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Final Report of the Working Group on Electrical Trawling

17-19 January 2017

IJmuiden, the Netherlands

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Contents

Executive summary

WGELECTRA met three times (22–24/10/2014; 10–12/11/2015, and 17–19/01/2017) to discuss the ongoing research projects in Belgium, the Netherlands, and Germany and provide an overview of the state of the art knowledge of the ecological effects. Pulse trawls are used in the North Sea fishery for flatfish and brown shrimp. The shrimp pulse applies a low frequency pulse that invokes a startle response (tailflip) in shrimps. The sole pulse applies a higher frequency that invokes a cramp response that immobilise the fish species facilitating the catching process. The use of electricity in fishing has raised considerable concern among stakeholders which is mainly focused on the unknown effects on marine organisms and the functioning of the benthic ecosystem but also altered fishing efforts & catch efficiencies.

A number of laboratory experiments have been carried out in which a selection of fish species and invertebrate species have been exposed to electrical stimuli to study possible adverse effects. The maximum pulse treatment applied exceeded the strength of the pulse used by the fishery. Electrical stimulation did not cause direct mortality during exposure. Exposure to the sole pulse stimuli invoked vertebral fractures and associated haemorrhages in roundfish species (cod), but not in flatfish species (sole, plaice, dab) or seabass. The results suggest that fractures are restricted to the larger size classes of cod that are retained in the net, whereas smaller cod that can escape through the 80 mm meshes did not develop fractures even when exposed to high field strength. The fracture incidence in cod increases with field strength and decreases with pulse frequency. Fracture incidence varied between experiments. Experimental induced fractures corresponded to fractures observed in cod and whiting sampled from commercial pulse trawls. Further studies are required to study the relationship between the fractures and the body size and determine the differences in fractures across fish species. Shrimp pulse exposure did not invoke fractures in roundfish or flatfish species.

Histological examination of fish exposed to pulse stimuli in laboratory experiments, did not reveal other abnormalities in species examined, except for a small haemorrhage in 2 of the 25 exposed plaice, and a significant increase in melanomacrophage centres in the spleen of cod exposed to the shrimp pulse 24 h after exposure. No adverse effect could be detected on the electro-sense organ used in food detection behaviour of small-spotted catshark. In an experiment exposing brown shrimp and ragworms to a sole pulse showed no consistent adverse effects, but shrimps that were exposed 20 times during a 4-day period to a sole pulse showed an increased mortality compared to one of the control treatments, but not compared to the 2nd control treatment or to mechanically stimulated shrimps.

Little is known on the effects of electrical stimulation on the development of eggs and larvae. One experiment exposing early life stages of cod (egg, larvae, early juveniles) to a pulse stimulus exceeding the pulse used in the fisheries did not find an increase in developmental abnormalities in exposed animals, but observed a reduced hatching rate and an increased mortality in 2 out of the 8 experiments. No adverse effects were observed in sole eggs and larvae.

No studies have been done on the effect of pulse stimulation on the functioning of the benthic ecosystem and nutrient dynamics. Although the laboratory experiments suggest that fish and invertebrates resume their normal behaviour after exposure, no information is available on for instance the threshold levels at which the functioning of species is being adversely affected.

Electrical stimulation changes the species selectivity of the trawl. The catch efficiency of the pulse trawl for sole is higher, and the catch efficiency for plaice and other fish species is lower, when expressed in terms of the catch rate per swept area. It is uncertain whether the pulse trawl has a better size selectivity (reduced bycatch of undersized fish), but all experiments show that the bycatch of benthic invertebrates is substantially reduced. Applying electrical stimulation in the fishery for brown shrimp, offers a promising innovation to reduce the bycatch of fish and benthic invertebrates, while maintaining the catch rate of marketable sized shrimps. The reduction in bycatch depends on the design of the net, in particular the specifics of the groundrope.

In ecological terms, the replacement of the tickler chain beam trawl with pulse trawl with electrodes diminish the mechanical impact of trawling on the North Sea benthic ecosystem. Although the irreversible effects of electrical stimulation seem to be restricted to the vertebral fractures in cod and whiting, further research on the effects of electrical stimulation on marine organisms and ecosystem functioning is needed to assess the effects on the scale of the North Sea.

1 Administrative details

Working Group name
WGELECTRA
Year of Appointment within the current three-year cycle
2013
Reporting year concluding the current three-year cycle
3
Chairs
Bob van Marlen, the Netherlands
Bart Verschueren, Belgium
Adriaan Rijnsdorp, the Netherlands
Meeting venue(s) and dates
20–22 October 2014, ILVO, Ostend, Belgium (7 participants)
10–12 November 2015, IMARES, IJmuiden, the Netherlands (8 participants)
17–19 January 2017, IMARES, IJmuiden, the Netherlands (8 participants)

2 Terms of Reference

a) Review knowledge of the effects of Electrical Fishing on the marine environment (changes to bycatch, impact on bottom habitat, impact on marine fauna, energy and climate related issues), in view of current technical developments and recent studies carried out in The Netherlands, Scotland, Belgium and Germany.

b) Evaluate the effect of a wide introduction of electric fishing, with respect to the economic impact, the ecosystem impact, fleet dynamics, the energy consumption, and the population dynamics of selected species.

c) Conduct a pilot study on control and enforcement procedures for flatfish pulse trawling.

d) Evaluate the impacts of restrictions on pulse characteristics for shrimp pulse trawling and groundrope configurations.

e) Make an inventory of views on pulse fishing among various stake-holders in European member states.

f) Respond to a request by France for ICES to review the work of SGELECTRA and IMARES and to provide an updated advice on the ecosystem effects of the pulse trawl, and especially on the lesions associated and mortality for targeted and non-targeted species that contact or are exposed to the gear but are not retained on board, and with special reference to those species covered by the on Natura 2000 species and habitats Directives.

3 Summary of Work plan

Year 1	Fundamental research on the effect of pulse stimulation on a range of species, both juvenile and adults stages by PhD workers under guidance of ILVO and University Ghent, Belgium. Pilot study on defined control and enforcement procedures for flatfish pulse trawling by IMARES, Netherlands. Further tank experiments on wild-caught cod, using pulse simulators by IMARES, Netherlands, and ILVO, Belgium. Study effects of pulse beam trawling on benthic invertebrates in EU-project BENTHIS by IMARES, Netherlands, and ILVO, Belgium. Monitor economic performance of more vessels in EU-project BENTHIS by LEI, Netherlands. Ongoing experiments with electrical shrimp fishing in Belgium and the Netherlands by ILVO Fishery, Belgium. Study on effects on electric fishing for Ensis by Marine Scotland Science, and the possibilities of using other, lower energy pulse systems than currently used. Study to optimize the front part (particularly the groundrope) of shrimp-pulse-trawls with respect to a) maintaining commercial catch rates; b) reducing unwanted bycatch; c) reducing energy consumption in Germany by Thünen Institute. Comment on the technical development of an electrical twin-trawl system as part of the Dutch "Masterplan Duurzame Visserij" by IMARES IJmuiden, The Netherlands.
Year 2	Fundamental research on the effect of pulse stimulation on a range of species, both juvenile and adults stages by PhD workers under guidance of ILVO and University Ghent, Belgium. Study effects of pulse beam trawling on benthic invertebrates in EU-project BENTHIS by IMARES, Netherlands, and ILVO, Belgium. Monitor economic performance of more vessels in EU-project BENTHIS by LEI, Netherlands. Ongoing experiments with electrical shrimp fishing in Belgium and the Netherlands by ILVO Fishery, Belgium. Study on effects on electric fishing for Ensis by Marine Scotland Science, and the possibilities of using other, lower energy pulse systems than currently used. Study to optimize the front part (particularly the groundrope) of shrimp-pulse-trawls with respect to a) maintaining commercial catch rates; b) reducing unwanted bycatch; c) reducing energy consumption in Germany by Thünen-Institute. Comment on the technical development of an electrical twin-trawl system as part of the Dutch "Masterplan Duurzame Visserij" by IMARES IJmuiden, The Netherlands. Evaluate the impacts of restrictions on pulse characteristics for the shrimp pulse fishery and consider recommendations for groundrope configurations by IMARES, Netherlands, Thünen-Institute Germany, and ILVO, Belgium. Make an inventory of views on pulse fishing among various stakeholders in European member states. Respond to a request by France for ICES to review the work of SGELECTRA and IMARES and to provide an updated advice on the ecosystem effects of the pulse

Year 3	Finalize fundamental research on the effect of pulse stimulation on a range of species, both juvenile and adults stages by PhD workers under guidance of ILVO and University Ghent, Belgium. Study effects of pulse beam trawling on benthic invertebrates in EU-project BENTHIS by IMARES, Netherlands, and ILVO, Belgium. Monitor economic performance of more vessels in EU-project BENTHIS by LEI, Netherlands. Ongoing experiments with electrical shrimp fishing in Belgium, Germany and the Netherlands by ILVO Fishery, Belgium and Thünen-Institute, Germany. Evaluate the impacts of restrictions on pulse characteristics for the shrimp pulse fishery and consider recommendations for groundrope configurations by IMARES, Netherlands, Thünen-Institute Germany, and ILVO, Belgium.

4 Summary of Achievements of the WG during 3-year term

A number of laboratory experiments have been carried out in which a selection of fish species and invertebrate species have been exposed to electrical stimuli to study possible adverse effects. The maximum pulse treatment applied exceeded the strength of the pulse used by the fishery. Electrical stimulation did not cause direct mortality during exposure. Exposure to the sole pulse stimuli invoked vertebral fractures and associated haemorrhages in roundfish species (cod), but not in flatfish species (sole, plaice, dab) or sea bass. The results suggest that fractures are restricted to the larger size classes of cod that are retained in the net, whereas smaller cod that can escape through the 80 mm meshes did not develop fractures even when exposed to high field strength. The fracture incidence in cod increases with field strength and decreases with pulse frequency. Fracture incidence varied between experiments. Experimental induced fractures corresponded to fractures observed in cod and whiting sampled from commercial pulse trawls. Further studies are required to study the relationship between the fractures and the body size and determine the differences in fractures across fish species. Shrimp pulse exposure did not invoke fractures in roundfish or flatfish species. Histological examination of fish exposed to pulse stimuli in laboratory experiments, did not reveal other abnormalities in species examined, except for a small haemorrhage in 2 of the 25 exposed plaice, and a significant increase in melanomacrophage centres in the spleen of cod exposed to the shrimp pulse 24h after exposure.

References:

Soetaert *et al.* (2015c, 2016a, and 2016c); de Haan *et al.* (2015 and 2016); Desender *et al.* (2015)

No adverse effect could be detected on the electro-sense organ used in food detection behaviour of small-spotted catshark after exposure to electrical fields.

Reference:

Desender *et al.* (2017)

In an experiment exposing brown shrimp and ragworms to a sole pulse showed no consistent adverse effects, but shrimps that were exposed 20 times during a 4 day period to a sole pulse showed an increased mortality compared to one of the control treatments, but not compared to the second control treatment or to mechanically stimulated shrimps.

References:

Soetaert *et al.* (2015a, 2015c, and 2016b)

Knowledge of the effects of electrical stimulation on the development of eggs and larvae is limited. One experiment exposing early life stages of cod (egg, larvae, and early juveniles) to a pulse stimulus exceeding the pulse used in the fisheries did not find an increase in developmental abnormalities in exposed animals, but observed a reduced hatching rate and an increased mortality in 2 out of the 8 experiments. No adverse effects were observed in sole eggs and larvae.

Reference:

Desender *et al.* (Submitted)

Electrical stimulation changes the species selectivity of the trawl. The catch efficiency of the pulse trawl for sole is higher, and the catch efficiency for plaice and other fish species is lower, when expressed in catch rate per swept-area. It is uncertain whether the pulse trawl has a better size selectivity (reduced bycatch of undersized fish), but all experiments show that the bycatch of benthic invertebrates is substantially reduced. Applying electrical stimulation in the fishery for brown shrimp, offers a promising innovation to reduce the bycatch of fish and benthic invertebrates, while maintaining the catch rate of marketable sized shrimps. The reduction in bycatch depends on the design of the net, in particular the specifics of the bobbin- and groundrope.

References:

van Marlen *et al.* (2014); Verschueren *et al.* (2014)

In ecological terms, the replacement of the tickler chain beam trawl with pulse trawl with electrodes diminish the mechanical impact of trawling on the North Sea benthic ecosystem. Although the irreversible effects of electrical stimulation seems to be restricted to the vertebral fractures in cod and whiting, further research is on the effects of electrical stimulation on marine organisms and ecosystem functioning and to assess the effects on the scale of the North Sea. No studies have been done on the effect of pulse stimulation on the functioning of the benthic ecosystem and nutrient dynamics. Although the laboratory experiments suggest that fish and invertebrates resume their normal behaviour after exposure, no information is available on for instance the threshold levels at which the functioning of species is being adversely affected.

In relation to this, Pim Boute (Wageningen University, the Netherlands) started in August 2016 with his PhD research within the Impact Assessment Pulsetrawl Fishery (IAPF) project for the next 4 years. This research includes possibilities for collaboration with ILVO, NIOZ, and WMR. By combining modelling, laboratory studies, and analysing samples from commercial fishing vessels his research aims to predict the effect of various electrical parameters on marine organisms.

In addition to this, Justin Tiano (Netherlands Institute for Sea Research, Yerseke, the Netherlands) is also conducting a PhD research, exploring the repercussions of pulse and beam trawling on benthic ecosystem functioning and biogeochemistry. Three research campaigns are planned focusing on *in situ* effects, experimental effects, and long-term consequences. In addition, laboratory experiments investigating electrical stimulation impacts on bio-irrigation, oxygen consumption and nutrient dynamics are expected to take place. Preliminary results from an experiment looking at the effect of mechanical disturbance on nutrient dynamics show varying responses with oxygen consumption and nitrate fluxes between different mechanical treatments.

5 Final report on ToRs, workplan, and Science Implementation Plan

5.1 Review knowledge of the effects of Electrical Fishing on the marine environment (ToR a)

5.1.1 Pulse trawls used in the North Sea

Three different pulse gears are being used in the Dutch fishery (Table 5.1). The ***flatfish fishery*** either use the pulse trawl produced by HFK engineering (79%) or Delmeco BV (15%). The ***shrimp fishery*** uses the pulse trawl developed by Marelec (6%) for shrimp pulse gear (Turenhout *et al.*, 2016). Under the temporary derogation a total of 84 licenses were given: 27 to cutters ≤300 hp (flatfish and/or shrimps) and 57 to cutters >300 hp of which six were not used in 2015. Seventy-four cutters use the pulse technique to catch flatfish and four cutters use the pulse technique to catch common shrimp.

The electrical pulses are characterized by the maximum voltage, frequency, pulse-width, and pulse shape. The product of the pulse weight and the pulse frequency, which is called the duty cycle, gives the time that there is an electric current flowing between the conductors. The two flatfish pulse systems differ marginally in their electrical characteristics and in the number and the design of the electrodes.

All pulse systems use wired electrodes. The sole pulse electrodes comprise of alternating conductor and isolator elements. The heterogeneous electrical field that is generated shows highest field strength close to the conductor. The field strength decreases at increasing distance from the conductor in the horizontal and vertical plane (Figure 5.1) (de Haan *et al.*, 2016). The electrical characteristics of the shrimp pulse are described in Verschueren *et al.* (2014). The main difference between the sole pulse and the shrimp pulse system is the lower pulse frequency applied in the shrimp pulse

Table 5.1. Characteristics of the tow flatfish pulse systems and the shrimp pulse system (from Rijnsdorp *et al.*, 2016b)

	Flatfish pulse (Euro cutter)		Flatfish pulse (Large vessels)		Shrimp pulse
	Delmeco	**HFK**	**Delmeco**	**HFK**	**Marelec**
Width of the trawl	4.5	4.5	12	12	9
Towing speed	~5	~5	~5	~5	2.5–3.5
Length of electrodes (m)	Max 4.75	Max 4.75	Max 4.75	Max 4.75	2.5–3
Length of conductor elements (cm)	18	12	18	12.5	150
Number of conductor elements	6-12	6-12	6-12	6-12	-
Diameter of conductor	28	28	28	28	12
Distance between electrodes	42	42.5	42	42.5	60–70
Voltage between conductors	50	50	50	50	65
Pulse frequency (Hz)	38–42	40–80	38–42	40–80	5
Pulsewidth (μs)	210–	100–330	210–230	100–330	500
Duty cycle (%time)	2.5	2.5	2.5	2.5	0.03

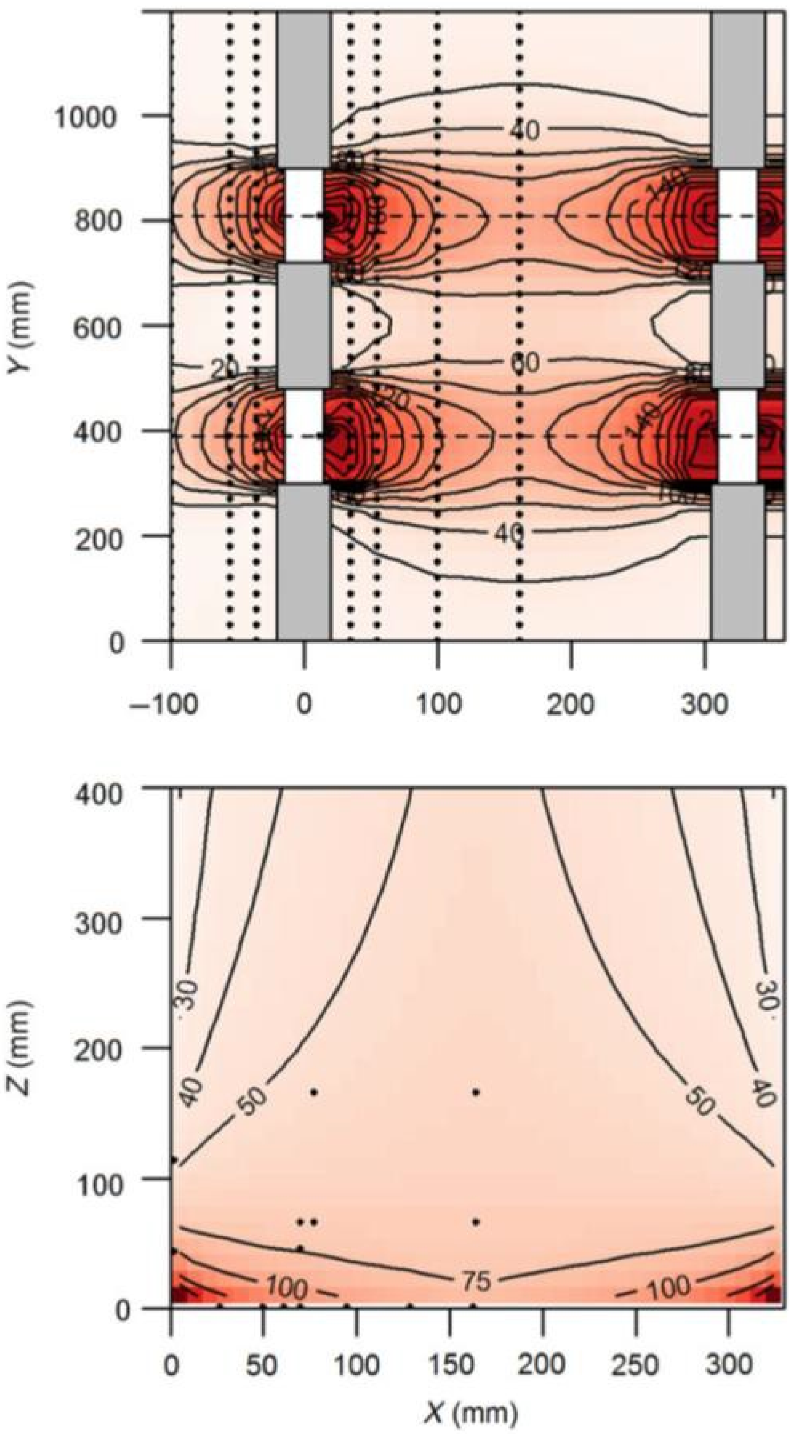

Figure 5.1. Contour plot of peak field strength (V/m) around a pair of Delmeco electrodes positioned at X = 0 mm and X = 325 mm. The field strength is shown in the horizontal plane (a) and the vertical plane (b). Locations of measurements are indicated by black dots. White parts show the conductor elements. The grey parts show the isolator elements. From de Haan *et al.* (2016).

5.1.2 Catch efficiency and selectivity

Sole pulse

During the developmental phase of the pulse trawl between 1998 and 2011, a series of catch comparison experiments between a 7 m and 12 m prototype 'pulse' trawls and a conventional beam trawl were conducted on board of research vessel Tridens (summary in Quirijns *et al*., 2015). The results showed that the pulse trawl catch rate of sole matched those of conventional tickler chain beam trawls, while the catch rate of plaice was generally reduced and the bycatch of benthic invertebrates was substantially reduced.

These results are in line with the expectations based on the response of the target species to the electrical stimulus. The flatfish pulse invokes a cramp response which immobilize the fish and prevent the fish to escape from the approaching gear. The contraction of the body muscles during exposure raises the head and the tail of the flatfish by which it comes lose from the seabed. This is particularly pronounced in sole, which bends its body in a U-shape where the tail and nose are almost touching each other (van Stralen, 2005). The U-shape of a cramped sole makes it easier to catch in a bottom trawl. This effect is less pronounced in other flatfish which show a much shallower U-shape.

In 2011, after the successful implementation of the pulse trawl technique in the Dutch flatfish fishery, the selectivity and catch efficiency was compared between a HFK-pulse, a Delmeco-pulse and a conventional vessel using a tickler chain beam trawl. The data have been reanalysed and published in the scientific literature substituting earlier reports (van Marlen *et al.,* 2014). The catch rate per hour fishing in the pulse trawl was reduced by 21% and 28% for marketable sized sole and plaice, respectively. The lower catch rate was mainly due to the lower towing speed, and hence the smaller surface area covered per hour fishing. For discarded bycatch, the catch rate of the pulse trawl was reduced by 67%. The size selectivity for the two main target species sole and plaice suggests that the pulse trawl is more selective in catching marketable sized flatfish.

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

In 2016, a mesh selection experiment was conducted studying the effect of pulse stimulation on the probability of sole and plaice to escape through the meshes. The study was carried out in the context of the FP7-BENTHIS project on board of the sumwing pulse vessel TX43. The vessel was fishing with her normal gear and a small-meshed cover to collect the fish that had escaped through the codend mesh. During the experiment the electrical stimulation of the starboard and port-side net was alternately switched on and off. The preliminary analysis indicated that the electrical stimulation had a small but significant effect on the slope of the selection ogive. Plaice and sole had a higher chance to escape through a codend mesh after being exposed to an electrical stimulus than when caught without electrical stimulation (3rd Periodic Activity and Management Report BENTHIS).

Shrimp pulse

The low frequency shrimp pulse invokes a tail flip response by which shrimp jumps up from the seabed. The tail flip response depends on the field strength and the size of the shrimp. Exposure to a field strength of 4 V/m is already sufficient to invoke a response in large (>6 cm) shrimps, whereas small shrimps (3 cm) require a field strength of 6 V/m. These values refer to shrimps that have a perpendicular orientation to the electrodes. For shrimps with a parallel orientation, the critical field strength to invoke a tail flip response are higher, e.g. 18 and 24 V/m, respectively (Verschueren *et al.*, 2014).

The catch efficiency of a pulse shrimp trawl was compared with a conventional shrimp beam trawl during four trips on board of a commercial shrimp trawler fishing in the Wadden Sea (Verschueren *et al.*, 2014). The pulse trawl caught more market sized shrimp in summer (June: +16%; September: +9.4%), whereas in October and December, no significant difference was observed. In three of the trips, the bycatch of undersized shrimps was 19% to 33% lower. The bycatch of fish and benthos in the pulse trawl was reduced by 50% to 76%.

Conclusion

The available evidence shows that the sole pulse has a higher catch efficiency for sole and the lower catch efficiency for plaice and other fish species when expressed in catch rate per swept-area. The comparative fishing experiment in 2015 suggests that the catch efficiency of the pulse trawl may have improved. The better size selectivity of the pulse trawl indicated by the 2011 comparative fishing experiment, is not corroborated in later experiments. However, compared to the catch of marketable sized sole, the bycatch of undersized fish in the pulse trawl is lower than in the conventional beam trawl. All experiments carried out show that the bycatch of benthic invertebrates is substantially reduced.

For the beam trawl fishery for brown shrimp, electrical stimulation offers a promising innovation to reduce the bycatch of fish and benthic invertebrates other than shrimps, while maintaining the catch rate of marketable sized shrimps. The reduction in bycatch depends on the design of the net, in particular the specifics of the groundrope.

5.1.3 Effects on marine organisms

Various adverse effects of electrical stimulation on fish have been reported. Electrofishing in freshwater has been well studied and there is ample evidence of vertebral fractures and associated haemorrhages (review in Soetaert *et al.*, 2015). Electrofishing in the marine environment is less well studied. Laboratory experiments related to the sole pulse have been reviewed by Quirijns *et al*. (2015). Table 5.2 presents an updated overview of the relevant studies. Below we will summarize and synthesize the available information and distinguish between the effects on the physiology, behaviour, egg, and larval stages, fractures in fish, invertebrates, and ecosystem.

Physiology

The effect of electricity will primarily be related to the activation of nerve cells and muscles (Soetaert *et al.*, 2015). Muscle contractions are due to the activation of nerve cells responding to an electrical stimulation. Muscles may also contract as a direct response to an electrical stimulus. The effect of electricity depends on the conductivity and isolating properties of the body relative to the conductivity of the water.

Behaviour

The effect of electrical stimulation on the behaviour will depend on the strength and characteristics of the stimulus (such as frequency, pulse shape) as well as the duration of the exposure. A fish may respond to an electrical stimulus of increasing strength by showing a flight response (startle), a cramp response, and epileptic seizures. The type of response depends mainly on the pulse frequency. The field strength experienced depends mainly on the position and orientation relative to the conductors as well as the size of the fish.

Sole exposed to a 5 Hz pulse may show a flight response and muscle contractions similar to the normal fin fluttering. Pulse frequencies of 40 Hz or higher invoked a cramp response during which the fish bended in a U-shape. After exposure, all soles showed normal behaviour (Soetaert *et al.*, 2016).

Cod showed a flight response to pulse frequency of 5 Hz. A cramp response was induced in cod exposed to pulse frequencies of 30 Hz or higher (Soetaert *et al.*, 2016; de Haan *et al.*, 2016) and in cod exposed to a field strength of 37 V/m and higher (de Haan *et al.*, 2016). Very high field strength may invoke an epileptic response. Within 10 minutes after exposure, most of the fish were breathing normally but showed little swimming activity and weak reactivity to tactile stimuli. All fish survived and showed normal behaviour 24 h post exposure (Soetaert *et al.*, 2016). Cod resumed feeding after exposure although their appetite was related to the field strength. Cod exposed to a field strength that invoked vertebral fractures (82 V/m) were passive and did not resume feeding (de Haan *et al.*, 2016).

Sea bass showed a cramp response when exposed to a pulsed bipolar current of 80 Hz, pulsewidth of 250 μs, duty cycle of 2% and exposure duration of 2 s of wire-shaped electrode (Soetaert, 2015). Directly after exposure, the fish showed a variable flight response swimming away from the point of exposure. When removed to their housing tank, all fish resumed normal swimming behaviour. During the 2 week observation period after exposure, all fish showed normal feeding behaviour.

Elasmobranchs possess electro-sense organs to detect food, which may make them particularly sensitive for pulse fishing. Two experiments have been conducted with the small-spotted catshark, *Scyliorhinus canicula* as model organism. In the first study, de Haan *et al.* (2009) exposed three groups of 16 fish to a series of 4 pulse bursts at maximum amplitude of a sole pulse at three different distances from a conductor pair, in a set-up similar to the experiments of de Haan *et al.* (2016), while a fourth group was used as a control. Fish in all tested groups started feeding normally directly after the exposures. Fish were kept in husbandry for 9 months after the exposure and produced eggs in numbers varying between 5 and 39 per group. Surprisingly the control group did not produce eggs.

In the second study, Desender *et al.* (2017) studied the effect of sole and shrimp pulse stimulation on the electro-detection ability. The electro-response of the sharks to an artificially created prey-simulating electrical field was tested before and after exposure. No statistically significant differences were noted between control and exposed animals, both in the number of sharks exhibiting an electro-response prior to and following exposure as well as regarding the timing between onset of searching behaviour and biting at the prey simulating dipole. These results indicate that, under the laboratory circumstances as adopted in this study, the small-spotted catshark are still able to detect the bio-electrical field of a prey following exposure to the electrical stimuli applied in pulse trawls.

Brown shrimps responded with tail flips when exposed to a pulse stimulus of 5 Hz. When exposed to a frequency of 60 Hz or 200 Hz, a cramp response was observed that made them jump 0.1–0.15 m out of the sediment. This cramp persisted during the entire exposure. Within 0.25 s after the exposure, all shrimp showed tail flip escape behaviour. During the week after exposure, the exposed shrimps showed active food searching behaviour and ate all food provided (Soetaert *et al.*, 2014).

Ragworms showed squirming behaviour during and immediately after exposure irrespective of the pulse frequency. The intensity of the squirming behaviour increased with duty cycle and field strength. No cramp response was observed. Control animals showed minor squirming in response to mechanical stimulation (Soetaert *et al.*, 2014).

Egg and larval stages

There is one study that investigated whether shrimp pulse stimuli may affect the egg and larval stages of fish (Desender *et al.*, in prep). Preliminary results presented in WGELECTRA showed no detectable effects in 6 out of 8 experiments with egg, larval and juvenile stages of cod. In one of the three egg stages exposed a reduced hatching rate was observed and in one larval stage of the four larval stages exposed a reduced survival was observed. In an experiment in which sole eggs and larvae were exposed no adverse effects could be detected. No increase in developmental deformities were recorded in both cod and sole.

Fractures in fish

Field observations

There is compelling evidence that roundfish, such as cod and whiting, caught in a flatfish pulse trawl may develop injuries related to the cramp invoked by the pulse stimulus. Van Marlen *et al*. (2014) reported that 4 out of 45 cod (9%) caught in the comparative fishing experiment in 2011 showed a spinal fracture. In whiting, only 1 out of 57 fish examined showed a spinal fracture (2%). A similar result was obtained by Rost in her MSc thesis (2015) reporting a pulse related fracture in 5 out of 226 whiting collected on board of 4 pulse trawl vessels.

Laboratory experiments

Vertebral injuries were studied in laboratory experiments in cod, sea bass, sole, and dab exposed to commercial pulse stimuli.

Cod. de Haan *et al*. (2016) reported on experiments conducted over a number of years with aquaculture cod exposed to a sole pulse. None of the cod of a size class that can escape through the 80 mm meshes of the sole fishery, that were exposed to the highest field strength close to the conductor did develop fractures, whereas almost 70% of the marketable sized cod exposed to the highest field strength close to the conductor developed a fracture in the spine, haemal and/or neural arches. Vertebral fractures were associated with a haemorrhage and a discolouration of the body. The probability to develop a fracture (or haemorrhage) increased with field strength and decreases with frequency. In the marketable sized cod, the fracture probability decreased with body size in marketable sized cod. In another experiments with cod with similar pulse settings and similar location of the cod next to the conductor, much fewer fractures were observed (0–5%), suggesting that body condition may influence the sensitivity for injuries (Soetaert *et al.*, 2016a). Cod exposed to a homogeneous electric field with a range of pulse settings, including those of the commercial fisheries, did not show any abnormalities when examined histologically, except for 1 cod showing a spinal fracture

(Soetaert *et al.,* 2015). Cod exposed to a shrimp pulse did not develop fractures (Desender *et al.*, 2016).

Sea bass. None of the small and large sea bass exposed to a sole pulse stimulus developed a vertebral fracture or any other lesion and all survived the 14 days after exposure. The number of fish tested (31 tested, 13 control) was relatively small (Soetaert, 2015).

Sole. None of the sole exposed to a homogeneous electric field with a range of pulse settings, including those of the commercial fisheries, died and histological examination did not show any abnormalities (Soetaert *et al.,* 2016; Desender *et al.,* 2016).

Dab. In an experiment in which 100 wild-caught dab were exposed to commercial pulse stimuli, no fractures, ulcerations or haemorrhages were observed (de Haan *et al.,* 2015).

Bull-rout and **armed bullhead** exposed to a shrimp pulse did not develop fractures (Desender *et al.*, 2016). The number of fish tested (around 20 tested and 20 control) was relatively small.

Conclusion vertebral fractures

The available evidence shows that electrical stimulation by the flatfish pulse settings may lead to fractures and haemorrhages in fish. No fractures have been observed in fish exposed to the shrimp pulse. The sensitivity to develop fractures in response to a pulse stimulus differ between fish species. Samples taken from the commercial fishery indicates that cod shows the highest incidence rate (about 10%), followed by whiting (about 2%). Sea bass and several flatfish species appear to be insensitive and not developing vertebral fractures. These results are only indicative and needs further study as the number of observations is too low to draw any firm conclusion.

The experiments indicate that cod exposed to a field strength of less than 37 V/m, typical for the maximum field strength that is measured outside the array of electrodes, will unlikely develop a vertebral fracture. The experiments also indicate that small cod, that are small enough to escape through the 80 mm meshes of the codend, do not develop fractures. This indicates that only cod that are located within the trawl track run the risk of being exposed to a field strength that may invoke a vertebral fracture. In particular, the cod that are located in close range to the electrodes are prone to develop a vertebral fracture. Because the occurrence of vertebral fractures seems to be restricted to the cod that are retained in the net, it will not result in additional mortality affecting the population. The size effect on the fracture probability needs further investigation.

Other lesions in fish

In response to reports on an increase in the incidence rate of ulcers in dab off the Belgium coast coinciding with the start of the pulse trawling, a laboratory experiment was conducted in which 100 wild-caught dab were exposed close to the conductor generating a commercial pulse trawl stimulus and 50 dab were used as control. The fish were kept for 2 weeks in the lab and euthanized for post-mortem analysis. After exposure, all fish showed normal behaviour and resumed feeding. One dab died on day 13 without any visible injury and likely unrelated to the pulse stimulus. No difference in the incidence rate of lesions of the exposed dab with the control fish was observed (de Haan *et al.,* 2015).

Desender *et al.* (2016) exposed plaice, sole, cod, bull-rout, armed bullhead to a shrimp pulse. Histological examination revealed a small haemorrhage in 2 of the 25 exposed plaice, and a significant increase in melanomacrophage centres in the spleen of cod exposed. These lesions may be reversible since they were not observed after 14 days. It is uncertain whether these are caused by the pulse stimulus.

Effects on benthic invertebrates

Smaal and Brummelhuis (2005) exposed a variety of benthic invertebrates to a Delmeco sole pulse for 10 s. Some species showed a response to the electrical stimulus by closing their shells (bivalves), withdrawing themselves in their shell (whelk, hermit crab) or showing a tail flip response (decapod shrimps), while other species (polychaetes, Echinodermata) did not show a visible response. The experiments did not suggest that electrical stimulation affected the filtration rate of bivalves or the mortality as compared to the control group. Because the company providing the pulse generator did not disclose the details of the pulse characteristics, the results are only indicative for the possible effects.

To detect the safe range of pulse parameters, Soetaert *et al.* (2014) exposed brown shrimps and ragworms to a homogeneous electric field for up to 5 s and studied their behaviour, 14-d mortality rate, gross and histology. Pulse setting included the commercially applied frequency and field strengths. No adverse effects were detected except for an increase in a virus infection (IBV) in the hepatopancreas in shrimps exposed to the maximum field strength (200 V/m). In a follow up experiment studying the effects of repetitive exposure in shrimps, however, this result could not be corroborated. In this experiment, brown shrimps were exposed 20 times during 4 days to either the sole pulse or the shrimp pulse. The survival, egg loss, moulting and the degree of IBV infection was compared shrimps exposed to electrical pulses, shrimps exposed to mechanical disturbance mimicking the conventional shrimp trawling and a control group. The sole pulse treatment gave a significant lower 14-day survival as compared to one of both control treatments but not compared to the mechanically stimulated shrimp, while moulting was reduced by mechanical disturbance compared to one of both control treatments as well.

5.1.4 Effects on the marine ecosystem

Bottom-trawls impact the structure and functioning of the benthic ecosystem (Jennings and Kaiser, 1998). The impact is related to the mechanical effects of the gear components that either sweep or penetrate into the seabed (Eigaard *et al.*, 2016). Bottom trawls may homogenize the texture of the seabed, disturb the sorting of the sediments and bring sediment into resuspension in the wake of the gear (O'Neill *et al.*, 2016). Mechanical disturbance will also kill benthic invertebrates and may destroy biogenic structures (Kaiser *et al.*, 2006). In addition to the mechanical impact, electrical stimuli may affect the ecological functioning of the benthos and may influence chemistry of the seabed. In order to assess the implications of a transition of the tickler chain beam trawl to the pulse trawl, we need to assess the mechanical disturbance as well as the effects of electrical stimulation.

Mechanical disturbance

Available evidence indicate that the mechanical disturbance of the seabed by a pulse trawl is less than the disturbance by the tickler chains of a conventional beam trawl. In the FP7-BENTHIS project the sediment disturbance by a 4 m Delmeco pulse trawl was compared to a conventional tickler chain beam trawl (Depestele *et al.*, 2016). Results indicate that sediment disturbance of the pulse trawl is less than the conventional tickler chain beam trawl. No difference in the resuspension of sediments could be detected.

A numerical model predicted that the tickler-chain trawl penetrates the seabed more deeply than the pulse gear.

The mechanical disturbance of benthos by a bottom trawl is determined by the weight of the gear components and the towing speed at which it collides with the benthos (Eigaard *et al.*, 2016; Rijnsdorp *et al.*, 2016). As a pulse trawl is lighter and is towed at a lower speed than a conventional tickler chain beam trawl, we expect that the energy at which it collides with benthos will be lower. This expectation was supported by the field study carried out in the REDUCE project (FAIR-CT97-3809, "Reduction of environmental impact of demersal trawls") which suggested that the mortality imposed by a pulse trawl was less than the mortality imposed by a tickler chain beam trawl (van Marlen *et al.*, 2001). Preliminary results of FP7-BENTHIS could not detect a difference in mortality due to the large variability of benthic samples (Teal *et al.*, 2014).

Effects of electricity

It is hypothesized that the electrical field may affect chemical reactions which might release pollutants that are bound to sediment particles (Soetaert *et al.*, 2015). To our knowledge, no studies have addressed this question.

It is unknown how chronic sublethal exposure will affect the functioning of the benthic invertebrates. Although the few experiments with benthic invertebrates seems to suggest that the exposed organisms resumed their normal behaviour soon after the pulse treatment, further studies are required.

5.1.5 Discussion

Direct mortality imposed by electrical stimulation

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

Sublethal effects

How the exposure of organisms to low field strength will affect their functioning is unknown and further research on the critical field strength at which the functioning is affected is required. We expect that the threshold levels for the sublethal effects will be species-specific.

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

Selectivity and catch efficiency

The empirical evidence clearly shows that the pulse trawl has a higher selectivity to catch sole as compared to the conventional tickler chain beam trawl. All comparative fishing experiments have shown a higher catch efficiency for sole than for plaice or other demersal species.

The comparative fishing experiments suggest that the catch efficiency of the pulse trawl may have increased, but the available evidence, however, is too thin to draw a firm conclusion. It is well known that the catch efficiency of a fishing gear may increase over time due to technological developments and improved skills of the fishers, in particular when new techniques are introduced (Eigaard *et al.*, 2014).

The available data are also inconclusive whether pulse trawls may have a better size selectivity, e.g. catching fewer undersized fish. The promising results reported by van Marlen *et al*. (2014) were not corroborated in a later study. Additional comparative studies may shed light on this question. We expect that knowledge of the effect of fish size on the dose-effect relationship between pulse stimulation and the cramp response in sole and other flatfish species will allow us to give a mechanistic interpretation of the size selectivity of the pulse gears used in the commercial fishery.

A better understanding of the response of fish to electrical stimuli and the characteristic of the pulses used, could guide us to improve the pulse stimuli to increase the length threshold for the cramp response.

Table 5.2. Overview of experimental studies in which marine organisms were exposed to a flatfish or shrimp pulse stimulus. N refers to the number of exposed animals. Vpeak refers to the potential difference over the pair of electrodes. (* This publication includes earlier IMARES reports)

Species	Results	Pulse stimulus	Field strength (V/m)	Frequen- cy (Hz)	Duration (sec)	Source
Cod (35–60 cm) N = 320	Maximal exposure close to conductor resulted in spinal fractures up to 70% of the cod. Fracture incidence increase with field strength and decrease with frequency	Sole pulse	4–103	30–180	1	De Haan *et al.* (2016)*
Cod (<20 cm) N = 140	No injuries.	Sole pulse	76–370	30–180	1	
Cod (30–80 cm) N = 180	Exposure of 180 cod close to conductor resulted in spinal fractures in 0–5% of the cod.	Sole pulse	60–120 (Vpeak)	40–80	1-2	Soetaert *et al.* (2016) Marine Coastal Fisheries
Cod (40–70 cm) N = 26	Exposure to a homogeneous field did not cause lesions except for a spinal fracture in 1 animal.	Square PDC, PBC	100–200	40–200	2	Soetaert *et al.* (2016) Fish. Res.
Sole (25–30cm) N = 146	Exposure of 146 soles to a homogeneous field did not cause lesions. One sole died 13 d after exposure but without any injuries. One sole showed minor gill haemorrhage during exposure.	Square PDC, various pulse types	150–200	5–200	2–5	Soetaert *et al.* (2016) Fish. Res.

Dab **N = 100**	Cramp response. No lesions detected. No mortality observed related to exposure.	Sole pulse				De Haan, D. *et al*.. (2015) IMARES Report number C171/14.
Catshark **N = 23**	No effect on the success rate of prey detection was observed after exposure to the pulse stimulus in catsharks trained to locate artificial prey buried in the seabed with their electro-sense organs.	Sole pulse and Shrimp pulse	60 V (V_{peak})	5, 80	5	Desender *et al*. (2017)
Catshark **N = 48**	No mortality and no visible injuries observed. Fish in all tested groups started feeding normally directly after the exposures. Fish of all pulse-exposed groups produced eggs in numbers varying between 5 and 39 per group during 9 month post exposure.	Delmeco sole pulse	8, 48, 162	40	4 x 1 second	De Haan, D., *et al.* (2009) IMARES Report C105/09
Plaice (n = 25) **Sole (n = 30)** **Cod (n = 20)** **Bull-rout (n = 19)** **Armed bullhead (n = 20)**	Flatfish: minor reactions in flatfish, 15% sole swam upwards. Roundfish: active swimming during exposure. No fractures detected. Histological examination showed small haemorrhage in 2 exposed plaice. Number of melanomacrophage centres in spleen of exposed cod was higher.	Shrimp pulse	60 V_{peak}	5	5	Desender *et al*. (2016) Fish Res

Cod **3 egg stages** **4 larval stages** **1 juvenile stage**	Hatching rate reduced in 1/3 egg stage. Mortality increased in 1/4 larval stages No development deformities	homogeneous field	150		5	Desender in ICES (2016)
Sole **1 egg stage** **1 larval stage**	No adverse effects or deformities recorded	homogeneous field	150		5	Desender in ICES (2016)
Helmet crab, Swimming crab	Freeze upon stimulation	Delmeco sole pulse	Due to confidentiality, no details on the pulse characteristics were provided by the company. The potential difference over the electrodes was twice the potential difference of the Delmeco prototype of 2004.	1st group exposed 10 s; 2nd group exposed 10 s for 3 days in a row.		Smaal and Brummelhuis (2005) RIVO Report: C089b/05
Decapode: brown shrimp, steurgarnaal	Tail flips and/or freeze. After 1 s resume to normal movements. When mechanically stimulated directly after exposure the animal moves normal.					
Hermit crab	Freeze or withdraw in shell upon stimulation.					
Echinodermata: Common sea star, Echino- cardium, Ophiuroidea	No visible response.					

Polychaetes: Ragworm, sea mouse	No visible response.						
Bivalves: razor clam, cockle, *Acanthocardia echinata*	Closes shell, Ensis slightly extends its foot. No effect on filtration activity						
Whelk	(partly) withdraws in shell.						
Brown shrimp N = 30–60 per group (tot = 1730)	Tail flip response at 5 Hz. Cramp response at ≥60 Hz. No increase in mortality or injuries. Increase in virus infection at highest exposure	Sole and shrimp pulse; homogeneous field	150–200		5–200	1–5	Soetaert *et al*. (2014) ICES JMS
Ragworm N = 23–50 per group (tot = 616)	Squirming response. No increase in mortality or injuries						
Brown shrimp N = 479 (pulse) N = 178 (mechanical)	Sole pulse reduced survival. Mechanical stimulation gave reduced moulting rate. No increase in IBV infection.	Sole and shrimp pulse	60 V (Vpeak)		5 and 80	20 times 1 sec exposure during 4 days	Soetaert *et al*. (2016) Marine Coastal Fisheries

5.2 Evaluate the effect of a wide introduction of electric fishing (ToRb)

In order to assess the ecological consequences of the use of pulse trawls, the consequences should be assessed against the consequences of using the conventional mechanical beam trawl. The assessment should not only take account of the effects of electricity on marine organisms and the functioning of the benthic ecosystem, but should also take account of the effects of the potential redistribution on the above impacts and on the implications for the bycatch and population dynamics of the target species.

5.2.1 Economic impact

The analysis of Wageningen Economic Research on the economic performance of the beam trawl vessels targeting sole showed that an increased profits of the vessels that switched to the pulse trawl improved (Turenhout et al., 2016). This improvement is mainly due to the lower fuel cost related to the lower towing speed.

5.2.2 Fleet dynamics

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

5.2.3 Ecosystem impact

Fish

The available evidence indicates that roundfish species are sensitive for vertebral fractures due to the cramp response invoked by the sole pulse trawl, whereas flatfish species are insensitive. The experiments further suggest that the sensitivity may show a dome-shaped relationship with body size. It is unlikely that a similar effect will be caused by the shrimp trawl as the typical frequency of 5 Hz is below the critical threshold for the cramp response. A mechanistic understanding, that explains the differences in sensitivity between species and body size to the pulse stimuli applied, is required to quantitatively assess the consequences on the fish community level.

This mechanistic understanding may also help to interpret the contradictory information about the size-selectivity of the pulse trawls. To evaluate the consequences of the transition from the tickler chain beam trawl to the pulse trawl on the bycatch of undersized flatfish, we not only need information about the size-selectivity and species-selectivity, but we also need to understand why fishers change their fishing grounds.

An area of concern is the potential effect of pulse stimulation on the Elasmobranchs. The tank experiment with catsharks indicated that pulse stimulation did not impair their electro-sense organ to detect prey that is buried in the seabed. The observed shift in fishing effort distribution towards the western part of the southern North Sea, the area where the abundance of skates and rays is relatively high, has likely increased the bycatch. Information on differences in survival rate of skates and rays caught in the conventional beam trawl fishery and the pulse trawl fishery is needed.

The effect of pulse stimuli on eggs and larvae will be restricted to those species with demersal eggs and larvae. In the southern North Sea, only a few fish species produce demersal eggs, such as herring and some estuarine species. The contact rate of pulse trawls with the eggs and larvae of most fish species, which are dispersed in the water column, will be negligible. For the species that lay demersal eggs, the population consequences of possible adverse effects of pulse stimuli will likely be negligible because of the extreme high mortality rate of eggs and larvae.

Benthos

The impact of a bottom trawl on the benthos depends on the footprint of the gear used and the sensitivity of the benthic community. The great unknown in the assessment of the impact of pulse trawls is the lack of knowledge how the pulse stimulus affects the functioning of benthic organisms. The mechanical effects are probably lower because of the reduced mechanical disturbance. The replacement of tickler chains running across the net opening by electrodes running in longitudinal direction, has halved the bycatch of benthic invertebrates (van Marlen *et al.*, 2014). In addition, the trawling footprint, defined as the seabed area swept per hour trawling, is 23% lower than the footprint of the conventional beam trawl due to the reduction in towing speed from about 6.5 to less than 5 knots. In ecological terms these two factors constitute a positive contribution to diminishing the impact of trawling on the North Sea benthic ecosystem. Because the pulse trawl vessels showed a change in their spatial distribution, differences in habitat sensitivity need to be taken into account on top of the additional impact of electrical stimulation to assess the ultimate change in impact on the seabed.

5.3 Control and enforcement procedures for flatfish pulse trawling (ToR c).

The working group has discussed the draft documents specifying the technical boundaries set for the pulse trawls. The boundaries of the sole pulse gear are described in a directive issued by the Dutch Ministry of Economic Affairs on 18 November 2016 (01. 20161111 "Nieuwe Voorschriften Pulstoestemming Platvis version 1.3") and refers to the conditions of electric gear application as described in article 31bis, lid 2 of the European reference for Technical Measures (EU 850/98). The latest version 1.3 is the final result of coordinated meetings chaired by NVWA (The Netherlands Food and Consumer Product Safety Authority), pulse gear manufacturers and fishing industry. Wageningen Marine Research was involved during earlier meetings and performed an advisory role.

For flatfish gears the main boundaries are:

- A maximum power consumption of 1 kW per metre beam length;
- A pulse amplitude of 60 V 0 to peak maximum;
- An electrode length of max 4.75 m, (the section that has bottom contact);
- Conductor length 125 to 200 mm with a maximum of 12 per electrode;
- Electrode distance not smaller than 0.4 m;
- Number of electrodes adapted to the width of the licenced gear (4 or 12 m);
- Operational conditions of the Delmeco system are registered on a computer as part of the pulse equipment. The HFK system does not record the electrode voltage and current real time but operates with a pulse hardware certificate

which assures the equipment will operate within the licensed bands. The Delmeco system stores information of:

  - the electric power discharged over the electrodes;
  - over at least 100 fishing hauls;
  - any access to the data storage;
  - the date, times and positions of pulse operation;
- Groundrope rigging will not contain additional tickler chains

5.4 Evaluate the impacts of restrictions on pulse characteristics for shrimp pulse trawling and groundrope configurations (ToR d).

At the time of compiling this report, no summary of the ongoing research on this topic was available.

5.5 Views on pulse fishing among various stakeholders in Eurpean member states (ToR e).

The concerns and views on the pulse fishing of various stakeholders has been reviewed by Kraan *et al.* (2015) based on media items countries bordering the southern North where pulse gear is being used, and from additional interviews with representatives from the government, NGOs, fishing industry and scientist. The majority of the concerns are related to the effects of electricity on marine organisms and the benthic ecosystem functioning, the effect on the efficiency of the fishery and the effects this may have on the sustainable use of the target species and the fishing opportunities of other fleets. The remaining questions were related to governance issues of economic consequences. In addition, stakeholders questioned the large number of temporary licenses issued. The Dutch ministry of Economic Affairs have funded a 4-year research project (2016–2019) to provide the required scientific basis to assess the ecological effects.

5.6 Request by France to provide advice on the ecosystem effects of the pulse trawl.

WGELECTRA was asked to provide an updated advice on the ecosystem effects of the pulse trawl, and especially on the lesions associated and mortality for targeted and non-targeted species that contact or are exposed to the gear but are not retained on board, with special reference to those species covered by the Natura 2000 Directives.

WGELECTRA (2015) concluded that the likelihood of an adverse effect of the pulse trawl on the Natura 2000 species and habitats is low (sole pulse) to very low (shrimp pulse). Negative effects can only be expected in cod-like fish. The assessment of the ecosystem effects of pulse trawling is based on the extrapolation of the results of experimental studies which could only show adverse effects in cod. The number of species studied, however, is rather small, and none of the Natura 2000 species listed were exposed to the commercial pulse stimulus to study their response. The estimation of the effect of electrical stimuli was therefore based on a hypothetical predictive framework that explains the sensitivity of fish to develop lesions, in particular spinal fractures and the related haemorrhages, in response to the exposure to the commercial pulse stimuli. The predictive framework assumes that the sensitivity is related to the number of vertebrae and the relative size of the musculature as sup-ported by the available experimental data. It is emphasized that our interpretation is uncertain since the framework is not based on a detailed analysis of the morphology and bio-mechanics of the fish species involved, nor of their physiology, and the number of species studied is very low.

6 Cooperation

Cooperation with other WG

- Members of WGELECTRA participated in Working Group on Fishing Technology and Fish Behaviour (WGGFTFB).

Cooperation with Advisory structures

- WGELECTRA provided advice on the request from France on the effect of pulse trawls on marine organisms.

Cooperation with other IGOs

- Members of WGELECTRA participated in the FAO Fisheries Working Group.

7 Summary of Working Group self-evaluation and conclusions

A copy of the full Working Group self-evaluation is included as an annex.

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Annex 1: List of participants

Name	Address	E-mail	Years participated
Pim Boute	Wageningen University, 6708 PB Wageningen, The Netherlands	Pim.boute@wur.nl	2017
Phillip Copland	Marine Laboratory 375 Victoria Road Aberdeen AB11 9DB UK	coplandp@marlab.ac.uk	2017
Dick de Haan	IMARES, PO Box 68 1970 AB IJmuiden The Netherlands	Dick.dehaan@wur.nl	2014, 2015, 2017
Marieke Desender	Ghent University Sint-Pietersnieuw-straat 25, B-9000 Ghent Belgium	Marieke.desender@ugent.be	2014, 2015
Pieke Molenaar	IMARES, PO Box 68 1970 AB IJmuiden The Netherlands	Pieke.molenaar@wur.nl	2017
Adriaan Rijnsdorp	IMARES, PO Box 68 1970 AB IJmuiden The Netherlands	Adriaan.rijnsdorp@wur.nl	2015, 2017
Maarten Soetaert	ILVO D1 – Fisheries Ankerstraat 1 B-8400 Oostende, Belgium	Maarten.soetaert@ilvo.vlaanderen.be	2014, 2015, 2017
Josien Steenbergen	IMARES, PO Box 68 1970 AB IJmuiden The Netherlands	Josien.steenbergen@wur.nl	2015
Daniel Steputis	Thünen-Institute (TI) for Baltic Sea Fisheries Alter Hafen Süd 2 18069 Rostock, Germany	Daniel.stepputtis@thuenen.de	2014, 2015, 2017
Justin Tiano	Royal Netherlands Institute for Sea Research – Yerseke, Korringaweg 7, 4400 AC Yerseke, The Netherlands	Justin.tiano@nioz.nl	2017
Bob van Marlen	IMARES, PO Box 68 1970 AB IJmuiden The Netherlands	Bob.vanmarlen@wur.nl	2014, 2015
Bart Verschueren	ILVO D1 – Fisheries Ankerstraat 1 B-8400 Oostende, Belgium	Bart.verschueren@ilvo.vlaanderen.be	2014, 2015, 2017
Antony Viera	CRPMEM, France, 12 rue de Solférino, 62 200 Boulogne-sur-Mer, France	antony.viera@copeche.org	2014

Annex 2: WGELECTRA terms of reference (2018-2020)

2016/2/SSGIEOM22

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

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2018	End 2017 or Start 2018	WMR IJmuiden, the Netherlands	Interim report by end of April 2018 to SSGIEOM	
Year 2019	TBD	TBD	Interim report by end of April 2019 to SSGIEOM	Change in chair (Adriaan Rijnsdorp will step back)
Year 2020	TBD	TBD	Final report by end of June 2020 to SSGIEOM	

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Produce a state-of-the-art review of all relevant studies on marine electrofishing. Yearly update it by evaluating and incorporating new research to it.	a) Science Requirements b) Advisory Requirements	14,19,20,27,29	Yearly update	Review report to SCICOM
b	Supply required information to answer on request of member states concerning electrotrawling	b) Advisory Requirements	14,20,26,29,30	Upon request	Advice documents Responses to re-quests of member states
c	Discuss and prioritize knowledge gaps, and discuss ongoing and upcoming research projects in the light of these knowledge gaps, including the experimental set up	a) Science Requirements b) Advisory Requirements	11,12,14,17,19, 20,27	Year 1, 2 and 3	Scientific research adressing knowledge gaps or questions from management

d	Create a platform for the application for supra-national joint research projects on electrotrawling and scientific publication of the obtained results	a) Science Requirements b) Advisory Requirements	17,29	Year 1, 2 and 3	Joint projects and publications among participants and others Collaboration with other related WG's such as WGNSSK, WGCRAN

Summary of the Work Plan

Year 1	- Initiating the review document - Discussing and evaluating ongoing and recently completed research - Brainstorm and application of a joint research project - Answering possible requests
Year 2	- Updating the review document - Discussing and evaluating ongoing and recently completed research - Evaluating and presenting results from joint research projects - Answering possible requests
Year 3	- Finalizing the review document - Discussing and evaluating performed research - Presentation achievements and further goals joint research projects - Answering possible requests - Writing the final 3year report

Supporting information

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

Annex 3: Working Group self-evaluation

1) **Working Group name:** WGELECTRA

2) **Year of appointment:** 2013

3) **Current chairs:** Adriaan Rijnsdorp (the Netherlands) and Bart Verschueren (Belgium)

4) 20–22 October 2014, ILVO, Ostend, Belgium (7 participants)

10–12 November 2015, IMARES, IJmuiden, the Netherlands (8 participants)

17–19 January 2017, IMARES, IJmuiden, the Netherlands (8 participants)

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

- ICES Science plan priority #29: Promote the development and testing of new fishing gear technology and methods for selective reduction of by-catch and discards and for mitigation of other environmental impacts of fishing.

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc.

- Batsleer J, Rijnsdorp, A.D., Hamon KG, van Overzee HMJ, Poos JJ. 2016. Mixed fisheries management: Is the ban on discarding likely to promote more selective and fuel efficient fishing in the Dutch flatfish fishery? Fisheries Research 174:118-128
- de Haan D, Fosseidengen JE, Fjelldal PG, Burggraaf D, Rijnsdorp AD 2016. Pulse trawl fishing: characteristics of their electrical stimulation and its effect on behaviour and injuries in Atlantic cod (*Gadus morhua*). ICES Journal of Marine Science 73(6): 1557–1569

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

- 2015: Respond to a request by France for ICES WGELECTRA to review the work of SGELECTRA and IMARES and to provide an updated advice on the ecosystem effects of the pulse trawl, and especially on the lesions associated and mortality for targeted and non-targeted species that contact or are exposed to the gear but are not retained on board, and with special reference to those species covered by the on Natura 2000 species and habitats Directives.
- WGELECTRA concluded that the likelihood of an adverse impact of pulse trawling on the Natura 2000 species and habitats is low (sole pulse) to very low (shrimp pulse). Negative effects seem to be restricted to cod-like fish.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

- 2/07/2015: International Dialogue Meeting on Pulse Fishing, Scheveningen, the Netherlands
- 20/01/2017: International Dialogue Meeting on Pulse Fishing, Amsterdam, the Netherlands

9) **Please indicate what difficulties, if any, have been encountered in achieving the workplan.**

- The political and legal framework is still in development. This hampered the working group's research.
- Finding extra international expertise and participants with the right, specific knowledge seemed difficult, since not many countries are involved in this specific research niche.

Future plans

10) **Does the group think that a continuation of the WG beyond its current term is required?**

- Yes, the research and the application of pulse fisheries is ongoing.
- There's still a strong need for an international, scientific discussion platform.
- There's an important need for a body in defining research needs and coordinating research.
- It is expected that ICES will be requested in future to give advice on the assessment of the impact of the current use of the pulse fishery in the North Sea.

11) **If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.**

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) **What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?**

- Expertise in social science (stakeholder views on gear transitions)
- Expertise in economic science (economical part of the story)
- Expertise in population dynamics
- Expertise in freshwater electric fishing since there is mutual interest and similar challenges.

13) **Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)**

- Studied effects of traditional and pulse fishing techniques could be used in stock assessment processes.

- The use of electricity in fishing gears has potential to improve selectivity, but raises concern about adverse effects on marine organisms and ecosystems.
- Knowledge of changes in the species- and size-selectivity of pulse trawling relative to traditional beam trawling, will have direct implications for: a) stock assessment of the target species; b) the estimation of the ecosystem effects, in particular on discard production and benthic impacts.
- Knowledge of the effect of electricity on marine organisms is important to advise on potential harmful effects of the implementation of electricity in fishing gears.