Flatfish pulse fishing

Research results and knowledge gaps II.

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Summary

This report is an extension and translation of the report of Quirijns, F., Strietman, W.J., Van Marlen, B., Rasenberg, M. 2013. Flatfish pulse fishing: research results and knowledge gaps. IMARES Report C193/13.

Knowledge about the effects of pulse fishing is spread over various reports and policy documents; a complete and accessible overview of knowledge is lacking. This report provides an overview of the research results and knowledge gaps in pulse fishing.

Pulse fishing is a relatively new fishing method: in this fishery, fish are caught by means of electric pulses. Those pulses cause muscle contractions in fish, that consequently are startled from the seabed and caught in the net. The application of pulse technique in commercial fishing is relatively new and electric fishing is not allowed in Europe through EC Reg. 850/1998. Consequently pulse fishing is done under derogation from the EU and questions were asked on the ecosystem effects of pulse fishing. The fishery study group Pulse and SumWing (part of the fishery study group Flatfish) asked IMARES and LEI to make a summary of the available knowledge and knowledge gaps on the effects of pulse fishing. This resulted in the report of Quirijns *et al*. of 2013. The Dutch ministry of Economic Affairs asked IMARES to update this report in 2015 with the latest results. This report provides the up to data account on current knowledge on the effects of pulse stimulation of marine organisms and marine ecosystems, and summarises the effects on the catch efficiency and selectivity (landings and discards), management of the fishery and CO_2 emission. At the end of the report, gaps in knowledge are identified.

- Dab: no lesions were observed in the fish, neither analysed directly after, nor when analysed five days after the exposure to electrical stimulation.
- Preliminary sampling of roundfish caught by commercial pulse trawl gear showed that about 10% of the cod and 2% of the whiting showed a fracture of the vertebral column.
- Cod: laboratory experiments showed that the probability of fractures in spinal column occurs in marketable sized fish but not in cod that are small enough to escape through the meshes of the net. The injury probability increase with field strength and decrease with pulse frequency;
- Dogfish: behavioural response but no injuries observed when exposed close to electrodes. Effects on the proper functioning of their electro receptor organs after exposure to the electric fields was not studied;
- Benthic invertebrates: some species did not respond to pulse (spisula and starfish); other species did (razor clam, shrimp, common crab and rag worm). Mortality increase, if at all, was low (3-7% for ragworm, common crab and razor clam), and food intake and behaviour recovered after exposure;
- Marketable plaice and sole: the pulse gear has similar catch levels of marketable sole as the conventional beam trawl, but lower ones of marketable plaice;
- Plaice and sole quality and survival: the species caught with pulse trawl are damaged to a lesser extent than those caught with a conventional beam trawl. A significant higher survival rate for plaice was found for the pulse trawl after 192 hours of observation in comparison with a conventional beam trawl;
- Discards: the catch level of undersized fish and benthos that are usually discarded is distinctly lower (30-50% fewer fish discards, 48-73% fewer benthic species);
- Fuel consumption: a pulse trawl is towed at a lower speed than the conventional beam trawl, resulting in reduced fuel consumption and emissions of $C0_2$ and other greenhouse gases.
- Penetration of gears: Seabed bathymetry changes between ~ 1 and 2 cm and is further increased by higher trawling frequencies. The tickler-chain trawl affected seabed bathymetry to a greater extent than the pulse trawl, when comparing depth differences at 320 kHz. Depth differences were < 6 mm

for both gears at a 25% probability (of occurrence of a certain depth difference), but the changes to the seabed bathymetry at a 50% probability were up to 20 mm for tickler-chain trawling and 14 mm for pulse trawling.

- Shrimp and ragworm: No significant increase in mortality or injuries . Shrimp demonstrates tail flip (depending on frequency) and the ragworm demonstrates squirming reaction (independent of the frequency). Increase in severity of virus infection in shrimp at highest electrical field strength (200 V m-1).

Despite the large number of studies that have been carried out, several topics need more investigation:

- Indirect (or: delayed) mortality;
- Non-mortal effects;
- Effects on reproduction;
- Long term effects on species that encounter pulse trawl gear and on their populations;
- Minimum and maximum values for pulse characteristics (is there a 'safe range'?);
- Effects of pulse fishing on early life stadia of marine organisms that reproduce in shallow water;
- Effects on seabed, substrate and water column: can the use of pulse result in dissolving toxic chemicals?

The EU STECF stated that control and enforcement issues should be resolved before the number of vessels using pulse trawls can be increased. In 2012, procedures for control and enforcement were developed in close cooperation with producers of pulse fishing gears, fishermen's organisations, the Dutch Ministry of Economic Affairs, representatives of control agencies and scientists, but they are not applied in detail in practice yet.

1. Introduction

This report is an extension and translation of the report of Quirijns, F., Strietman, W.J., Van Marlen, B., Rasenberg, M. 2013. Flatfish pulse fishing: research results and knowledge gaps. IMARES Report C193/13.

This report summarises existing knowledge on the effects of electric pulse fishing on flatfish. In this report the effects of pulse fishing on catches and discards, the effects on the ecosystem, the management of pulse fishery and CO_2 emissions are specifically examined. This knowledge is distributed over various reports and policy documents, but a complete, accessible overview on the subject was lacking at the time (2013). For this reason, the fisheries study group Pulse en SumWing (part of the flatfish study group) asked research institutes LEI and IMARES to summarise the knowledge and identify the knowledge gaps. This resulted in the report of Quirijns *et al.* of 2013. The Dutch ministry of Economic Affairs asked IMARES to update this report in 2015 with the latest results which is done in the current document.

Objective

The aim of this report is to present a simple and clear overview of the knowledge currently available about catches (landings and discards) of pulse fishing gears in comparison with conventional fishing gears and the effects of these new gears on the marine ecosystem and to identify gaps in knowledge. Comments are also made on management issues of electric pulse fishing.

The pulse technique is applied in both the flatfish and shrimp fishery. This report focuses only on the pulse fishery targeting flatfish.

Reading guide

In Chapter 2, we first explain the operation of the pulse technique in the flatfish fishery and in the various conditions occurring in the North Sea. In Chapter 3, we give a short historical overview of pulse fishing in the Netherlands and the current (European and Dutch) policy on pulse fishing. In this overview we sometimes refer to socio-economic research, but do not discuss the results. In Chapter 4, the electric field is described as it is generated in the electric pulse gear. In Chapter 5, we consider the results of research conducted into the effects of the pulse technique on the catches and its effects on the ecosystem. Chapter 6 deals with the management of pulse fishing. Finally, in Chapter 7 we indicate which subjects require extra research.

Acknowledgements

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2. Introduction of pulse: its operation and effects

In the Netherlands, the conventional beam trawl with tickler chains has been used traditionally in demersal fishing from the 1960s. Since 2009, a gradual transition has taken place towards pulse fishing, in which the tickler chains have been replaced by electrodes. This fishing gear has a different working principle, flatfish are stimulated primarily by electric pulses and not mechanical touch. This clearly distinguishes the electric pulse technique from the beam trawl with tickler chains.

Information from a fishery study group member
Fishing companies transfer to pulse fishery because with this technique they use much less fuel. The lower fuel consumption is mainly due to a lower towing speed, a pulse fishing gear is towed at a speed of approximately 1.5 nautical miles an hour less than a conventional beam. This lower speed also results in less area covered (as the total width of the gears, and fishing time are not reduced), so the area of seabed disturbed by its gears per vessel is reduced.

This introductory section explains the operation of the pulse technique in flatfish fishery and the various conditions occurring in the North Sea.

Operation of the pulse technique in the flatfish fishery

Flatfish spend a large part of their time on or in the seabed. In the flatfish fisheries, techniques are used to chase fish from the seabed so that they can be scooped up into the nets (while towing). In the conventional beam trawl fishery tickler chains are used to chase the fish out of the sea bed (figure 2.1, left). These are steel chains attached along the width of the net opening or further back in the net attached to the ground rope, that are dragged over the seabed.

FIGURE 2.1. FROM LEFT TO RIGHT: TRADITIONAL BEAM TRAWL, HFK PULSWING, DELMECO PULSKOR

An electric pulse vessel has no tickler chains, but cables/electrodes containing isolated and conductive parts hung parallel to the direction of motion (figure 2.1 centre and right). A pulsating electric field is generated through these conductors by a pulse generator and feeding cables. Fish entering this field experience an electric shock.

The electric shocks cause the muscles of fish to contract, curling them up or startling them from the seabed. It appears that sole, being more flexible, is more prone to this reaction than other species such as plaice. The fish is not killed or stunned by these electric shocks, but merely startled. Once the electric shocks have passed, the muscles relax and the fish tries to dig itself in again or swim away.

Electric pulse system used in the Netherlands

Two companies have developed a pulse prototype for the Dutch flatfish fishery: Delmeco (previously Verburg-Holland) and HFK Engineering (see figure 2.1). These systems have their own individual pulse characteristics [1]. The differences are marginal, and mainly in the characteristics of the pulse: the number of pulses per second (pulse frequency), pulse duration, and pulse shape. In addition, the number of electrodes used in the gears differ, as well as the distance between the electrodes and the number and size of the conductors.

Pulse characteristics

The pulse characteristics can be defined as follows [2][3][4]:

- Amplitude in volts (V): potential measured between two conductive elements.
- Electrical field strength (V/cm).
- Pulse frequency (Hz): number of pulses per second.
- Pulse duration (μs): duration of one pulse.
- Gradient of the pulse wave form (pulse shape)
- Shape of the electric field ('composition of field', resulting directly from the pulse shape but also depends on the type and number of electrodes and the distance between the electrodes and the length/combination of conductive and isolating elements).

In catching fish, the electric current that is transmitted through its body is most important. Field strength (potential difference per unit length across the body of the animal) and resistance (conductivity) are determinant here, as is the duration of the electricity. Electrical fields are not homogeneous in the pulse trawls and have a three-dimensional shape. The potential difference between nose and tail of a fish therefore depends on the orientation of the fish within the field and the length of the fish. A detailed description of an electric field is given in chapter 4.

Effects of pulse under different conditions

The electric field generated by the system does not have the same effects under all conditions and for all fish (and other organisms)[3][4][5]. The current between any points in the field under water depends on:

- The conductivity of the seabed and the seawater;
- The salinity of the water: saltwater has a higher conductivity than freshwater;
- The water temperature: warm water has a higher conductivity than cold water.

And possibly on:

- The composition of the seabed: more silty seabed have a better conductivity than sandy beds. However, this may need further investigation.

The effects of pulse on fish and other marine organisms vary depending on:

- The conductivity of its body depending on its anatomy;
- The intensity (μs and Hz) and the field strength (V/cm) of the pulse;
- The speed at which the fish are caught with the pulse fishing gear: if a vessel is towed at a higher speed the fish may be exposed to the electric field for a shorter time;
- The length and design of the conductive and isolating electric parts;
- The distance to the conductor: the closer to the conductor, the stronger the electric stimulus;

- The shape and length of the fish and/or muscle mass: the longer the fish and/or the higher the muscle mass, the more powerful the muscles contract as a result of the electric field;
- The orientation of the fish: it makes a difference whether a fish is swimming or floating parallel to or perpendicular to the electric field. The potential difference across the body is the determining factor.

3. Electric pulse fishing in the Netherlands - history and policy

The development of electric pulse fishing started in the 1970s but it owes its present form to mayor steps taken from 2005 onwards. There have been rapid developments since then. This chapter provides a historical overview of pulse fishing in the Netherlands and of current (European and Dutch) policy on pulse trawling.

Historical development of electric pulse fishing in the Netherlands

1970-1990: The first steps taken towards using electric pulse in fishery [2].

- 1970-1988: Pulse fishing is considered as an experimental fishery and is therefore permitted;
- 1970-1985: Development of electric pulse trawl gear for shrimp and flatfish fisheries by the Dutch Institute for Fisheries Research (RIVO);
- 1985: ICES[1] seminar on electric fishing with participants from Belgium, the Netherlands, Germany and England [6];
- 1986: Development of a pulse prototype for flatfish on the GO65, in cooperation with Oranjewerf B.V. – Giesselbach B.V.;
- 1988: The European (and Dutch) ban in EC Reg. 850/1998 Article 3.1 on electric fishing terminates the study and development at RIVO with Oranjewerf B.V. – Giesselbach B.V..

1991-2000: Technical research into electric fishing is permitted again by the EU.

- 1992-1998: Verburg-Holland B.V. and the Dutch Ministry of Agriculture investigate the technical possibilities of the pulse trawl. They carried out fishing tests (e.g. on sole) and experiments with a trawl in a land based tank in which a pulse trawl could be placed;
- 1992-2000: Experiments with a pulse trawl gear of 4 and 7 m width [2];
- 1998-2000: Research into ecosystem effects by IMARES (RIVO) and scientific guidance of the development by Verburg-Holland B.V.. The European research project REDUCE enabled studies of the effects on catches and mortality of benthic invertebrates in the trawl path of the pulse gear and conventional beam trawl gears [7].

2001-2010: Field trials on commercial use of electric pulse trawls with an up scaled version of 12 m width.

- 2004-2005: Study of RIVO carried out on board of the Tridens into catch differences between the beam trawl and the pulse trawl and exploratory research into the survival of undersized sole and plaice caught by both trawl types [8];
- 2005: RIVO study into the effects of the pulse trawl and conventional beam trawl on sole and plaice regarding their condition, survival and catches, and stress hormone levels in the fish's blood [9];
- 2005: Preliminary RIVO study into the effects of electric pulses on invertebrates [10];
- 2005: The Dutch ministry of Agriculture creates a steering group on electric pulse fishing, which consists of representatives from the ministry and from the fishing industry (FFA, Dutch Fishermen's Federation), and scientists from LEI and RIVO (later: IMARES) acting as advisors for the steering group;
- 2005: ILVO investigates effects of pulse on shrimp and by-catch species in shrimp fishery in lab experiments and sea trials [48][49].

[1] International Council for Exploration of the Sea

- 2005-2006: Tests on-board the commercial beam trawler UK153 using the Verburg-Holland system: ecological study with comparisons of pulse trawl catches and conventional beam trawl catches by IMARES [11];
- 2005-2006: Comparative study by LEI of the pulse trawl and the conventional beam trawl regarding: production costs, necessary investments, prognoses and monitoring of economic results, fuel consumption and fish prices;
- 2006: Request to ICES for advice through STECF, on the effect of electric pulse fishing on the ecosystem; this is discussed by the WGFTFB expert group (ICES-FAO Working Group on Fishing Technology and Fish Behaviour) and in ICES ACOM and SCICOM;
- 2006-2009: European DEGREE project [12], involving a study by LEI on the economic feasibility of electric pulse fishing and monitoring of catches on-board the TX68. The project is a precursor to the current EU BENTHIS project.
- 2007-2011: In 2006, ICES advised on the pulse technique and raised further questions that resulted in additional laboratory studies by IMARES on benthic invertebrates, dogfish and cod [1][13][14][15];
- 2007: The 'Kotteroverleg', representing the fishing industry, withdrew its support for research on pulse fishing because of disappointing plaice catches. As a result, the financing of the research project with the UK153 ceased [16]; the UK153 continued testing electric pulse trawls on its own initiative [17];
- 2007: LEI advised positively on the economic feasibility of electric pulse fishing to the Steering group, Fishery Innovation Platform and the Dutch ministry of Agriculture;
- 2007: From 2007 onwards, the Netherlands receive an annual exemption to equip 5% of the beam trawl fleet with electric pulse trawls (EC regulation No. 41/2006 Annex III);
- 2007-2008: Minister Verburg agreed to extend the use of pulse fishing in the Netherlands to five trawlers. The Dutch government provided the five companies with subsidies of up to 40% for investment in pulse fishing [18];
- 2008: LEI and IMARES established the first expert group with support from the Ministry: Study group Pulse and Sumwing [18];
- 2008: IMARES calculated the potential fuel savings when using pulse fishing gear and other technical and operational adaptations in project ESIF [19][20];
- 2009: ICES reviewed recent laboratory studies by IMARES and gave additional recommendations [21];
- 2009, May: The first of the 5% licenced trawlers started using pulse gears. The TX68 was equipped with the pulse trawl by Verburg-Holland (later acquired by Delmeco);
- 2009, October: HFK Engineering developed its own pulse fishing gear (Pulswing, a combination of the pulse and sumwing). The system was installed on-board the TX36, the 2^{e} trawler from the pioneer group;
- 2010: The electric pulse gear is installed on the remaining two trawlers. One trawler withdrew his plans to equip his vessel with pulse gears due to doubts about the profitability;
- 2010: ICES organised a workshop focusing on electric pulse fishing: ICES WKPULSE [22]
- 2010 October: Another eighteen trawler owners invested in pulse fishing gears and the maximum number of derogations, 5% of the fleet i.e. 22 vessels, was reached;
- 2010 December: The European Commission agreed to 20 additional temporary derogations for pulse fishing for the Netherlands based on EC regulation 850/1998 article 43 [23].

2011-2013: Electric pulse trawling is up-scaled to 42 vessels.
- 2011: In June the derogations for the additional 22 exemptions were extended [24];
- 2011: ICES launched the SGELECTRA study group, specifically focused on pulse fishing for a term of three years [25][26];

- 2011: A new steering group for electric pulse fishing is established, with participation from the Ministry of Economic Affairs, the fishing industry and the scientific community, with the objective of developing regulations, control and enforcement protocols and policy on pulse fishing;
- 2011: IMARES studied the catches and carried out comparative research into the conventional beam trawl, the HFK Pulswing and the Delmeco pulse trawl while fishing in proximity to each other during one fishing week [27];
- 2011: IMARES continued the study into the effects of electric pulse on cod [27];
- 2011: IMARES answered a helpdesk question from the Dutch ministry of Economic Affairs and provided an overview of studies on electric pulse and recommendations for follow-up studies [2];
- 2012: STECF submitted recommendations on pulse fishing and underlined the importance of a proper control and enforcement [28];
- 2012: IMARES drew up a control and enforcement protocol in close collaboration with fishermen's organisations and fishermen, producers of pulse fishing gears, the relevant ministries and its control agencies, and the scientists involved[29];
- 2012: All temporary derogations are in use; 42 trawlers are fishing with electric pulse trawls;
- 2011-2013: The additional derogations applied for in 2011 were granted on the condition that more data is collected. The fishing industry and IMARES started a pulse monitoring programme. Data on catches is collected for over a year using self-sampling and observer trips [37];
- 2012-2016: European BENTHIS project, in which the impact of fishing on the benthic ecosystem is studied. Different fishing gears were examined including the pulse trawl gear targeting flatfish and the pulse trawl gear targeting shrimp (For more information, see www.benthis.eu) [42];
- 2012-2016: At the University of Ghent under guidance of ILVO-Fishery of Ostend, Belgium, two PhD students study the ecological effects of pulse fishing on different species in order to define the 'safe range' of pulse parameters [5][43];
- 2013, May: ILVO tested the effect of pulse on cod which gives results deviating from the IMARES study of 2011, in spite of using the same methodology;
- 2013, October: Follow-up tests on cod were carried out in Norway by IMARES and ILVO in order to compare results of earlier data [44].

2014-March 2015: Electric pulse trawling is scaled-up to 84 vessels and development of a research agenda.

- 2014, January: IMARES wrote a research agenda for the flatfish pulse fishery in cooperation with LEI, the Dutch fishing industry and NGO's;
- 2014, April: The Dutch ministry of Economic Affairs applied for an additional 42 pulse derogations based on EU regulation 1380/2013 Article 14. A pilot project with an extensive pulse research programme was set up linked to the implementation of the discard ban [52];
- 2014: IMARES studied the effect of pulse stimulation on dab (*Limanda limanda* L.) under laboratory conditions;
- 2014: A MSc student, supervised by IMARES and WU studied the process of the introduction of the pulse in the Netherlands [45];
- 2014: IMARES studied the perceptions of European stakeholders concerning pulse fishing. This input was used to update the pulse research agenda for flatfish. At present the study is ongoing;
- 2014-2015: Discussion with NSAC on the pulse research agenda for flatfish. The NSAC will formulate their own advice regarding pulse fishing which will come available in 2015, www.nsrac.org;
- 2015: IMARES develops in cooperation with LEI, the Dutch fishing industry and ILVO-Fishery a research agenda for the shrimp pulse fishery.

Future developments

- 2015: Start of the pulse research which was defined in the research agenda;

Policy on the introduction of the pulse trawl

In the European Union there is a ban on electric fishing (EC Regulation 850/98). Since 2007, for the southern part of the North Sea, each Member State has been granted a derogation for 5% of their beam trawl fleet, allowing that part of the fleet to use pulse trawls (EC Regulation 850/98 Article 3.1a). In 2010 and 2011 the EU granted an extra 20 experimental pulse derogations to the Dutch government based on EC Regulation 850/1998 article 43. By the end of 2011 the total Dutch derogations existed of 4 shrimp-fishing vessels and 38 flatfish-fishing vessels.

Seven Dutch companies with interests in trawlers fishing under a foreign flag - British and German - have also been granted permission to fish on flatfish using pulse gears.

In 2014 the EU decided that the number of experimental licenses was to be expanded to 10% of the Dutch cutter fleet based on EC Regulation 1380/2013 article 14 [45]. This resulted in approximately 84 licenses made available for using the pulse trawl technique, an additional 42 licenses to the existing 42 licenses.

The EU has, however, set the following limitations for electric pulse fishing [32]:

- A maximum of 1,25 x the length of the beam trawl may be used to its full power (kW);
- A maximum of 15 V effective voltage may be used between the electrodes;
- The vessel must be equipped with an automatic system for logging electrical performance of the pulse fishing gears, and recording at least the last 100 hauls;
- It is prohibited to use tickler chains in front of the footrope.

The Dutch Ministry of Economic Affairs aims for an ecological and economical sustainable fishing sector. Mayor challenges for the Dutch cutter fleet are lowering seabed disturbance, discards and fuel consumption. The ministry sees pulse fishing as an important instrument for reaching this goal and as an alternative for the traditional beam trawl gear. The ministry supports further development of the pulse fishing technique. The goal of the pilot project started in 2014 is to create a firm scientific basis for a total allowance of the pulse technique in Europe, if results are positive [33]. It is evident that reluctance from other Member States to allow electric fishing must first be addressed [31][33] in order to gain compliance and amend current regulations. A number of Member States have asked for more research results in order to come to a decision, without specifying the kind of research required [34]. Besides conducting research, full transparency and good communication is key.

As part of the introduction of the pilot project ‘pulse fishing and the landing obligation’, the Dutch government is obliged to involve the NSAC in the process of obtaining a firm scientific basis on the pulse technique. The NSAC has formed a pulse focus group to examine all existing knowledge on pulse and to form an advice on pulse fishing. This advice is expected later in 2015 (www.nsrac.org).

4. Description of an electric field.

This chapter is based on a manuscript that has been submitted to the ICES Journal of Marine Science [53]. It describes the electric field as it is generated in the electric pulse gear.

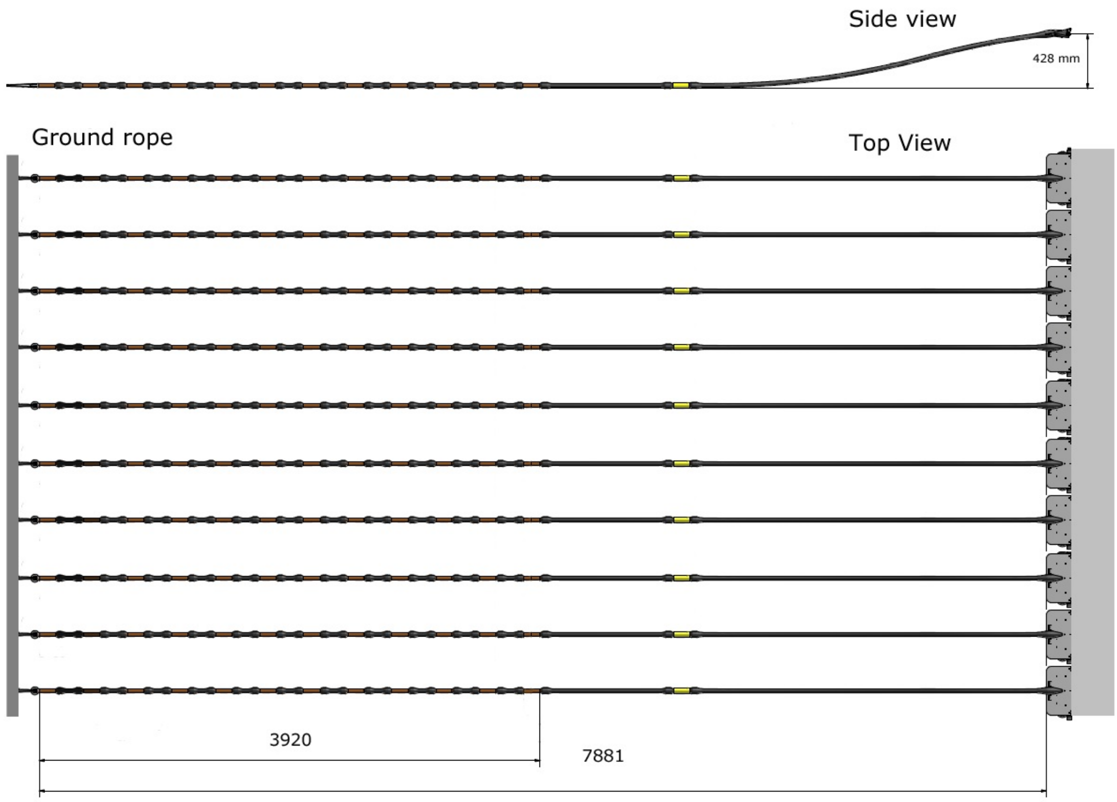

FIGURE 4.1. RIGGING OF HFK ELECTRODES OF A 4 M BEAM TRAWL. THE TOP PANEL SHOWS THE SIDE-VIEW WITH A VERTICAL TRAWL OPENING OF 0.43 M. THE BOTTOM PANEL SHOWS THE TOP-VIEW OF THE 10 ELECTRODES RIGGED BETWEEN THE WING AND THE GROUND ROPE. EACH ELECTRODE CONSISTS OF A MAXIMUM OF 12 CONDUCTOR ELEMENTS, EVENLY PLACED OVER A LENGTH OF 3.92 M, THAT ARE IN CONTACT WITH THE SEA BED. AN ISOLATED JOINT (MARKED YELLOW) IS USED TO EXCHANGE ELECTRODES.

The electrodes of the electric pulse gear run between the beam (or wing) and the ground rope (Figure 4.1). Electrodes are composed of alternating conductor and isolator elements. In the HFK system the discharge energy is simultaneously delivered to all electrodes. In the Delmeco systems, the discharge energy is sequentially distributed to each pair of electrodes. Denoting the electrodes by a number (1, 2, …. 12) and their role of distributor (+) or receiver (-), the sequential distribution will be 1+, 2-, 3+, 4-, 5+, 6-, …., 11+, 12- and 1-, 2+, 3-, 4+, ….. 11-, 12+ etc. The distribution rate is adapted to the number of electrodes as the distribution sequence has to be completed within a single pulse discharge cycle, with the distribution cycle synchronised to the pulse frequency. The conductors have a cylindrical profile. The voltage potential across a conductor pair generates an electric current (A), which is modulated by the conductivity of the water. The current can be visualised by current flux lines (Figure 4.2).

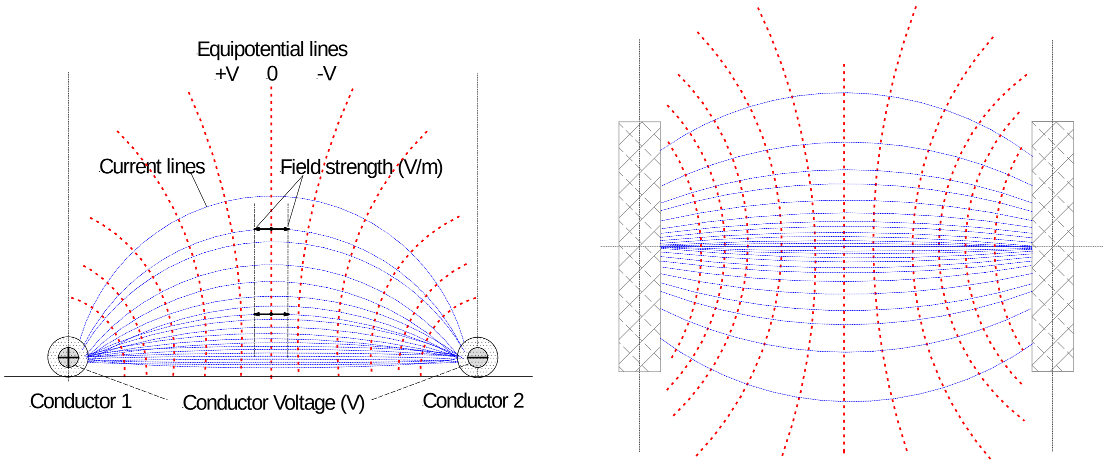

FIGURE 4.2. CURRENT FLUX LINES BETWEEN A PAIR OF CYLINDRICAL CONDUCTORS IN THE VERTICAL AND HORIZONTAL PLANE. CURRENT LINES ARE DENSELY PACKED AT THE CENTRE AXIS PERPENDICULAR TO THE CONDUCTORS. NOTE THAT AREAS OF MINOR FIELD STRENGTH OCCUR BELOW AND ABOVE THE CONDUCTORS.

Due to the cylindrical profile the current flux lines are not evenly distributed but densely packed in the plane of the conductors. The field strength (V.m-1), which is an interrelated quantity of the current flux lines, can be measured in the direction of the current flux lines. The lines of equal field strength run perpendicular to the current flux lines. It should be noted that the packing of current lines was higher in the lab than in the sea because of the fixed bottom used in the tank where the field strength was measured.

All three pulse systems use a bipolar (alternating) pulse but differ in the shape of the pulse and the timing of the bipolar parts. Since the active part of the pulse period is a fraction of the pulse period, the time period the energy is discharged (duty cycle) is about 2 %.

Field strength was measured in an experimental tank at IMARES at 35 mm above the bottom of the tank. The highest field strength is measured at the centre of the conductor and decreases towards the ends of the conductors before reaching the isolating sections of the electrode. The change in field strength was abrupt in close range of the conductor and became more gradual as the distance along the X-axis perpendicular to the electrode increased.

Figure 4.3 shows the pattern in maximum field strength in the horizontal plane (top panel) and vertical plane (bottom panel). In the horizontal plane, field strength shows a heterogeneous pattern that is related to the position of the conductor and isolator elements. Areas midway between the electrodes and opposite to the isolated sections show the lowest field strength.

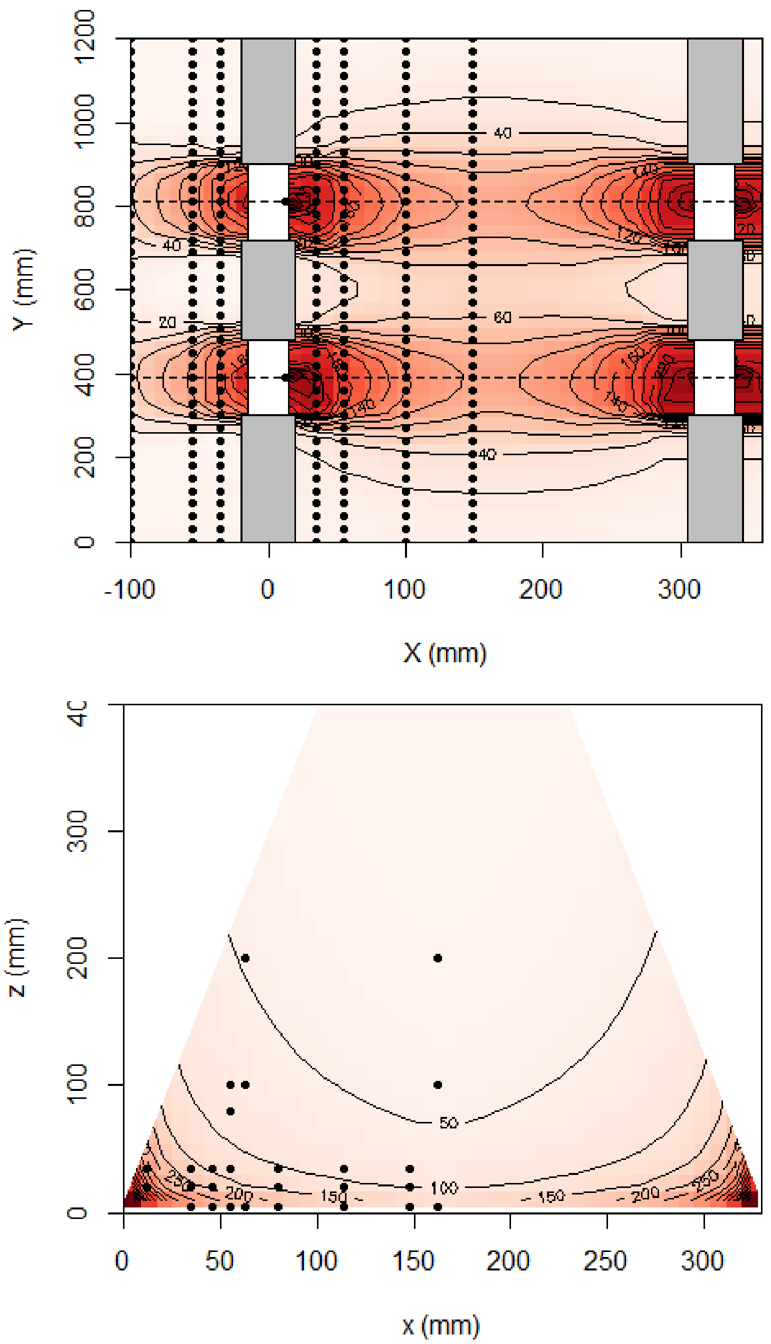

Figure 4.3. Field strength (V.m-1) contours around a pair of Delmeco electrodes positioned at X=0 mm and X=325 mm. The top panel shows the contours in the horizontal plane. The white parts show the conductors, grey parts show the isolators. The pattern on the left side of the electrode shows the decline in field strength outside the array of electrodes. The bottom panel shows the contours in the vertical plane. The head rope level is located at Z=430 mm. The dashed lines in the top panel show the location of the vertical plane depicted in the bottom panel. Locations of the field measurements are indicated by black dots.

5. Effects of electric pulse fishing

As it is a relatively new technique, the development of pulse fishing raises many questions. For this reason, over the past decades the fishing industry, the Dutch government, the European Commission and ICES have commissioned a number of studies into its effects. This chapter gives a summary of the conclusions of the studies performed so far.

To structure the review we distinguish the following aspects:

- Mechanical effects of electric pulse fishing
- Effect of electricity on species
- Effect of electricity on the ecosystem
- Catch efficiency and selectivity
    - o Share of marketable fish or other animals in the catch.
    - o Share of discards in the catch.
- Technological development
- Fuel consumption and CO2 emissions

A variety of research methods can and have been used to determine the effect of electric pulse fishing. Depending on the purpose of the investigation, the following research methods have been applied:

- Laboratory experiments (controlled conditions)
- Field experiments
- Model studies (statistical, simulation)

We will also discuss the limitations of the various studies and the differences in the effects caused by the entire pulse gear and the effects caused only by the pulse part of the gear.

Mechanical effect of electric pulse fishing

As with other fishing gear, the pulse gear may have mechanical effects (footrope, net) on the seabed and on marine organisms.

In 2012, the European BENTHIS study project was started, focusing on the effects of fishing in its current form on seabed ecosystems. Different gears are examined under which the flatfish and shrimp pulse trawl gear. All field tests have been executed and first results show that the penetration depth of the pulse gear is less than the penetration depth of the beam trawl gear [42][51]. Additional results showed that the pulse and conventional beam trawl did not differ significantly in the quantities of sediment mobilised in the wake of the gear, although the total concentrations of resuspended particles was slightly higher for the pulse gear at 25 and 45m behind the beam. The reduction of dissolved oxygen in the water column following a pulse trawl or a conventional beam trawl is similar, and oxygen levels appear to revert back towards the baseline levels soon after trawling [42].

The BENTHIS project will also develop a model that enables calculation of the impact of fishing gears on the ecosystem on and in the seabed based on the number of vessels, geographical distribution of the fishery and the fishing gears being used, with results expected in 2017.

Effect of electricity on species

All species that are in the path of the pulse trawl will be exposed to the electrical pulses. The strength of the exposure will depend on the distance and orientation at which the organism is located from the conductor (see chapter 4.). This may cause injury, long term effects and/or influence the chances of survival. Effects have been studied in a variety of organisms in laboratory tests and tests at sea using the Delmeco and HFK pulse systems [1][2][13][14][15]. The laboratory tests focused on species representative for their species group in the North Sea. An overview of the results for each species group is given below.

<u>Dab</u>

A recent experiment was conducted on wild-caught dab (*Limanda limanda L.*). Two groups of 51 fish were exposed to electrical stimuli commercially applied in Dutch flatfish trawls with differing bipolar intervals, while a third group was used as “control” group being given the same handling without exposure to electrical stimulation. After exposure the fish were analysed for external and internal lesions, possibly attributable to pulse exposure. In case of lesions attributable to infections, bacteriological tests were conducted. Of the exposed dab, two fishes died after the treatment, with unclear relation to pulse exposure. Dissection results showed that external and internal anomalies occurred in all groups, with no clear differences between the exposed categories. Approximately 12% of the fish had a Glugea infection in their gut, and only in a single case, a bacterial fish disease by *Vibrio anguillarum* was found. It was concluded that no lesions were observed in the fish, neither analysed directly after, nor when analysed five days after the treatment [47].

<u>Cod and whiting</u>

The most notable effect found in the studies on cod and whiting is the risk of spinal fractures in particularly larger cod. The first samples investigated showed that about 10% of the cod and 2% of the whiting showed a fracture of their spinal column. This is caused by strong muscle contractions as a reaction to the electric pulses [1][14] (table 5.1).

The length of the cod and its distance from a conductor were recognised as important factors for the appearance of this effect: smaller fish, measuring 12-16 cm, were not injured while larger fish, measuring 40-60 cm, had an increased chance of spinal fractures [1]. Exposure to higher field strengths is important for the effect to be present, the cod were injured when held at a 10-20 cm distance from the conductor; but at a distance of 40 cm no injuries were observed [14]. At the minimum distance of 5 cm to the conductor the chance of injuries was 50-70% [1]. Conflicting results were found in a new study by Soetaert in May 2013 in which he used the same methods, repeating the previous study [1] and investigating the effects in a homogeneous field. He recorded no injuries in any of the set-ups [5].

In October 2013 a follow-up study was done by IMARES and ILVO to investigate the cause of these differences. The results of this study resulted in five cases of vertebral injuries in adult cod. Four injuries occurred at 120 V (twice the maximum commercially applied amplitude) and 1 at 60 V (resp. an injury rate of 13% and 4.5%) .This study confirmed the outcome of the study by Soetaert in 2013 [5]. The origin of the conflicting outcome between the earlier two studies is expected to be related to differences in the body condition of the fish used (e.g. differences in muscular system, mineral content) [44].

TABLE 5.1. DAMAGE TO THE SPINES OF ROUND FISH, BASED ON TWO STUDIES [1][14]

Study	Result
2011: Electric pulse stimulation in 20 cod under laboratory conditions [14]	Effect on cod closer than 10 cm to electrode: • 4 dead shortly after pulse stimulation (20%); • 2 dead in observation period following the pulse stimulation (10%); • Total of 6 died (30%). Of the 16 fish that survived initially: • 5 had haemorrhages near the spine; • 4 had a broken spine; • 9 of 16 had injuries (56%).
May 2013:	No injuries found in both small and bigger cod.
October 2013:	Effect on adult cod exposed to 60 V: • 4 had injuries (13%) Effect on adult cod exposed to 120 V (twice the maximum commercially applied amplitude); • 1 had a vertebral injury (4.5%)
Spine examination after being caught at sea [1]	- HFK gear: spinal fractures in 7% of the 27 cod caught; - Delmeco gear: spinal fractures in 11% of the 18 cod caught; - Both gears: spinal fractures in ~2% of the 47 whiting caught; - Beam trawl: no fractures: 0% of the 48 cod caught;

Sharks and rays

Sharks and rays have sensitive electro-receptor organs to detect the electric fields. This suits to orientate themselves and detect their prey, which emit weak electric fields by muscle contractions [21]. The electro-receptor system might be disturbed when they enter the electric field of the pulse trawl.

The effects of electric pulses emitted by pulse fishing gears on dogfish have been studied under laboratory conditions [15]. The conclusions were as follows:

- Electric stimulation did not cause mortality;
- Physical reactions occurred (muscle contractions and swimming towards the surface) when fish are close to the electrodes;
- Fish behaviour and food intake after tests were affected to some degree;
- Egg production was not affected.

ICES advised to conduct additional tests in order to determine whether the electro-receptors still function when sharks or rays enter the electric fields generated by pulse fishing gears [21]. Such a study is carried out in Belgium by Desender (PhD) and the results are expected at the end of 2015 [35].

Benthic species

The effects of the electric stimulation of pulse gears on a range of six benthic species (ragworm (*Nereis virens* L.), common prawn (*Palaemon serratus* L.), subtruncate surf clam *(Spisula subtrunca-*

ta L.), European green crab (*Carcinus maenas* L.), common starfish (*Asterias rubens* L.), and Atlantic razor clam (*Ensis directus* L.)) have also been studied under laboratory conditions by IMARES in 2009. Three distance ranges were tested [13].
The conclusions were as follows:

- Certain species did not show a behavioural reaction; other species did. The strongest reactions were seen in prawn and common crab, and weaker reactions in rag worm and razor clam. No reactions were seen in surf clam and starfish irrespective of exposure.
- Effect on survival, if at all, was low (3-7% for ragworm, common crab and razor clam);
- The food intake of the common crab dropped somewhat (5-15%), but not at the greatest distance. The ragworms, razors, and surf clams (spisula) consumed all offered food without any significant effect.
- The burial speed of ragworm, surf clam and razor clam might be affected by pulse stimulation.
- In general terms the effects of the pulse stimulus in terms of mortality and food intake can be described as low.

In 2014, the effects of electric pulse on brown shrimp (*Crangon crangon*) and ragworm *(Alitta virens S.*) were studied by Soetaert (PhD student from ILVO and the university of Ghent) [43]. Both animals were exposed between plate electrodes to the shrimp and sole pulse, as well as non-commercial pulses with altered pulse settings. The conclusions were as follows:

- The vast majority of shrimp demonstrated a tail flip response when exposed to electric pulses depending on the frequency;
- The ragworm demonstrated a squirming reaction when exposed to electric pulses, independent of the frequency;
- No significant increase in mortality or injuries was encountered for either species within the range of pulse parameters tested;
- An increase in severity of intranuclear baculoform virus infection was found in brown shrimp exposed to the highest electrical field strengths (200 V m^{-1}), warranting further research.
- This study does not rule out indirect effects, warranting further research.

Survival chances for undersized plaice and sole

In 2004 and 2005, studies were carried out on board of the research vessel ‘Tridens” into survival and physical condition of undersized plaice and sole caught with the pulse gear and the conventional beam trawl gear. The chance of survival for plaice and sole was examined by transferring the fish caught into survival tanks with registration of survivors at regular intervals. The conclusion from these tests was that the pulse gear caused less damage (subcutaneous haemorrhage, skin damage) to the fish than the conventional beam trawl.

A significant higher survival rate for plaice was found for the pulse trawl after 192 hours of observation. For sole an effect on the survival rate could not be demonstrated for gear used [9].

These kind of tests have been criticised by the fishing industry and other researchers. In the fishing industry the opinion was that fish discarded at sea are able to return to their natural environment and would have better chances of survival than when kept in observation tanks. In the review of this study by the scientific community it was argued that the trials did not enable to distinguish between effects of capture and processing and effects due to storage in survival tanks and monitoring survival. It was therefore recommended that control groups should be used in future studies. An improved test method was developed since and currently IMARES is studying the survival of species (sole, plaice and dab) on board of vessels using different gears under which the pulse trawl gear, a project related to the coming landing obligation of discard fish species [33].

Chance of survival for benthic species in the trawl trail

The trawl path left by the fishing gear of both the pulse trawl and the conventional beam trawl is influenced by the mechanical components, such as footrope and the net itself when it touches the sea bed. With the pulse trawl, the trawl path is also affected by the electric pulses.

A portion of the benthic species (and fish) in the trawl path ends up in the net and another portion remains on the seabed. In order to analyse fishing effects on the ecosystem it is essential to investigate the effect on species that are not caught but are left behind in the trawl path. A study at sea executed in 2000 with gears of 7 m gave strong indications of increased chances of survival for 15 benthic species in the trawl path of the pulse trawl as opposed to the traditional beam trawl (median direct mortality 24% compared to 36% for the conventional beam trawl; $p = 0.09$) [7][36].

Effect of electricity on the ecosystem

The possibility exists that electric pulse fishing may affect the structure and composition of the underwater ecosystem via both direct and indirect mechanisms. Soetaert et al. (2013) suggests the necessity to investigate the pulse effect on the seabed substrate and the water column composition as a result of electrolysis (direct). In addition, long term effects on reproduction, juvenile stadia and growth may occur and may influence population dynamics (indirect). This warrants further investigation. Up to now, little research is done on the effects of electric pulse fishing on the ecosystem.

Catch efficiency and selectivity

There are three main questions related to the catch efficiency and catch composition of the pulse trawlers

- What is the catch efficiency as compared to the conventional beam trawl
- What is the selectivity with respect to size and species
- What is the amount of discards caught by the pulse trawl fleet in comparison to the tradition al beam trawl fleet

The effects on catch composition (landings and discards) and selectivity of conventional beam trawls and pulse trawls were studied by catch comparison experiments and monitoring programmes at sea [11][27]. Data on the amount of discards caught by pulse trawl gear and traditional beam trawl gear were collected during monitoring programmes at sea [37].

Selectivity experiments

A series of catch comparisons of a 7 m and 12 m prototype ‘pulse’ trawl were conducted on board of RV Tridens in 1998, 2000, 2001, 2002, 2003, 2004, 2005 and 2011 [8][9][27][54][55].

The catch comparison experiments in 1998 showed that the pulse trawl catch rate of sole (*Solea vulgaris L.*) matched those of conventional tickler chain beam trawls, plaice catches being reduced by some 50%, and benthos catches reduced by 40%. [54][55]. In 2000, a catch comparison study between a conventional 7 m tickler chain gear and the 7 m prototype ‘pulse’ gear gave strong indications of increased chances of survival for 15 benthic species in the trawl path of the pulse trawl as

opposed to the traditional beam trawl [7][36]. As discussed in the previous paragraph under *Chance of survival for benthic species in the trawl trail* (page 22).
Technical trials with the new 12 m beam length prototype were carried out in November-December 2001 on board FRV “Tridens”, and were continued in 2002 and 2003, resulting in catch rates for sole and plaice equalling those of conventional 12 m beam trawls [11].

Comparative studies were undertaken in 2004 and 2005 on FRV “Tridens” on the differences in catches and on differences in survival of undersized sole and plaice between a 12 m pulse beam trawl and a conventional 12 m tickler chain beam trawl [8][9]. A significant higher survival rate for plaice was found for the pulse trawl after 192 hours of observation. For sole an effect on the survival rate could not be demonstrated for gear used [9]. As discussed in the previous paragraph under *Survival chances for undersized plaice and sole* (page 21).

In 2004, the decision was made to test the 12m-pulse trawl on a commercial fishing vessel [57]. Results of this pilot study showed a reduction of 45% in litres fuel consumption per week and higher prices for fish caught with the pulse trawl due to the improved quality of the fish caught [45].

A catch comparison of commercial vessels was conducted in in 2011 between two vessels with a pulse gear (DELMECO and HFK pulse gear) and one vessel with a conventional tickler chain beam trawl gear [27]. The results of this experiment is reported in IMARES report C122b/11 [56]. The data have been reanalysed recently and is published in the scientific literature [27]. This report substitutes the earlier reports. The main findings are described below.

The comparative fishing experiment of three commercial vessels clearly showed clear differences in the catch efficiency and selectivity of the pulse gears as compared to the traditional tickler chain beam trawl. For sole and plaice, the catch rate per hectare of the pulse trawl did not differ significantly from that of the traditional beam trawl. The total catch rate in kg hectare^{-1} of all commercial species of the pulse trawl was significantly lower (-20%, $p<0.001$).

The pulse trawls could fewer fish discards (-57%, $p < 0.0001$), including 62% undersized plaice ($p < 0.0001$), and 80% discarded weight of benthic invertebrates ($p = 0.0198$) per hectare. The higher towing speed of the traditional beam trawl, and the larger surface area of the sea bed trawled per hour fishing, implies that the lower catch rate of the pulse trawl the differences in catch rate becomes higher when expressed as catch per hour fishing.

A comparison of the catch rates by size class indicated that the pulse trawl caught significantly less undersized sole and plaice (Fig. 5.2).

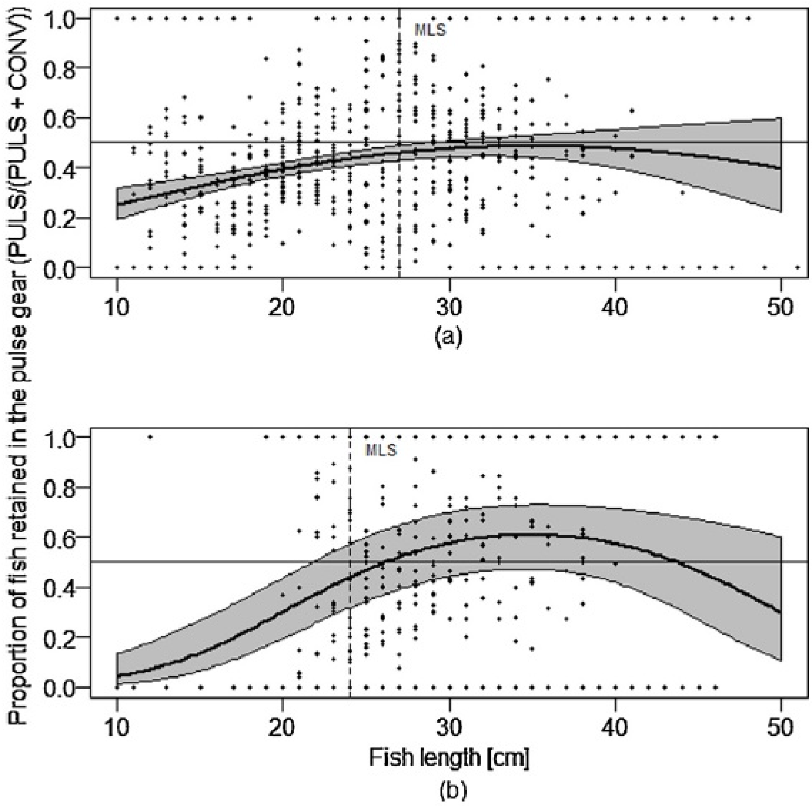

FIGURE 5.2. PROPORTION OF FISH RETAINED IN PULSE GEAR VS. LENGTH FOR PLAICE (A) AND SOLE (B). THE VALUE OF 0.5 MEANS BOTH GEARS CATCH EQUAL NUMBERS (> 0.5 MEANS PULSE GEAR CATCHES HIGHER NUMBERS; < 0.5 MEANS PULSE CATCHES LOWER NUMBERS). THE SOLID LINE GIVES THE MEAN, AND THE GREY BAND GIVES THE 95% CONFIDENCE LIMIT. DATA POINTS ARE GIVEN IN BLACK DOTS. MLS IS MINIMUM LANDING SIZE (PLAICE: 27 CM, SOLE: 24 CM)[27]

Monitoring of catch composition

The pulse monitoring programme of 2011-2013 collected data on the catch composition for the entire Dutch pulse fishing fleet targeting flatfish that existed of 38 vessels at that time [37]. The data were partly collected by fishers and partly by IMARES and ILVO researchers that went on board as observers.

The pulse monitoring programme showed that the pulse vessels caught similar quantities of sole as vessels using tickler chains although less plaice was caught [37]. A LEI study - yet to be published – demonstrates that the pulse fishery catches more marketable sole (+14%) than the beam trawl fishery; however, other species are caught in lower quantities, such as plaice (-41%) (see Table 5.3) [38][46].

The catch is composed of landings – the portion that is brought to land and sold – and discards - the portion that is thrown back into the sea. The comparison of the aggregated catch composition data does not necessarily reflect differences in catch efficiency or selectivity , because the catch composition is highly variable and is dependent on the fishing ground and fishing season as well as rigging of the gear.

TABLE 5.3 MAIN OUTCOMES PULSE WING AND OTHER FLATFISH FISHING METHODS, IN EURO'S, 2011 (TRAWLERS 2.000 PK; [46])

Per day at sea	Pulse	Conv.
Value of landings	8.668	9.141
Diesel costs	2.404	4.491
Litres diesel	4.055	7.780
Litres diesel/kg fish	2,32	3,10
Total kg fish	1.687	2.508
Part sole	525	460
Part plaice	823	1.398

Source: LEI

If the landings are expressed in kg per litre of fuel we can state that the pulse gear roughly catches 1.5 times as much, i.e. 0.3 kg/litre. The conventional beam trawl catches 0.2 kg/litre [27]. The LEI study resulted in 0.4 kg/litre for the pulse catches (total kg fish) and in 0.3 kg/litre for the conventional beam trawl catches (total kg fish). Resulting in the pulse gear roughly catching 1.3 times the amount of the landings per litre, in comparison to the conventional beam trawl gear [45].

The pulse monitoring programme showed that the pulse fishery catches fewer organisms to be discarded than the conventional beam trawl fishery with tickler chains (see table 5.4) expressed in either kg/hour or numbers per hour [37]. This coincides with the result found in the comparative study in 2011 [27].

TABLE 5.4. DISCARDS BY VESSELS WITH A CONVENTIONAL BEAM TRAWL (CONV.) AND VESSELS WITH PULSE TRAWL (PULSE). THE PERCENTAGE IN RELATION TO LANDINGS IS SHOWN IN BRACKETS. TWO SOURCES: ONE WEEK OF COMPARATIVE STUDY BETWEEN THREE VESSELS (PULSE HFK, PULSE DELMECO AND CONVENTIONAL) [27] AND PULSE MONITORING, COMPARED TO REGULAR DISCARDS MONITORING BY IMARES [37].

Discards	Conv.	Pulse	Pulse/Conv. (%)
Plaice [37]	87 kg/hour (49%)	27 kg/hour (42%)* 66 kg/hour (52%)**	31-76%
Sole [37]	29 kg/hour (17%)	6 kg/h (15%)*/ 4 kg/h (10%)**	14-21%
Non-commercial fish [27]	174 per hour	128 per hour	74%
Benthic species [27]	4972 per hour	3170 per hour	64%
Starfish [37]	8453 per hour	1411 per hour	17%
Crab [37]	1120 per hour	465 per hour	42%

* Pulse monitoring programme: sampling by fishers
** Pulse monitoring programme: sampling by observers

Technological development

As the pulse trawl is a relatively new technique, it is likely that the electric pulse gear is subject to continuous development within the existing regulations. As the gear is further developed in the future, it is expected that it will affect catch efficiency and selectivity. For the further development of the gear close attention is required, as is done at present, on the economical, ecological and social consequences of these developments.

Fuel consumption and CO_2 emissions

The comparative study from 2011 shows that fuel consumption of the pulse is significantly lower than the fuel consumption of the conventional beam trawl gear [27]. The vessel with tickler chains used 5.3 litres of fuel for each kilogram of landed fish. The vessel with the Delmeco pulse gear used 3.7 litres fuel/kg and the vessel with the HFK Pulswing used 3.1 litres fuel/kg. This is respectively 70% and 58% of the fuel consumption of the vessel with tickler chains. The LEI study showed that the SumWing gear used 2,6 litres fuel/kg, the Pulse Wing gear used 2.3 litres fuel/kg, and the conventional beam trawl gear 3.1 litres fuel/kg. This is respectively 85% and 75% of the fuel consumption compared to the conventional beam trawl gear [46].

In 2008, model based predictions showed that greenhouse gas emissions such as CO_2 would decline if a change was made from conventional beam trawl fishery to pulse fishery [39]. See table 5.5 for the results. The gear resistance of a typical beam trawler of 2000 pk would be reduced by 25%, resulting in fuel savings of 34.6% per year. CO_2 emissions would drop from 2788 tonnes/year to 1796 tonnes/year (*i.e.* a ratio of 35.6%).

TABLE 5.5. DIFFERENCE IN FUEL CONSUMPTION AND GHG-EMISSIONS FOR A DUTCH REFERENCE VESSEL (2000PK) WITH BEAM TRAWL AND WITH PULSE TRAWL. [39]

[tonnes/yr]	**Conv. (Speed 6.5 kn)**	**Pulse (Speed 5.5 kn)**	**Pulse/Conv. % reduction**
Gas oil	1075.62	703.48	34.6
CO_2	2788.41	1796.26	35.6
SO_x	21.51	14.07	34.6
NO_x	49.17	39.51	19.7
HC	35.72	23.01	35.6
CO	312.52	222.54	28.8

Study limitations

The results of various studies into the effects of electric pulse fishing may not always be comparable because of varying research conditions:

1. The studies focused on a limited number of fish and benthic species indicative for the ecosystem because of limitations in means (research grants, time, manpower, housing capacity) and practical limitations;
2. Various types of pulse systems were used in the different studies making comparison of the results more difficult;

3. There is no on-field monitoring of pulse trawlers, nor any legislation, and as a consequence the pulse settings used are different for each trawler and most often unknown (even by the fisherman). Technology is developing all the time, as well as the pulse parameters, and the fishing gear.
4. The study methodology has improved over time as a result of the review and discussion by ICES experts.

Integration of effects on fishery scale

In order to make an assessment of the overall effect of a transition of the beam trawl fleet with traditional tickler chain gear to a fleet with pulse trawls, we need to be able to integrate the results of the different studies and scale up the effects from the level of the experiment to the level of the whole fleet and the level of the North Sea ecosystem. In addition, we should take account of the possible changes in the pulse trawls due to the autonomous developments in the fishing gears.

Distinction in the effects of the pulse and the whole gear

Part of the studies were done on effects caused by the whole pulse gear, e.g. the combination of electrical and mechanical stimuli. Laboratory studies were done on the effect caused by electric pulses only. Where possible, effects were attributed to either the electric pulses themselves or the whole pulse gear. This is essential because the design of the pulse system - the pulse characteristics and gear design - and the way it is used have differing effects on fish, benthic species, plants and the soil structure.
The results of the laboratory experiments cannot directly be extrapolated to the effect of the gear without taking into account that marine organisms will be exposed at different positions in the electrical field and be exposed to different field strength levels.

Damage caused by the electric pulses is typical of the pulse gear, whereas mechanical damage caused by contact with other parts of the gear is not as marine organisms also suffer this kind of damage in traditional beam trawl fishing. In addition, a distinction can be made between the heavier pulse gears and the lighter pulse gears, also influencing the degree of mechanical damage.

Comparing the effects of the conventional beam trawl and the pulse trawl

The conventional beam trawl causes more mechanical damage to captured species, species that are left on the seabed, and the seabed itself than the pulse gear [9][42][51]. This is caused by the movement of the heavy weight of the chains of the conventional beam trawl running over the sea bed at an angle to the direction of motion. However, the pulses generated by the pulse trawl can cause other effects, such as spinal fractures in cod and distorted behaviour in sharks and rays and in some benthic species.

Pulse trawl catches are smaller than conventional beam trawl catches, resulting in a clearly lower total quantities of landings and discards [27]. Fuel consumption, however, is distinctly lower in pulse trawling causing higher landings per litre of fuel, a beneficial situation for the pulse fishers.

Currently, 84 vessels have got licences for fishing with pulse trawls (70 to target flatfish, 14 to target shrimp). There are only 8 vessels left using the conventional beam trawl. What effect would this transition to pulse fishing have on catches, discards and the ecosystem? In 2012, ICES SGELECTRA carried out a scenario study using a model developed in Piet *et al*., 2009 [40] into the effects on landings and discards if a full transition to pulse trawling was to take place in the relevant metiers in the North Sea fisheries assuming that the distribution of the fleet would not be affected by the change in fishing gear [25]. Predictions based on this model and the latest field data [27], showed that the total quantities of discards of cod, haddock, sole, plaice and whiting would decrease considerably. Because of the differences in catch efficiency and selectivity of the pulse trawl and the traditional beam trawl, we expect that the distribution of fishing effort of the pulse trawl fleet will differ to some extend from the distribution of the traditional beam trawl fleet. Hence an assessment of the effects of a transition should take account of the effects of the changes in catch efficiency on changes in the allocation of fishing effort.

6. Electric pulse fishing management

By introducing a new fishing method it is important that it contributes to sustainable fishing practices, so that besides economic and social profitability, it meets the conditions for ecological sustainability. This means that catches of target species must meet total allowable catch (TAC) requirements and that discards must be limited. Unwanted effects on the ecosystem must be avoided. Technology must be manageable, maintainable and enforceable; its safety must be guaranteed for users and inspectors.

The Ministry of Economic Affairs, fishery representatives, pulse trawl producers, the Dutch Food and Consumer Product Safety Authority (abbreviated in Dutch as NVWA), foreign experts, the Shipping Inspectorate and IMARES are working together on control and enforcement procedures. They have also collaborated on a report concerning the conditions for managing electric pulse fishing [29]. As a result, general conditions and basic requirements could be proposed and incorporated into European and national legislation. Moreover, the specific characteristics of the pulse trawl will be recorded in a document accompanying the vessel, the Technical Dossier. The control and enforcement procedures are now being implemented.

7. The research agenda (knowledge gaps and future research)

This chapter deals with the current knowledge gaps. This is the knowledge needed to regulate electric pulse fishing internationally and the knowledge required to assess the potential ecological risks, economic consequences and the governance aspects of the pulse. ICES and the Scientific Technical and Economic Committee for Fisheries (STECF) are the two most important international scientific institutions in Europe that have commented on the knowledge required regarding pulse fishing. Their feedback, an overview article of Soetaert *et al*. (2013) and some workshops with scientists of ILVO, IMARES and LEI have led to the Research Agenda on Pulse fishery.

This Research Agenda was discussed with the NSAC and in addition stakeholders in Europe were interviewed, meetings observed and media messages analysed to assess whether the concerns and questions stakeholders expressed were sufficiently addressed in the Research Agenda [50]. The NSAC established a pulse trawl focus group in 2014. Advice from the NSAC will follow later in 2015.

Below shortly the main points mentioned by ICES, STECF and those presented in the article of Soetaert *et al.*[5].

ICES acknowledges that pulse fishing is a possible alternative to traditional beam trawl fishing, because, based on current knowledge, it may be less damaging to the environment, and there are still questions to be answered [41]. According to ICES there is currently too little information available to justify expansion of the pulse fleet; it advises that any expansion should only be permitted if more studies into its ecological effects are carried out. This includes the following matters:

- Indirect mortality (enters with delay);
- Long term effects on populations;
- Effects that are not fatal;
- Effects on reproduction;
- Pulse characteristics.

STECF advised that proper enforcement and control of pulse fishing must be in place before the number of pulse fishers is increased [28]. Moreover, expansion of the pulse fishery to new locations or with other trawls must only be considered after impact studies have been made on the ecosystem and on species currently without an impact study.

In their 2013 article Soetaert and his colleagues raised the following questions concerning possible long term effects for the ecosystem and species populations [5]:

- Is there a safe range of pulse characteristics within which the pulse has no significant effect on marine organisms?
- What are the effects of the use of pulse in shallow waters on the first life phases of marine organisms that breed in shallow water?
- Does the pulse affect the substrate and the water column, possibly creating toxic substances?

The complete research agenda can be found in appendix A.

Future research

Future research related to pulse fishing is identified in the Research Agenda on Pulse fishery (see appendix A). The research agenda on pulse fishery lists preliminary prioritized research topics with issues to address in the short- and long-term. The agenda has been developed based on literature, discussions with scientists (of IMARES, ILVO, NIOZ, ICES WGELECTRA), policy makers and stakeholders (see Kraan *et al* forthcoming; and the NSAC).

Further prioritization will take place in the Steering Committee Pulse Fishery under a newly defined Pilot Project on Flatfish Pulse Fishing. Some elements from the research agenda ask for long term research. As these are large projects, they need to be tendered. The Dutch ministry of Economic Affairs has therefore started a tender procedure. The tender concerns four studies:

- Effect on marine organisms; predictive model of the distribution of the electrical field in various organisms and their effect on activity and survival of fish and benthic invertebrate taxa
- Effect on the benthic ecosystem; predictive model of the impact of electrical pulses on benthic ecosystem functioning
- Effect on the seabed; predictive model on the small scale distribution of a fleet in relation to the nature of the sea bed characteristics
- Field study in areas with different fishing regimes.

These research projects (both the pilot as well as the tendered studies) will start in 2015 and take 4 years.

In addition to this pilot project on flatfish, there will also be a designated research agenda for shrimps. As recently, the development of a pulse gear for catching shrimps has taken up again as an opportunity to decrease discards, inspired by developments in the flatfish pulse fishery. For the shrimp pulse fishery, a long-term research agenda was still lacking. Therefore, the Ministry of Economic Affairs asked IMARES and ILVO to develop a research agenda for the shrimp fishery pulse in consultation with the shrimp fishing industry. The underlying question in setting up this research agenda is: What are the (in)direct effects on the marine ecosystem of fishing with shrimp pulse gear?

Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Appendix A. The Research Agenda on Pulse fishery

Issue	Need expressed	Existing knowledge	Knowledge gaps	Proposed research	Cost	Priority
Ecology						
Claims of damaged or dead fish and additional fish mortality from the industry.	Stakeholder analysis	Very little active monitoring of stakeholder claims	Claims are being presented of adverse effects due to pulse trawling without real evidence.	Collect and log the 'anecdotes', discuss them with pulse fishers and others (if possible), try to understand a pattern if possible.	BO project puls	1
Current research only focusses on limited number of species. More species come into contact with pulse trawl that are not captured. New fisheries with pulse are developing (e.g. nephrops, spisula)	STECF	Cat sharks, cod, six benthic species studied. Effect on cod can be prominent, other effects were limited.	Why did Dutch find spinal damage in cod, and Belgians not? Potential impacts on non-researched species	Study effect of pulse on nephrops and on their burrows (since nephrops don't move). Underwater observation (Contacts with Scotia well advanced)		1
				Behavioural study on the effects of electricity on nephrops. Contacts with CSIC Barcelona, Spain.	PhD1	1
				Develop monitoring approach for unaccounted mortality (e.g. by sampling on board of non-pulse vessels?)	Integrate with DCF discard monitoring?	2
				Compare Dutch and Belgian studies in a repeated experiment.		Done
Sole and dab have blisters that are allegedly due to pulse fishing	Popular media	ILVO has done research on occurence of blisters on dab and sole	Can we verify experimentally whether pulse could lead to blisters?	Test in laboratory conditions on farmed sole and dab taken from North Sea. After testing observe for 3 months.	Short study (12 kE)	In progress
Thresholds of short and long-term effects of pulse characteristics are not known. Pulse used in flatfish gears may be too strong	STECF, ICES	Optimal pulse for shrimps and sole developed	Can settings be reduced to decrease effects?	Fundamental research on various species under pulse stimulation with varying pulse characteristics.	PhD1	1
Effect on electro-receptor organs of elasmobranchs fish is not known. Stocks of these fish are in decline, and special conservation measures might be required.	ICES	Such organs are very sensitive to electric currents, and may get disturbed. Only cat sharks as indicator species studied.	Fish may not be able to detect prey after exposure to electric fields of pulse trawls. What about rays?	Study elasmobranch prey detecting capabilities after exposure. Include rays.	PhD1	1
Long-term effects on populations (including mortality over longer time, reproduction, juvenile stadia and growth).	ICES/ Soetaert	Only short-term effects studied with limited pulse settings, and limited on direct mortality and larger sizes, only some indicator species.	Long-term effects (including mortality over longer time, reproduction, juvenile stadia and growth) on populations are not known.	Studies on target and non-target biota in contact with gears: indirect mortality, growth, reproduction, of adult and juvenile stadia on longer term.	PhD2 Pulse Monitoring proposal	1

Issue	Need expressed	Existing knowledge	Knowledge gaps	Proposed research	Cost	Priority
Effect on substrate (habitats) and chemical composition in water column from electrolysis.	Soetaert et al.	Some claims of potential effects were given (e.g. Mike Breen on chlorine production).	Effect on substrate (habitats) and chemical composition in water column not known.	Research into effect on sediments of electric pulses. Research into dissolution of chlorine compounds by electric pulses.	PhD3	2
Technology						
Technology progresses beyond the current status. Pulse trawling will be developed for other gears than beam trawls, e.g. twin-trawls, dredges,...	ICES	DELMECO integrates shrimp and flatfish pulse.	What are the new pulse settings, what are effects?	Monitor pulse technology development beyond the current status and the beam trawl applications.	~ 5 kE	1
Monitoring of spatial deployment of pulse gears	Stakeholder analysis	VMS data available	Do pulse vessels explore different grounds?	Monitor spatial deployment of pulse gears	Pulse monitoring proposal	2
Economy						
Economy of pulse trawling applications, and socio-economic aspects are not all known.	STECF?	Some existing systems are evaluated. This shows economic potential. NL industry invests in the method as the best alternative to tickler chain.	Does this apply to all systems? Can this be extended to new technical developments?	Monitor economic performance of more vessels (BENTHIS).	Covered under BENTHIS project	3
Governance						
Resistance to allow pulse trawling within other European member states (BE, DE, FR, UK). Problem perceived as a Dutch problem only.	Dutch government	Some EU member states oppose the implementation of pulse trawling on a wider scale.	Perceptions? Interests? Fears? Hidden agendas?	Stakeholder analysis, interviews. Research on political aspects.	BO 2014	1 (In progress)
Control and enforcement needs to be assured.	STECF / ICES	Control and enforcement documents and technology defined.	Practical experience with the suggested rules and technology.	Do pilot study with newly suggested regulations and performance monitoring technology with inspection agencies.	IMARES guidance, ~85 K€	1
Decision framework and models are not fully developed.	IMARES	Crude models exist (e.g. Piet et al., 2009) and show potential in reducing discards in five target species.	Effects of new effort allocations, fishermen's response, effects on benthic species, definite ecosystem indicators.	Extend ecosystem research and models.	P.M.	3
Most reports only in grey literature.	ICES, STECF	Several papers in preparation, one published (van Marlen)		Finalize (x) papers in progress.	~15-20 k€	1
Insufficient visibility of international research	IMARES workshop	SGELECTRA platform for research	Need for more comprehensive expert groups on effects of electricity in marine environment	Expand scope and outreach of SGELECTRA	2 extra persons per year to SGELECTRA, ~55 k€ per year	1

Justification

Report C091/15
Project Number: 4311810007

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Prof. dr. Adriaan Rijnsdorp
Professor fisheries ecology

Signature:

Date: 19 June 2015

Approved: Dr. ir. Nathalie Steins
Department Head Fisheries

Signature:

Date: 19 June 2015