliver findings to inshore North Sea UK fishing interests). One took place in Lowestoft on the 14th of November 2017 and the other in Ramsgate on the 21st of November 2017.

The overarching message from the fishing stakeholders at both meetings was frustration and anger at a fishery that is perceived to be damaging, impacting significantly on other fisheries and expanding unchecked against both EU regulations and the precautionary principle. There are fears, more predominantly in Ramsgate, that pulse trawling could decimate the sole fishery in the North Sea and thus the livelihoods of local trawlers. Although it was not always clear where the industry felt that research could be done, or even be helpful, it was clear that they are extremely unhappy with the status quo and want 'something' to be done. There is also a reasonably widespread concern about the ethics of using fishing with electricity.

Headline messages from the stakeholder groups were:

- A belief that pulse fishing is depleting sole stocks and killing the seabed invertebrates that they and other fish species depend on for food.
- Distrust in the Dutch research, ambiguity about the Belgian research.
- Anger that Cefas/Defra has not addressed pulse trawling in the nearly 10 years since it began.
- Suspicion that pulse trawlers may be fishing past the 12 nm line (evidence cited as the ability to detect the Dutch fishers disabling their AIS).
- Suspicion that plaice trawlers and inshore vessels will also be equipped with pulse gear.
- A desire for a temporary prevention of pulse fishing in the outer Thames area and completely in UK waters after EU Exit.
- Distrust that the UK government will take any steps to rectify the problems they cite.
- Buy-in from at least some of the fishers to work with Cefas to study the effects of pulse trawling, both in evidence gathering and at the planning stages. A view that this should be directly between Cefas and the fishers and not through third parties.

Editorial note: since the stakeholder meetings, the Dutch industry and UK fishers have reached an interim voluntary spatial separation agreement for the Dutch fishers to avoid pulse trawling in three areas around the south-east English coast (Ramsgate/Thames and two areas off Lowestoft). The agreement came into effect from the 15th of February, 2018 (see http://nffo.org.uk/uploads/attachment/145/pulse-interim-spatial-separation-agreement.pdf).

Conclusions and recommendations for a research programme

The systematic literature search identified twenty-eight references that address the effects of flatfish pulse trawling on the marine ecosystem. These comprise both studies on board commercial pulse trawlers and dedicated laboratory experiments, as well as a few data analysis and modelling studies. The majority of the studies originate from Dutch research organisations (primarily Wageningen Marine Research), but there is also a significant contribution from Belgian researchers. There has been limited UK involvement in the research, to date. Seventeen species or species groups have been investigated; six fish and

eleven[7] benthic invertebrates. Most of the species have been included in only one or two studies each. Sole, plaice and cod are the best-studied.

As a body of evidence on a new fishing technique, it is currently limited in terms of determining whether the existing legislative ban on the practice should be removed (the pulse fishery is currently operating under derogation and pilot study arrangement). It is worth noting that additional evidence may exist that has not been retrieved by the systematic search, including studies that are currently in analysis or preparation and those currently published only as internal reports. There is always potential that the search terms used in the systematic search do not capture all of the evidence on the topic being investigated. Moreover, it is possible the confidence assessment may have overlooked some more concrete evidence – topics with only one record would be assigned lowest confidence, but these records could have included a study of many hundreds of test animals.

While there is a growing body of evidence on the impacts of pulse trawling, this evidence addresses many aspects of a complex subject. The main limitations with the evidence base revolve around insufficient numbers of studies comparing pulse to conventional beam trawling for some topics, inconsistency in the application and reporting of the fifteen different pulse parameters listed across the studies, a lack of clarity on which are the key parameters that must be included in studies, lack of clarity on differences in methodological approach and inconsistency in the use of formal statistical analysis of study data. These issues do not affect each of the studies, but are common in some cases, particularly (and, perhaps, understandably) in the earlier work. The lack of studies for specific species with respect to some of the topics is also a limitation.

We have most confidence in the bodies of evidence that hail from multiple studies that present consistent results. In line with our assessment of whether the bodies of evidence are sufficient to allow the topics to be resolved, we can conclude the following with respect to pulse trawling:

- Total catch per haul for pulse trawling is much less than in conventional beam trawling. There is a reduction, both in terms of the overall catch taken per fished area and the catch taken per hour.
- There is no substantial difference in discard rates for plaice and sole when using the pulse trawl (the same proportion of the catch is thrown back). Discards of benthic invertebrates are lower than when beam trawling.
- Discard survival estimates for plaice and sole are similar for beam and pulse trawls (15-30%).
- Exposure to electrical pulses under laboratory conditions does not affect survival in cod, dogfish or common starfish
- Cod can be injured by pulse trawling, most commonly in the form of haemorrhages or spinal damage. The prevalence and extent of the problem is unclear, as is whether

[7] Two of the studies included a fairly large number of benthic invertebrate taxa - Teal et al.'s (2014) study used seabed samples containing 23 invertebrate taxa and Small and Brammelhuis' (2005) experimented on 18. Teal et al.'s study showed no clear patterns of response to pulse trawling and Small and Brummelhuis returned no significant effects from their experiments so, for simplicity, the data from their studies, with the exception of taxa also included in other studies (common starfish, prawns, ragworms, razor clams, prickly cockles and swimming, hermit and helmet crabs) were aggregated to 'benthos' for the purposes of the review.

these injuries could induce mortality in later life. Dogfish are not injured by pulse trawling.

- Pulse trawling induces behavioural change in cod, ranging from reflexes and muscle contractions to paralysis, seizures and disorientation; there is, however, a lack of clarity on the severity of the response in cod exposed to pulse settings used on the fishing grounds. Recovery occurs within a day.
- Pulse trawling may induce some form of behavioural change in dogfish, but the extent is unclear. There is no behavioural effect on common starfish.
- Pulse trawling disturbs the seabed less through seabed penetration and sediment mobilisation than beam trawling.
- Effort distribution has diverged between the pulse and beam trawl fleet, with the pulse fleet concentrated more around the Dutch, Belgian and eastern/south-eastern English coasts.
- There is a clear economic benefit in pulse trawling compared to beam trawling at the fleet level through reduced fuel consumption.

Proposed work

The research on pulse trawling provides the evidence base that will enable the EU to reach a decision on whether to lift the current ban. There are relatively few areas in which we can confidently draw conclusions at the present time and there are clear gaps in some key areas related to longer-term implications for animal population health. Therefore, a programme of works is recommended to solidify and expand the evidence base, particularly focusing on comparisons to conventional beam trawling. The Data Gaps section above identified areas where existing knowledge could usefully be supplemented by new work. These pieces of work range from desk based studies to systematic laboratory experiments and field studies. There are three options for future work to address the recognized knowledge gaps, each of which has a different scale and funding implications:

Option 1: *Comprehensive programme of laboratory and field research and desk studies*:

Fundamental research on pulse characteristics on selected species, replicate previous laboratory experiments, conducting between-gear comparative field trials, delivering statistically designed experiments to assess comparative impacts of beam and pulse trawling; provide role as independent reviewer and support for Dutch/Belgian research. This option has a high resource requirement and would deliver detailed, complete and fully-independent evidence.

Option 2: *Programme of field research and desk-based studies*:

Conducting between-gear comparative field trials, delivering statistically designed experiments to assess comparative impacts of beam and pulse trawling; data analysis, provide role as independent reviewer and support for Dutch/Belgian research. This has a moderate resource requirement, it would provide evidence from applied and practical work, but without laboratory-based studies it would not generate fundamental evidence.

Option 3: *Programme of selected desk-based studies*:

Further analyses of existing information and data from studies conducted by others, provide a role as independent reviewer and support for Dutch/Belgian research. This option would produce no independent, new evidence and has a low resource requirement.

Option 1 would entail a significant resource investment so, while comprehensive and neutral (fully independent), it may not be feasible. The Dutch have recently begun a multi-year programme of fundamental experimental work and it would be more efficient to investigate the potential to provide input (suggestions on target species and methodologies, advice on data interpretation, etc.) to that, rather than undertake a parallel independent programme of laboratory work. Moreover, repeating experiments conducted elsewhere may raise ethical issues considering that some of the experimental end-points could result in discomfort or injury to the fish. Option 3 would be the cheapest because it consists only of desk-based work. However, there is benefit in commissioning a set of independent field studies to compare key parameters between pulse and beam trawling to deliver evidence that is tailored to the concerns of the UK fishing industry. Option 2, therefore, is the recommended approach. The programme of field research and desk studies could then include:

Field studies

1. Comparative studies of pulse and beam trawling, including both pulse systems and accounting for a range of fishing intensities and conditions (to include the 'new' grounds not accessible to conventional beam trawlers). Methods would include expansion of existing observer and self-sampling programmes and/or dedicated sea trials, which would assess impacts associated with the landing of a unit weight of the target catch.

2. Experiments to determine the ecosystem effects of pulse trawling. The opportunity to conduct large scale ecological experiments to determine the effect of pulse trawling has been missed. We propose setting up a statistically designed experiment that would enable pulse trawlers to operate in some fishing areas but exclude them from others, in which only conventional beam trawlers can operate. The methodological design should also include reference areas not subject to pulse or beam trawling, where possible, to determine the impact of pulse trawling against a no-trawling scenario (recognising that this may be difficult to achieve in the southern North Sea grounds). All field studies would be dependent on positive collaboration with one or more pulse trawl operators.

Desk studies

3. Further analysis of the existing data on survival, behaviour, injury, reproduction and disease, to ascertain which of the results already produced are relevant to the pulse characteristics used in the fishery. Could be conducted in collaboration with Dutch and Belgian colleagues.

4. Initial assessment of implications of pulse trawling for species and habitats in UK waters protected under conservation designations (e.g. harbour porpoise protected

under the Southern North Sea SAC). Should consider foodweb or other indirect effects for key species.

5. Analysis of fisheries data to gain a greater understanding of spatio-temporal effort distribution across the fishing grounds, including any areas accessible to pulse but not beam trawls. This would only be possible with provision of data from the Dutch and Belgian authorities and would be compared with effort exerted by other fleets.

6. An economic assessment of the expansion of the pulse fishery from the perspective of potential impacts on small vessel inshore fisheries and angling. Can be conducted at a UK level, but a more comprehensive picture will emerge from engagement with, and consideration of, international stakeholder groups (e.g. Dutch, Belgian and French anglers). This would use outputs from 1 and 5.

Independent reviewer

7. Support for the research conducted in other European countries in the form of contributing to research plans, reviewing documents and potentially providing staff for practical research. To include representation at relevant ICES groups and other meetings.

This programme of work would provide objective scientific evidence to allow Defra to decide whether the catches, landings and discards from pulse trawling out-perform conventional beam trawling and how they fare with respect to landing obligations in the flatfish fishery, whether the ecosystem effects of pulse trawling are better, worse or the same as beam trawling; where and when the flatfish fishery is operating and whether the fishing grounds are expanding and, lastly, how the level of catches and the environmental effects of flatfish pulse trawling are impacting inshore fisheries and recreational angling.

It is considered that the priority areas for study are the ecosystem surveys and experiments on the fishing grounds, the comparative trials between beam and pulse trawls, and the economic analysis of the implications of the new pulse trawl fleet on all the effected fisheries. Research in these areas will address the key management questions in terms of understanding the performance of the two gears, the effect on the ecosystem of the pulse technology and the implications for fisheries beyond the Dutch flatfish trawl fishery.

References

ABPmer & Ichthys Marine (2015) Supporting Risk-Based Assessments of Fisheries in MPAs, Final Report.ABPmer Report No. R.2551. A report produced by ABPmer for National Federation of Fishermen's Organisations, December 2015.

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? J. Fisheries Research 174 118–128

Cefas (2005) Fishing gears with mitigating ecological impacts. Defra project MF0706. SID5 Research Project Final Report

de Haan, D., van Marlen, B., Kristiansen, T.S. and Fosseidengen, J.E. (2009a) The effect of pulse stimulation on biota - research in relation to ICES advice - progress report on the effects on cod. Report no C098/08, Wageningen IMARES

de Haan, D., van Marlen, B., Velzenboear, I. and van der Heul, J. (2009b) The effects of pulse stimulation on biota - research in relation to ICES advice - effects on dogfish. Report no C105/09 Wageningen IMARES

de Haan, D., Fosseidengen, J.E., Fjelldal, P.G. and Burggraaf, D. (2011) The effects of electric pulse stimulation to juvenile cod and cod of commercial landing size. IMARES Wageningen UR Report number C141/11

de Haan, D., Soetaert, M. and Verschueren, B. (2013) The effects of electrical pulse stimulation on cultured adult cod, continued research 2013 IMARES Wageningen UR, Report number C183/13

Haan, D., Haenen, O., Chen, C., Hofman, A., van Es, Y., Burggraaf, D. and Blom, E. (2015) Pulse trawl fishing: The effects on dab (*Limanda limanda*). Report number C171/14

de Haan, D.; Fosseidengen, J. E.; Fjelldal, P. G.; Burggraaf, D.; 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 73(6), 1557-1569

Depestele, J., Ivanovic´, A., Degrendele, K., Esmaeili, M., Polet, H., Roche, M., Summerbell, K., Teal, L.R., Vanelslander, B. and O'Neill, F.G. (2015) Measuring and assessing the physical impact of beam trawling ICES Journal of Marine Science doi:101093/icesjms/fsv056

Desender, M., Kajiura, S., Ampe, B., Dumolein, L., Polet, H., Chiers, K., and Decostere, A (2017) Pulse trawling: Evaluating its impact on prey detection by small-spotted catshark (Scyliorhinus canicula) JOURNAL OF EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY, 486, 336-343

EU, 1998. Council Regulation (EC) No. 850/98 of 30 March 1998 for the Conservation of Fishery Resources through Technical Measures for the Protection of Juveniles of Marine Organisms (OJL 125, 27.4.1998) (55pp).

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.

Quijrijns, F., Strietman, W. J., van Marlen, B., Rasenberg, M., and Smith, S. R. (2015). Flatfish pulse fishing. Research results and knowledge gaps II. Report C091/15. 39 pp.

Rasenberg, M., van Overzee, H., Quirijns, F., Warmerdam, M., van Os, B. and Rink, G. (2013) Monitoring catches in the pulse fishery. IMARES Report number C122/13

Rijnsdorp, A., Dick de Haan, Sarah Smith, Wouter Jan Strietman (2016). Pulse fishing and its effects on the marine ecosystem and fisheries - An update of the scientific knowledge. Wageningen, Wageningen Marine Research (University & Research centre), Wageningen Marine Research report C117/16, 30 pages.

Smaal, A.C. & Brummelhuis, E. (2005). Onderzoek naar mogelijke effecten van de pulskor op bodemdieren. In Dutch.

Soetaert, M., Chiers, K., Duchateau, L., Polet, H., Verschueren, B. and Decostere, A. (2015) Determining the safety range of electrical pulses for two benthic invertebrates: brown shrimp (*Crangon crangon*) and ragworm (*Alitta virens*). ICES Journal of Marine Science 72(3), 973-980

Soetaert, M., Verschueren, B., Chiers, K., Duchateau, L., Polet, H. and Decostere, A (2016a) Laboratory Study of the Impact of Repetitive Electrical and Mechanical Stimulation on Brown Shrimp *Crangon crangon* MARINE AND COASTAL FISHERIES 8(1), 404-411

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

Soetaert, M., Lenoir, H. and Verschueren, B. (2016c) Reducing bycatch in beam trawls and electrotrawls with (electrified) benthos release panels ICES Journal of Marine Science 73(9), 2370–2379.

Soetaert, M., de Haan, D., Verschueren, B., Decostere, A., Puvanendran, V., Saunders, J., Polet, H. and Chiers, K. (2016d) Atlantic Cod Show a Highly Variable Sensitivity to Electric-Induced Spinal Injuries. Marine and Coastal Fisheries Dynamics Management and Ecosystem Science 8(1), 412-424

Steenbergen, J. and van Marlen, B. (2009) Landings and discards on the pulse trawler MFV Vertrouwen. TX68 in 2009. IMARES Report Number C111/09

Sys, K., Poos, J.J., van Meense, J., Polet, H. and Buysse, J. (2016) Competitive interactions between two fishing fleets in the North Sea ICES Journal of Marine Science (2016), 73(6), 1485–1493.

Teal, L.R., Depestele, J., O'Neill, B., Craeymaersch, J., van Denderen, D., Parker, R., Perdon, J., Polet, H., Rasenberg, M., Vanelslander, B. and Rijnsdorp, A.D. (2014) Effects of beam and pulse trawling on the benthic ecosystem IMARES Wageningen UR, 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.; 18 fig.; 1 tab.; 5 ref.

Uhlmann, S.S., Theunynck, R., Ampe, B., Desender, M., Soetaert1, M. and Depestele, J. (2016) Injury, reflex impairment, and survival of beam-trawled flatfishICES Journal of Marine Science, 73(4), 1244–1254.

van der Reijden, K.J., Molenaar, P., Chen, C., Uhlmann, S.S., Goudswaard, P.C. and van Marlen, B. Survival of undersized plaice (*Pleuronectes platessa*), sole (*Solea solea*), and

dab (*Limanda limanda*) in North Sea pulse-trawl fisheries ICES Journal of Marine Science, 74(6), 1672–1680.

van Marlen, B., Ybema, S., Kraayenoord, A., de Vries, M. & Rink, G. (2005a). Vergelijking van vangsten van een 12m pulskor met een conventionele wekkerboomkor. RIVO-rapp. C043/05. RIVO, IJmuiden. In Dutch.

Van Marlen, B., van der Vis, J.W., Groeneveld, K., Groor, P., Warmerdam, M., Dekkeer, R., Lambooij, E., Kals, J., Veldman, M. & Gerritzen, M. (2005b). Overlevening en fysieke conditie van tong en schol gevangen met een 12 m pulskor en een conventionele wekkerboomkor. RIVO-rapp. C044/05. RIVO, IJmuiden. In Dutch.

van Marlen, B., Grift, R., van Keeken, O., Ybema, M.S. and van Hal, R. (2006) Performance of pulse trawling compared to conventional beam trawling. IMARES Report Number: C014/06

van Marlen, B., v.d. Vis, H., de Haan, D., Burggraaf, D., van der Heul, J. and Terlouw, A. (2007) The effect of pulse stimulation on biota - research in relation to ICES advice - progress report with preliminary results. Report no C098/07, Wageningen IMARES

van Marlen, B., de Haan, D., van Gool, A. and Burggraaf, D. (2009) The effect of pulse stimulation on biota - research in relation to ICES advice - progress report on the effects on benthic invertebrates. Report no C103/09 IMARES Wageningen

van Marlen, B., Wiegerinck, 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

Appendix 1: Summary field notes for Netherlands fact-finding trip (May 2017)

- Cefas scientists visited key stakeholders associated with the development and use of the pulse trawl used by the Dutch fishing fleet.
- Motivated by high fuel consumption and oil prices and the impact of conventional beam trawls, pulse trawl technology has been developing since the 1970s and is continuing.
- The SumWing is an innovative alternative to the beam component of a beam trawl, which reduces the impact on the seafloor and reduces fuel costs. The SumWing has been combined with pulse trawl technology and is now used by almost all Dutch vessels when targeting sole (around 74 vessels actively using their licences).
- The pace of development of the pulse technology accelerated when the Dutch Ministry backed the development process. There has been pressure from the Dutch fishing industry on the Dutch Ministry to enable more vessels to use pulse trawls.
- Derogation to allow the use of pulse trawls has been awarded since 2005 to allow pulse trawling on 5 % of the total number of vessels and, due to it being defined as an innovative gear subject to related scientific studies, 100 % of the sole targeting fleet are currently licenced.
- Pulse trawling is suitable only when targeting sole (and brown shrimp, not considered here), it is less efficient than conventional beam trawl at catching other commercial species, such as plaice.
- It is not viable to use the pulse technology unless vessels have sufficient sole quota; one UK (flagged vessel) beam trawler has rejected the use of pulse trawls as it has insufficient sole quota.
- The pulse trawl is a commercial success. Companies that were making substantial financial losses when using conventional beam trawls when the oil price was high are now making substantial profits.
- There are technical regulations on the use of pulse trawls, these are based on what has developed under the commercial application of the gear. Additional work to define a regulatory framework and protocols is in progress.
- Substantial evidence has been collected on the performance of pulse trawls, however, the emphasis of trials so far has been to demonstrate the positive commercial application of the technology but without a fundamental understanding of how the technology works.
- Without tickler chains, the catch of benthos and sediment is reduced substantially. Evidence on the reduction of fish bycatch (particularly small plaice) in pulse trawls is inconsistent; an issue remains with substantial levels of unwanted catches of plaice.
- The survival rate of discarded plaice is perceived to be high but this is not substantiated with trials undertaken by WMR (15% discard survival).
- A new 2.5 M Euro Dutch research programme is commencing on pulse trawling impacts. This will focus on understanding the fundamental process of the capture method and the influence of different pulse characteristics. The aim is to develop a mechanistic model that will enable predictions of the effect of electric pulses on different organisms.
- In earlier trials, owing to commercial sensitivities, the characteristics of the pulse being used in the trawls and in experiments was not known. Further research is planned on understanding the effect of changing the pulse characteristics, the damage caused by the pulse to the spine of some size classes and species of fish and on benthos, the chemical effect on nutrients in the sediment, and the effect on elasmobranch species that use electroreceptors to find food.
- WMR are supportive of collaboration with Cefas. It was suggested that Cefas help to provide independent evaluations and reviews of the research done and it was suggested that a collaborative project focussed on the east coast of England would be possible.

Cefas, June 2017

Appendix 2: Data extracted from the references included in the pulse trawling review

Catches, landings and discards

Aims	Evidence base	Reported results and comment
Total catch		
van Marlen *et al*., 2014: Compare catches between beam and two types of pulse and assess fuel savings.	Total of 45 beam trawl hauls, 48 with DELMECO pulse and 45 with PulseWing (33 hauls sampled for discards; 25 paired for beam v pulse for **plaice** and 33 for **sole**).	Total catch: 52% reduction by area with pulse; 63% reduction by hour, **cod** catch 69% reduction. Caught fewer undersized **plaice**, fewer small **sole**, no difference in larger sizes of **plaice.**
Uhlmann *et al*., 2016: To investigate vitality measures for beam trawled flatfish.	Three experiments (30 hauls beam, 21 hauls pulse) to identify and test reflex parameters for **plaice** and **sole**; total catch weight was measured in 16 hauls and length measurements were taken for ~400 fish.	Catch per haul larger on beam than pulse (mean 1599 kg vs 601 kg). Overall **plaice** and **sole** caught were smaller with pulse than beam (TL 25 cm vs 28 cm; 25 cm v 28 cm; but based on low numbers).
Rasenberg *et al*. (2013): To set up a catch monitoring program for the Dutch pulse fishery, consisting of a self-sampling program and independent observer trips.	A catch monitoring program consisting of 25 vessels participating in a self-sampling program and ten observer trips on different vessels and fishing grounds throughout the year.	Self-sampling program showed a catch composition of 31% landings, 17% fish discards, 18% benthos, and 34% debris. Observer program: 29% landings, 29% fish discards and 42% benthic species and debris.
Van Marlen *et al.,* (2005a): Catch comparison 12m pulse trawl (Delmeco) *vs* conventional beam trawl with tickler chains on research vessel.	67 hauls for catch comparison, starboard with conventional gear and portside with pulse. Tow duration 64-126 min. at 5.5 knots. Weight and length of total catch, landings and discards of fishes and sole and plaice >MLS<. Weight of total benthos, *Acanthocardia echinata* and *Arctica islandica* and for 17 hauls also swimming, hermit and helmet crabs.	Results expressed in kg/h. Significant reduction in pulse trawl **total catch** (-24%). Significantly less **benthos** (-25%) *A. echinata* reduced by 78%. No significant differences for *A. islandica*, swimming, hermit and helmet crabs.
Landings		
van Marlen *et al*., 2014: Compare catches between beam and two	Total of 45 beam trawl hauls, 48 with DELMECO and 45 with HFK (33 hauls sampled for discards; 25 paired for beam v pulse	A 20% reduction in total landings by area, but no difference in landings by area fished for **plaice** and **sole**. Total landings reduced by 38% by hour fished; **sole** landings 79 % of beam

Aims	Evidence base	Reported results and comment
types of pulse and assess fuel savings	for plaice and 33 for sole.	landings (skipper records) and 86% of beam landings (auction records), though modelling estimates tendency to catch somewhat more sole. **Plaice** 28% reduction in landings per hour with pulse.
van Marlen *et al*., 2006: To appraise the performance of pulse beam versus conventional tickler chain beam trawls	Nine fishing trips (67 hauls) with observers on a pulse trawl vessel and two beam trawlers;f comparative catching ability. Five of these comparable trips were analysed.	Landings increased by 1% by area for sole and decreased by 17% for **plaice**. By hour landings of **sole** reduced by 22% and for **plaice** 36%. Total landings per hour reduced by 32% with the pulse.
Rasenberg *et al*. (2013): To set up a catch monitoring program for the Dutch pulse fishery, consisting of a self-sampling program and independent observer trips.	A catch monitoring program consisting of 25 vessels participating in a self-sampling program and ten observer trips on different vessels and fishing grounds throughout the year.	32-58% reduction in **plaice** landings per hour; and 10-20% increase in **sole** catches per hour.
Van Marlen *et al.,* (2005a): Catch comparison 12m pulse trawl (Delmeco) *vs* conventional beam trawl with tickler chains on research vessel.	67 hauls for catch comparison, starboard with conventional gear and portside with pulse. Tow duration 64-126 min. at 5.5 knots. Weight and length of total catch, landings and discards of fishes and sole and plaice >MLS<. Weight of total benthos, *Acanthocardia echinata* and *Arctica islandica* and for 17 hauls also swimming, hermit and helmet crabs.	Landings **in general** reduced by 5% kg/h. Significantly more marketable **sole** >MLS (+22% kg/h, especially more market grades 3 and 4. **Plaice** above MLS reduced by 17% kg/h.
Discards		
van Marlen *et al*., 2014: To compare catches between beam and two types of pulse and assess fuel savings	A total of 45 beam trawl hauls, 48 with DELMECO and 45 with PulseWing (33 hauls sampled for discards; 25 paired for beam v pulse for plaice and 33 for sole.	43% reduction in **total** discards by area fished in discards with pulse; 67% reduction by hour. Catch fewer undersized **plaice**, fewer small **sole** (van Marlen et al., 2014). Overall discard rate for beam trawl was 86% vs 75% for pulse.
van Marlen *et al*., 2006: To appraise the performance of pulse beam versus conventional tickler chain beam trawls	Nine fishing trips (67 hauls) with observers on a pulse trawl vessel and two beam trawlers comparative catching ability. Five of these comparable were analysed.	Discards of undersized **plaice** per hour fished were the same with pulse, but 25% fewer for **sole**. Reduced **benthos** by 76% for sandstar, 25% common starfish and 47% for swimming crab with pulse.
Rasenberg *et al*. (2013): To set up a	A catch monitoring program consisting of 25 vessels	A 24-69% reduction in **plaice** discards per hour when using

Aims	Evidence base	Reported results and comment
catch monitoring program for the Dutch pulse fishery, consisting of a self-sampling program and independent observer trips.	participating in a self-sampling program and ten observer trips on different vessels and fishing grounds throughout the year.	the pulse. Mean discard rate for **plaice** 52% for pulse trawl and 49% for beam trawls (observer program) and 42 % for pulse based on self-sampling. Mean discard rate for **sole** from the pulse trawl self-sampling program of 15% similar to the beam trawl trips 17%. Observer estimate for pulse trawls was 10%.
Van Marlen *et al.,* (2005a): Catch comparison 12m pulse trawl (Delmeco) *vs* conventional beam trawl with tickler chains on research vessel	67 hauls for catch comparison, starboard with conventional gear and portside with pulse. Tow duration 64-126 min. at 5.5 knots. Weight and length of total catch, landings and discards of fishes and sole and plaice >MLS<. Weight of total benthos, *Acanthocardia echinata* and *Arctica islandica* and for 17 hauls also swimming, hermit and helmet crabs.	**Total** discards of fish -14% kg/h. No significant difference in undersize **sole**. **Plaice** below MLS were reduced by 18%. Additionally, including length measurements, the relative **sole** discard fraction reduced by 26%. No significant difference for the **plaice** relative discard fraction. Significantly less **benthos** (-25% kg/h). *A. echinata* reduced by 78% kg/h. No significant differences for *A. islandica* or swimming, hermit and helmet crabs.

Survival

Aims	Evidence base	Reported results and comment
<u>Fishes: discard survival</u>		
van Marlen *et al*., 2006: To appraise the performance of pulse beam versus conventional tickler chain beam trawls.	32 pulse and 31 beam hauls; plaice assessed for damage classes on board, then published survival rates used to estimate 8-day hour survival.	More **plaice** classed as "lively" in pulse than beam trawls (though no information on whether marketable or discard fish); discard survival estimated as 28% in the pulse *versus* 15% in the beam trawls.
Uhlmann *et al*., 2016: To test the influence of air exposure during sorting and impact from trawl capture with tickler chain and pulse trawl on impairment reflexes.	16 trawls, with 176 sole and 198 plaice across the size range collected at the start, mid and end of sorting and tested for impairment reflexes; gear type and air exposure tested.	Fewer fully impaired **sole** were sampled from the pulse vessel than the beam trawl; no difference in **plaice** reflex impairment between the pulse and beam trawls (though includes both discard and marketable fish).
van der Reijden *et al*., 2017: To assess survival of discard plaice, sole and dab in the pulse fishery.	Vessel catches (sole from 7 trips, plaice from 6 and dab from 1) classified into four vitality classes (lively to lethargic) during on-board sorting. Then fish (226 sole, 349 plaice and 187 dab) transported to the lab in holding tanks and observed for 21 days.	Undersized **sole** mainly "less lively", few “lively” undersized **plaice** mainly "lethargic" and "lethargic or dead"; **dab** mainly "lethargic or dead". Mean 25-day survival (not corrected for predation etc) of undersized **sole** estimated at 29% (significantly lower than controls), undersized **plaice** at 15% (significantly lower than controls in week 1) and undersized **dab** at 16% (significantly lower than controls in week 1). 95% of mortality in week 1.
Van Marlen *et al.* (2005b): To assess survival, injury and blood parameters of sole and plaice caught with a 12m pulse trawl.	20 hauls between 90-120 min at 5.5 kn for survival analysis. 494 plaice and 237 sole over different injury categories retained and observed for 72h and 192 hours.	Significantly higher survival for **plaice** in pulse trawl for each injury class (A and B+C). Not significant different for **sole**. No estimate of the amount of fish in injury class D (with 0% chance of survival) between gears.
<u>Fishes: pulse exposure experiments</u>		
van Marlen *et al*., 2007: To conduct a preliminary test of dogfish responses to pulse treatment.	9 dogfish exposed to a simulated pulse (11 controls), survival monitored for 48 hours.	All **dogfish** survived

Aims	Evidence base	Reported results and comment
de Haan *et al*., 2009a: To generate more information on the effects of electrical pulses on cod.	20 cod of 41-55 cm per group in 'near field', 'far field', 'above field' and controls, exposed to pulses.	14 of 20 'near field' **cod** survived (4 died immediately, 2 during the observation period), all survived in 'above', 'far' and controls.
de Haan *et al*., 2009b: To understand the effects of pulse stimulation on dogfish.	48 dogfish of 30-65 cm length were exposed to 'near', 'above' and 'far' field treatments, with 16 controls. Fish were kept for 9 months.	No evidence of an effect on **dogfish** survival (1 fish from 'above' died after 8 months and 1 from 'near' after 9 months).
Soetaert *et al*., 2016b: To determine the range of pulse parameters which can be regarded as safe and to evaluate the effect of the pulses already being used in commercial electrotrawls.	154 sole (25-30 cm), 46 farmed cod (70 cm) and 14 wild cod (~40 cm) exposed to homogenous pulse with varying values of pulse parameters and 14-day post-exposure survival assessed.	No **sole** mortality attributed to pulse effects (1 fish died, but no signal of abnormalities) and all **cod** survived.
Desender *et al*., 2017: To assess effect of pulse trawling on dogfish electro-receptor organs.	8 dogfish were deprived of food then exposed to the pulse.	All **dogfish** survived
<u>Invertebrates: pulse exposure experiments</u>		
van Marlen *et al*., 2009: To assess the effect of a simulated pulse on selected invertebrate species.	Ragworm (*Nereis virens*), common prawn (*Palaemon serratus*), subtruncate surf clam (*Spisula subtruncata*), European green crab (*Carcinus maenas*), common starfish (*Asterias rubens*), and Atlantic razor clam (*Ensis directus*). 20 animals per group in 'near', 'medium' and 'far' field and controls. Mortality up to 14 days.	Overall, survival was 3% lower for **ragworm** and 5% lower for **green crab**, with no differences for the other species. When the different exposures were examined the picture was mixed ('near field', reductions for **ragworm** and **razor clam**; 'medium field' reduction for **green crab** and increase for **razor clam**; 'far field' reduction for **ragworm** and **green crab**, increase in **razor clam**).
Teal *et al*., 2014: To investigate the effects of trawling on the seabed	Monitoring prior to and 48 hrs after pulse and beam trawling. 15 benthos samples from the beam and reference areas, 11 samples from the pulse area.	There were no significant differences in density for most **invertebrate species** and those with differences had inconsistent responses or showed responses in both trawled and reference areas.

Aims	Evidence base	Reported results and comment
Soetaert *et al*., 2015: To determine the range of safe pulses for model crustaceans and polychaetes (brown shrimp and ragworms), including effects of pulse ranges currently used.	Shrimp and ragworm exposed to a range of pulse parameters and exposure times. Survival assessed at 7 and 14 days.	No differences in survival for **brown shrimp** or **ragworm**.
Soetaert *et al*., 2016a: To evaluate the effects on brown shrimp of repeated exposure to the cramp pulses used by commercial electrotrawls.	20 exposures to the pulse (238 shrimp), mechanical stimulus (a chain; 179 shrimp) and controls (179 shrimp); survival monitored for up to 14 days.	No differences in **brown shrimp** survival at 7 days, though at 14 days survival was lower than the two controls (57% *versus* 70% and 66%).
Smaal and Brummelhuis (2005): To assess the effects of pulse on benthos.	Pulse amplitude and duration 2 x and 8 x higher than used commercially, exposure time 10s. Single (2-38 ind/species) and triple exposure (2 ind/species) over 3 days. Homogeneous electrical field. Survival monitored for 3 weeks.	Some reductions, but no major differences in survival between control and exposed groups for the taxa studied (**crustaceans**, **polychaetes**, **molluscs** and **echinoderms**).

Injuries

Aims	Evidence base	Reported results and comment
Fishes:		
van Marlen *et al*., 2007: To investigate possible spinal damage of commercially caught cod.	Cod caught by commercial trawler using pulse beam trawls were assessed by X-ray photography.	2 of 25 **cod** had dislocated spines.
de Haan *et al*., 2009a: To generate more information on the effects of electrical pulses on cod.	20 cod of 41-55 cm per group in 'near', 'far' and 'above' fields and controls exposed to pulses. Dissection and x-ray of 'near' and 'above' fish.	9 of 20 **cod** in 'near field' had bone fractures and/or haemorrhages, none in 'above' or 'far' field or controls.
de Haan *et al*., 2009b: To understand the effects of pulse stimulation on dogfish.	48 dogfish of 30-65 cm length were exposed 'near', 'above' and 'far' from the electric stimulus, with 16 controls. Fish were kept for 9 months.	There was no evidence that **dogfish** sustained injuries as a result of the exposures.
de Haan *et al*., 2013: To investigate whether variable results on injury between IMARES and ILVO studies was due to differences in the equipment.	Cod exposed to variable pulse parameters. 94 cod of 0.3-0.45 m. Post-mortem examination (euthanised same day).	A single vertebral fracture out of 43 **cod** at 60 V (2%), 4 of 30 with vertebral fractures at 120 V (13%); the injured fish measured 0.37-0.42 m.
van Marlen *et al*., 2014: To ascertain whether catch composition was the same in the beam and pulse trawls.	Beam, Delmeco and HFK vessels, fishing side by side where possible. The cod and whiting catches were filleted and injuries photographed in the 45 cod caught from the pulse trawlers and 47 whiting caught from the HFK.	No spinal fractures in **cod** from the beam trawl, but spinal fractures in juvenile and marketable **cod** from the pulse - 2 of 27 from the HFK (7%) and 2 of 18 from the Delmeco (11%); frequent haemorrhages noted. Spinal fracture in 1 of the 47 **whiting**, no haemorrhages.
de Haan *et al*., 2015: To investigate whether pulse stimuli could injure dab and enhance the development of diseases, such as ulceration.	Wild-caught dab were exposed to two pulse stimuli applied in Dutch flatfish trawls (50 control, 50 HFK, 51 Delmeco).	No significant difference in **dab** injuries or internal lesions between pulse and controls.
de Haan *et al*., 2016: To study the behavioural response and injuries in cod	460 cod in 39 experiments (3 in 2008 and 36 in 2010) exposed to a range of pulse parameters	None of the control and none of the small **cod** (0 of 132) became injured, but 39% of the large cod in 2010 (101 of 260) and 45% of

Aims	Evidence base	Reported results and comment
exposed to electrical pulses under controlled conditions.	(plus 3 control tests with 10-20 fish). Two size classes - cod that escape through the mesh (11–17 cm) and marketable cod (34–56 cm). Some fish observed for 15 days after.	those in 2008 (27 of 60) had a vertebral fracture, a haemorrhage, or both. Some had discoloured tails (62 immediately post-exposure; single bars, chevrons or fully discoloured) and there was occasional anal bleeding or anal/caudal fin haemorrhage. Probability of injuries increased with field strength and body size and decreased when frequency rose from 100 to 180 Hz; no effect of pulse type.
Soetaert *et al*., 2016b: To determine the range of pulse parameters which can be regarded as safe and evaluate the effect of the pulses used by trawlers.	154 sole of 25-30 cm, 46 farmed cod of 70 cm and 14 wild cod of ~40 cm were exposed to a range of pulse parameters, with gross and histological examination.	1 small **sole** of the 154 bleeding at one gill during exposure, no irreversible lesions or abnormalities. 1 of 60 **cod** had gross lesions and black colouration from internal bleeding associated with a spinal compression.
Soetaert *et al*., 2016c: To evaluate an electrified benthic release panel inserted in a pulse trawl.	58 trawls, 16 of which had pulse stimulation on the release panel (no pulse trawling).	4 out of 52 **cod** (7.7%) had paravertebral haemorrhages.
Soetaert *et al*., 2016d: To investigate whether different groups of cod under different pulse conditions respond differently.	4 groups of cod from a different wild or farmed stock were exposed to pulse. Lesions were assessed up to 14 d afterwards.	5 out of 205 **cod** had paravertebral haemorrhages - 4 of these with dark discolouration, one with anal bleeding and 3 with acute spinal injuries. No internal or external lesions in fish without spinal injuries.
Desender *et al*., 2017: To assess effect of pulse on dogfish electro-receptor organs.	8 dogfish were deprived of food then exposed to pulse treatment.	No macroscopic injuries in the **dogfish**.
Van Marlen *et al.* (2005b): To assess survival, injury and blood parameters of sole and plaice caught with a 12m pulse trawl.	11 hauls between 90-120 min at 5.5 kn to assess injuries such as bleeding in plaice and sole below MLS. +/- 10 individuals per species per haul.	Less injury for **plaice** and **sole** (in % damage on the dorsal side) in the pulse trawl, though there can be more bleeding on the ventral side in **sole**. Significant reduction in specific injuries (internal bleeding ventral side and dorsal skin damage) in **plaice**.

Aims	Evidence base	Reported results and comment
Invertebrates: Soetaert *et al*., 2015: To determine the range of safe pulses for model crustacean and polychaete species, including effects of pulse ranges currently used.	Exposure of ragworm and shrimp to a range of pulse parameters. Animals examined after 14 days gross lesions and histology, including intranuclear bacilliform virus infection (shrimp) and melanomacrophage aggregates (ragworm).	No gross lesions in **ragworm** or **shrimp**.

Reproduction, illness and disease

Aims	Evidence base	Reported results and comment
Reproduction		
de Haan *et al*., 2009b: To understand the effects of pulse stimulation on dogfish.	48 dogfish of 30–0.65 cm length exposed 'near', 'above' and 'far' from the stimulus (16 controls). Fish were kept for 9 months.	No impact on **dogfish** egg production.
Soetaert *et al*., 2016a: To evaluate the effects on brown shrimp of repeated exposure to pulses.	20 repeat exposures to pulse (238 animals), mechanical stimulus (a chain; 179 animals) and controls (179 animals), with egg loss monitored for up to 14 days.	No differences in the numbers of **shrimp** losing eggs.
Illness/disease		
de Haan *et al*., 2015: To investigate whether pulse stimuli could injure dab, and enhance the development of diseases, such as ulceration.	Wild-caught dab exposed to two pulse stimuli (50 control, 50 HFK, 51 Delmeco).	No differences in **dab** internal parasites or bacterial infection between pulse treatment and controls.
Soetaert *et al*., 2016a: To evaluate the effects on brown shrimp of repeated exposure to the cramp pulses used in the field by commercial electrotrawls targeting sole.	20 repeat exposures to pulse (238 shrimp), mechanical stimulus (a chain; 179 shrimp) and controls (179 shrimp), with degree of viral infection monitored for up to 14 days.	No effect of electrical stimulation on **shrimp** IBV (virus) infection.
Soetaert *et al*., 2015: To determine the range of safe pulses for model crustacean and polychaete species, including effects of pulse ranges currently used.	Exposure to a homogenous field with a range of pulse parameters. After 14 days animals examined for gross lesions and histology, including intranuclear bacilliform virus infection (shrimp) and melanomacrophage aggregates (ragworm).	More **shrimp** IBV infections in the highest field strength (200 Vm^{-1}) compared to controls and other strengths for the first experiment but not the second. No significant differences in the number of **ragworms** with MMA nor in the mean MMA scores.
Van Marlen *et al.* (2005b): To assess survival, injury and blood parameters of sole and plaice caught with a 12m pulse trawl.	18 hauls between 90-120 min at 5.5 kn for blood parameters analysis (glucose, free fatty acid, cortisol and lactate). Blood extracted after	No significant difference between gear or injury categories for **sole** and **plaice** for levels of blood glucose, free fatty acids, cortisol or lactate.

	0, 4 and 9 days, +/- 5 fish per parameter, maximum 240 per species sampled.	

Behaviour

Aims	Evidence base	Reported results and comment
Fishes:		
van Marlen *et al*., 2007: To conduct a preliminary test of responses of dogfish to pulse treatment.	9 dogfish exposed to a simulated pulse under laboratory conditions (11 controls), with observation of behaviour including foraging.	Little **dogfish** reaction during exposure, only by one fish above the electrodes. No response to food after 1.5 hours for pulse or controls. Weak responses in both groups for 48 hours, with those exposed to pulse slightly weaker.
de Haan *et al*., 2009a: To generate more information on the effects of electrical pulses on cod.	20 cod of 41-55 cm per group exposed to 'near field', 'far field', 'above field' and controls. Video observation of responses and feeding behaviour over 17 days.	Minor and occasional responses of **cod** in 'far'. Significant reflexes and muscle contractions in 'above', but weaker than those in 'near', which had strong reflexes and muscle contractions with paralysis, then post-exposure disorientation and strong and rapid actions indicating shock. All fish including controls reduced feeding activity post-exposure, but those 'near' did not respond to food or show normal searching behaviour.
de Haan *et al*., 2009b: To understand the effects of pulse stimulation on dogfish.	48 dogfish of 30-65 cm length were exposed 'near', 'above' and 'far' from the electric stimulus (16 controls).	Few **dogfish** responses in 'far'. Around ~60 % had contractions in 'above', some with tail bends or body curls; 53 % with rapid body reverse and 11% a minor reaction towards the water surface. In 'near', major responses were 90% body contractions, then 62% reversed and 23 % swam upwards post-exposure. No evidence of effects on food response.
de Haan *et al*., 2013: To investigate whether different results of injury between IMARES and ILVO studies was due to differences between the equipment.	Exposure to variable pulse characteristics using both ILVO and IMARES pulse generators with differences in pulse amplitude and duration. 94 cod of 0.3-0.45 m; video observations.	The **cod** produced medium to strong contractions at the normal pulse settings, but no startle responses. At 120 V the cod became stunned and showed behaviour indicating epilepsy or reaching electro-narcosis, but they recovered after some minutes.
de Haan *et al*., 2015: To investigate whether electric stimuli practiced in	Wild-caught dab were exposed to two different electrical pulse stimuli both commercially applied	**Dab** commonly had a muscular cramp, immobilising them during exposure. The Delmeco stimulus caused contraction into a "U-shape"

Aims	Evidence base	Reported results and comment
pulse gear could cause injuries in dab, and enhance the development of diseases, such as ulceration.	in Dutch flatfish trawls (50 control, 50 HFK, 51 Delmeco) and observed for 5 days.	with tail and head upward, while HFK prompted a lifting of the body with the side fins downward. All produced a short strong startle response post-exposure, upwards for the Delmeco and forwards for the HFK. Dab responded well to the food offered post-exposure.
de Haan *et al*., 2016: To study the behavioural response and injuries in cod exposed to electrical pulses under controlled conditions.	460 cod in 39 experiments (3 in 2008 and 36 in 2010) exposed to a range of pulse parameters (plus 3 control tests with 10-20 fish). Two size classes - cod that escape through the mesh (11–17 cm) and marketable cod (34–56 cm). Some fish observed for 15 days after.	Muscle contractions and immobilisation in all **cod** at field strengths above 4 V m^{-1}. Small cod at 212-370 V $^{-1}$ had a contraction and incidental epileptic seizure-like response directly post-exposure; recovery and feeding response within 1 min. Electro-narcosis like responses in 6/20 small cod; recovery within 1 min. and resumption of normal feeding behaviour over the next days. Large cod at 37 and 155 V $^{-1}$ moderate-to-strong contractions/strong tail flapping during exposure, some epileptic seizures post-exposure. Started feeding at the first offering after 36 h, though less responsively than pre-exposure. Appetites of fish exposed at 37 V $^{-1}$ increased during the observation period and were higher than those at 4 V $^{-1}$ and controls. Most fish at 82 V $^{-1}$ passive and no return to normal feeding.
Soetart *et al*. (2016b): The objective was to determine the range of pulse parameters which can be regarded as safe and to evaluate the effect of the pulses already being used in commercial electrotrawls.	154 sole of 25-30 cm and 46 farmed cod of 70 cm and 14 wild cod of ~40 cm exposed to a range of pulse parameters and behaviour observed during and post-exposure.	**Sole** cramped above 40 Hz, followed by escape behaviour. Variable reactions between individual sole even when exposed to the same pulse. All **cod** cramped, with distended opercula above 40 Hz. Followed by post-exposure escape behaviour at low loads, while at high loads 59.5% had epileptiform seizures, sometimes with regurgitation and/or egg or sperm release; weak reactivity persisted for a few hours, normal behaviour after 24 hours.
Soetaert *et al*., 2016d: To investigate whether different groups of cod under different pulse conditions respond differently.	4 groups of cod from a different wild or farmed stock exposed to pulse, with assessment of behaviour up to 14 d after.	All 205 **cod** cramped during exposure. Variable reactions to 60 V (10-20% no reaction, 60-70% weak escape, 10-30% very agitated swimming). Fish more agitated pre-exposure (eg wild) had a stronger flight reaction. 11/20 fish at 120 V epileptiform seizures (none at 60 V). Fish remained uncoordinated up to 30 min, with dazed swimming for first few hours.

Aims	Evidence base	Reported results and comment
Desender *et al*., 2017: To assess effect of pulse on dogfish electro-receptor organs.	8 dogfish deprived of food then exposed to pulse treatment. Electroresponse to an electrical prey simulator was elicited before pulse treatment and then for 3 days after.	No effect on **dogfish** prey detection and selection.
<u>Invertebrates:</u>		
van Marlen *et al*., 2009: To assess the effect of simulated pulse on selected invertebrate species.	Ragworm (*Nereis virens*), common prawn (*Palaemon serratus*), subtruncate surf clam (*Spisula subtruncata*), European green crab (*Carcinus maenas*), common starfish (*Asterias rubens*), and Atlantic razor clam (*Ensis directus*). 20 animals per group in 'near', 'medium' and 'far' field, controls. Food intake and behaviour monitored for 14 days.	Strongest reactions in prawn and green crab. **Prawn** reactions were strongest in 'near', jumping when stimulated and no return to the feeding levels of the controls. **Green crabs** usually stiffened, with strongest reactions in 'near' and 9-13% lower and very variable food intake. **Ragworms** had jerky movements or no reaction, with no effects on food intake. **Razor clams** can react quite strongly using their foot and siphon, often enough to propel them away; reactions were strongest in 'near' and there were no effects on food intake. No reactions to pulse or effects on feeding in **starfish** or **surf clams**.
Soetaert *et al*., 2015: To determine the range of safe pulses for model crustacean and polychaete species, including effects of pulse ranges currently used.	Exposure to a homogenous pulse field with a range of frequencies, strengths, polarities, pulse shapes, durations and exposure times. Behaviour noted.	95 - 100% of **shrimp** tail-flipped (above 60 Hz with one strong contraction that expelled them from the sediment); the cramp persisted during exposure and resulted in the shrimp overturning and sinking briefly to the sediment before escaping with tail flips. The only **ragworm** reaction was squirming, the intensity of which varied and did not seem to correlate with pulse parameters (although post-exposure squirming intensified with increasing duty cycle).
Soetart *et al*., 2016a: To evaluate the effects on brown shrimp of repeated exposure to the cramp pulses used in the field by commercial electrotrawls targeting sole.	20 repeat exposures to the sole pulse (238 animals), mechanical stimulus (a chain; 179 animals) and controls (179 animals), with moulting monitored for up to 14 days.	**Shrimp** exposed to the pulse cramped, followed by an escape response (jumped in random directions for 1–3 s, then reburied), compared to the mechanical stimulus where shrimp either immediately reburied or exhibited a short escape reaction. No differences in moulting between pulse and controls.

Aims	Evidence base	Reported results and comment
Smaal and Brummelhuis (2005): To assess the effects of pulse on benthos.	Pulse amplitude and duration 2 x and 8 x higher than used commercially, exposure time 10s. Single (2-38 ind/species) and triple exposure (2 ind/species) over 3 days. Homogeneous electrical field. Behaviour monitored during exposure and for 30 minutes after; digging activity of bivalves for 1 day, filtration behaviour for 2 hours.	**Crustaceans** freeze, **bivalves** close and **whelks** retract partly into their shells. No reaction for **polychaetes** and **echinoderms**. **Common prawns** on the bottom for 1 minute but responded immediately when touched. No differences in filtration activity, digging or attachment for **bivalves**.

Non-biological effects: the physical environment and socio-economics

Aims	Evidence base	Reported results and comment
Physical disturbance		
ABPmer & Ichthys Marine, 2015: Risk based assessments for fisheries in MPAs - prediction of seabed disturbance in a protected area.	Used published relationships between weight, drag and sediment type to estimate sediment penetration and resuspension after PulseWing pulse trawling.	Lower estimated overall **sediment penetration** for pulse than beam (8 mm vs 15 mm on average across the swept width of the gear). Lower **sediment mobilisation** (2-4 mm across the swept area vs 3-10 mm).
Depestele *et al*., 2015: To measure the physical impact of pulse trawling on the seabed.	Compared alteration in bathymetry and mobilised sediment between Delmeco pulse and beam trawling, model differences in penetration depth.	Less alteration of **seabed bathymetry** in pulse; no differences in quantity of **sediment mobilised**. Pulse trawl shoes predicted to **penetrate** deeper than beam shoes (60 mm *vs* 8 mm) but pulse estimated to have lower overall penetration.
Batsleer *et al*., 2016: To investigate the consequences of a discard ban on discarding decisions and whether discarding may promote transition towards the pulse trawl.	Modelled catches of size-structured sole, cod and plaice, with predictions re-scaled to SSB of 2004-2013 and beam and pulse trawling compared.	Predict a shift in **effort** under a discard ban, with beam trawling focussed more on the offshore central and eastern North Sea and pulse trawling mainly in the Southern Bight and appearing in the coastal eastern North Sea (no shift when discarding allowed).
Turenhout *et al*., 2016: To examine economic consequences and geographic displacement of the change from beam to pulse trawling.	Displacement compared between 2008/2009 (before pulse) and 2014-2015.	Increased pulse **effort** off Belgian, Dutch and eastern/south-eastern English coasts, shift of the remaining beam fleet into offshore central/eastern North Sea
Socio-economics		
Sys *et al*., 2016: To assess the effects of competitive interactions among Dutch and Belgian fishing fleets resulting from different uptake speed of pulse trawls and the adaptive response of fishers.	Analysis of VMS and landings data by Dutch and Belgian fleets in 2006-2009 (start of pulse fishing) *versus* 2010-2013.	Dutch **vessels** tend to stay in port over the weekend (beam and pulse), Belgian **vessels** (beam only) fish all week.
Batsleer *et al*., 2016: To investigate the consequences of a discard ban on discarding decisions and whether discarding may promote transition towards the pulse trawl.	Modelled catches of size-structured sole, cod and plaice, with predictions re-scaled to SSB of 2004-2013 and beam and pulse trawling compared.	Predict net **revenue** for pulse trawlers always higher than beam trawlers, whether discarding or not.

Turenhout *et al*., 2016: To examine economic consequences and geographic displacement of the change from beam to pulse trawling.	Focusing on economic results, effort, fuel consumption, price of sole quotas, catch-based pay levels and displacement of effort using data from the Dutch Ministry of Economic Affairs and Wageningen Economic Research.	Pulse gear makes trawling more profitable; in 2014, ~17 million Euro profits for pulse while beam nearly broke even. Fuel consumption ~46 % lower per day for large vessels, crew pay increased. After 2012 demand for sole quotas increased (profitability of pulse, but also quota reductions), rising from 60 Euro c per kg to 3.38 Euro c per kg in 2015.

Appendix 3: Initial comments on technicalities of the pulse gear from the Cefas electronics team

The information in the following tables provides an explanation of some of the pulse parameters and comments on factors that need to be considered when assessing the impact of pulse trawling.

Parameter	Control	Notes
Controllable electrical factors		
Voltage	Fixed voltage.	A constant voltage will give rise to an uncontrolled current density through the water/seabed that is dependent on the conductivity (salinity), temperature and seabed type.
Current	Constant current.	This is a constant current driven though the water by means of automatically varying the voltage. More difficult/expensive to achieve but should give a better control of current density.
	AC or DC.	Alternating or direct current is the type of current that ether periodically reverses direction about a mean of zero (AC) or applied in one direction only (DC).
Power	Fixed power (Energy)	Vary the voltage and hence the current (Current = Voltage x Conductivity) to output a fixed power (Power = Voltage x Current) (Energy = Power x Time Interval).
Pulse	Width	Is the time (pulse length) the voltage or current is applied.
	Shape	Rise, hold & fall times of the pulsed D.C, A.C (Sine wave) etc.
	Frequency	How often the pulses are applied in a second. (Cycle time = 1/Frequency)
	Duty cycle	Expressed as a percentage of the pulse on time to the cycle time (the time interval between pulses).
Physical Electrical Factors		
Trailing cables	Number of electrodes per cable	
	Length of the electrode (exposed conductor)	
	Weight and shape of the electrodes	Cable, drogue etc. does it dig into the seabed or drag on the surface?
	Length between the electrodes (insulated conductor)	
	Distance between the cables	

Parameter	Control	Notes
Electrode arrangement (Anode Cathode)		Cables used as strings of anodes in, on or above the seabed with the trawl used as the cathode?
		Alternate cables used as a string of anodes, the next as a string of cathodes and back to anodes etc. in, on or above the seabed?
		Position of electrodes relative to the trawl net.
Electrode material		Copper, steel etc.
Environmental Factors		
Variability of water conductivity.	Conductivity (Salinity).	The conductivity would be affected by a rain storm particularly more so in shallow water, an outfall of fresh or brackish water in or near a river mouth or estuary.
	Temperature.	
	After large rain storms and run-off.	
	Mixing of different water masses.	Water masses from different depths, shelf sea and Atlantic ocean waters etc.
	Pressure.	Very small effect, possibly not significant in shelf seas and trawling depths.
	Amount and type of suspended sediment.	Sand, sediment etc.
Variability of the seabed conductivity	Seabed Composition	Sediment, clay, sand, rock, etc.
Biology		
Fish	Flat or round	The bigger the muscle mass (heavier) the stronger the contraction; this combined with the greater width would make the fish a less flexible structure, hence roundfish will be more prone to damage due to the increased compression and tension forces on the flesh and spine, making roundfish more susceptible to damage than flatfish.
	Weight	
	Species/Conductivity	Different conductivities relative to the water will affect the current density in the muscle.
	Length	Effects the current density and direction in the muscle.
	Orientation and position relative to the electrodes	
	In the water column or buried/how deep	

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Cefas

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