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Executive summary

The Study Group on Electrical Trawling (SGELECTRA) chaired by Bob van Marlen, and Bart Verschueren, met from 7–8 May 2011 at the Marine Research Institute of Reykjavik, Iceland. A total of seven participants attended from Netherlands, Belgium, Germany, Scotland, Russia and Lithuania.

Following the ICES Advice on Pulse Trawling on flatfish of 2006 further studies were carried out by IMARES, the Netherlands on catsharks (*Scyliorhinus canicula* L.), cod (*Gadus morhua* L.) and a range of benthic species (ragworm (*Nereis virens* L.), common prawn (*Palaemon serratus* L.), subtruncate surf clam (*Spisula subtruncata* L.), European green crab (*Carcinus maenas* L.), common starfish (*Asterias rubens* L.), and Atlantic razor clam (*Ensis directus* L.) under pulse stimulation of the Verburg-Holland system. These studies were reviewed and discussed at WKPULSE.

Further studies were conducted on cod in 2010 that were presented and discussed here. Juvenile cod (10–12 cm) were affected to a lesser degree by electric pulse stimulation than larger individuals (44–51 cm). By increasing pulse frequency or decreasing pulse amplitude harmful effects on larger cod can be avoided. A remaining question is whether these pulse settings would still enable catching the target species sole and plaice.

A presentation was also given about the development of a pulse trawl for the brown shrimp (*Crangon crangon* L.) fishery in Belgium and the beginning of sea trials in the Netherlands.

In addition a report was given on electric fishing for razor clams (*ensis*) in Scotland, and work in Russia and Lithuania from 1972–1988. A vast body of reports in the Russian language exist that might contain valuable information for this group.

The work already done in EU DEGREE-project and study FISH/2009/07 LOT3 for flatfish fishery was extended. A new scenario was run (scenario 2c) with pulse trawling replacing standard beam trawling in the 24–40m and >40m métiers of 80–90 mm mesh size using the model of Piet *et al.*, 2009. The results indicate that cod landings and discards can be reduced by ~7%. It was advocated to update the models used with results from new full-scale tests.

It was intensively discussed how electric fishing gears can be regulated and controlled to avoid negative impacts. A major problem is that the impact of electric pulses potentially depends on a variety of parameters. Relevant puls characteristics and other variables were identified such as: amplitude in V, electric field strength in V/m, pulse frequency in Hz, pulse duration in μs, pulse form, method: continuous or intermittent, the configuration of the electrodes (diameter, length, insulator/conductor mounting etc.), as well as: species, length in cm, seawater temperature, conductivity of organism, seawater conductivity, position of organism in electric field, sediment characteristics and conductivity, and towing speed. It is quite clear, that it is not optimal to specify all these parameters in legislation and difficult to control them. Therefore, it is hoped that simpler limits can be found, such as capacitor size, as these will physically limit any increase in the output energy the system can deliver. It may be the case that for different species groups (shrimps, flatfish) different limits need to be defined.

The reviewing experts recommended to:

- Continue work on TOR's a), ... , e)

- Follow and participate in the debate of the Dutch Working Group on Control & Enforcement
- Consider producing an ICES Cooperative Research Report (CRR) on electric fishing, possibly through working by correspondence
- Meet again spring 2012 (prior to WGFTFB), possibly in conjunction with WGFTFB
- Consider including other experts (e.g. on fish physiology, modelling effects).

1 Opening of the meeting

The Chairs Bob van Marlen and Bart Verschueren welcomed the Study Group on Electrical Trawling (SGELECTRA) participants and explained some practical arrangements. A list of participants is given in Annex 1. Daniel Stepputtis and Bob van Marlen acted as rapporteur, and text inputs were also given by Bart Verschueren.

The terms of reference for this meeting are given in Annex 2.

2 Confidentiality issue

The commercial activities of Verburg-Holland Ltd. of Colijnsplaat, the Netherlands were transferred to the DELMECO Group at Goes, the Netherlands. All restrictions concerning confidentiality that hampered discussions in the past have been lifted. The DELMECO Group asked us to mention the patent they have in future publications. The second producer of pulse trawling systems, HFK Engineering of Baarn, the Netherlands announced not to impose any restrictions concerning confidentiality.

3 Adoption of the agenda

The agenda was adopted with/without modifications.

4 Review of earlier work and recommendations at WKPULSE

4.1 History and background presented by Bob van Marlen

4.1.1 Background and state-of-the-art

Bob van Marlen gave a short overview of the history of the development of pulse trawling, the ICES Advice of 2006, the follow-up research done by IMARES, the review of this work leading to the ICES Advice of 2009. A detailed Report is given in (ICES, 2010). For reference sake some major topics are copied below.

4.1.2 Questions raised by the European Commission addressed to ICES

The questions raised by the European Commission to were:

a) *What change in fishing mortality could be expected following the adoption of such gear in the commercial fishery, assuming unchanged effort measured in kW-days at sea?*

b) *What effect would such a widespread introduction have in terms of (i) the mixture of species caught; (ii) the size of fish caught?*

c) *What, if any, effects would such introduction have on non-target species in the marine ecosystems where this gear was deployed?*

4.1.3 ICES conclusion and recommendation in 2006 on additional data needs

ICES Concluded in 2006:

"The available information shows that the pulse trawl gear could cause a reduction in catch rate (kg/hr) of undersized sole, compared to standard beam trawls. Catch rates of sole above the minimum landings size from research vessel trials were higher but the commercial feasibility study suggested lower catch rates. Plaice catch rates decreased for all size classes. No firm conclusions could be drawn for dab, turbot, cod and whiting but there was a tendency for lower catch rates.

The gear seems to reduce catches of benthic invertebrates and lower trawl path mortality of some in-fauna species.

Because of the lighter gear and the lower towing speed, there is a considerable reduction in fuel consumption and the swept-area per hour is lower.

There are indications that the gear could inflict increased mortality on target and non-target species that contact the gear but are not retained.

The pulse trawl gear has some preferable properties compared to the standard beam trawl with tickler chains but the potential for inflicting an increased unaccounted mortality on target and non-target species requires additional experiments before final conclusions can be drawn on the likely overall ecosystem effects of this gear."

The recommendations of ICES in 2006 were:

"Further tank experiments are needed to determine whether injury is being caused to fish escaping from the pulse trawl gear. The experiments need to be conducted on a range of target and non-target fish species that are typically encountered by the beam trawl gear and with different length classes. In these trials it should be ensured that the exposure matches the situation in situ during a passage of the pulse beam trawl. Fish should be subjected to both external and internal examination after exposure.

If the pulse trawl were to be introduced into the commercial fishery, there would be a need to closely monitor the fishery with a focus on the technological development and bycatch properties."

4.2 ICES Advice of 2009

In consultation with the European Commission, in September 2009 the Dutch Ministry requested ICES review the reports and to provide updated advice on the ecosystem effects of the pulse trawl. The reports were independently reviewed by a group of experts in the fields of electric fishing techniques, fishing gear technology, benthic ecology, unaccounted mortality and fish survival experimentation. This was coordinated by the chair of WGFTFB. The reviewers were specifically requested to consider the questions raised by ICES in the 2006 advice and whether the additional experiments had successfully addressed these issues. This advice was submitted to ICES ACOM and based on the expert reviews, ACOM concluded that:

- *The experiments are a valuable further step to evaluate the ecosystem effects of fishing with pulse trawls.*
- *Laboratory experiments on elasmobranchs, benthic invertebrates, and cod to test the effects of electric pulses were generally well designed and interpreted correctly. However, the experimental results have some weaknesses as discussed below.*
- *The experiments indicate minimal effects on elasmobranchs and benthic invertebrates.*
- *Electric pulses resulted in vertebral injuries and death of some cod which were in close proximity (<20 cm) to the conductor emitting the electric pulses. There is inconclusive evidence that the capture efficiency of cod by pulse trawls is higher than for conventional beam trawls (see attached review by Norman Graham). Widespread use of the pulse trawl has the potential to increase fishing mortality on cod as a result of injuries caused by electric pulses (and possibly higher capture efficiency) but further research is needed to draw firm conclusions.*
- *While the results of laboratory experiments are informative, many factors could result in different effects during actual fishing operations. In particular, specifica-*

tions contained in the derogation for the pulse trawl allow a wider range of electric pulse characteristics than were tested in the experiments. Therefore, pulse trawls permitted under the EC derogation may generate substantially different effects than those observed in the experiments.

- *This advice is narrowly based on the review of three reports provided by The Netherlands. Concerns and uncertainties raised in the advice may be addressed by further research, refinement of the derogation, and monitoring the fishing operations and performance of vessels using pulse trawls.*

The Report of the WGFTFB Ad hoc Group of 2006 specifically mentioned potential spinal damage to cod exposed to electrical stimulation, potential effects on invertebrates and possible disruption of the electric sensory systems of elasmobranchs. Subsequently, the European Commission granted The Netherlands a derogation for 5% of the fleet to use the pulse trawl on a restricted basis provided attempts were made to address the concerns expressed by ICES. This derogation has been granted every year since 2007.

The Netherlands (specifically IMARES) has studied the effect of the electric pulse trawl during the period 2007–2009 to fill these gaps in knowledge through a series of tank experiments on elasmobranchs, invertebrates and cod. The experimental species were subjected to electrical stimuli believe to be representative of *in situ* fishing conditions. The findings from these experiments are given in three reports:

i) The effect of pulse stimulation on biota – Research in relation to ICES advice – Progress report on the effects to cod (De Haan *et al*., 2009a).

ii) The effects of pulse stimulation on biota – Research in relation to ICES advice – Effects on dogfish (De Haan *et al*., 2009b).

iii) The effect of pulse stimulation on marine biota – Research in relation to ICES advice – Progress report on the effects on benthic invertebrates (Van Marlen *et al*., 2009)

4.3 Points raised at WKPULSE

4.3.1 General Comments

Methodology and Pulse Characteristics

It was questioned whether the pulse simulator used in laboratory experiments were a good representation of the stimuli that marine organisms will undergo in a pulse trawl *in situ*. Regarding the pulse characteristics, it was identified that three aspects must be distinguished: the pulse characteristics themselves, the pulse composition (e.g. 1 second bursts), and the dynamic trawling situation with fish behaviour in the field.

4.3.2 Cod

Observations on the Trial Results

The issue was raised whether other species than cod should also be taken into consideration, such as dab, turbot and whiting, which are important bycatch species.

Level of Cod Catches

It was questioned whether pulse trawling would affect the cod stock to a larger degree. Van Marlen showed two datasets at WKPULSE on cod catches per unit of time:

one from FRV "Tridens" where two nets were fished simultaneously side by side, the pulse trawl and the conventional tickler chain beam trawl, at the optimal speed for the pulse trawl, i.e. 5.5 kts, and the other from a comparison of a fully equipped commercial beam trawler fishing with two pulse trawls with trawlers fishing with conventional tickler chain beam trawls in the same area and time. The results seem to contradict. In the first set a higher cod catch was found (ratio pulse/conventional 2.28), and in the second set the catch was lower (ratio pulse/ conventional 0.48). More data collection was advocated.

Behaviour

In the actual situation a fish entering a pulse trawl moves in relation to the non-uniform electric field, and the dose is determined by the field strength over the fish' body which depends on the duration and relative position to the conductors of the electrodes, and also depends on the fish' length. The wish for underwater observations to learn more about fish (cod) behaviour in the real *in situ* pulse trawl was expressed.

4.3.3 Elasmobranchs

It was commented that the results did not show whether there are any effects on the electro-receptor organ of the catsharks (*Scyliorhinus canicula* L.) tested, as they were offered food which they need not detect themselves.

4.3.4 Benthic Invertebrates

It was questioned whether the electric stimuli can have an effect on the reproductive processes of invertebrates. Russian scientists had experienced that this might be the case.

4.3.5 Historical overview of pulse characteristics used in experiments

An overview is given in Annex 6, Table 1. The literature is not always clear about the details of all these characteristics, e.g. the voltage produced by various systems, especially since these values can be given as output from the electrical generator on deck, or output on electrodes measured *in situ*. Recent information is added.

4.4 Russia/Lithuanian research on E-fishing, presented by Sarunas Toliusis (Lithuania)

Toliusis presented work done in the Institute at Klaipeda, Lithuania as part of the former USSR over the years 1972–1988. It is worth to note that the development of electrical fishing was the aim of this institute with 140 staff members (of which 40 electrical engineers, and 20 ichtyologists) were working in it. The gears used were otter trawls and midwater trawls. The document is titled: "Once again about electrofishing" by S. Toliusis, and given in Annex 9.

Other issues mentioned in this presentation are:

- Usage of electrified gears in Wladiwostok, Black Sea, Murmansk, and Kaliningrad
- Cooperation with GDR, Bulgaria, and with Poland
- Tests were made off the African coast, but in one case the vessel was brought up by south African Marine
- E-fishery was tried for bottom and pelagic fishery

- In the pelagic application electronarcosis was used to wash fish aftwards to the codend.
  - The system worked well on Atlantic mackerel and horse mackerel.
  - The circumference of the net part where the electrodes were placed was ~5 m.
  - Most experiments/usage carried out in pelagic trawl (in mouth part/belly to prevent escaping through big meshes using electrotaxis), an increase in catches by 60% on average was obtained
- Few experiments were done with bottom trawls (e.g. on cod), and electrotaxis could be used to separate cod from haddock. The effect on flatfish was not studied.
  - The circumference of the net part where the electrodes were placed was ~2 m.
  - By using electrotaxis with the anode in the top sheet and the cathode in the bottom sheet the trawl could be lifted 0.5–1.0 m above the seabed to avoid bottom contact.
  - Very good results were obtained, and knowledge for "clean" bottom fishery resulted.
- Shrimp experiments:
  - A pulse was found, which resulted in a 1m jump by shrimps.
- Late 1980s: cooperation started with SCANMAR (including batteries in trawl doors)
- Research stopped in 1988 after regulation (international ban on E-fishery)
- Many results are published in books and articles (in the Russian language)
- Question: where the generators were installed on deck or at the gear?
  - Both approaches were used.

4.5 Literature studies so far

An overview of previous and recent work on electric-fishing is given in Annex 6.

5 ToR a) To review current technical developments on electrical fishing (with the main focus on marine fisheries)

5.1 The effects of electric stimuli on cod (presentation by Dick de Haan)

De Haan gave a summary of the experiments in 2010 in IMR Austevoll Norway. An overview about the flatfish E-Systems developed in the Netherlands was given with recent changes in these flatfish-systems, linking to ToR b). The DELMECO-system (former Verburg) and the HFK-system (called 'pulse wing' were explained. The HFK-system has sealed buffers, which are hard to change and form a physical limit to the output of the system. At amplitudes higher than 100V the system will break down. In DELMECO's system the conductor diameter was recently enlarged from 28 mm to 41 mm, the electrode distance increased from 0.325 to 0.41 m, and the transformer ratio changed from 60V to 50V (0 to peak value). The insulators and conductors used in the electrodes of both systems allow more energy to be discharged through the conductors, and give a voltage fluctuation in length direction during passage.

Both, small and large cod were tested with simulating both the DELMECO and HFK stimuli at fixed distances to the electrodes. It appeared that small cod are less susceptible to spinal damage, and the occurrence in large cod can be decreased with lower pulse voltage and higher frequency. More details are given in Annex 6.

Discussion

Both, the DELMECO and HFK system are very different in the way they work, although in recent developments they are approaching each other (de Haan). The Dutch systems work on the startle response. Toliusis asked why the electrodes were horizontally oriented; he proposed to have the anode on the upper side of the netting above the cathode, since fish always go to the anode (anodic attraction). By alternating polarity electrolytic corrosion can be limited. Both De Haan and Verschueren answered that the effect of the Dutch systems is reached by muscle contraction and not electrotaxis. The efficiency is probably higher using electrodes side by side.

The question was asked of which material the electrodes in the Dutch systems are made of, and the answer is bronze (de Haan).

Copland wondered how selectivity is derived. De Haan replied: by pulse rate, pulse type, and electrode distance. Toliusis commented that selectivity would not be as effective when using this response.

Verschueren asked why the electric field strength varies along an electrode. The answer is that there are several conductors and insulators along the electrode (in contrast to the HOVERCRAN in which only one conductor is used lengthwise in the electrode (de Haan).

Verschueren and Stepputtis asked whether the given values for injuries are given for both pulse trawling systems (DELMECO and HFK), and De Haan replied that this is the case indeed.

Verschueren argued that if higher frequencies are applied (since De Haan had shown, that injuries were reduced at higher frequencies), than other parameters must change. Verschueren commented that when maintaining the same duty cycle pulse duration would alter when varying the pulse frequency. Thus a second variable is introduced. It was replied that if the duty cycle (ratio between pulse frequency and pulse duration) is kept constant, then the pulse duration indeed shortens if frequency is increased for the same energy output. Field strength affected by frequency and voltage would be the decisive variable. (de Haan).

It was also mentioned that there is a difference in the timing of the occurrence of spinal injury. The breaking of spines of cod can be heard; De Haan made recordings of this sound, which may be used to infer the fate of fish without the need for taking X-rays (de Haan).

Stepputtis commented that the numbers of injuries for larger cod are rather high, but at WKPULSE it was discussed, that it may be of minor importance if related to all cod encountering the trawl, if most of the cod pass the electrodes at a larger distance. Are there any video observations done to estimate the average distance of cod to electrodes when entering the net? De Haan and van Marlen answered that further studies will be done during field tests in Week 19 of 2011 to see whether injuries occur in cod and how they compare with conventional beam trawling.

De Haan stresses that in order to correctly interpretate the results of the experiments there is a need to complete the X-ray observations of the tested cod, and conducting *in situ* fields strength measurements with a pulse trawl placed on the seabed on both systems to determine the exact reference to the tank experiments (there might be some artificial effect in it due to condensed electric field). Conducting such measurements is proposed to the Dutch Ministry (using fixed field strength probes).

Verschueren explained that Lieven Geeraerts of Marelec has made a 2D-model of the field strength for the HOVERCRAN (only 2D needed, since there is only one conductor per electrode). The output of this model was shown.

Toliusis wondered whether the electrodes are made of monoliths (solid bars) or made of tubes/. In Lithuania tubes have been used since tubes are lighter and more effective electrically.

Verschueren asked what the reason is, that small cod do not get injured. The muscle strength might not be large enough related to the spinal diameter to break it, whereas in larger fish the muscles are much stronger (de Haan).

It was commented that in the tests on small cod worst case conditions were applied, as rather high field strength was used, based on a high input voltage, since small cod have not shown any effect at lower input voltage. In addition without sediment in the tank the field strength would be higher close to the bottom than in reality at sea where the bottom sediment also acts as conductor to some extent. Thus in the tank trials the field lines did not penetrate the tank bottom and therefore showed a higher density close to the bottom (de Haan).

5.2 Electric fishing on razor clams

Phil Copland gave a short summary of electric fishing on razor clam (*ensis sp.*) in UK Scotland. The reference of this report is: Breen *et al*., 2011. An executive summary is given in Annex 8.

Points mentioned were:

- E-fishery in UK: there are hints, that there is an increasing electric fishery targeting *Ensis*
- Illegal fishery, hard to control
- Much better quality of *Ensis* obtained.

- Informal information by the divers, that these systems use so much energy, that it is possible to see a "dead"/ "yellow" mark where the gear went over.
- 5 kW (kVA) welding generators are being used per side (little detailed information is available)

5.3 Electric fishery on brown shrimp (presentation by Bart Verschueren)

5.3.1 HOVERCRAN testing on commercial shrimp trawler TX 25

The HOVERCRAN, a modified shrimp beam trawl, aims at stricter selectivity and reduced seabed contact. The fundamental idea is to replace the heavy bobbin rope with lightweight electrodes, in order to use electrical pulsation as a stimulation alternative. Prior research by ILVO showed that the use of a specific electric field close to the seabed induces a startle response in shrimp, meanwhile not affecting most of the other benthic species. The elevated footrope lets non-target species escape underneath the trawl and collects the shrimp that jump up into the water column. Herein lays the selective fishing potential of this alternative technique.

Preservation of the commercial catches and the reduction of discards and seabed contact are the decisive criteria in the evaluation of the HOVERCRAN. Extensive testing of the prototype on a Belgian shrimp cutter, by direct catch comparison with a standard shrimp trawl, revealed important and hopeful results. First and foremost could be shown that at least as much shrimp can be caught with the new technique compared with the traditional gear. An important remark hereby is that the catch efficiency of the HOVERCRAN seems less influenced by the fishing conditions. Different hauls during daytime, night-time, in clear or turbid water, in good and bad weather conditions produced relatively constant catches, while the traditional gear showed rather diverse catch results. On top of that, an average bycatch reduction of 35% in volume is a major step forward in the discard issue of the brown shrimp fishery. These results showed that the raised groundrope plays an essential role in separating shrimp from unwanted bycatch. The higher the footrope is placed, the more bycatch is reduced. As a consequence also more shrimp tend to escape beneath the groundrope. Therefore the ideal footrope height should be a trade-off between acceptable shrimp catches and sufficient bycatch reduction. Reduction of bottom contact by 75% is a radical change in the environmental impact issue. Opinions on the effects of the bottom contact on the seabed and its associated organisms differ a lot. Avoiding bottom contact in the brown shrimp fishery makes the discussion redundant.

It should, however, be borne in mind that the sea trials only covered a relatively short time range of 6 months in summer and autumn and only took place in Belgian waters. For this reason, it was recommended to elaborate the research. An extensive range of sea trials on commercial vessels in different conditions and fishing grounds should precede commercial application.

In the mean time ILVO and IMARES have begun new testing in collaboration with the Dutch shrimp fishery. In spring 2011 a Dutch commercial shrimp cutter (TX 25) was equipped with an improved version of the system. In summer 2011 a second vessel (HA 31) will follow. These vessels will perform year-round testing, operating in the Wadden Sea. This will hopefully reveal the feasibility of the technique under variable commercial circumstances.

5.3.2 Effects of the HOVERCRAN pulse (low-frequency pulsed direct current) on captive-housed sea fish

To reduce the unwanted bycatch in shrimp trawling, alternative stimulation techniques such as electricity which selectively invokes a reaction in shrimp might be used. The effects of the specific HOVERCRAN electric pulse on a selection of sea fish were investigated by ILVO.

Sea fish

Seven different species were selected i.e. (Pleuronectes platessa, n=41, length: 9.5–41.0cm), sole (Solea solea, n=44, length: 13.0–36.0cm), dragonet (Callyonimus spp., n=40, length: 8.0–21.0cm), pogge (*Agonus cataphractus*, n=40, length: 6.0–14.0cm), armed bullhead (*Myoxocephalus scorpius,* n=29, length: 14.0–27.0cm), fivebeard rockling (*Ciliata mustela*, n=14, length: 12.0–19.5cm) and Atlantic codfish (Gadus morhua, n=30, length: 17.5–40.0cm). Fish were captured on the Belgian coast with an 8m twin flatfish beam trawl or an 8m shrimp beam trawl during 3 different sea trips. Once ashore, all fish were visually inspected for liveliness and injuries, only animals in good condition were transferred to the aquarium facilities. All fish were given an adaptation period between 14 and 45 days, during which general condition and feeding was constantly observed.

Experimental setup

After the adaptation period each fish was alternately transferred to a glass exposure aquarium containing approximately 240 litres of seawater (120cm L x 50cm W x 40cm H) and was allowed to swim free. Seawater quality and temperature in the exposure tank was the same as the housing aquariums. The bottom of the aquaria was covered with rinsed sand. The tank was equipped with two threadlike electrodes, placed on the bottom plate of the tank. Each 50cm long electrode was composed of seven solid cupper strands and had a circular section of 16 mm^2. These conductors were placed parallel at a distance of 60cm from each other, 30 cm from the adjacent aquarium wall. Both electrodes were electrically connected with a custom built adjustable impulse generator. After a fish was transferred to the exposure tank, the behaviour of the animal was observed during 10–20 minutes. As soon as the animal was at rest, the generator was manually switched on by means of an interrupter. During a period of approximately ten seconds a pulsed direct current electric field was generated in the tank between the two conductors. After ten seconds the interrupter was manually switched off again. During the experiment pulse characteristics were closely monitored. The amplitude between the electrodes was fixed at 60 volt. Pulses were generated at a frequency of 5Hz. The low frequency direct current pulses had an almost square pulse shape and a duration of 0.5 milliseconds. A total of 21 plaices, 22 soles, 21 dragonets, 21 pogges, 14 armed bullheads, 8 fivebeard rocklings and 20 Atlantic codfish were exposed to electric pulses according to the procedure mentioned above. In each species control animals were included. In total, they consisted of 20 plaices, 22 soles, 19 dragonets, 19 pogges, 15 armed bullheads, 6 fivebeard rocklings and 20 Atlantic codfish. All control animals were treated similarly, except for the exposure to the electric field.

Observation

During and 30 minutes after the exposure to the electric field, reactions such as movement, flight response, deviant behaviour and mortality were reported. In almost all fish, minor reactions were observed during the 10 seconds of exposure to electric pulses. Immediately thereafter, they returned to their normal position. Abnormal behaviour was not observed in control animals.

Plaice

During the settling period, plaice dug into the sand until only the head was partly visible. As soon as the animal was exposed to the pulses, the fish body gently vibrated to the frequency of the pulses without leaving its buried position. This lasted for full 10s, and after the generator was switched off, the animal remained where it was

Sole

Sole showed comparable reactions to plaice. In about one quarter of the cases, however, the fish rose from its buried position and started swimming actively in random directions. After the generator was switched off, the animals returned to the bottom were dug into the sand.

Dragonet

While resting, dragonets were partly dug into the sand. After the pulses started, they showed strong irregular muscular contractions and moved over very short distances. They stayed, however, close to the bottom.

Pogge

Most pogges lay on the bottom before the pulses started. Some of the fish, however, kept on swimming around in the tank. When the pulses started, the fish lying on the bottom started moving around slowly with their bodies vibrating at the frequency of the pulses. The fish higher in the water column immediately returned to the bottom.

Armed bullhead

At rest, the armed bullheads lay on top of the sandy bottom. Under the influence of the pulses, the fish showed slight vibrations, but did not move their position.

Fivebeard rockling

Before the pulses started, the fivebeard rocklings rested on the bottom or swam slowly over the sand. During the electric stimulation, they agitatedly swam close to the bottom. After the pulses were switched off, these fish soon resumed the behaviour they showed before stimulation.

Atlantic codfish

During the settling period, Atlantic codfish stayed relatively motionless in the middle of the exposure tank. As soon as the electric field was switched on, they started swimming agitatedly in random directions, hereby regularly bumping against the walls of the tank. During the full 10s of exposure, the fish body showed small jerks to the frequency of the pulses. After the pulses were switched off, these fish soon resumed the behaviour they showed before stimulation.

Necropsy and histology

Immediately after euthanasia, all animals were examined for gross lesions. Special attention was given to haemorrhages, discolouration and injury of skin, abdominal organs, muscles and vertebrae. Samples from gills, liver, spleen, kidney and dorsal muscle were immediately immersed in phosphate buffered formalin (10%) and processed for paraffin sectioning according to standard techniques. For histological examination, 5 μm sections were stained with haematoxylin and eosin.

In general gross and histological abnormalities were rarely present in both the group of exposed fish and the control group. In one control and two electrical exposed plaices, small multifocal cutaneous haemorrhages were observed. In the remaining animals, macroscopic and histological abnormalities suggestive for electrocution were not found, except for one small focal interstitial haemorrhage in the muscle tissue of a sole.

Conclusion

At least under experimental conditions, the HOVERCRAN electric pulse for catching brown shrimp could be promising since this has low impact on fish. The presentation featured:

5.3.3 Discussion on HOVERCRAN presentation

Bycatch of sole and others species is important. Do we then need different rules for shrimp or distinguish species groups in the regulation? This seems to be the case.

Verschueren emphasized that in the shrimp trawling system the only variable is pulse amplitude, all the others are fixed, such as pulse frequency at 4.5 Hz. Also it was found that there is no point in aiming for higher output, as the best catch results were found at 80% output (30 V/m), and beyond that the catch efficiency drops.

Bycatch was not yet studied in the TX-25 trials. The footrope has been raised by 15 cm off ground. This would result in lower bycatch but also fewer shrimps. It was not yet tried out to raise the anodes and leave the cathodes on the bottom to enhance the jumping effect. In addition this would lead to higher corrosion if the polarity is not alternated.

The output of a 2-D model of field strength was shown, programmed by Lieven Geeraert of Marelec.

The HOVERCRAN might be a good alternative for the bobbin groundrope. The square net has been tried for two weeks now, with a length of electrodes of 3 m to the footrope. It appeared that more rubbish is caught in this net, possible stirred up in the wake of the trawl shoes.

The electrodes are made of stainless steel wire with one strand replaced by copper.

There is communication between DELMECO and Marelec about a combined flatfish shrimp pulse trawl (Verschueren). This may affect the ideas of creating species-specific regulations (van Marlen).

6 ToR b) To review studies on the relationship of pulse characteristics (power, voltage, pulse shape) and thresholds in terms of effects on fish and other organisms (mortality, injury, behavioural changes)

Part of this ToR is dealt with in ToR a), and many details are given in Section 4.

The main characteristics of pulse stimulation are:

- Amplitude in V
- Electric field strength in V/m
- Pulse frequency in Hz
- Pulse duration in μs
- Pulse form
- Method: continuous, intermittant
- The configuration of the electrode (diameter, length, isolator/conductor mounting etc.)

Other variables are:

- Species
- Length in cm
- Water temperature
- Conductivity of organism
- Seawater conductivity
- Position of organism in electric field
- Sediment characteristics and conductivity
- Towing speed

There are three main tasks which require a better understanding of the mechanisms behind the effect of electric fields on marine organisms:

a. Optimization of the efficiency of the capture process
b. Ecosystem concerns
    - Effects on target and non-target species which may encounter the gears.
c. Regulation and control of pulse trawling systems (partly based on findings from ToR b)
    - To identify those parameters, which can be easily specified and controlled, e.g.
        - To avoid negative impacts on the marine environment
        - To avoid developments as in China where shrimp stocks were overfished due to unrestricted technical developments and fisheries were consequently closed involving thousands of fishers.

A Dutch Working Group on Control and Enforcement of e-fishing systems has recently been established with membership for the fishing industry, pulse trawl producers, scientists (IMARES and ILVO), and policy-makers from the Ministry (van Marlen).

Goals:

- to identify variables, that can be used in control and enforcement
- to define thresholds and set limits of relevant parameters
- to create a policy framework for control and enforcement

Discussion

Potential Parameters to be regulated:

This issue was intensively discussed during SGELECTRA. The members of SGELECTRA were not successful to identify (or better: did not agreed on) relevant parameters and a simple scheme to regulate and control the deployment of electric fishing gear in the marine environment. Several opinions were discussed:

Such a framework should be fraud resistant, by choosing a buffer for discharging electrical energy physical limits can be set (de Haan). Verschueren argued, that also (e.g.) the change of the frequency can result in a different effect with the same energy output (Verschueren). OK, but amplitude should also be limited (de Haan).

Current documentation of deployment of e-gears:

The discussion then focused on how registration of performance of electrical systems is taken care of now.

Stepputtis recollected EU Reg. 43/2009 (Annex 3, Paragraph 3) which reads as follows: *"The vessel shall be equipped with an automatic computer management system which records the maximum power used per beam and the effective voltage between electrodes for at least the last 100 tows. It shall be not possible for non-authorized person to modify this automatic computer management system"*;

This requirement was checked for the current pulse trawl systems:

- HOVERCRAN: no recording of parameters is applied.
- DELMECO: there is a recording system available, but also open for unauthorized persons.

De Haan proposes a physical limitation of the system. Buffering energy in a capacitor limits the maximum power applied to the system. When trying to exceed this maximum power, the capacitor will be overloaded and blown up.

Verschueren argumented against this simple approach. The experiments by De Haan have shown, that even if the power output is constant, other variables can significantly change the effect on organisms (e.g. a pulse frequency increase reduced spinal injuries of cod significantly). There are many possible electric fields possible, even if the same energy is put into a system. Some may cause injuries, while others do not. Can we as group accept that E-fishery has an adverse effect? Is it acceptable, that 50% of large cod die due to spinal damage?

Stepputis claimed that every human activity has side effects; the question is to define a limit which is acceptable. It is not clear what the percentage is of large cod in a full-scale trawl that come so close to the electrodes, that it has a chance of e.g. 50% to die

Van Marlen mentioned that the output of the model developed in FISH/2007/07 LOT3 (Flatnose) has shown, that both the landings and discards of cod may be reduced by replacing the relevant beam trawl métiers of the fleet with pulse trawl systems, so the overall effect on cod may be nevertheless positive (Polet *et al*., 2010).

Stepputtis replied that it is not the goal to have a system, which is a little bit less worse than the worst traditional beam trawl system.

De Haan mentioned that it should be noted that full-scale fishing experiments have never been conducted in the most relevant season (from December to February the next year), in which cod bycatches are highest (and thus effects on cod discards could be shown with higher accuracy). Therefore this group: recommends doing experiments in this season.

Furthermore it is deemed of importance to come up with a recommendation on setting and controlling the limits. A problem is that little is known about the effect of parameters on different species and many factors are influencing effects.

Verschueren asked whether it is possible for the industry to come up with a range of optimal parameters for the target species. Then the limits could be tested and set in accordance. This could lead in a certification scheme for new gears. This would be no problem for the HOVERCRAN, for which only the maximum power applied can be varied (usually set to 80%). But this may alter, if for instance the lengths of the electrodes are changed.

Another variable to be prescribed should be the diameter of conductors. The problem is that it is difficult to define the limits/rules now, since there are systems out in use, which have to be covered within such regulation. On the other hand it should be easy to control (Copland).

The experience in limiting the engine power of fishing vessels taught me that regulations should be made as simple as possible (de Haan).

Summary of findings:

- Based on the current knowledge it is difficult to identify commonly used / general limits, especially since several target species are involved, and therefore species-specific regulations can perhaps not be avoided.
- The aim could be to make simple regulation (with only a few parameters to be defined and to be fixed, perhaps physically). By doing so we can - follow the European trend of moving away from micromanagement and ever growing complexity in rules towards shifting more responsibility to the industry sometimes referred to as the reversal of the burden of proof.
- On the other hand this will be difficult to establish for all systems/target species together, since parameters differ significantly, which might mean that separate settings/limits for different target groups are needed.
- A possible way could also be to set up a certification scheme for systems, where producers have to proof they stay within limits defined.
- In the Netherlands a national Working Group on Control and Enforcement has been established to find a solution. SGELECTRA will observe and (partly) contribute to this WG and comment on its outcome in the near future.
- Setting a physical limit to system components such discharge capacitors would be a way to avoid very complex regulations, and it also would be easily controllable.

7 ToR c) To improve knowledge of the effects of Electrical Fishing on the marine environment (reduction of bycatch, impact on bottom habitat, impact on marine fauna, energy saving and climate related issues)

A list of ongoing and planned activities was made. As one of the main aims of SGE-LECTRA is the coordination of activities (planning and analysis) in the field of e-fishery, the results of these activities will be reviewed at the next meeting. This joint analysis will be basis for future work and advice on request.

These activities are:

- A comparative Dutch fishing experiment with two pulse trawl vessels and one conventional beam trawler working at close range in May 2011.
- Full-scale tests using the HOVERCRAN on two Dutch commercial shrimp trawlers.
- Full-scale tests using the HOVERCRAN on one -German commercial shrimp trawler (depends on funding).
- Additional work to Dick de Haan's experiments (e.g. full-scale measurements of pulse characteristics on-board to link/compare them to tank experiments).

8 ToR d) To evaluate the effect of a wide introduction of electric fishing, with respect to the economic impact, the ecosystem impact, the energy consumption and the population dynamics of selected species

Van Marlen explained the work done in EU-project FISH2007-7-LOT3"Flatnose"

(See also document "Tender FISH2007-7-LOT3_Draft finrep_Scenario 2_SecDbis.doc" on the sharepoint).Full details are given in Annex 10. The spatially explicit model given in (Piet *et al*., 2009) was used to combine abundance data for all the main fish species in the demersal North Sea fish community with international effort data and estimates of gear-, species-, and size-dependent catch efficiency to determine the mortality of non-target fish species caused by bottom trawl fisheries and its spatial variation. Fishing effort data were collected from the STECF database. The standard unit to express effort in this project was "kWdays". An alternative unit was "days at sea".

A total of 73 métiers in demersal fisheries in the North Sea were used based on vessel type and length class, gear type, and mesh size range and grouped in (Annex 9:Table 6):

- three vessel length classes: <24m; 24–40m; >40m
- eight fishing gear groups: GNS, GTR, OTB, OTT, OTX, PTB, SDN, TBB

four mesh size groups: 80mm; 90mm; 100mm; 120mmIn scenario 2a the métiers Beamhp3 (vessel size >40m, mesh size range 80–90 mm) were replaced by pulse trawls based on the catch efficiencies on plaice, sole and roundfish found in 2006. In scenario 2b Beamhp2 (vessel size 24–40m, mesh size range 80–90 mm) the métiers were added (Annex 9: Table 10, Table 11, Table 12).

A new scenario was run (scenario 2c) with pulse trawling replacing standard beam trawling in the 24–40m (Beamhp2) and >40m (Beamhp3) métiers of 80–90 mm mesh size. New gear efficiencies were given based on anecdotal information and proxis. The result is shown in Annex 9: Table 13 and seems to indicate that cod landings and discards will be reduced by introducing pulse trawling in the beam trawl fleet. It was suggested to look closer into the model and comment on how realistic the outcome may be, when the results of the catch comparison to be conducted in May 2011 become available.

There was also work done on pulse trawling in EU-project DEGREE for pulse trawling on flatfish. It was recommended to update the findings based on results from new full-scale tests.

First estimates on a wide range introduction of the HOVERCRAN based on the results of coming full-scale tests are to be discussed in SGELECTRA in 2012.

Conclusion

Further work on this TOR is needed.

9 ToR e) To consider whether limits can be set on these characteristics to avoid unwanted effects (e.g. unwanted and uncontrolled growth on catch efficiency, unwanted ecosystem effects) once such systems are allowed and used at wider scale

Pulse trawling is allowed on a yearly basis for a part of the (Dutch) cutter fleet under derogation from the EU, and two limiting variables were defined to avoid an uncontrollable increase in fishing efficiency. These are: electrical power limited to 2.5 kW/m beam length, and the maximum effective voltage between electrodes limited to 15 V. It was recognized that these two will not be sufficient to ensure that fishing efficiency or negative impact with pulse trawls will not increase in future through technical adaptations of the systems. Recently, in the Netherlands a working group has been established dealing with issues of Control and Enforcement, with participation from the Dutch Fishermen's Organization, the newly formed Ministry of Economics, Agriculture and Innovation (EL&I), IMARES, ILVO, and the pulse trawl producers.

In a short national project the following questions raised by EL&I were addressed:

1. Which pulse characteristics affect catch efficiency and what are effects on the ecosystem?
2. What are the specifications used for these pulse characteristics?
3. Has there been any fundamental research on these characteristics in relation to effects?
4. Are there any gaps in knowledge?
5. If so, what can be the implications?
6. What research is needed to fill these gaps?

Relevant characteristics of pulse stimuli were identified from a literature review (Table 5: Overview of pulse characteristics in electrofishing studies in Annex 7), and recommendations for further studies made. Our discussions can feed into this process.

Conclusions

- Further work on this TOR is needed.
- SGELECTRA to keep a watching brief on the outcome of this working group, and where appropriate (Dutch and Belgian inputs) participate in it.

10 Sea trials/ full-scale experiments

It was suggested to make up a common design and protocols for full-scale experiments with contents as suggested below (Stepputtis). This should come in addition to various standards already defined, such as the "discard protocol" of IMARES (van Marlen).

Points should be harmonized:

1. Design of the experiment
    - Equipment of vessel:
        - One vessel fishing with two gear types (standard beam trawl vs. pulse or e-beam trawl)
            - Used in HOVERCRAN-studies and Verburg-studies on FRV "Tridens" in the past.
            - Problem: Pulse and conventional gears need different optimal vessel speed.
        - Each vessel using only one type of gear
            - Used in NL during tests in 2005–2006
            - Used in NL during tests in May 2011
            - Problem: other confounding factors introduced, comparison of data limited
2. Compensation of fishers
3. Recording of gear data
    - Especially relevant to pulse characteristics (see discussion in chapter XXX).
4. Recording of catch data
    - What is the level of data needed for the evaluation of effects of e-fishery

During SGELECTRA 2011, due to time restrictions, this topic was not discussed in detailed. More input is needed to complete this.

11 Conclusions and recommendations

Recommendation on further Work/Experiments/Analysis

Recommendations were made on topics not sufficiently covered so far that have to be addressed. But it should be noted that additional funding is necessary.

Further work

- Additional effect studies
  - Larger studies on effects of pulses
    - Identify the parameters, which drive significant damages (such as spinal damages in cod)
    - Needed: experiment settings where only one parameter is changed at a time
  - Including other species: elasmobranch (electroreceptor organs) and benthos (reproduction)
  - Effect of wider introduction of pulse trawling on target and non-targets species
    - Further studies using the model of Piet *et al.*, 2009 with updated gear efficiencies.
  - Effect on different life stages (e.g. eggs and larvae) of important species (e.g. sole)
  - Effects of low frequency in the range of shrimp stimulation and long pulse duration on species, which are not, targeted in shrimp fisheries (sole, plaice, cod).
    - Evaluate the effects on such species
    - Could these pulses be used to increase catchability also for these species?
- More full-scale tests, not only in the Netherlands
  - Conduct *in situ* measurements on the field strength of the two existing Dutch pulse trawling systems as a reference to the experiments of 2010 on cod in Norway.
  - Review the results of the comparative fishing experiments in the Netherlands in May 2011.
  - Study the effects of pulses identified as less harmful (high frequency/lower voltage) in flatfish systems on target species, e.g. sole.
  - For the HOVERCRAN system: continue monitoring catches and by-catches.
- Control and Enforcement
  - Continue involvement in the Dutch Working Group on Control and Enforcement by relevant participants with feedback to SGELECTRA.

11.1 SGELECTRA recommend to produce a Cooperative Research Report (CRR) on the "Use of Electricity in Marine Fishing"

11.1.1 Potential authors:

- Members of SGELECTRA
- Other scientists
  - e.g. China (which could have repercussions on the status of an ICES CRR)
  - countries of former USSR (especially Lithuania)

- Physiologists

11.1.2 Suggested contents (see also ToR's of SGELECTRA):

- Electricity in general
- Physiological aspects of electricity (effect on tissues, nerves, etc.)
- Principles of marine electrical fishing;
- Effects of electrical fishing on marine organisms and habitats;
- Review of work done
  - Authors should also include knowledge from the research published in Russian and Chinese language
- Current systems and gears
  - Technology
  - Stimuli
  - New developments
- Health and safety implications of electrical fishing operations
- Economic prospects of E-fishery
- Fuel saving potential

Future research requirements to assess the effects of electrical fishing on the marine environment

- Control and Enforcement issues
- Conclusions and recommendations
- List of references

11.1.3 Suggested working methods

- Write by correspondence
- Review and SG-meetings

11.2 Further Meetings

SGELECTRA recommend a second meeting in 2012:

- Timing: 2 days in spring 2012 (to be decided by correspondence (e.g. doodle)).
- Place: the Netherland (e.g. Texel) in combination with possible excursion to different E-systems installed on commercial vessels and producing companies, or in conjunction with WGFTFB pending finances and practicality.
- More expertise is highly appreciated (especially including supplementary expertise in physiology and ecology).
- ToR's and supporting information to be drafted and agreed by correspondence.

12 References

Agricola, J. B., 1985. Experiments on electrical stimulation of flatfish in beam trawling during 1984. ICES CM 1985/B:36.

Ainslie, B. J., Post, J. R., Paul, A. J. 1998. Effects of pulsed and continuous DC electrofishing on juvenile rainbow trout. North Americ. J. Fisher. Managem. V.18. № 4. P. 905–918.

Anon., 1988. Report of the Study Group on the Effects of Bottom Trawling. ICES C.M. 1988/B:56, 30 pp.

Anon., 1995. Report of the Study Group on Ecosystem Effects of Fishing Activities. ICES Cooperative Research Report No 200, 120 pp.

McK.Bary, B. 1956. The effect of electric fields on marine fishes. Marine Research Scotland, 1.

Balaev, L. A. 1969. Reactions of small Black Sea horse mackerel in the homogenous field of constant electric current. Trudy AzCherNIRO (Transactions of Azov and Black Sea Scientific Research Institute for Fisheries and Oceanography). Iss. 26. P.143–151. (In Russian) Балаев, Л.А. Реакции мелкой черноморской ставриды в однородном поле постоянного электрического тока. Тр. АзЧерНИРО. 1969. Вып.26. С.143–151. (In Russian)

Beek, F. A. van, P. I. van Leeuwen and A. D. Rijnsdorp, 1990. On the survival of plaice and sole discards in the otter trawl and beam trawl fisheries in the North Sea. Neth. J. Sea Res., 26 (1): 151–160.

Bergman, M. J. N., and Santbrink, J. van, 2000. Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. ICES Journal of marine Science, 57 (5): 1321–1331.

Boonstra, G. P., and Groot, S. J. de 1974. The development of an electrified shrimp trawl in the Netherlands. J. Cons. int. Explor. Mer., 35 (2): 165–170.

Breen, M., Howell, T., and Copland, P. 2011. A report on electrical fishing for razor clams (*ensis* sp.) and its likely effects on the marine environment. Marine Scotland Science Report Volume 2 No 3, February 2011.

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

Danyulite, G. P., and Fursa, N. N. 1976. On the reactions of vimba (*Vimba vimba*) in the electric field of constant and pulse currents. Vimba. Complex studies in the multiple locations within the area. Vilnus. P. 211–217. (In Russian) Данюлите Г.П., Фурса Н.Н. О реакциях сырти (Vimba vimba) в электрическом поле постоянного и импульсного токов. Рыбец. Комплексные исследования в нескольких точках ареала. Вильнюс, 1976. С.211–217. (In Russian)

Dijkgraaf, S., Kalmijn, A. J. 1966. Versuche zur biologischen Bedeutung der Lorezinischen Ampullen bei der Elasmobranchiern. Zeitschrift fur vergleichende Physiologie, 53: 187–194.

Enger, P., Kristensen, L., Sand, O. 1976. The perception of weak electric D.C. current by the European eel (*Anguilla anguilla*). Comp. Biochem. and Physiol. A., Vol. 54. No 1. P. 101–103.

Fonteyne, R., and Polet, H. 2002. Reducing the benthos bycatch in flatfish beam trawling by means of technical modifications. Fisheries Research, 55: 219–230.

Groenewold, S., and Fonds, M. 2000. Effects on benthic scavengers of discards and damaged benthos produced by beam trawl fishery in the southern North Sea. ICES Journal of Marine Science 57 (5): 1395–1406.

Groot, S. J. de, and Boonstra, G. P. 1970. Preliminary notes on the development of an electrical tickler chain for sole (*Solea solea* L.). ICES C.M. 1970/B:4.

Haan, D. de, Marlen, B. van, Kristiansen, T. S., and Fosseidengen, J. E. 2008. The effect of pulse stimulation on biota – Research in relation to ICES advice – Progress report on the effects to cod. IMARES Report C098/08, 25 pp.

Haan, D. de, Marlen, B. van, Velzenboer, I., Heul, J. van der, Vis, J. W. van der, 2009. The effects of pulse stimulation on biota – Research in relation to ICES advice – Effects on dogfish. IMARES Report C105/09, 32 pp.

Hopkins, C. D., Lovell, P., Harned, G., Satoshi Amagai, 1997. An Electric Sense for an African Electric Fish. Section of Neurobiology and Behavior, Cornell University, Ithaca, NY, USA, p. 2.

Horn, W. 1976. Rationalization of sole fisheries by means of electrified beam trawls. *In:* Coun. Meet. ICES/B:7, Report of the Working Group on Research on Engineering Aspects of Fishing Gear, Vessels and Equipment.

Horton, R. S. 1984. Trials of the electric beam trawling system on MFV Zuiderkruis, summer 1983. Seafish Report, IR 1180.

ICES. 2006. Report of the working group on the assessment of demersal stocks in the North Sea and Skagerrak. Copenhagen, 6–15 September 2005. ICES C.M. 2006/ACFM: 09.

ICES. 2010. Report of the Workshop to Assess the Ecosystem Effects of Electric Pulse Trawls (WKPULSE), 24–26 February 2010, IJmuiden, the Netherlands.

Ingolfsson, O′. A., Soldal, A. V., Huse, I., and Breen, M. 2007. Escape mortality of cod, saithe, and haddock in a Barents Sea trawl fishery. ICES Journal of Marine Science, 64: 1836–1844.

Hemmings, C. C. 1973. Direct observation of the behaviour of fish in relation to fishing gear. Helgolander wiss. Meeresunters. 1973. 24. P. 348–360.

Jennings, S., and Kaiser, M. J. 1998. The Effects of Fishing on Marine Ecosystems. Adv. Mar. Biol., 34: 221–233.

Kaiser and De Groot (editors), 2000, Effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. ISBN 0-32-05355-0, 399 p.

Kruuk, H. 1963. Diurnal periodicity in the activity of the common sole, Solea Vulgaris Quensel. Journal of Sea Research, 2: (1) 1–28.

Lamarque, P. 1990. Electrophysiology of fish in electric fields. *In:* Cowx I. G. and Lamarque P., eds. Fishing with electricity, applications in freshwater fisheries management: Oxford, England, Fishing News Books, Blackwell Scientific Publications, Ltd. P. 4–33.

Lapkin, V. V., and Zaitsev, K. N. 1976. Reaction of fish to the electric field of various frequencies. Biology of Inland Waters. Information Bulletin. Leningrad. No 30. P. 17–19. (In Russian) Лапкин В.В., Зайцев К.Н. Реакция рыб на электрическое поле различной частоты. Биология внутренних вод: Информ. бюл. Л., 1976. N 30. С.17–19. (In Russian)

Lindeboom, H. J., and Groot, S. J. de (Eds.), 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic eco-systems. EU-project AIR2-CT94-1664 (IMPACT-II), Final Report ISSN 0923-3210, 404 p.

McBary, B. 1956. The effect of the electric fields on marine fishes. Marine Research. No 1. 32 pp.

McMichael, G. A. Examination of electrofishing injury and short-term mortality in hatchery rainbow trout. North. Americ. J. Fisher. Managem., 1993. V.13. P. 229–233.

Muraveyko, V. M. 1980. Electrical sensitivity of salmonid fishes. Signalling and behaviour of marine fishes. Leningrad: Nauka. P. 11–23. (In Russian) Муравейко В.М. Электрическая чувствительность лососевых рыб. Сигнализация и поведение морских рыб. Л., Наука, 1980. С.11–23. (In Russian)

Özbilgin, H., and Wardle, C. S. 2002. Effect of seasonal temperature changes on the escape behaviour of haddock, *Melanogrammus aeglefinus*, from the codend. Fisheries Research, 59: 323–331.

Paschen, M., Richter, U., and Köpnick, W. (editors), 2000. TRAPESE - Trawl Penetration in the Seabed. Final Report EU Contract 96-006, University of Rostock, ISBN 3-86009-185-9.

Peters, R. C., and Evers, H. P. 1985. Frequency selectivity in the ampullary system of an elasmobranch fish (*scyliorhinus canicula*). J. exp. Biol., 118: 99–109.

Petrov, F. P. 1935. Action of electromagnetic field on the isolated organs. Physical and chemical grounds of neural activity. Leningrad. P. 97–105. (In Russian) Петров Ф.П. Действие электромагнитного поля на изолированные органы. Физико-химические основы высшей нервной деятельности. Л., 1935. С.97–105.

Piet, G. J., Rijnsdorp, A. D., Bergman, M. J. N., and Santbrink, J. van, 2000. A quantitative evaluation of the impact of beam trawling on benthic fauna in the southern North Sea. ICES Journal of Marine Science, 57, (5): 1332–1339.

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

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

Polet, H., Tidd, A., Van Hal, R., Madsen, N., van Marlen, B., Soma, K., Depestele, J., Buisman, E., Sølgaard Andersen, B., Piet, G. J., Catchpole, T. 2010. Scientific advice concerning the impact of the gears used to catch plaice and sole in the North Sea. Final report of the open call for tenders FISH/2007/7, studies and pilot projects for carrying out the common fisheries policy, European Commission, June 2010.

Pupyshev, V.A. 1966. Studying the response of some tropical fishes to the pulsed current in the homogenous electric field of aquarium. Trudy VNIRO (Proceedings of All-USSR Scientific Institute for Fisheries and Oceanography). V. 61. C.133-139 (In Russian) Пупышев В.А. Исследование реакции некоторых тропических рыб на импульсный ток в однородном электрическом поле аквариума. Тр. ВНИРО. 1966. Т.61. С.133-139. (In Russian)

Rachounas, L. 1977. Reproduction of daphnia, freshwater shrimp and brine shrimp. Post effects of the electric fields upon the water animals. Vilnus: Mokslas. P. 81–86. (In Russian)

Report of the Ad-hoc Group on Pulse trawl evaluation. ICES April 2006.

Report of the Working Group on Fish Technology and Fish Behaviour. ICES April 2006.

Reports of the EU funded IMPACT study which provides data on mortality caused by beam trawls, see review by ICES (ACME report 2001, CRR 248).

Rommel, S. A., and McCleave, J. D. 1972. Oceanic electric fields: perception by American eels? Science, V.176, No 4040. P. 1233–1235.

Rommel, S.A., and McCleave, J.D. 1973 Sensitivity of American eels (*Anguilla rostrata*) and Atlantic salmon (*Salmo salar*) to weak electric and magnetic fields. J. Fish. Res. Bd. Can. V. 30. No 5. P. 657–663.

Smaal, A. C., and Brummelhuis, E. 2005. Explorative studies of the impact of an electric fishing field on macrobenthos. RIVO Report No. C089b/05, pp 15.

Snyder, D. E. 2003. Electrofishing and its harmful effects on fish, Information and Technology Report USGS/BRD/ITR -2003-002: US Government Printing Office, Denver, CO, 149 p.

Stewart, P. A. M. 1975. Catch selectivity by electrical fishing systems. J. Cons. int. Explor. Mer, 36 (2): 106–109.

Stewart, P. A. M. 1976. Observations on flatfish reactions to a model electrified beam trawl. ICES CM 1976/B:41, 4 pp (mimeo).

Stewart, P. A. M. 1978. Comparative Fishing for Flatfish using a Beam Trawl fitted with Electric Ticklers. Scottish Fisheries Research Report 11, ISSN 0308-8022, 10 pp.

Stralen, M. R. van, 2006. The pulse trawl – Developing alternative fishing gear for flatfish fisheries using an electrical stimulus – A summary. marinX-report 2005. 26, pp 25.

van Marlen, B. 1985. Report of a seminar on electro-fishing at RIVO-IJmuiden on 24 January 1985.

van Marlen, B., de Haan, D. 1988. Elektrische stimulering van platvis (verleden, heden, toekomst).

van Marlen, B., de Haan, D., Wardle, C.S., Glass, C.W., Huse, I., Engås, A., Horton, R., Lart, W. J., Gabriel, O., Lange, K., Lehtonen, E., Kiviniemi, M. 1997. Revised Final Report EU Concerted Action ALTSTIM - Alternative Stimulation in Fisheries. p. 163.

van Marlen, B., Lavieren, H. van, Piet, G. J., and Duijn, J. B. van, 1999. Catch comparison of a prototype 7 m electrical beam trawl and a conventional tickler chain beam trawl. RIVO internal report 99.006b, April 1999.

van Marlen, B. 2000. Technical modifications to reduce the bycatches and impacts of bottom gears on non-target species and habitats. *In:* Kaiser and De Groot (editors), 2000, Effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. ISBN 0-632-05355-0, p. 253–268.

van Marlen, B, A. R. Boon, L. G. Oschatz, J. B van Duijn, M. Fonds. 2000. Experiments in 1999 on a 7 m beam trawl with electrical stimulation. RIVO-report C028/01, May 2001.

van Marlen, B., Bergman, M. J. N., Groenewold, S., and Fonds, M. 2001. Research on diminishing impact in demersal trawling – The experiments in The Netherlands, ICES CM 2001/R:09.

van Marlen, B. 2003. Improving the selectivity of beam trawls in The Netherlands. The effect of large mesh top panels on the catch rates of sole, plaice, cod and whiting. Fisheries Research, 63: 155–168.

van Marlen, B., Ybema, M. S., Kraayenoord, A., Vries, M. de en Rink, G. 2005. Catch comparison of a 12 m pulse beam trawl with a conventional tickler chain beam trawl. RIVO-Report C043b/05.

van Marlen, B., Vis, J. W. van de, Groeneveld, K., Groot, P. J., Warmerdam, M. J. M., Dekker, R., Lambooij, E., Kals, J., Veldman, M., and Gerritzen, M.A. 2005. Survival and physical condition of sole and plaice caught with a 12 m pulse beam trawl and a conventional tickler chain beam trawl. RIVO-report Nr. C044b/05.

van Marlen, B., Grift, R., O. van Keeken, M. S. Ybema, R. van Hal. 2006. Performance of pulse trawling compared to conventional beam trawling. RIVO-report Nr. C014/06.

van Marlen, B., Vis, J. W. v.d., Haan, D. de, Burggraaf, D., Heul, J. van der, Terlouw, A. 2007. The effect of pulse stimulation on biota. Research in relation to ICES advice. Progress report with preliminary results. IMARES Report C098/07, 24 pp.

van Marlen, B., Haan, D. de, Gool, A. van, Burggraaf, D. 2009. The effect of pulse stimulation on marine biota. Research in relation to ICES advice. Progress report on the effects on benthic invertebrates. IMARES Report C103/09, 49 pp.

Vekilov, E. H. 1977. Influence of constant field of electric current upon some Baltic Sea fishes. Rybnoye Khozyastvo (Fisheries). No 8. P. 41–42. (In Russian) Векилов Э.Х. Воздействие электрического поля постоянного тока на некоторые виды рыб Балтийского моря. Рыб. х-во. 1977, № 8. С.41–42. (In Russian).

Vibert, R. 1963. Neurophysiology of electric fishing. Transactions of the American Fisheries Society, V. 92. P. 265–275.

C. Yu, Z. Chen, L. Chen and P. He. 2006. The rise and fall of electrical beam trawling for shrimp in the East China Sea: technology, fishery and conservation Implications. ICES J. Mar. Sci., 64: 1592–1597.

Zonov, A. I., Shilenko, V. A., Koreshev, A. Ya. 1974. Threshold values of voltage gradients depending on the orientation of fish in the electric field. Izvestia GosNIORH (Proceedings of Scientific Research Institute for Fisheries). V.90. P.42–46. (In Russian) Зонов А.И., Шиленко В.А., Корешев А.Я. Пороговые значения напряженностей в зависимости от ориентации рыб в электрическом поле. Изв. ГосНИОРХ. 1974. Т.90, С.42–46 (In Russian).

Annex 1: List of participants

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Annex 2: Terms of Reference for the 2011 meeting

2010/2/SSGESST09 The Study Group on Electrical Trawling (SGELECTRA), chaired by Bob van Marlen*, the Netherlands and Bart Verschueren*, Belgium, will be established and will meet in Reykjavík, Iceland, 7–8 May 2011 to:

a) To review current technical developments on electrical fishing (with the main focus on marine fisheries).

b) To review studies on the relationship of pulse characteristics (power, voltage, pulse shape) and thresholds in terms of effects on fish and other organisms (mortality, injury, behavioural changes).

c) To improve knowledge of the effects of Electrical Fishing on the marine environment (reduction of bycatch, impact on bottom habitat, impact on marine fauna, energy saving and climate related issues).

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

e) To consider whether limits can be set on these characteristics to avoid unwanted effects (e.g. unwanted and uncontrolled growth on catch efficiency, unwanted ecosystem effects) once such systems are allowed and used at wider scale.

SGELECTRA will report by 30 June 2011 (via SSGESST) for the attention of the SCICOM.

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. Consequently, these activities are considered to have a very high priority.
Scientific justification	Term of Reference The use of electricity in fishing is currently banned in EU regulations due to concerns on the impact and efficiency. Several countries, however, notably the Netherlands and Belgium have been testing the potential for electrical pulse trawl systems to replace conventional beam trawls, which are classified as having high environmental impacts. Such systems are currently being tested under derogation on commercial vessels and the results of the Dutch trials have been reviewed by ICES and STECF. A number of This involves substantial investments that are stimulated by the Dutch Ministry LNV. In order to lift this ban and/or continue to work under derogation additional information on ecosystem effects of introducing this technique in the EU beam trawl fleets was requested by ICES and the EU's STECF in 2006. Since 2006 additional trials have been conducted to try to address the issues raised by ICES and STECF and the results to need be reviewed to assess whether the concerns raised have been satisfied. There is a lack of data on the response thresholds for various species and length classes, describing the power limits for survival and reproduction of fish. Pulse trawling is currently being developed for other species than flatfish i.e. brown shrimp (*Crangon crangon* L.). Consequently a growing number of (European) fishing vessels is potentially involved, with a considerable value in terms of landings. There is a need for clearer identification of workable and enforceable limits in defining regulation than the two (power per unit of length and maximum voltage) currently in use in the present EU-derogation for use of electrical fishing in The Netherlands, that will aid to a sustainable development

	of electric fishing. There is interest in fishing with electrical stimuli on other species, e.g. Atlantic razor clams (Ensis directus L.).
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 Study Group will be attended by some 10–12 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no obvious direct linkages with the advisory committees
Linkages to other committees or groups	This work is of direct relevance to the Working Group of Fishing Technology and Fish Behaviour, WGCRAN, WGECO and WGNSSK.
Linkages to other organizations	There is a very close working relationship with all groups of SSGESST.

Annex 3: Draft agenda

1) Welcome and housekeeping
2) Appointment of a rapporteur
3) Current state of affairs in flat fish pulse trawling, ToR a)
4) Further studies on cod, ToR a), b), c)
5) Helpdesk question report for Dutch Ministry, ToR a), b),
6) Current state of affairs in brown shrimp pulse trawling, TOR a)
7) Forecasting methods, e.g. LOT3 Flatnose, ToR d)
8) Recommendations for further research
9) Conclusions
10) Closure

Annex 4: Recommendations

This section contains a summary of recommendations. Further work is pending finances.

Recommendation	For follow up by:
1. Conduct in situ measurements on the field strength of the two existing Dutch pulse trawling systems as a reference to the experiments of 2010 on cod in Norway	IMARES
2. Review the results of the comparative fishing experiments in the Netherlands in May 2011.	SGELECTRA
3. Study the effects of with pulses identified as less harmful in flatfish systems on target species (e.g. sole)	IMARES
4. For the HOVERCRAN system continue monitoring catches and bycatches.	ILVO and IMARES
5. Investigate the effect of pulses on the electro-receptor organs of elasmobranchs, and determine the catch rates of these fish in beam trawls.	IMARES
6. Investigate the effect of the pulse on the reproductive capabilities of benthos.	IMARES
7. Study the effects of low frequency in the range of shrimp stimulation and long pulse duration on species, that are not targeted in shrimp fisheries (sole, plaice, cod).	ILVO
8. Continue studying the effect of wider introduction of pulse trawling on target and non-targets species	IMARES
9. Study the effect on different life stages (e.g. eggs and larvae) of important species (e.g. sole)	unspecified
10. Continue involvement in the Dutch Working Group on Control and Enforcement by relevant participants with feedback to SGELECTRA	IMARES and ILVO
11. Produce a Cooperative Research Report on Marine Electric Fishing	SGELECTRA

Annex 5: Terms of Reference for the 2012 meeting

The **Study Group on Electrical Trawling** (SGELECTRA), chaired by Bob van Marlen, the Netherlands and Bart Verschueren, Belgium, will meet in Lorient, France, from 21–22 April 2012 [1] to:

a) To improve knowledge of the effects of Electrical Fishing on the marine environment (reduction of bycatch, impact on bottom habitat, impact on marine fauna, energy saving and climate related issues), in view of current technical developments on electrical fishing and emphasis on the relationship of pulse characteristics (power, voltage, pulse shape) and thresholds in terms of effects on fish and other organisms (mortality, injury, behavioural changes).

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

c) To consider whether limits can be set on these characteristics to avoid unwanted effects (e.g. unwanted and uncontrolled growth on catch efficiency, unwanted ecosystem effects) once such systems are allowed and used at wider scale.

SGELECTRA will report by 30 June 2012 (via SSGESST) for the attention of the SCICOM.

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. Consequently, these activities are considered to have a very high priority.
Scientific justification	Term of Reference The use of electricity in fishing is currently banned in EU regulations due to concerns on the impact and efficiency. Several countries, however, notably the Netherlands and Belgium have been testing the potential for electrical pulse trawl systems to replace conventional beam trawls, which are classified as having high environmental impacts. Such systems are currently being tested under derogation on commercial vessels and the results of the Dutch trials have been reviewed by ICES and STECF. A number of This involves substantial investments that are stimulated by the Dutch Ministry LNV. In order to lift this ban and/or continue to work under derogation additional information on ecosystem effects of introducing this technique in the EU beam trawl fleets was requested by ICES and the EU's STECF in 2006. Since 2006 additional trials have been conducted to try to address the issues raised by ICES and STECF and the results to need be reviewed to assess whether the concerns raised have been satisfied. There is a lack of data on the response thresholds for various species and length classes, describing the power limits for survival and reproduction of fish. Pulse trawling is currently being developed for other species than flatfish i.e. brown shrimp (*Crangon crangon* L.). Consequently a growing number of (European) fishing vessels is potentially involved, with a considerable value in terms of landings. There is a need for clearer identification of workable and enforceable limits in defining regulation than the two (power per unit of length

[1] Pending dates of SCICOM meeting in 2012.

	and maximum voltage) currently in use in the present EU-derogation for use of electrical fishing in The Netherlands, that will aid to a sustainable development of electric fishing. There is interest in fishing with electrical stimuli on other species, e.g. Atlantic razor clams (Ensis directus L.).
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 Study Group will be attended by some 10–12 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no obvious direct linkages with the advisory committees
Linkages to other committees or groups	This work is of direct relevance to the Working Group of Fishing Technology and Fish Behaviour, WGCRAN, WGECO and WGNSSK.
Linkages to other organizations	There is a very close working relationship with all groups of SSGESST.

Annex 6: Literature review by Bob van Marlen

Introduction

A comprehensive literature search was done in EU-project ALTSTIM, which ran from 1995–1997(van Marlen *et al*., 1997). The following chapters copied from the ALTSTIM-report give the major findings at the time.

The idea to use electricity in fishing is very old. De Groot (1974) mentioned a reference to Job Baster stating as early as 1765 that electricity might affect shrimps, and that this should be investigated. Experiments with electricity on fish were conducted in the middle of the 19th. In the 1930s Holzer and Scheminsky investigated the effects of direct, alternate and intermittent currents on fish and introduced quantitative analyses. Many scientists quote the work done by Mck. Bary (1956) who studied the behaviour of round fish in electric fields, and found profound differences for fish in seawater, compared to studies related to freshwater species. More details of this work are provided later.

Physiological studies done by Danyulite and Malyukina (1967) revealed that reactions to electric fields could not be contributed to skin receptors or the fish brain. This was found by cutting the spinal cord which caused forced swimming reactions to stop. Locomotory activity and swimming are apparently controlled by the spinal cord.

Holt (1992) describes developments in the United States on electrified shrimp trawls. It is interesting that a special design was made (so-called 'frame trawl') that could more easily be stored on the deck of fishing vessels by using hinges on the beam. The gear was of similar dimensions (30' or 9.14m width) as its European counterparts. The beam construction offered a more rigid platform to install electrical equipment than a flexible otter trawl maintaining its geometry by dynamic equilibrium when towed. Power supply was initially led through cables, later by placing batteries on the beam. Total energy requirement of the system was as low as 100W. Five electrodes ran perpendicular to the towing direction, covering a total distance of about 4.5m in towing direction. Shrimp catches for the electrical gear were recorded up to twice of that of the standard gear. Similar to the situation in Europe this technology was not taken over by the fishing industry. Reasons were not given.

The work in Europe was mainly done in The Netherlands (RIVO-DLO, now IMARES), Belgium (RvZ, now ILVO), the UK (SEAFISH), Germany (BFAFI), and France (Ifremer) sometimes in combination with private companies. In many cases ideas were copied and very similar problems occurred. The technologies developed along similar lines, with The Netherlands producing devices with the highest energy input. Reading through the literature one can easily wonder why in all these countries not any system emerged that is used commercially. In many cases the fishing industry expressed great interest in the developments, and cooperation with fishers took place on a wide scale. Nevertheless, the large investments involved combined with the vulnerability of any electro-fishing device hampered its introduction. In retrospect one can state that the development was mainly driven by scientific workers and marketing attempts were only made towards the end of the project. At the time it was questionable whether such a complicated device as an electrified fishing gear may work in commercial conditions over a long period at all, and pay its investment back, but a present this is shown to be possible. The similarity of conditions found in all these countries was striking. The principle has been proven to work, the problem consisted of making a cheap, robust version of a prototype, that could proof its feasibility and convince fishers of its usefulness and profitability, but apparently the state of technology then was not developed enough.

Research done in The Netherlands until 1988 as reported in the ALTSTIM report

The work done at RIVO in The Netherlands covered a long period from 1966 to 1988 with various phases. The various design specifications for the electrical systems and results are given in Table 6.1. Report TO 88–06 of RIVO explains the whole history of the project (van Marlen and de Haan, 1988). Three phases are distinguished as follows:

Phase A: The shrimp period from 1966 until 1979

Phase B: The flatfish (sole) period from 1979 until 1985

Phase C: Commercialization attempts from 1985 until 1988

Most of the work was not formally published, but given in internal RIVO-reports written in the Dutch language. At the beginning some publications were made as ICES-papers or in fisheries science magazines. In the commercialization phase most work was laid down in memoranda and remained unpublished to protect commercial interests.

The objective for the whole project is:

- to create better chances of survival of discards, to improve the quality of the catch and the selectivity of the gear, and to reduce the fuel consumption.

It is interesting that the objectives changed throughout the project. The energy consumption issue was not regarded as high priority from 1986, and for a long time more emphasis is laid on the environmental aspects, but recently with the sharp increase in fuel prices energy saving returned as an important driver.

Phase A: The shrimp period from 1966 until 1979

De Groot and Boonstra started to study literature about electric stimulation around 1966. In shrimp trawling the major aims was to increase the efficiency of the gear and to reduce discards of juvenile fish. In flatfish trawling the major objective became to replace the array of tickler chains by a lighter stimulator thus reducing the drag of the gear when towed over the seabed and consequently its fuel consumption. The energy crises of 1973 and 1979 resulted in emphasizing this aspect. Interesting is to note that the impact of relatively heavy groundgear as used in beam trawling on Benthic organisms was already mentioned as a point of concern and with it the possible advantages of the electrified beam trawl.

In the early phase of the project the development hinges on two separate lines of research, one on shrimps and one on sole. Until 1969 behaviour experiments were carried out in aquaria at RIVO and oyster basins both on shrimps and sole subjected to electric fields. The potential for using this kind of stimulus for catching the animals was clearly identified, leading to an increase in effort in the development of a commercially applicable system. From these basin trials the following specifications arose: optimum pulsewidth for shrimps 0.2 ms, and for sole 0.7ms. The generator was placed on board with cables running to the electrodes in the gear, a construction leading to a significant loss in voltage between the electrodes.

In 1971 a second pulse generator was developed. It was mounted directly on the beam of the trawl and used an internal power unit, but apparently its specifications in amplitude (≤10V) were too low. Field tests were carried out in 1972 with the first pulse unit on 3m beam trawls. Results were discouraging and led to new specifications defined for a follow-up pulse unit, that was built in 1973 and used in field trials in 1973 and 1974 on trawls with 9m beams on vessel TH-6 at speeds of 3 to 3.5 kn. Reports describe an improvement in catches of shrimps ranging from 8 to 35%, but also malfunctioning of the equipment in 20% of the time. Again a new pulse generator was built with higher amplitude (65V). In 1975 this machine was tested on vessel WR-87. It showed many malfunctions. Research on electrified shrimp trawling stopped in 1976 after a series of experiments on vessel WR-17 which led to a shrimp catch ratio of 1 to 1.

From then on priority was given to flatfish (sole and plaice). On the WR-87 trials were conducted on a 9m beam trawl. The catch ratio for both species was about 1 to 1, and no difference was reported on the length distribution of fish caught. Similar experiments were done in 1977 on WR-17 with some modifications on the equipment. Catches were almost equal and the scientists reported a higher selectivity for the electrified beam trawl. Further trials were conducted in 1978 on the GO-4 in the southern North Sea. The equipment did not function satisfactory and the catch results were not sufficient.

6.2.3 Phase B: The flatfish (sole) period from 1979 until 1985

In this period more manpower was allocated to this project with the important distinction that electric equipment was designed and built by RIVO-staff and not by outside companies (Figures 6–9). Three generations of pulse generators were developed over the period, one in 1979, one in 1982 and one in 1984. The main principle did not change, the pulses were generated by capacitor discharge. Field trials were conducted on the UK-141. An underwater camera was also used in attempts to observe fish reactions. Variables under investigation were: frequency, voltage on electrodes and length of electrodes. It appeared that the catches on the electrified side increased with rising frequency and voltage. Ratios of over 1.0 could be obtained. No difference was found as a result of changes in electrode length, nor between various gear designs. Extensive trials were also done in 1981 on the UK-141. Four different electrode arrangements were studied with best results with 4m electrodes (central position). Differences in catchability were found between day and night with higher effectiveness at night. Experiments on electrical fish barriers resulted in the idea to decrease the pulsewidth. The amplitude of the pulse generator was again increased in a new design, now to 1000V. This design featured also: higher voltage of the power supply generator, safety circuits for current and voltage, sequential discharge of pairs of electrodes by an electronic ring counter, discharge through thrusters. Trials were continued in 1982 on MFV UK-141, with better catches at night (+50%) for the electrified net, but lower during the day (-10%). Claims were given of a higher selectivity for the electrified gear. Especially small soles did not appear in the catches. The electrodes showed a large degree of corrosion, and the pulse unit was not reliable at high capacitor voltages. Catches increased with higher voltages, but the maximum appeared not be have been achieved with this machine. A new design followed with a maximum capacitor voltage of 2000V. A large watertight container to carry these capacitors was incorporated into the beam of the trawl. Better designs were made for electronic circuitry, and in addition a new design of gear was made which enabled fitting electrodes of equal length. Extended sea trials were carried out in 1984 first on RV "Isis", later on the UK-141. A new gear design appeared to be successful +45%

more sole during the day and +65% more sole during the night. The optimum voltage with this net was around 700V, at 20Hz frequency. Sole catches with the electric gear were relatively higher at lower towing speed. All leading scientists were brought together in a one day seminar held at RIVO in IJmuiden in January 1985 (van Marlen, 1985). It was an excellent opportunity to compare the various technical solutions found over the years and to exchange ideas and experience. As most workers had developed prototypes according to different design philosophies it was not technically possible to merge all these designs into one generally applicable system. Further research was done into the effect of towing speed in the course of 1985 and was reported by Kraaijenoord. Lower speeds produced a higher percentage of sole in the catches of the electrified trawl. Size selectivity was not improved by the electric stimulus. Comparative fishing trials in the end of 1985 on RV "Isis" with the RIVO system and one developed by BFA-Fi in Hamburg, Germany showed the RIVO system catching more sole, but also breaking down more often.

6.2.4 Phase C: Commercialization attempts from 1986 until 1988

This phase is characterized by attempts to create a commercially applicable system. A thorough analysis of reasons of failure of RIVO's system was carried out and design improvements given. A comparison was also made between RIVO's system and one based on a Rhumkorff solenoid principle (System "Van der Vis") after a request from the Dutch Fishermen Federation resulting in higher catches of sole and plaice for RIVO's system. Additional software engineering and performance measurements were carried out in 1987 to improve the design of RIVO's system and enhance its reliability. A private electronic company developed a system based on the knowledge built up at RIVO which was transferred. Extensive collaboration emerged between RIVO and this company in order to commercialize the system. The company developed a prototype with two capacitor containers that were mounted on the shoes of the beam trawl. The power unit also differed from RIVO's system with a three phase current. The design was based on requirements concerning robustness and quick interchange of components. Tests of the commercial prototype were done on the beamer GO-65 at the end of 1987 resulting in higher sole and lower plaice catches than the conventional beam trawl. No improvement in size selectivity was found. Further research was advocated but the project stopped with a ban on electric fishing by the Dutch Ministry of Agriculture and Fisheries out of fear of further increasing fishing effort in the beam trawling fleet which was under severe international criticism at the time. Curiously the research in other nations stopped around the same time, partly for unknown reasons, in other cases due to untimely death of scientific workers involved. Recently new development work was done by a private company in The Netherlands without any cooperation with RIVO. The current status of this work is currently unknown.

Research done in The Netherlands after 1988

IMARES, part of Wageningen UR (former RIVO) became again involved in an existing trilateral cooperation between a private company (Verburg-Holland Ltd.), the Dutch Fishermen's Federation and the Ministry of Agriculture, Nature and Food Quality in 1998. A series of trials were conducted on-board FRV "Tridens" on a 7 m prototype electrified beam trawl, called 'pulse' trawl, resulting in sole (*Solea vulgaris* L.) catches matching those of conventional tickler chain beam trawls, plaice catches being reduced by about 50%, and benthos catches reduced by 40%. These promising results led to follow-up experiments in 1999 with a modified gear. The first objective was to improve the catches of plaice, appraise the effect of towing speed, compare the warp loads of both gears, and appraise the effect of the electrical stimulation on short-term fish survival. The second objective was to further improve the catching performance of the net attached to the beam of the pulse trawl, and to collect more data on short-term survival, also of benthic animals (Van Marlen, *et al.*, 1999; Van Marlen, *et al.*, 2000; Van Marlen, *et al.*, 2001a, 2001b).

A study on differences between a conventional 7 m tickler chain gear and the 7 m prototype electrical gear in direct mortality of invertebrates living on and in the sea-bed was conducted in June 2000 on-board FRV "Tridens" and RV "Zirfaea". Benthos samples were taken from the Oyster grounds prior to fishing, and from trawl tracks caused by the two gear types. The direct mortality calculated from densities in these samples was lower for an assembly of 15 taxa for the pulse trawl, indicating the potential of electrical fishing to reduce effects on benthic communities (Van Marlen, *et al.*, 2001).

After these experiments it was decided to develop a prototype for 12 m beam length, being the most common value in the Dutch fleet. Technical trials with the new prototype were carried out in November-December 2001 on-board FRV "Tridens", and continued in 2002 and 2003, resulting in catch rates for sole and plaice equalling those of conventional 12 m gear.

Recently the bycatch and discarding of undersized fish, particularly plaice (*Pleuronectes platessa* L.) gained attention. Comparative studies were undertaken in 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 (Van Marlen *et al.*, 2005a, b). A higher survival rate for plaice, but not for sole, was found for the pulse trawl, while the level of blood parameters (glucose, free fatty acids, cortisol, and lactate) and the changes over time in blood samples taken from both species showed no significant differences between both stimulation techniques.

In autumn 2004 it was concluded that the 12 m prototype was technically ready for a series of long-term trials on a commercial fishing vessel. The Motor Fishing Vessel (MFV) UK153 "Lub Senior" was outfitted with a complete system of two pulse trawls and cable winches. A series of experiments was carried out on the UK 153 in the period between October 2005 and March 2006 and compared to the performance of similar beam trawlers fishing with the conventional gear type in the same period, and on the same fishing grounds in the North Sea, on the Dutch continental shelf. The MFV UK153 was outfitted with a complete system of two pulse trawls and winches with feeding cables. Nine trips in total were undertaken. Five trips were used to make actual comparisons with a second vessel (Van Marlen *et al.*, 2006). The main findings were that landings of plaice and sole were significantly lower, but there was no significant difference in the catch rates of undersized (discard) plaice between the pulse trawl and the conventional trawl. In the pulse trawl, the catch rates of undersized (discard) sole were significantly lower than in the conventional beam trawl. The catch rates of benthic fauna (nrs/hr of *Astropecten irregularis*, *Asterias rubens,* and *Liocarcinus holsatus*) were significantly lower in the pulse trawl. Also, as found before, there were indications that undersized plaice is damaged to a lesser degree and have better survival chances in the pulse trawl.

ICES Advice 2006

In March 2006, the European Commission issued a request to ICES to evaluate the use of a "pulse-trawl" electrical fishing gear to target plaice and sole in beam trawl fisheries. ICES was requested to give advice on the ecosystem effects of a potential implementation of pulse beam trawling.

An Ad Hoc Expert Group on Electric Fishing was formed and this group made a report that was discussed by members of the group, and in a plenary session at the meeting of the ICES Working Group on Fishing Technology and Fish Behaviour (WGFTFB) in Izmir, Turkey in April 2006. This report and the additional data analyses undertaken after the WGFTFB meeting were the basis of the ICES advice that ICES provided in May 2006 of which the results are summarized below (ICES 2006b).

Questions raised by the European Commission addressed to ICES

The questions raised by the European Commission to were:

a) *What change in fishing mortality could be expected following the adoption of such gear in the commercial fishery, assuming unchanged effort measured in kW-days at sea?*

b) *What effect would such a widespread introduction have in terms of (i) the mixture of species caught; (ii) the size of fish caught?*

c) *What, if any, effects would such introduction have on non-target species in the marine ecosystems where this gear was deployed?*

ICES conclusion and recommendation on additional data needs

ICES Concluded:

"The available information shows that the pulse trawl gear could cause a reduction in catch rate (kg/hr) of undersized sole, compared to standard beam trawls. Catch rates of sole above the minimum landings size from research vessel trials were higher but the commercial feasibility study suggested lower catch rates. Plaice catch rates decreased for all size classes. No firm conclusions could be drawn for dab, turbot, cod and whiting but there was a tendency for lower catch rates.

The gear seems to reduce catches of benthic invertebrates and lower trawl path mortality of some in-fauna species.

Because of the lighter gear and the lower towing speed, there is a considerable reduction in fuel consumption and the swept-area per hour is lower.

There are indications that the gear could inflict increased mortality on target and non-target species that contact the gear but are not retained.

The pulse trawl gear has some preferable properties compared to the standard beam trawl with tickler chains but the potential for inflicting an increased unaccounted mortality on target and non-target species requires additional experiments before final conclusions can be drawn on the likely overall ecosystem effects of this gear."

The recommendations of ICES were:

"Further tank experiments are needed to determine whether injury is being caused to fish escaping from the pulse trawl gear. The experiments need to be conducted on a range of target and non-target fish species that are typically encountered by the beam trawl gear and with different length classes. In these trials it should be ensured that the exposure matches the situation in situ during a passage of the pulse beam trawl. Fish should be subjected to both external and internal examination after exposure.

If the pulse trawl were to be introduced into the commercial fishery, there would be a need to closely monitor the fishery with a focus on the technological development and bycatch properties."

Suggested further research topics following the ICES Advice

As a response to the ICES Advice on Pulse Trawling (see Annex and the report by the Expert Group of WGFTFB) three topics for further study were selected, namely:

1) Study into spinal damage in cod (*Gadus morhua* L.)

2) Research into the effects of electrical stimuli on elasmobranch fish.

3) Further study into the effects on benthic invertebrates that are subject to the electric field generated by the electrodes in the gear.

Further research related to the ICES Advice

Further research related to the ICES Advice is summarized below.

Preparatory Studies

Preliminary studies were undertaken in 2007 to address some of the issues raised in the discussions with the Expert Group under EU Project DEGREE.

These activities involved:

1) Measurements on the detailed stimulus applied in the pulse trawling system developed by the company Verburg-Holland Ltd., i.e. the amplitude, pulsewidth, rise and fall times, repetition rate and field strength along the electrodes. These measurements were done on-board of the commercial fishing vessel MFV "Lub Senior" (UK153), and in tank facilities of the manufacturer of the pulse beam trawl.

2) Simulation of this stimulus in the recirculated aquaculture system available at IMARES

3) Development of a protocol for keeping small-spotted catsharks alive and well, including dietary requirements.

4) The exposure of small-spotted catsharks (*Scyliorhinus canicula* L.) to a simulated pulse under laboratory conditions and observation of behaviour, including foraging, and monitoring mortality

5) Investigation of possible spinal damage of cod caught by a commercial vessel using pulse beam trawls by X-ray photography.

The details of this work are reported in Van Marlen *et al*., 2007.

Further studies on cod.

Experiments 2008

Research was continued on catsharks and cod in 2008, but with a differing research protocol, in which the stimuli were applied on fish that were positioned in the electrical field, to know exactly the exposure.

The stimulus was simulated with a system of two parallel electrodes with a duration matching the expected duration *in situ* of fish inside a trawl. The work on catsharks was done in the laboratory of IMARES in IJmuiden, and the work on cod was carried out in close cooperation with IMR Austevoll, that has experience in hatching cod.

Preliminary studies on cod were undertaken in the period between 1 September 2008 and 01 March 2009. These activities involved the exposure of cod to a simulated electric pulse under laboratory conditions and observation of behaviour, including the foraging response, and monitoring mortality and possible internal injuries such as vertebral damage by X-ray photography. The research was conducted in cooperation with the Institute of Marine Research Bergen, IMR research station, Austevoll. This research station facilitated the research, target fish which were derived from their own aquaculture research stock and video observation equipment. The electric pulse simulator was made available by Verburg-Holland Ltd. with pulse characteristics similar to the commercial Verburg pulse system.

Groups of 20 fish with similar lengths (0.41 – 0.55 m) were exposed to the electric stimulus, with each group in one of three distance ranges:

1) A "far-field" range with the fish exposed at 0.4 m side ways of a conductor element,
2) A "medium field" range with the fish exposed at 0.2–0.3 m above the centre of a conductor pair,
3) A "nearfield" range with the fish exposed at 0.1 m from the conductor element;

To exclude the effects of transfer and other unknown influences a control group of 20 fish was confined in the same way, but not exposed to the electric stimulus.

The fish exposed in the "far-field" range, representing the fish just outside the working range of the trawl, showed hardly a reaction to the exposures and responded normally to the feeding cycles. The fish exposed in the "medium field" range showed a moderate contraction of the muscles, but all recovered well and responded normally to the feeding cycles. The effects on the fish exposed in the "nearfield" range were more pronounced, 4 fish died shortly after the exposure, and another 2 died in the observation period thereafter, resulting in a mortality of 30%. In the observed period of 14 days after the exposures the surviving fish packed together outside the feeding zone and hardly responded to the feeding cycles.

The fish of the control group, exposed to a similar treatment as the exposed groups except receiving the pulse stimulation, showed a decrease in appetite compared to the fish exposed in the "far-field" and "medium field" ranges. This could have been related to the fact that this group was treated towards the end of the experimental period and thus stayed the longest time in the transfer tank.

Post mortal analysis using X-ray scans revealed that 5 out of 16 remaining fish exposed in the "nearfield" range had haemorrhages close to the vertebral column, and of these five, 4 had vertebral bone fractures. No injuries were found on the fish exposed in the "medium field" range, which showed weaker reactions to the electric exposure.

More details are given in De Haan *et al.*, 2008.

ICES Advice 2009

- In consultation with the European Commission, in September 2009 the Dutch Ministry requested ICES review the reports and to provide updated advice on the ecosystem effects of the pulse trawl. The reports were independently reviewed by a group of experts in the fields of electric fishing techniques, fishing gear technology, benthic ecology, unaccounted mortality and fish survival experimentation. This was coordinated by the chair of WGFTFB. The reviewers were specifically requested to consider the questions raised by

ICES in the 2006 advice and whether the additional experiments had successfully addressed these issues. This advice was submitted to ICES ACOM and based on the expert reviews, ACOM concluded:

- *The experiments are a valuable further step to evaluate the ecosystem effects of fishing with pulse trawls.*
- *Laboratory experiments on elasmobranchs, benthic invertebrates, and cod to test the effects of electric pulses were generally well designed and interpreted correctly. However, the experimental results have some weaknesses as discussed below.*
- *The experiments indicate minimal effects on elasmobranchs and benthic invertebrates.*
- *Electric pulses resulted in vertebral injuries and death of some cod which were in close proximity (<20 cm) to the conductor emitting the electric pulses. There is inconclusive evidence that the capture efficiency of cod by pulse trawls is higher than for conventional beam trawls (see review by Norman Graham). Widespread use of the pulse trawl has the potential to increase fishing mortality on cod as a result of injuries caused by electric pulses (and possibly higher capture efficiency) but further research is needed to draw firm conclusions.*
- *While the results of laboratory experiments are informative, many factors could result in different effects during actual fishing operations. In particular, specifications contained in the derogation for the pulse trawl allow a wider range of electric pulse characteristics than were tested in the experiments. Therefore, pulse trawls permitted under the EC derogation may generate substantially different effects than those observed in the experiments.*
- *This advice is narrowly based on the review of three reports provided by The Netherlands. Concerns and uncertainties raised in the advice may be addressed by further research, refinement of the derogation, and monitoring the fishing operations and performance of vessels using pulse trawls.*

The Report of the WGFTFB Ad hoc Group of 2006 specifically mentioned potential spinal damage to cod exposed to electrical stimulation, potential effects on invertebrates and possible disruption of the electric sensory systems of elasmobranchs. Subsequently, the European Commission granted The Netherlands a derogation for 5% of the fleet to use the pulse trawl on a restricted basis provided attempts were made to address the concerns expressed by ICES. This derogation has been granted every year since 2007.

The Netherlands (specifically IMARES) has studied the effect of the electric pulse trawl during the period 2007–2009 to fill these gaps in knowledge through a series of tank experiments on elasmobranchs, invertebrates and cod. The experimental species were subjected to electrical stimuli believe to be representative of *in situ* fishing conditions. The findings from these experiments are given in three reports mentioned earlier:

1) The effect of pulse stimulation on biota – Research in relation to ICES advice – Progress report on the effects to cod (De Haan *et al.*, 2009a).

2) The effects of pulse stimulation on biota – Research in relation to ICES advice – Effects on dogfish (De Haan *et al.*, 2009b).

3) The effect of pulse stimulation on marine biota – Research in relation to ICES advice – Progress report on the effects on benthic invertebrates (Van Marlen *et al.*, 2009)

Experiments 2010

Following the ICES advice of 2009 and the discussions at WEKPULSE and WGFTFB in 2010 further research was done on the effects of pulse stimulation on cod (*Gadus morhua* L.). The research was conducted in cooperation with the Austevoll Aquaculture division of IMR, Bergen, Norway and the sequel to the pilot study conducted in 2008. The trials started on 1/12/2010 and ended on 14/12/2010. In this period 38 trials were conducted using simulated electric stimuli of two different commercial Dutch electric fishing systems. As the X-ray analysis of the exposed fish is still ongoing this summary is based on interim results of visual observations.

Aims of the research:

The objectives of the study were:

- To observe the effects of electric pulse stimuli on juvenile cod of 0.12–0.16 m length, which represents fish that would normally escape through meshes (mesh size 80 mm) of beam trawl codends;
- To test the electric stimuli in a range of different pulse characteristics with pulse amplitude, duration and frequency as main variables to determine if the observed effects can be related to a specific pulse parameter;
- To repeat the tests with the stimulus conducted in 2008 on cod of 0.41–0.55 m in length which produced vertebral injuries in these trials, and determine if these effects also occur with the latest developments in electric pulse characteristics and hardware.

Methodology

In these experiments two fish sizes were used, the size range more or less similar to the one tested in 2008 of 0.4 to 0.6 m (denoted: "large"), and a smaller size of 0.12–0.16 m (denoted: "small"), representing juvenile cod that would normally escape through the meshes of the pulse trawl and of which injuries related to the electric exposure would remain unknown.

Doses of the electric exposure

The dose of the exposure of an electric stimulus is determined by the amplitude of the voltage across the conductors and the time duration of the stimulus. The potential difference and field strength in V/m between any two points of the electric field depends on the position of these two points. This means that the exact position of the fish' beak and tail in the field relative to the conductor and the length of the fish are additional factors determining the dose. As field strength is related to distance (V/m), the position of the fish in the electric field and the composition of the electric field around the conductor have similar importance in the definition of the dose of the electric exposure. Both issues will have to be known as side reference and how the tested simulated condition relates to full-scale practice.

Positioning of the fish

In the study of 2008 the highest effects on large fish (0.41 -0.55 m) were observed in the "nearfield" range with the fish at 55 mm aside of the conductor and a height varying between 0.1 and 0.2 m. In this present study the variation in the height of the fish was reduced to be able to tune the observed effects more closely to the reference field strength. Figure 1 illustrates one of the two positions of small fish relative to the conductor. For both fish sizes the nylon flange at the end of the conductor was the cue to position the fish lengthwise. Both cages were kept against the flange on exposure and the fish was placed with the beak against the side of the cage near the flange. For large fish this meant that only the head would receive the highest dose of the exposure. For small fish it implied that the complete body would be exposed and the head as nerve centre would receive a relatively lower dose. Due to this difference in condition a second position, 90 degrees rotated, was tested for small fish with the head perpendicular to the centre of the conductor and the beak against the conductor (Figure 2). A second motive to test the rotated position was that small fish usually swims in a disorientated way as had been seen by direct observation (de Haan *personal communication*).

Large fish

The large fish were exposed using the materials and procedures of positioning applied in 2008. The cage in which the fish was housed during the exposure consisted of flexible polyethylene netting with a triangular profile of 0.6x0.3x0.55 m (length x width x height). The polyethylene netting had a mesh size of 20 mm, wide enough to observe the caged fish by underwater camera. The distance of the body axis of the fish relative to the conductor was 55 mm and was the shortest possible distance with the head of the fish aside of the conductor. In 2008 the fish tested in the "nearfield" range could freely swim through the cage and on exposure the height of the animal from the bottom varied between 0.1 and 0.2 m. This variation had a strong effect of the electric dose as in the given height range the electric field strength reduces from 82 V/m to 37 V/m.

In this study the large cod were forced to the bottom of the cage with the horizontal body axis was 80 mm above the bottom and the head of the fish 55 mm aside of the conductor. In this exposed position the field strength of the VB UK153 system at nominal power setting (57 V peak amplitude) was 102 V/m. In the lowest tested power setting (20 V peak amplitude) the field strength reduced to 38 V/m.

At the bottom of the fish tank the density of the electric field increased due to the artificial bottom, which acts as an un-penetrable layer. Due to this condition the field strength increased at the bottom to 224 V/m (at a distance of 55 mm from the conductor). This is an artefact compared to real fishing conditions, where the electric field can extend more into the seabed, and will be not as high as in the tested condition. Real field strength data under commercial conditions are not available and have to be measured as a reference to our experiments.

Small fish

The small fish were exposed in two horizontal positions relative to the conductor. The first position was with the body of the fish in parallel with the conductor with body axis of the fish at a distance 35 mm of from the conductor. Figure 1 and Figure 2 illustrate the positioning of the fish. The fish were exposed using a cylindrical plastic meshed cage of 200 x 70 mm. The small fish could freely swim in this limited space and was even able to turn inside the cage. Due to this free-swimming condition small fish were exposed with the body axis at 20 and 35 mm above the bottom. Field strengths opposite the centre of a conductor varied from 300 (at the bottom) to 250 V/m (35 mm above the bottom, the centre axis of the cage).

Alternative positions

In two cases the position of large fish was changed. In one case the height of the position of the large fish was increased with 50 mm (by lifting the cage), and in another case with the cage with fish was moved 210 mm forward with the body of the fish opposite the conductor and the head outside the zone of highest field strength.

We started our experiments with trials with multiple (a series of four of 1 s duration within a period of 3 minutes as in the first study in 2008), and single exposure of 1 s duration to find out whether there are differences in effect. As the first results on large fish showed that the effects were similar to the results of 2008, and did not reduce with a single exposure, it was decided to conduct the research with a single exposure per fish. It appeared that the effects with a single exposure were similar to the effects observed in the study in 2008. It was also thought that a series of four exposures would be an overdose and multiple exposures would probably not occur under real fishing conditions as in the study of 2008 cod showed a reaction after the first pulse with an immediate acceleration from the exposed area.

Pulse systems

There are two different electric pulse prototype systems used in the Dutch beam trawl fleet fishing for flatfish. Both systems produce a bi-polar waveform, of which the main parameters slightly differ. The first two systems are developed by "Verburg-Delmeco" Colijnsplaat (NL), the third by HFK Engineering, Baarn (NL). Figure 3 illustrates the three different wave forms.

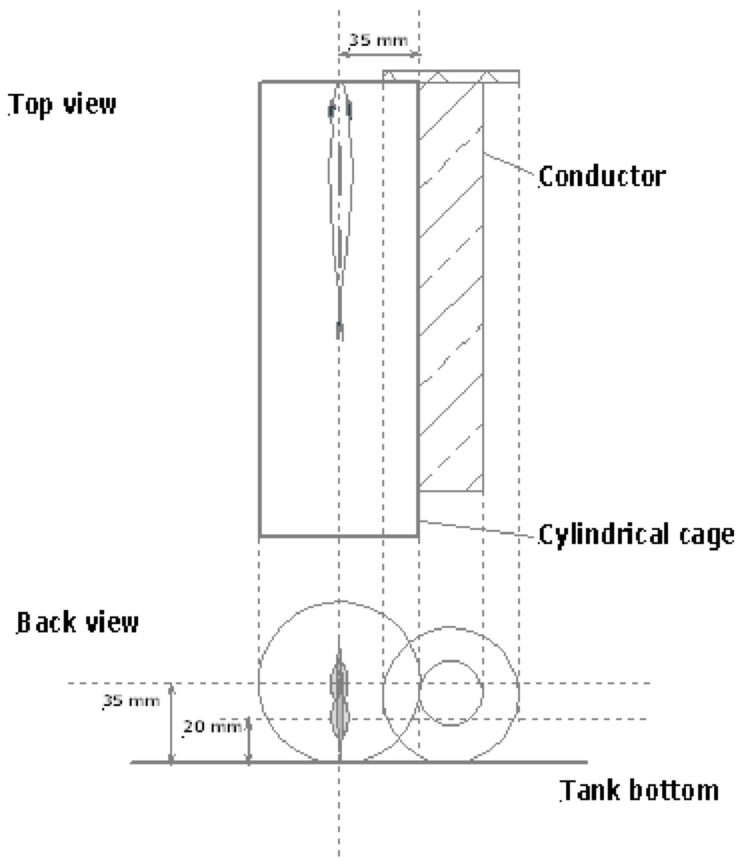


Figure 1. Schematic position of small fish when exposed alongside of the conductor.

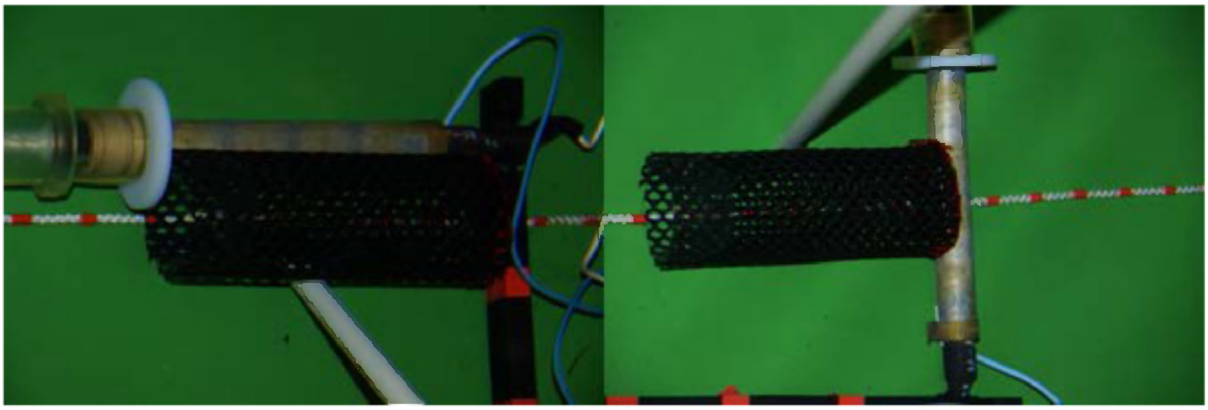


Figure 2. The two different tested positions of the small fish in the real set-up.

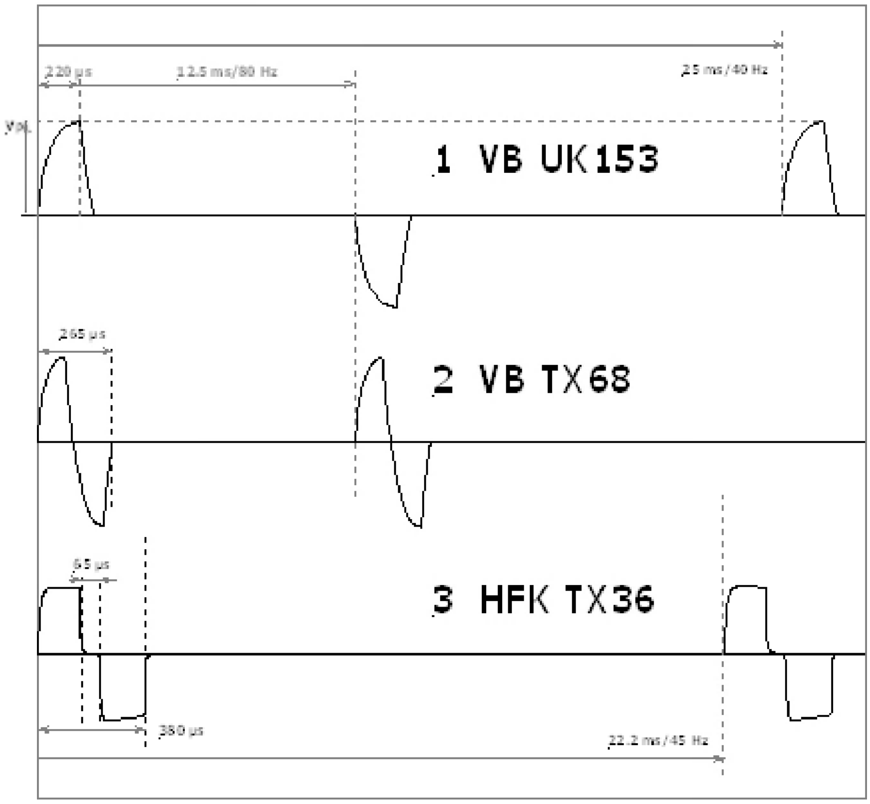


Figure 3. Simulated waveforms and main specifications.

"Verburg-Delmeco" supported two basic waveform simulations (VB UK153 and VB TX68), of which the first tested and reported in 2008 (VB UK153) is no longer used in commercial practice, but repeated in this study as a basic reference for the most recent pulse characteristics used and for changes in hardware (electrodes and conductors). Since the trials conducted in 2008 the pulse concept of the commercial Verburg-system was adapted. The symmetrical delay between the positive and negative parts was shortened to practically zero, while the nominal amount of discharged energy was reduced with approximately 20–30%. This was achieved by reducing the nominal settings of pulse amplitude from 60 V to 50 V, and pulsewidth from 220 to 200 µs, while the electrode distance was increased from 0.325 to 0.425 m. Both old and new waveforms were simulated with the equipment used in the 2008 study. The pulse menus of both waveforms allowed control of the main pulse parameters (frequency, pulsewidth) in a limited range.

The third simulated electric pulse system identified as "HFK TX36" or "Pulswing" is a new development and integrated in a wing type of beam trawl, the so-called "Sumwing". The electric waveform is similar to the Verburg TX68 system and consist of a bi-polar pulse with minor delay between the positive and negative parts. This pulse concept has a physical limitation on the discharge energy. The main deck energy source is decoupled from the discharge circuit by an energy buffer and by the size of its components fixed and maximized. The pulse amplitude of 40 V is the second fixation in the discharge electronics and cannot be increased at deck level. Frequency and pulsewidth are parameters that can be controlled at deck level.

Both simulated systems were tested with the nominal amplitude as maximum (Verburg-Delmeco") or with and increased amplitude of 60 V (HFK, 40 V nominal setting). Given the fact that the tested field strength was denser than under commercial practice the tests covered exposures beyond the maximum boundaries of both commercial systems.

The overview of Table 1 shows the range of settings of main parameters of the waveforms applied in this research. The pulse peak to zero amplitude (Vp, Figure 3) was varied between 20–60 V, the pulse frequency ranged between 30–80 Hz.

Table 1. Overview of ranges of main parameters of tested waveforms.

Simulation type	Amplitude (Vp)	Frequency (Hz)	Pulsewidth (µs)
VB UK153	20–57	30.6–40–57.5	150–200
VB TX 68	22–50	80	220
HFK TX36	30–60	30–45–80–100–180	50–380

Alternative waveform settings

In three cases changes were made to the waveform settings. In one case the burst period was reduced with 50% to 0.5 s and in another case the 1 s burst of the VB TX68 waveform was shaped to the dynamic changes of an array of 6 conductors and insulation parts passing along a static fixed point at 5 knots speed (Figure 4). In a third case the delay time between the positive and negative part of the HFK TX36 waveform was increased to 1 ms.

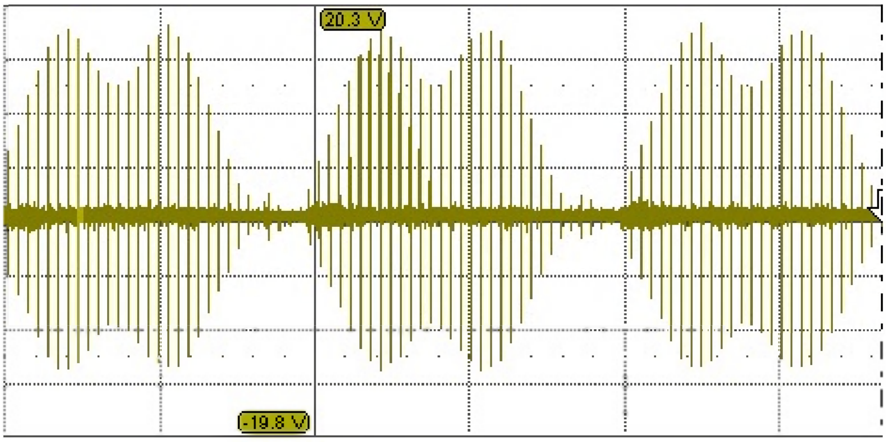


Figure 4. One second burst period of the VB TX68 representing the dynamic towing simulation of an electrode with six conductors and insulators lengthwise towed along a fish in a static position.

The electrode system of the tested Verburg-Delmeco and HFK systems is of similar physical dimensions with minor differences in the conductor elements. Each system was simulated using commercially identical electrode/conductors for practical use in the laboratory.

Procedures

Most animals were tested in groups of 10, and occasionally in groups of 20, when reference to the experiments of 2008 was required. Initially the small cod were tested in groups of 20, but given the minor effects numbers were reduced to 10.

The electric field strength was measured as reference to the observed effects. The observation of the effects mainly focused on mortality and in some cases (small cod) on short-term survival (24–48 hours). The behaviour of the fish during exposure was recorded on video and listed per case. After exposure the fish were killed and frozen to be X-rayed at a later stage at the IMR research station in Matre.

Summarised interim results

The interim results are based on 26 trials involving a total of 262 specimen of large cod (0.44–0.55 m, while MLS = 0.35 m) and 12 trials with small cod (total number 168).

The small cod were exposed in the nearest possible range and survived the harshest field strength condition, which cannot be produced in commercial practice. None of the small fish died after exposure and vertebral injuries were not observed. However strong paralysing effects did only occur in the first test series with four subsequent exposures, however, all small fish recovered. All small fish exposed with a single exposure returned immediately after the exposure to normal behaviour and no physical effects were observed over longer term when fish were kept alive over the weekend and reacted positively to feeding.

Vertebral injuries in large fish, as observed in the trials of 2008, were also found in this study under various pulse compositions and settings, even when the pulse amplitude was reduced to 50% of the nominal conductor voltage. At 20 V amplitude the number of injured fish reduced from 70 to 30%. Vertebral injuries were identified by tail colouring, anal and fin bleeding.

The vertebral injuries, measured with the dynamic compensation of the 1 s burst of the VB TX68 (Figure 4) at an amplitude setting of 30V, remained in the same order of magnitude of trials without this compensation at 60%, This means that the compensation did not have any effect on injuries, which validates the present methodology and that of 2008 without this compensation.

The number of injured fish seems to reduce with increasing pulse frequency. At 100 Hz 40% of the fish were injured and at 180 Hz this number reduced to 0%. It seemed that the latest pulse developments with directly diverted polarity (practised on board TX-68) produced a smaller number of injuries compared to the pulse pattern tested in 2008 with a symmetrical 12.6 ms delay between the positive and negative pulse (practised on board UK153 until 2008), especially when the frequency is outside the 45 Hz range.

The results indicate that injuries of large cod sharply decrease after a reduction the amplitude (to 20 V) and an increase of frequency (to 180 Hz). It is unknown how this adaptation will affect the fishing efficiency on the main target species sole. When the efficiency is determined by the energy content of the pulse, it implies that the pulsewidth will have to be increased when amplitude is lowered when keeping energy constant. Of the alternative waveform settings the reduction to a 0.5 s burst seemed effective in reducing vertebral injuries. This reduction would represent a faster passage of fish through the electrode array, which in the case of unchanged swimming speed can be obtained by either an increase of the towing speed or a reduction of the total length of conducting elements in the electrode system. All these aspects can be addressed as motives to continue research on the effectiveness on the main target species sole.

This interim result will have to be validated by field strength measurements with the full-scale gear at sea as than the present results can be scaled to the actual field strength reference and secondly it can be determined whether the simulated waveforms VB TX68 and HFK TX36 were fully equivalent to the commercial practice. These full-scale measurements are planned in the near future.

Further studies on small-spotted catsharks (dog fish).

This study involved the exposure of lesser spotted catsharks (dogfish) to a simulated electric pulse under laboratory conditions, and the monitoring of mortality, injuries and behavioural responses, in particular feeding response. The electric pulse simulator was made available by Verburg-Holland Ltd. with pulse characteristics similar to the commercial Verburg pulse system. On 4 December 2008, three groups of 16 fish with similar lengths (0.3 – 0.65 m) were exposed to the electric stimulus, with each group in one of three distance ranges:

1) A "far-field" range with the fish exposed at 0.4 m side ways of a conductor element.
2) A "medium field" range with the fish exposed at 0.1–0.3 m above the centre of a conductor pair;
3) A "nearfield" range with the fish exposed at 0.1 m from the conductor element

Furthermore, in order to be able to monitor the effects of transfer and other unknown influences a control group of 16 fish was confined in the same way, but not exposed to the electric stimulus. Each fish was exposed four times in a row. All fish were examined for injuries directly after the end of the last stimulus. Feeding response was monitored for 14 days after. Other behavioural responses (in particular contractions, swimming patterns) were monitored during stimulation and in the 14 days period following it. Finally the fish were kept in husbandry for another 9 months. Additionally long-term mortality and other behaviour such as egg production were monitored.

No evidence was found of differences in feeding response or likelihood of injury or death between the exposure groups. There was also no evidence that fish sustained injuries as a result of the exposures. Respectively 8 and 9 months after the experiment a single specimen of the "medium field" category and "nearfield" category died. In the 14 days observation period after the exposures no aberrant feeding behaviour could be seen. Fish in all tested groups started feeding normally the same day directly after the exposures. In a period of 7 months after the exposures all exposed groups produced eggs in numbers varying between 5–39 per group. Surprisingly the control group did not produce eggs. Regarding the other behavioural responses (mainly reflexes and muscle contractions, and post-reactions, such as a rapid body reverse, short-curled body rotations and acceleration towards the water surface), there were some clear differences between exposure groups. The responses of the fish exposed in the "far-field" range, representing the fish just aside the fished area of the trawl, were minor and ignorable. However, the responses of the fish exposed in the "medium field" range were more pronounced with contractions, rapid body reverses, short-curled body rotations and acceleration towards the water surface occurring. The responses of the fish exposed in the shortest possible range, the "nearfield" range, were the strongest with increased incidence of contractions and rapid body reverses, short-curled body rotations and acceleration towards the water surface. Although this experiment has not been set up, or designed, to investigate differences between exposure groups in terms of behavioural responses other than feeding responses, the authors noted that a common behavioural response in the "nearfield" group was to 'accelerate upward'. Since, in field situations this behaviour has been observed to lead to dogfish becoming entangled in the meshes of the top panel of the full-scale trawl this merits further investigation. In this cause it would help these animals to escape when larger meshes would be used in the top panel, as studied in Van Marlen, 2003.

More details are given in De Haan *et al*., 2009.

Further studies on benthic invertebrates.

Experiments were carried out in July 2009 on a range of benthic invertebrates (ragworm (*Nereis virens* L.), common prawn (*Palaemon serratus* L.), subtruncate surf clam

(*Spisula subtruncata* L.), European green crab (*Carcinus maenas* L.), common starfish (*Asterias rubens* L.), and Atlantic razor clam (*Ensis directus* L.)) under pulse stimulation based on the Verburg-Holland stimulus.

Groups of twenty animals per species were exposed to three treatments of four 1 s bursts of electrical pulses using a pulse simulator: nearby (0.10–0.20 m distance), at medium distance (0.20–0.30 m), and further away (0.40 m) of the electrodes. A 1 s pulse burst is deemed to represent the in situ passage of the pulse field of the gear beneath a non-moving fish. A control group was used for all species to correct for handling effects. The animals were caught with methods minimizing catch effects, and kept in water quality controlled circulating seawater tanks, and regularly fed. Survival, food intake and behaviour were monitored for a period of some two weeks after the exposure. The data were analysed with generalized linear models in the SAS statistical package.

For two species (ragworm and European green crab) a 3–5% statistically significantly lower survival was found compared to the control group, when all exposures were lumped together. For the nearfield exposure a 7% lower survival was also found for Atlantic razor clam. For the other species (common prawn, subtruncate surf clam, common starfish) no statistically significant effects of pulses on survival were found. Surf clam seemed not to be affected at all, common prawn seemed to show lower survival in the highest exposures (near and medium field), while common starfish showed lower survival, but not for the highest (nearfield) exposure.

Food intake turned out to be significantly lower (10–13% less) for European green crab, except in the far-field exposure for which the reduction (~5%) was non-significant. No effect at all was found for ragworm, surf clam and razor clam, lower food intake for common prawn, and higher for common starfish, but all these results were statistically non-significant.

Surf clam and starfish did not show any behavioural reaction at all, they did not move. The other species showed very low responses in the far-field exposure range. In the medium and nearfield ranges the reactions were stronger. Food intake and behaviour recovered after exposure.

In general terms the effects of the pulse stimulus in terms of mortality and food intake can be described as low. It is therefore plausible that the effects of pulse beam trawling, as simulated in this study, are far smaller than the effects of conventional beam trawling.

More details are given in Van Marlen *et al.*, 2009.

Concluding remarks

ICES concluded in 2006 that the pulse trawl, based on the specifications (given in Annex III of TQV 2009 and applied in the Verburg-Holland system has advantages over the standard beam trawl with tickler chains. A considerable reduction in fuel consumption and swept-area per hour was found, caused by the lighter gear (no tickler chains) and lower towing speed. On the other hand the potential for inflicting an increased unaccounted mortality on target and non-target species required additional experiments before final conclusions could be drawn on the likely overall ecosystem effects.

It was acknowledged that the pulse trawl gear could cause a reduction in catch rate (kg/hr) of undersized sole (*Solea vulgaris* L.), compared to standard beam trawls, while the results for sole above the minimum landing size were variable. It was also found that plaice (*Pleuronectes platessa* L.) catch rates decreased for all size classes. Additionally no firm conclusions could be drawn for dab, turbot, cod and whiting, but there was a tendency for lower catch rates.

Another conclusion by ICES was that the gear seemed to reduce catches of benthic invertebrates and lower trawl path mortality of some in-fauna species. As a matter of fact lower benthic catches were found to be statistically significant in many experiments and lower trawl path mortality almost for a range of 15 taxa ($p = 0.09$).

ICES recommended therefore further experimentation on a range of target and non-target fish species under representative stimulation. We extended this to non-target benthic invertebrates after the discussions in 2006.

Appraising the potential effects on the marine ecosystem of introducing pulse trawling in the beam trawl fleets is not an easy task. A great variety of species come into contact with any beam trawl being towed over the seabed. Many of those are not captured and are washed out through the meshes, but the dimensions of these are relatively small. What the effect of an electrical stimulus in a non-uniform field is concerned, this is generally less at smaller lengths, due to a lower potential difference between head and tail (Stewart, 1975). During the discussions in WGFTFB in 2006 it was asked to give guidance into the number and kind of species to test before a final decision on the overall ecosystem effects could be made, but the answer was only given in general terms. We based our choice on the discussions in 2006 and the occurrence in beam trawl catches, and took a range with a large variety in morphology and role in the marine ecosystem.

This choice involved: catsharks (*Scyliorhinus canicula* L.) as a representative species for elasmobranchs, cod (*Gadus morhua* L.) because of reports of potential effects on their spine, and a range of benthic invertebrates, namely: ragworm (*Nereis virens* L.), common prawn (*Palaemon serratus* L.), subtruncate surf clam (*Spisula subtruncata* L.), European green crab (*Carcinus maenas* L.), common starfish (*Asterias rubens* L.), and Atlantic razor clam (*Ensis directus* L.), as the preliminary research carried out in 2005 met some objections.

One should realize, that the existing fishing method for catching flat fish and particularly sole, i.e. beam trawling with heavy tickler chains, was shown to affect marine ecosystems by favouring short lived over long lived species (Lindeboom and De Groot, 1998). Any alternative should be weighed against conventional beam trawling. The recent studies focus on the effect on marine biota under the stimuli produced by the pulse trawl, but the relationship with the comparison with the conventional fishing method should not be forgotten. From that perspective our research showed a number of advantages when applying pulse stimulation, as we stated in de paragraph above l.

As general conclusions, related to the experiments requested by ICES in 2006, we found that the effects of the stimulus on catsharks and benthic invertebrates turned out to be minimal. One should also realize that the magnitude of exposure was relatively high in the experiments, as the animals in many cases were restricted in their movements away from the stimuli. For bottom dwelling organisms such as the shellfish tested, being buried inside the sediment would also reduce exposure.

Marketable cod (>MLS of 35cm) might be affected, but only if they reach a position inside the net close to the electrodes, which will not be the case for all fish entering the gear. Most of these will be caught and landed anyhow. Smaller lengths are expected to be less affected, due to behavioural effects and the generally lower susceptibility of shorter animals in electric fields.

Table 2. Overviews of experiments conducted by IMARES in 1998–2006.

Year	Months	Weeks	# valid hauls	Model, Beam width	Type of experiment	Method	Vessel(s)	Reference
1998	06	23–25	39	I, 7m	Catch comparison	Twin beam trawl paired experiment	FRV "Tridens"	Van Marlen *et al.*, 1999
	09	40–41	30					
	11–12	47–50	80					
1999	04	15–17	47	II, 7m	Catch comparison	Twin beam trawl paired experiment	FRV "Tridens"	Van Marlen *et al.*, 2001
		15–17	9		Survival experiments on sole and plaice	On-board storage and monitoring		
	11–12	45–49	55		Catch comparison	Twin beam trawl paired experiment		
		45–49	6		Survival experiments on sole and plaice	On-board storage and monitoring		
2000	06	24	10	II, 7m	Benthos mortality study	Comparing densities of samples taken from trawl tracks of both gear types	FRV "Tridens" + RV "Zirfaea"	Van Marlen *et al.*, 2001b
2004	11	?	n/a	n/a	Survival experiments on benthos	Laboratory study of behaviour and survival of benthic species in electrical fields	n/a	Smaal and Brummelhuis, 2005
2005		46–47; 49–50	67	I, 12m	Catch comparison	Twin beam trawl paired experiment	FRV "Tridens"	Van Marlen *et al.*, 2005a
		48	20		Survival experiments on sole and plaice	On-board storage and monitoring	FRV "Tridens"	Van Marlen *et al.*, 2005b
2005	10–11	41, 44	169	II, 12m	Catch comparison and economic appraisal	Parallel haul, unpaired experiment	MFV UK153 + other	Van Marlen *et al.*, 2006, Van Stralen, 2005, Taal, 2006
2006	01–03	5, 9, 11	252	II, 12m	Catch comparison and economic appraisal	Parallel haul, unpaired experiment	MFV UK153 + other	Van Marlen *et al.*, 2006, Van Stralen, 2005, Taal, 2006

Table 3. Major outcomes of studies conducted by IMARES in 1998–2006. (Legend: P = pulse beam trawl, C = conventional beam trawl).

Year	Model, Beam Width (m)	Major outcomes cpue (kg/hr) ratio P/C in % sole ≥ MLS	plaice ≥ MLS	sole < MLS	plaice < MLS	landings	discards	benthos	Other findings
1998	I, 7	50–100%	50%	50–100%	55%	55–65%	50–70%	55–70%	Gear functioned well. No improvement in size selectivity for target fish.
1999	II, 7	100%	40–50%	150–210%	40–50%	60–70%	50–60%	55–65%	Gear functioned well. No significant effect of bringing electrodes further back. Survival of sole and plaice not worse. Lower discard mortality in some benthic species. Warp loads smaller in pulse trawl.
2000	II, 7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Median direct mortality of an assembly of 15 taxa of invertebrates was reduced for the 7 m pulse trawl.
2004	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Exposure to the electric field did not cause irreversible effects in benthos. Some species showed direct responses, but these ceased after exposure. There was no additional mortality after three weeks of observation.
2005	I, 12	122%	83%	83%	82%	95%	86%	75%	The pulse trawl caught more large sole, but not more large plaice. Skin damage lower in pulse trawl for sole and plaice. No significant difference in blood parameters. Survival not worse.
2005–2006	II, 12								Landings of plaice and sole are significantly lower in the pulse trawl. No difference in catch rates of undersized (discard) plaice. The catch rates of undersized (discard) sole were lower. The catch rates of benthic fauna (nrs/hr of *Astropecten irregularis, Asterias rubens*, and *Liocarcinus holsatus*) were lower. There are indications that undersized plaice are damaged to a lesser degree in the pulse trawl and will survive better in the pulse trawl, but this conclusion should be treated with caution.

Other studies on elasmobranchs

Elasmobranch fish have electro-receptor organs (ampullary system, of ampullae of Lorenzini) with which they can detect electric fields. E.g. thornback ray (*Raja clavata* L.) can detect a field of 5 Hz frequency above the threshold of 0.01 μV/cm, enabling detection of muscle movements of their prey (Dijkgraaf and Kalmijn, 1966; Peters and Evers, 1985). One may wonder what happens with this ability after exposure to much stronger electric field strengths. A way to test this is to offer both an electric field potential and food and condition a fish to the presence of food when feeling the electric field. Then without offering food the fish should react on the electric field (Dijkgraaf and Kalmijn, 1966).

The ampullae of dogfish (*Scyliorhinus canicula* L.) are most sensitive at low frequencies. A sinusoidal electrical stimuli at field strength 40 nV/cm and frequencies between 0.1 and 1 Hz show highest sensitivity (Peters and Evers, 1985). The authors state that "*Three different behavioural frequency characteristics of 'outputs' of the electroreceptor system in Scyliorhinus have been found, each representing some neural information-processing circuit: the 'eyeblink' system with a maximum gain at 5 Hz (Dijkgraaf and Kalmijn, 1963), the 'freeze' system with a maximum gain from 0.1 to 1 Hz (this paper) and the 'feeding reaction' with maximum gain between d.c. and 4 Hz (Kalmijn, 1974).*"

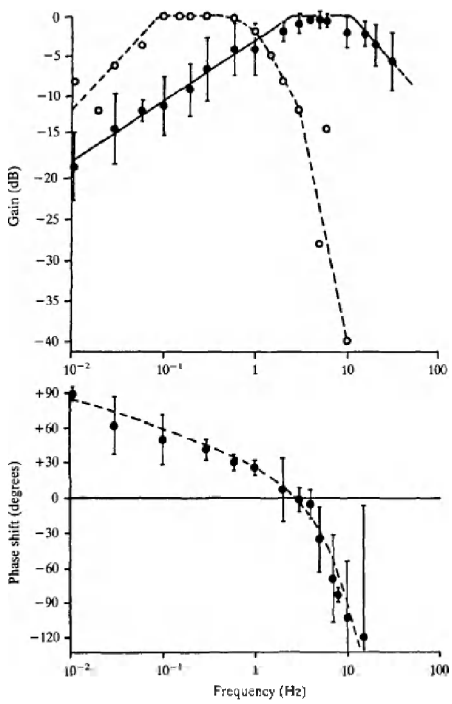


Figure 5. Frequency characteristics of the electroreceptive system in *Sycliorhinus canicula.* (A) Amplitude characteristics of primary afferents (filled circles) and 'respiratory reflex' (open circles) in uniform horizontal electric fields perpendicular to the body axis. The curve of the primary afferents was measured at stimulus strengths between 1 and 3 μVcm-1. Bars are standard deviations. The 'respiratory reflex' curve is the inverse threshold curve from Figure 3. 0 dB corresponds here to 40 nVcm-1 peak-to-peak. According to Kalmijn (1974) the curve of 'turning-towards-electric-dipole' would run at the 0 dB level from DC up to 4 Hz; Kalmijn found the -6dB point at 8 Hz. (B) Phase characteristic of primary afferents. The point at 0.01 Hz consists of only two samples. The other points are the average values from four animals. The values are corrected for phase shift induced by the integrator. Bars are standard deviations (Peters and Evers, 1985).

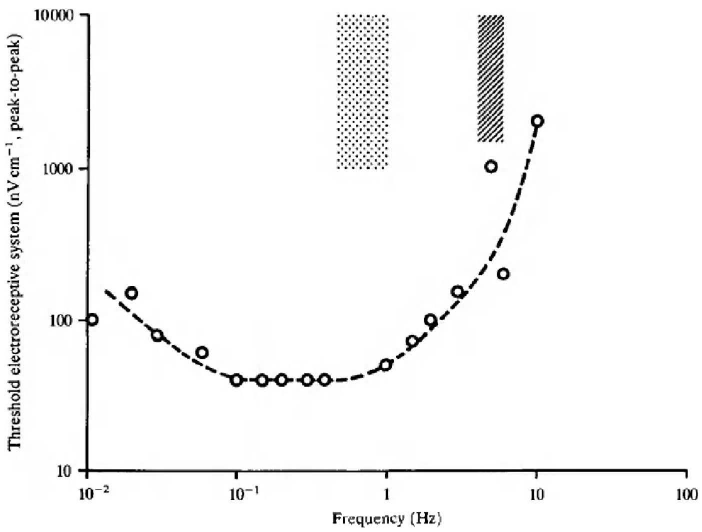


Figure 6. Threshold curve of the 'respiratory reflex' of *Scyliorhinus canicula* after stimulation in horizontal uniform electric fields perpendicular to the body axis. The values on the y-axis are given as peak-to-peak values. The threshold represents the lowest value at which a response would be evoked in animals in a 'reactive' state (see text). The hatched area indicates the stimulus strengths used by Dijkgraaf and Kalmijn (1963) for evoking the 'eyeblink' reflex. The dotted area represents the range of the respiratory potentials (Peters and Evers, 1985).

Work done in Belgium and France as reported in the ALTSTIM report

Introduction

In this review the work carried out in Belgium, by the Fisheries Research Station in Ostend, now called ILVO, on electric fishing is described. The earliest experiments started in 1972 on a beam trawl and with shrimp as the main target species. In a second stage the target species were expanded to shrimp and flatfish. Beside the beam trawl, also otter trawls equipped with an electric stimulation system were tried out. In this case, *Nephrops norvegicus* was the main target species. Experiments continued until 1988. By then the commercial application of electrified gears was legally forbidden in the Netherlands and following this example, also in Belgium no more effort was put into this fishery.

Electric beam trawls

The main aims of the research were to reduce fuel costs, to increase the marketable catch, and to obtain better length selectivity.

In 1972 the first trials with a shrimp beam trawl, equipped with electrodes were started. The principle idea was that shrimp and flatfish, which are startled from the bottom by mechanical stimulation, could now be disturbed with a higher efficiency and by means of less heavy equipment. The main intention of this first series of sea-trips was to evaluate the rigging of the electrodes and the catch composition. The voltage used for the pulse generator was 220V. Since the electricity produced by the dynamo on board of the vessels in that time was 24V, a transformer was necessary. The use of 220V was one of the weak points of the system because of the safety of the crew. The pulse generator produced the electric pulse to stimulate the fish. The frequency and the amplitude of the pulses could be altered by a control unit. The electrodes, rigged to the fishing gear were connected by a cable to the pulse-generator aboard the vessel. This cable was a second serious drawback of the system. It caused problems with safety on board and extra labour.

The second series of experiments in 1973 again gave higher catches for shrimp as well as for the bycatch species sole. Although the distance between the electrodes and the pulse frequency was different, the results were comparable to the ones in 1972.

In 1976 experiments were carried out on electric fishing for sole with a beam trawl. A refined pulse system was introduced. A frequency between 5 and 10 pulses per second and a voltage between 60 and 100V could be chosen. In order to reduce damage to the fish, a short pulse length of 1ms was applied. The results indicated that the heavy tickler chains rigged in traditional beam trawls could be replaced by lighter ones using the electrical stimulation, without loss of catch. The pulse length of seemed to play an important role in stimulating sole.

The experiments with electric fishing for shrimp with beam trawls were continued in 1977, with an improved system. The electric beam trawl showed higher catches for shrimp, but reduced catches for cod and whiting. Contrary to the traditional shrimp fishery, the difference between day and night catches was very low with the electric trawl. For sole the results were less promising. However, due to a lower trawl weight, the electric beam trawl could be towed at higher speeds and with larger beam lengths.

During the experiments, different numbers of electrodes were tried out. The main conclusion was that a distance between the electrodes of 0.75m was the better choice. If closer, the electrodes often collided causing short circuits. A larger spacing resulted in a too weak electric field. The catches of the electric gear were mostly higher for sole, especially for the night hauls.

In the early 1980s the trials were continued with a study of the electric field between the electrodes of an electric beam trawl, both in the laboratory and in commercial conditions. The study aimed at a configuration with an optimal electric field within the trawl mouth, without causing stimulation outside the trawl which could result in negative effects on the catchability of the trawl and which could cause damage to fish outside the trawl path.

In the following years continuous effort was put in improving the system, with tests with an electric otter trawl, an electric beam trawl with altered cutting rate and an electric beam trawl with an altered groundrope. Trials with an otter trawl demonstrated possibilities towards higher catchability in this fishery too. International cooperation between the North-Sea states lead to promising results. The development of a pulse-generator which could be fixed on the gear, however, was never completed in Belgium.

New work was done in Belgium in the early 2000s on the development of an electrified shrimp (*Crangon crangon* L.) trawl. It started with an extended series of laboratory tests on a range of fish and benthic invertebrates to study the reactions (Polet *et al.*, 2005a), followed by sea trials on FRV "Belgica", and MFV O-700 "Bisiti" (Polet *et al.*, 2005b). The work continues until the present day, with the new gear with reduced bottom impact called "HOVERCRAN", which received the runner-up price of WWF's "Smart Gear Competition" in 2009. Also further experiments will be done with electrified shrimp trawling in the Netherlands, based on this knowledge in Belgium.

<u>Electrified otter trawls</u>

A basic study was made on the reaction of Norway lobster towards electric pulses. Different pulses, pulse lengths, frequencies and tensions were tried out. The trials were done in an aquarium where the environmental conditions of Norway lobster grounds were imitated as close as possible. It seemed quite easy to stimulate the prawns and it was clear that larger prawns reacted sooner to the pulses than smaller ones. The most efficient stimulation pattern was determined with the aim to apply electric pulses to a commercial otter trawl. The system applying electrified ticklers, already often tried out on beam trawls, was now tested on an otter trawl on a commercial vessel. The electrified otter trawl has a higher catchability for sole. It also had improved selection characteristics, with smaller catches of undersized fish and larger ones of fish with lengths above the minimum landing size. Alternating positive and negative pulses were used in order to reduce the electrolysis effect. The results indicate that in this case catches are higher compared to the pulses derived from direct current. As previous studies indicated, the system had a serious drawback: the extra cable needed to connect the electrodes with the energy source. Extra manpower is necessary for hauling the cable and damage to the cable causes loss of fishing time.

The main aims in the study of the use of electric stimuli in trawl fisheries in Belgium were:

- A reduction of gear drag and consequently a reduction of fuel costs.
- An increase in marketable catch.
- Better length selectivity for the target species.

The system showed, however, at the time serious drawbacks:

- The need of an extra cable between the vessel and the fishing gear.
- Problems with safety of the crew in contact with electrified parts of the system.
- Losses in fishing time in the case of a system breakdown.
- Rather high investment and maintenance costs.

Although promising, the use of electric stimulation in trawl fisheries met a range of practical problems, which in Belgium, during a 15 year period of research were never really overcome. Consequently, when in the Netherlands electric fishing was stopped in 1988, the experiments in Belgium also ceased.

The following remark was made at the time: "However, with the present strong interest to reduce any adverse environmental impact of fishing gears, the concept of electric fishing has new potential. New research activities should focus on reducing the physical impact of trawled fishing gear on the seabed. This could be achieved in beam trawls particularly when the heavy tickler chains or chain mats can be replaced with electrodes, which are lighter in construction. But also the design of the whole trawl could be reconsidered. A better length and species selectivity might be obtained for target species with considerable reduction in bycatch."

Work done in France as reported in the ALTSTIM report

In France, already in the early sixties, studies were carried out to find methods for alternative stimulation to catch fish. Most of the effort was put into a system where fish were attracted by light and forced to move towards a pump by means of an electric field. At some stage in the development a cooperation was established with Poland. Most studies included a lot of basic research into the behaviour of fish in electric fields. Based on this knowledge the specifications of a system which could be commercially used for pelagic fish were defined. The advantages of this method would be a high catchability and sharp length selectivity.

Work done in the UK as reported in the ALTSTIM report

Introduction

This review presents background information on the physiological responses of fish and crustacea to electric fields. It describes the studies predominantly carried out by White Fish Authority (WFA) and the Sea Fish Industry Authority on the use of electrical stimulation in marine fisheries and discusses them in terms of environmental effects of fishing. The studies predominantly took place between 1976 and ended in 1986, included investigations into the use of electric fishing on beam and otter trawlers.

The aim of most of these studies was to reduce fuel consumption per unit catch of fish which was considered to be of importance during a time of high inflation in energy costs.

Electrical Stimulation

Marine Teleosts

McK.Bary (1956) describes reactions of fish to increasing electric stimuli. He classifies them as follows:

i) minimum response,

ii) electrotaxis,

iii) electronarcosis.

The minimum response consists of a jerk of the musculature at the make or break of the current. The DC field strength required to elicit this response varies with the orientation of the fish to the electric field; the voltage required for fish held with their heads pointing towards the anode was double that required for fish pointing towards the cathode. It was also found that the required stimulus for fish held with the longitudinal axis of the body varied between species. For the mullet (*Mugil auratus* L.) the field strength required was greater than for flounder (*Platichthys flesus* L.). This was considered to be due to the longer length of the segmented nerves in the flatfish (flounder) resulting in increased sensitivity in this orientation.

Electrotaxis (or 'forced swimming') is a reaction of fish to increased DC electric field strength. The fish swim in a direction relative to the electric field direction; the fish swim towards the anode and away from the cathode. Fish orientated at right angles to the current may curve towards the anode (Lamarque 1967). Studies cited in Lamarque (1967) suggest that flatfish do not exhibit this reaction – they simply flatten them-selves against the bottom of the tank.

The state of electronarcosis is described by McK. Bary (1956) as "......... respiratory movements cease, the opercula flare widely and the fish becomes rigid then sinks". Lamarque (1967) describes further subdivisions of the response of fish to electrical stimuli and discusses the physiological explanations for these observations.

The characteristics of the electric field has an important bearing upon the magnitude and type of the response observed. Pulsed DC was found to elicit responses at lower field strengths; thus this is considered to be the best stimulus for electric fishing. However, Lamarque (1967) points out that certain reactions are missing for interrupted current, and suggests that interrupted current affects spinal or medullary structures only.

McK. Bary (1956) found that larger fish required increased potential differences along their bodies to induce responses to electrical stimuli. However, for the different types of responses the gradient of response with length was sloped differently. The gradient for the potential required for minimum response with length was considerably less steep than for electrotaxis or electronarcosis.

Stewart (1975) using McK. Bary's results showed that for a given field strength larger fish showed a greater potential difference from snout to tail. Thus larger fish are likely to exhibit an increased response to a given electric field. He advocates defining reaction thresholds in terms of the electric field strength (V/m) and not the voltage (V) over the fish in non-uniforms fields. However, because the gradient of potential difference with length required to elicit a response differs for the three types of responses; it is minimal for the minimum response, increasing for electrotaxis and electronarcosis, the effects of the length of fish are likely to be different dependent upon the type of response being induced. This has implications for changes in selectivity during electrofishing; potential gradients sufficient for inducing 'minimum responses' may not affect the selectivity of the gear, as much as the higher potential gradients which induce electrotaxis or electronarcosis.

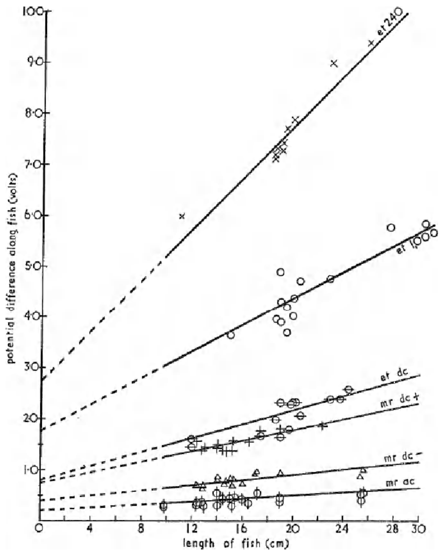


Figure 7. The effect of length of mullet on the potential difference between nose and tail required to induce electrotaxis (et) and the minimum response (mr); et 240 et 2000: electrotaxis at pulse duration of 240 and 1000 µs respectively; et d.c.: electrotaxis with d.c.; mr d.c. + , mr d.c. –: minimum response with d.c. + and d.c. – respectively; mr a.c.: minimum response with a.c. From Mck. Bary, 1956.

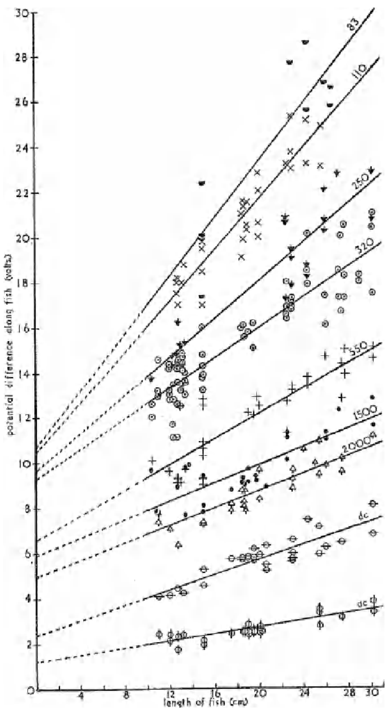


Figure 8. The effect of length of mullet on the potential difference between nose and tail required to induce electronarcosis when using pulse DC at pulse durations between 83 and 2000 µs and also using DC and AC. The pulse duration in µs is shown on the appropriate line. From Mck. Bary, 1956.

Crustacea

Stewart (1972) describes a number of laboratory experiments where *Nephrops norvegicus* were induced to emerge from their burrows under laboratory conditions as a result of the application of pulsed DC. He considers that the field strength used in the experiment could be realistically induced in the mouth of the trawl. However, field observations did not elicit the same response (Baker, 1973).

White Fish Authority and Seafish Experiments 1976–1986

Research on electrical stimulation was carried out by WFA/Seafish over the period 1976–1986 and reported in the ALTSTIM-project (van Marlen *et al.*, 1997).

The initial experiments were carried out on beam trawls; these results indicated that towing speeds should be reduced from 4–5 knots to 3–3.5 knots (Field Reports FR 556 and 557). Investigations were initiated into the use of electrical arrays on otter trawls (FR 945).

The next sets of experiments were designed to establish the optimum electrode and electrical characteristics. They consisted of field observations of resistivity in order to establish field strength, and laboratory observations of the effect of pulsed electric fields at 4Hz, an impulse of 1ms and estimated field strength of 150V/m on flatfish (Dover sole and turbot). These parameters proved adequate to elicit minimum response from Dover sole causing them to lift upwards off the seabed.

These electric field characteristics were achieved in experiments carried out from 1979 onwards. Later experiments on beam trawls solved a number of technical problems and tested various electrode configurations and materials. By late 1980 the system was developed to the point where long-term trials were contemplated. The main benefit was found to be in fuel saving for a similar catch per effort due to the reduced towing speeds and in reduced towing load required for electric fishing. However the reduction in the relative cost of fuel during the early 1980s rendered these savings less attractive than at the time when the research project was initiated so the work was discontinued ca. 1983.

The work on otter trawls (FR 945 and 1004) carried out in parallel with the beam trawl experiments proved more difficult because of the difficulty of maintaining the gear in a consistent geometry. The fuel savings were less and a number of handling problems were encountered so the otter trawl investigations were not considered to be as promising as the beam trawling studies.

Finally, there were investigations into inducing electronarcosis in roundfish (IR 1167) captured in otter trawls. This was based upon the observation that roundfish catches were increased in electrified beam trawls with catches from conventionally rigged beam trawls. In this case it was intended to electrify the trawl floats in otter trawls in order to induce electronarcosis in the mouth of the trawl. The experiments carried out on a test rig were curtailed before consistent results were obtained.

Environmental Effects

The potential environmental effects of demersal fishing operations fall into a number of categories:

i) Removal of target and non-target organisms through contact with and capture by the gear.

ii) Effects of the gear on the substratum and benthos.

iii) Consumption of fuel and discharge of waste.

iv) Effect of lost gear and other litter.

v) Effect of noise, light and other vessel activities.

In electric fishing there may also be the release of free ions of toxic metals from the electrodes. Electrode materials are discussed by Stewart (1972).

Since the experiments on electric fishing carried out by WFA and Seafish were orientated towards a reduction in the consumption of fuel per fish captured they only address this issue directly. However the results of the work may show some promise in reducing the extent of seabed contact and hence effect on the gear because a greater yield of fish is obtained per unit area. The intensity of environment effects on the benthos may also be reduced because tickler chains are removed.

No fish length measurements were made in any of the WFA/Seafish studies, so these results cannot confirm other experimental and theoretical studies (McK. Bary 1956 and Stewart 1975) which indicate that larger fish are more susceptible to the effects of electric fields. However characteristics of the electric fields were adjusted to elicit a 'minimum response' from the target species. This response is the least influenced by the length of the fish (Section 6.4.2.1) compared with electrotaxis and electronarcosis, which would require greater field strength. Thus at the field strengths used in these studies, benefits in terms of selectivity may be minimal.

Electric fishing was believed at the time to hold the expectation of:

i) Reducing the optimum speed and weight of trawling gear if this increases the yield per area fished. Then it could reduce the extent and intensity of fishing impact on the benthic environment per unit catch.

ii) Reducing the fuel consumption per unit catch.

iii) Possibly changing the selectivity of the gear by making the larger individuals more vulnerable to the gear, this would require close examination of the physiological response of fish to electrical stimuli, in particular at the level of minimum response.

The next comments were made at the time: "However before these benefits can be realized there must be a clear view taken in the management of the fishery to take these factors into account when making policy decisions. The research requirements; in terms of describing the impact of the gear and its selectivity could then be derived from this policy decision."

Further Work

It was concluded at the time that there is potential for further work in:

i) A better analysis of yield changes available and optimization of towing speeds.

ii) Some indication of the selectivity changes induced by electric trawling.

Work done in Germany as reported in the ALTSTIM report

The Institut für Fangtechnik, Hamburg, started first activities in the field of electrical fishing in 1965 when an electrified bottom trawl was tested on FRV "Walther Herwig". The results of these investigations were not sufficient to justify further development in the application of electrical fishing in the distant water fishery and during the following years the institute concentrated on electrified small bottom trawls for the eel fishery in German freshwater lakes.

To decrease the electric power consumption a pulse generator was developed using condenser discharge pulses instead of continuous DC voltage for the electrified gear. Fishing trials in three small freshwater lakes in northern Germany (Wittensee, Ratzeburger See and Steinhuder Meer) proved the efficiency of the electrified bottom trawls compared to the traditional bottom trawl gear. Catches of eel could be increased by a factor 10–20. Nevertheless commercial application of the system failed due to the fact that there were no boats available with sufficient engine power for trawling, and the local fishers preferred to stick to their traditional fishing gear e.g. baited pots and longlines.

Based on the know-how obtained in the freshwater fishery the institute started the development of an electrified beam trawl for the German inshore sole fishery in 1975 to replace the heavy tickler chains by electrodes with the aim of reducing the fuel consumption of the fishing vessels and to decrease the destructive impact of the gear to the seabed. The pulse generator designed for this purpose delivered pulses of a peak voltage of 82V, and a peak current of 1.95A at a frequency of 25Hz.

Comparative fishing trials with electrified and traditional beam trawls resulted in higher catches and improved selectivity of the electrified gear not only with sole but also with plaice and cod.

During the following tests of the equipment the electric characteristics of the pulse generator were varied to find the optimum of the configuration. A voltage of 110V and a current of 1.31A at every pair of electrodes with a pulse length of 0.51ms at a frequency of 25Hz proved to be most effective. An increase of catch (sole) in weight of 114% was obtained. At the same time the bycatch of benthic organisms and sand was reduced to almost 50%.

In 1985 a modified arrangement of electrodes and lower panel of the beam trawl was investigated to get a uniform electrical field in front of the groundrope.

Research and development in the field of electrified beam trawls were terminated in 1987 when the German authorities were not prepared to allow electrical fishing on a commercial basis. Since then environmental aspects have become much more important in the sea fishery. Especially the destruction of the benthos by heavy tickler chains of beam trawls is considered as a major disadvantage of this type of gear. From this point of view a revival of electrified beam trawls seems possible.

Work done in Klaipeda (Lithuania) as reported in the ALTSTIM report

Electrical stimulation was mainly investigated in the institute in Klaipeda, Lithuania (Masimov and Toliusis, *personal communication, 1996*). Species under investigation were: Baltic cod, herring, flounder, rainbow trout, shrimps (*Crangon crangon*) and Japanese scallop. Anode electrotaxis was studied intensively in pulsed electric fields and under direct current (Daniulyte *et al*., 1987; Simonaviciene, 1987; Daniulyte and Petrauskiene, 1987), as well as the effect of electric current on physiological parameters (Vosyline, 1987), and on electrocardiogrammes and the heart rhythm of fish (Kazlauskiene and Daniulyte, 1987; Kazlauskiene, 1987). The three basic types of reaction: first reaction, electro-taxis, electro-narcosis mentioned in the report of Lart and Horton were also identified by these workers. Species under investigation were *Gadus morhua* L. (cod), *Clupea harengus* L. (herring), and *Pleuronectes platessa* L. (plaice). The work started with observations on behaviour in dependence of field characteristics. Prototype electrical equipment was built and tested on experimental sea trips, including in situ observations on fish. Applications in gears followed both in midwater (Malkevicius and Toliusis, 1987), and in bottom trawls, but not in beam trawls that are unknown in these parts of the Baltic Sea. Crangon were observed to jump off-bottom, as reported by many other workers (Burba, 1987). In addition, anode attraction was used in sardinella fishery in combination with light attraction. In this application fish is pumped on-board. The effect on other benthic marine life was also extensively studied and reported as being negligible, due to the smaller sizes involved. It was also found that electric currents do not affect reproductive qualities. Plaice was observed to jump out of the seabed and rise 1.5–2.0 m off bottom under the influence of the electric field. The critical frequency for electro-narcosis was found to be around 80–100Hz. The reaction occurs mainly 3–4 sec after exposure. Other frequencies lead to slower responses. Sinusoidal pulse shapes were found to be most effective, and ways were found to optimize the energy efficiency of the pulser unit (Malkevicius and Malkevicius, 1987). It was also found that fish length determine reaction, as larger fish experience a larger potential difference in an electric field (Maksimov *et al*., 1987). The product of fish length * voltage for a given reaction was found to be constant, which means that larger animals are more strongly affected. Selective properties of the electrified gear were observed during experiments on the Jamaican Shelf on grounds unsuitable for trawling by using direct observation techniques. The pulse generators were placed on-board the vessel with cables running to the net as in most applications in Western Europe. Various electrode arrangements were tested with the anode placed in the lower panel and the cathode in the upper panel, an arrangement not tried out in beam trawls. The optomotor reflex mentioned by Wardle was also observed by direct observation in a pelagic trawl. A regime of 7s exposure to the electric field followed by a 60s unexposed interval at 100Hz resulted in all fish appearing in the codend. When a school enters the trawl, the fish start to react when the height of the section is about 4–6m. Then they begin to swim along with the trawl, which can be maintained for lengths of time depending on the towing speed. The electrode arrangement was chosen to elicit an upward movement of the fish, with the anode placed above the cathode attached to the groundrope. The workers believe that the trawl can be fished off-bottom thus avoiding any bottom contact and related bycatch and mortality of benthic organisms. This idea deserves more study.

Introduction into commercial fisheries did not take place, as in other countries, because of the following reasons:

- Fishers showed lack of interest.
- The robustness of the system was not adequate, leading to loss of fishing time.

Work done in India as reported in the ALTSTIM report

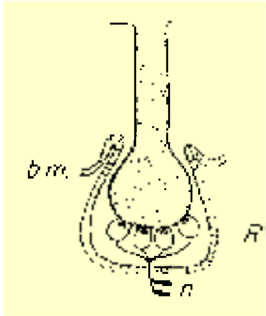
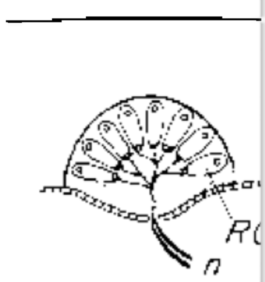
Sreekrishna (1995) reports on studies with electrical stimulation in India. In India, electrical fishing has been successfully applied on an experimental basis. Namboodiri *et al*. (1969) studied the effect of impulse current on certain freshwater fish. Mitra and Biswas (1968) studied the threshold current densities required for narcosis of Indian carps in captivity. Higher catch rates of prawns and fish were reported for an electrified trawl by Namboodiri *et al*. (1970).

Studies from the USA

A classification of electro-receptors is given in

Table 4 from (Hopkins *et al*., 1997)

Table 4. Classification of electro-receptors in fish.

Type	*Where Found*	*Sensitivity*	Structure
Ampullary	Sharks and Rays; Non-teleost fish (except holosteans); Certain teleosts (mormyrids, certain notopterus, gymnotiforms, catfish); Amphibians (except frogs and toads).	0.01 µV/cm in marine species, 0.01 mV/cm in freshwater; sensitive to DC fields or to frequencies less than 50 Hz	
Tuberous	Mormyrid fish (Knollenorgans, Mormyromasts); Gymnotiform fish (burst-duration coders, phase coders)	0.1 mV/cm to 10 mV/cm.	

Figures modified from Szabo (1965). R.C. = receptor cell; b.m. = basement membrane; n = nerve. The ampullary receptor has a jelly filled canal leading to the skin surface; the tuberous recepor has a loose plug of epithelial cells over the receptor organ.

Definitions of both types are given by (Hopkins *et al*., 1997) as follows:

"Ampullary electroreceptors are most sensitive to D.C. electric fields. The receptors have an "ampoule-shaped" canal that leads to the skin surface; the sensory cells lie at the base of the canal. Ampullary receptors are spontaneously active but modulate the rate of nerve impulses up or down in response to positive or negative electric stimuli.

Tuberous electroreceptors are sensitive to AC stimuli with frequencies above 100 Hz, but not to DC stimulation. They lack the canal to the surface. Instead, there is a loose plug of epithelial cells leading to the skin surface. The receptor cells lie buried under the skin surface. The nerve impulses are usually silent, but respond to electrical transients, such as the on or off of an electrical stimulus."

Annex 7: Summary of pulse characteristics

Table 5. Overview of pulse characteristics used in electrofishing studies.

Author	Year	Species	Length range (cm)	Current type	Field, electrode spacing (cm)	Pulse shape	Pulse amplitude (V), potential overfish (V/cm)	Pulse duration (µs)	Pulse freq. (Hz)	Stimulation interval (s)	Rest interval (s)	Comments
Mck. Bary	1956	Bass, flounder, **mullet**	8.6–30.2	DC, AC, pulsed DC	Uniform, 60	Sharp rise, exponential decay (triangle)	0–100 V/cm	83–9000	2–600	5	30, 60	Formulae given for electrotaxis and electronarcosis depending on fish length, V/cm, Hz and µs
P.A.M. Stewart	1977	plaice, dab, flounder, brill, lemon sole, dover sole	Small (< 15) Medium (15–25) Large (>25)	Pulsed DC	Non-uniform, 100	Exponential decay	40–80	4000	4–40	1 continuous	1 -	Stronger reactions above threshold tetanus. More paralysis > 20 Hz. Tetanus in sandeels at 40Hz. Ensis off bottom at >30 Hz. Shrimps jump at 4 Hz. Roundfish show tetanus or pulsations. Stronger reactions in larger fish.
De Groot S.J. Boonstra, G.	1974 1977	Brown shrimp	0–6	Pulsed DC	Non-uniform,	Capacitor discharge , Exponential decay	60	200	1–50	Continuous, 1 s on and 1 s off		
De Groot S.J. Boonstra, G.	1970	sole	15–30	Pulsed DC	30, 35	Capacitor discharge , Exponential decay	2.5–60	700	1–50			No effect was found of the temperature. Plaice, flounder, dab, and brill subjected to the same stimulus did not show a similar jumping behaviour, but were merely paralysed. Optimal was 20 Hz for flatfish.
Maksimov Malkevicius	1987 1987	cod, herring, plaice	n/a			Sinusoidal			80–100			The product of fish length * voltage for a given reaction was found to be constant, which means that larger animals are more strongly affected. The critical frequency for electro-narcosis was found to be around 80–100Hz.
Agricola, see also van Marlen 1985	1979 1981 1982 1985	sole, plaice	15–50	Pulsed DC	Non-uniform, 050, 75, 100	Capacitor discharge	40–150C, 60–100E 200C, 80E 500G, 1000C 500G, 2000C, 60–600E	600 340, 700? 300	2–20 16 0–25 20–25			Voltage generator G : condensers C : electrodes E = 1 : 0.9 : 0.41. Optimum: 700V C, 20 Hz, square net used. Beam length 8m. Power: 2 * 18.5 kW, total 37 kW.

Author	Year	Species	Length range (cm)	Current type	Field, electrode spacing (cm)	Pulse shape	Pulse amplitude (V), potential overfish (V/cm)	Pulse duration (μs)	Pulse freq. (Hz)	Stimulation interval (s)	Rest interval (s)	Comments
Horton, see van Marlen 1985	1985	sole, plaice	15–50	Pulsed DC	Non-uniform, ?	Sine waves, Vmax=340V	267G DC?, 130 V/m E	900	4			Beam length 8m. Power: 2 * 8.5 kW, total 17 kW. Hydraulic pumps for winches: 3kW, adds up to 20kW.
Horn, see van Marlen 1985	1985	sole, plaice	15–50	Pulsed DC	Non-uniform, 175	Capacitor discharge	110E	500	25			Beam length 8m. Power: 2*? 3–4 kW. Transformer on beam to avoid electrical losses.
VandeBroucke, see van Marlen 1985	1985	sole, plaice	15–50	Pulsed DC	Non-uniform, 75	Capacitor discharge	80–120G?	500	5.8, 10	continuous pulse train	0	Beam length 8m. Power: 2*0.45 kW.
Polet *et al*., 2005	2005	Brown shrimp	0–6	Pulsed DC	Non-uniform, 50	Capacitor discharge	230–400G, 45–200E	400–600	5; 1–9	30		The pulse amplitude was the most determining factor. A high temperature resulted in a better response over the whole pulse amplitude range and the maximum was reached at a higher amplitude. Beam length 8m. Power: 2*? kW.
De Haan, 2011, VB UK153	2011	sole, plaice	15–50	Pulsed AC	Non-uniform, 32.5	Capacitor discharge	20–57E	150–200	30.6–40–57.5			Beam length 12m.
De Haan, 2011, VB TX 68	2011	sole, plaice	15–50	Pulsed AC	Non-uniform, 42.5	Capacitor discharge	22–50E	220	80			Beam length 12m.
De Haan, 2011, HFK TX36	2011	sole, plaice	15–50	Pulsed AC	Non-uniform, 41.5	Capacitor discharge	30–60E	50–380	30–45–80–100–180			Beam length 12m.

Annex 8: Summary of report on razor clam fishery in UK Scotland

Mike Breen, Trevor Howell and Phil Copland, 2011. A report on electrical fishing for razor clams (*Ensis* sp.) and its likely effects on the marine environment. Marine Scotland Science Report Volume 2 No 3, February 2011.

This report summarises information relevant to electrical fishing for razor clams (*Ensis sp.*) in Scottish inshore waters and considers how the effects of this fishing method on the target species and the wider marine environment should be evaluated. It also highlights health and safety concerns associated with the fishing method and makes recommendations related to the management of any future fishery.

The information in the report has been assembled from scientific publications, "grey" literature and anecdotal sources and is presented in five sections:

1) Biology and management of the *Ensis. sp.* stocks in Scotland;
2) Principles of marine electrical fishing;
3) Effects of electrical fishing on marine organisms and habitats;
4) Health and safety implications of electrical fishing operations; and
5) Future research requirements to assess the effects of electrical fishing for *Ensis* on the marine environment

These sections are summarised below:

1. Biology and Management of the *Ensis. sp.* Stocks in Scotland

Of the six UK species of marine bivalve molluscs colloquially referred to as razor clams, two are of commercial importance in Scotland. These are the Pod Razor, *Ensis siliqua* (L, 1758), and the more common Curved Razor, *Ensis arcuatus* (Jeffreys, 1865). Both are widely distributed around the coast of Scotland and can be found in dense beds in areas with some shelter from wave action. Although both species are normally found from the lower shore down to about 20 m they have different habitat preferences with *E. siliqua* generally found in fine sands and muddy sediments while *E. arcuatus* prefers more coarse-grained sediments. *Ensis* are filter-feeders and normally lie vertically in the sediment with two small siphons, through which they feed, visible on the sediment surface. Although they are capable of burrowing rapidly when disturbed they are not confined to permanent burrows and relocate by crawling over the sediment or swimming.

In Scotland both species can live in excess of 20 years but *E. siliqua* is longer lived and grows to a larger maximum size, while *E. arcuatus* has more variable growth rates. Growth also varies in different locations and there is evidence that in some areas male *E. siliqua* grow at a faster rate and to a larger maximum size than females from the same area. The sexes are separate in both species and spawning generally takes place during spring or summer. The larvae are thought to have a pelagic phase lasting about a month prior to settlement. Studies in Scotland indicate that a substantial proportion of both species, but particularly *E. siliqua,* reach sexual maturity at sizes above 100 mm.

The commercial razor clam fishery in Scotland emerged during the mid 1990s with reported landings ranging between 40 – 220 tonnes until 2006, but then rose sharply to reach 718 tonnes in 2009 with a value of £1,754,000. Since 1997 between 14 and 27 vessels a year have been involved in the fishery. These are mainly small vessels (<10 m), with hand caught methods (mainly divers) dominating the fishery. The sharp rise in landings since 2006 is thought to be related to the increasing use of illegal electrical fishing methods.

There is currently no limit on catch or effort in the Scottish razor clam fishery. In Scotland current management measures relating to *Ensis* are: the EU minimum landing size (MLS) of 100 mm; some spatial restrictions on the use of mobile gears; and the requirement for all commercial fishing vessels to report weight landed and the ICES statistical rectangle where fishing took place. In response to the increase in illegal electrical fishing, changes to the vessel fishing licence relating to the carriage of electrical equipment were introduced in 2010.

Concern over the sustainability of the fishery has been prompted by the marked increase in landings allied to the use of electrical fishing methods. Because electrical fishing is illegal, reliable information on the impact of the method on target and non-target species, on gear selectivity and incidental mortality is scarce. The illegal component of the fishery compounds the problem of obtaining accurate fisheries data required to manage the fishery. Since the expansion of the fishery, there have been no stock assessments of *Ensis* or surveys to provide information on population dynamics, distribution of stocks and patterns of recruitment. Relative to other commercially important bivalves *Ensis* are long-lived, slow-growing, and attain sexual maturity late in life. Scottish studies indicate that substantial, but different, proportions of the two commercially exploited species reach sexual maturity above the EU MLS of 100 mm.

It is recommended that the effect on landings of recent initiatives to reduce illegal razor clam fishing activity should be closely monitored. Improved information on the state of the stocks is required. This would be provided by stock surveys in conjunction with more detailed logbook information. Scottish Inshore Fisheries Groups (IFGs) could facilitate the collection of more detailed (logbook) information. If landings continue to rise, precautionary measures to control harvesting may need to be introduced, until better information on the state of the stocks is available. Ideally, future harvesting should be based on stock surveys and removals should be regulated in a precautionary manner. It is also recommended that the MLS is increased so that *Ensis* are not harvested before they reach sexual maturity. A precautionary MLS of 130 mm is suggested.

2. Principles of Marine Electrical Fishing

In simple terms, electrical fishing works by using electrical currents to produce a response in the target species, which either compromises the target's ability to evade capture or makes it available for capture by stimulating it to move into the path of the fishing gear. The form and dimensions of the electric field generated in the water (and underlying substrate) and its effect on the target will be dependent upon many factors, including: the conductivity of the water (and substrate); the form (AC, DC and/or pulsing) and strength of the electrical output; the location, orientation and construction of the electrodes; and the target species itself, its biology/physiology, size, proximity and orientation within the electric field.

Electrical Fishing for *Ensis* in Scotland

Fishers are thought to have been using electrical fishing techniques in the Scottish razor fishery since 2004, and possibly earlier (McKenzie, pers. comm.). Because the practice is illegal, there is insufficient information available to provide detailed descriptions of the gears typically used and electrical fields applied. Approximate descriptions and insights into past and current practices have been obtained as a result of discussions with various agencies, including Marine Scotland Compliance (MSC), the Health and Safety Executive (HSE) Diving Inspectorate and Strathclyde Police. A more in-depth study of these accounts and any confiscated equipment would provide a valuable insight into the technologies used in this illegal fishing technique. On the basis of information available, it appears that intense electrical fields, emitted by electrodes towed slowly across the seabed, stimulate *Ensis* to temporarily leave their burrows. They are then collected most commonly by a diver following the fishing vessel, or alternatively by a dredge drawn across the surface of the seabed.

3. Effects of Electrical Fishing on Marine Organisms and Habitats

Based on the literature review, potentially detrimental effects associated with electrical fishing for *Ensis*, were identified as:

- physical disruption and damage of benthic habitats due to fishing activities;
- the release of pollutants (particularly metals, e.g. copper) from electrolysis at the electrodes; and
- effects of electrical fields on *Ensis* and non-target species, including fish and epifauna and infaunal invertebrates).

The physical effects from electrical fishing gears using divers are anticipated to be small, particularly compared with alternative fishing methods (e.g. hydraulic dredges). Direct comparison of electrical and other fishing methods, would require some level of quantification of the impact from electrical gears, which is not possible at this time.

There is insufficient information about the fishing methods to estimate the magnitude of any release of metal ions; the fate or effects of polluting metals are beyond the scope of this review. It is recommended that any future work should attempt to estimate release rates of copper and other metals as a result of electrical fishing and, if significant, consider the fate and effects of these pollutants.

Possible effects of electricity on target and non-target species are considered in the report in more detail. For each, the known behavioural responses to electrical fields and the likely effects of that interaction, in terms of injuries and resulting mortality, are considered. Most studies focus on fish as they are the normal target group for electrical fishing. The most damaging forms of electrical current are AC and low frequency (<200Hz) pulsed (DC and AC) signals, while the least damaging is a smooth DC current. Injuries most commonly observed in fish include broken spines and internal bleeding. The main cause of fish mortality is from respiratory arrest, due to synaptic fatigue caused by overstimulation of the autonomic nervous system. Significant mortalities have also been observed in invertebrate species exposed to intense electrical fields, although the likely causes were unspecified.

Short term direct effects of electrical fields on *Ensis* appear to be limited. This is inferred by the fact the catch is generally exported live and supported by observations that most *Ensis* specimens, if left on the seabed, typically rebury themselves within ten minutes. However, any exposed individuals left on the seabed (i.e. discarded) are at increased risk of predation.

Electric fields, of the required intensity to catch *Ensis,* are thought to be sufficient to injure and kill fish and invertebrates that are within a few meters of the electrodes.

The fished areas may be exposed to potentially high intensity electrical fields for relatively prolonged periods, typically between one and two minutes. This would suggest that this fishery could have a detrimental effect on non-target organisms at a local level. However, more information about electrical field strengths and form, as well as knowledge of the effects on exposed species, is needed before spatial limits can be defined with any degree of certainty. The geographical scale of any such effects will be determined by the distribution of *Ensis*. The capacity for recovery from and/or mitigation of any deleterious effects at a species and habitat level could not be reviewed due to the lack of available information, but would need to be determined in an appropriately designed impact study.

4. Health and Safety Implications of Electrical Fishing Operations

Electric fishing for *Ensis* sp. is considerably more hazardous than traditional fishing techniques. In addition to the risks and hazards associated with fishing from small inshore boats, the most common technique involves diving and the use of high power electrical currents and is not regulated. Under these circumstances, the likelihood of serious injury or fatalities is considerably increased. Of particular concern is the clandestine and *ad hoc* approach to the development of the electrical fishing technology. Without sufficient expertise in marine electrical systems, poor design and maintenance of the equipment are likely to increase the risk of injury and fatalities still further.

Codes of safe working practice already exist for the use of electrical fishing techniques for scientific purposes in freshwater. The theories behind the safe use of diving around electrical fields and relevant guidelines from the Health and Safety Executive are reviewed. It is thought that with suitable expert input these could be adapted and applied to commercial electrical fishing operations at sea. It is recommended that before any experimental or observational research is undertaken a code of safe working practice should be developed. It is further recommended that if this fishery were to be allowed to operate legitimately, an education programme should be established (in partnership with the HSE) to promote the resulting code of safe working practice within the fishery itself.

5. Future Research Requirements to Assess the Effects of Electrical Fishing for *Ensis* on the Marine Environment

Future research requirements for assessing the effects of razor clam electro-fishing on the marine environment were considered by a multidisciplinary expert group. The group identified six priority research areas and key research goals within each that would need to be addressed:

1) Determine safe limits and working practices for the health and safety of operatives and researchers working with electrical fishing gears:
   a) A comprehensive review of the methods and practices utilized in electro-fishing for shellfish;
   b) Direct guidance on safe limits and practices; and
   c) Where there is insufficient knowledge to provide and/or substantiate this advice, directed research should be undertaken to define appropriate safe limits and best practice.
2) Describe the effects of an electrical field on *Ensis*:
   a) Establish what stimulus *Ensis* is responding to;

   b) Describe the electrical conductivity (and/or resistance) of the substrates (sediments) populated by *Ensis*;
   c) Establish the thresholds (in terms of electrical field strength: V/m, A/m^2 and W/m^3) to which *Ensis* will respond; and
   d) Establish the detrimental effects of the electrical fields on *Ensis* and define the associated thresholds (in terms of electrical field strength: V/m, A/m^2 and W/m^3).
3) Describe the technologies and methods currently used to fish for *Ensis* using electricity, in terms of:
   a) The technologies used by this fishery;
   b) The electrical field generated by these technologies; and
   c) The methods used to operate this technology and collect the resultant *Ensis* catch.
4) Evaluate the environmental impact of present electrical fishing practices and available alternative techniques;
   a) Assess the direct effects of electrical fields on the species assemblages and habitats associated with *Ensis*;
   b) Estimate the likely output of copper (or other metal pollutants) released through electrolysis at the electrodes;
   c) Assess the direct effects of physical disturbance on the species assemblages and habitats associated with *Ensis*; and
   d) Assess the indirect, cumulative/additive effects and the likely post impact recovery.
5) Develop mitigation measures to address any detrimental effects of electrical fishing – design solutions to consider:
   a) The most appropriate form and level of electrical power;
   b) Safe design of the electrical delivery system;
   c) The most appropriate design of electrode for efficient delivery of electrical power, with minimal risk to the operator/diver and ecosystem;
   d) Inclusion of shielding to focus the electrical field into the seabed, to protect the diver and biota above the seabed;
   e) Appropriate mechanical design and operating practices to minimize physical impacts;
   f) Recommendations for safe working practices (see Priority 1); and
   g) Suitable monitoring systems to ensure compliance with recommended safe working practices.
6) Develop understanding of the biology and population dynamics of *Ensis* to ensure the sustainability of the fishery:
   a) Improve understanding of the biology of *Ensis* sp., in particular: growth, reproduction, recruitment, mortality and habitat;
   b) Describe the distribution of *Ensis* using stock surveys and logbooks;
   c) Research population dynamics by gathering data on age structure, length frequency distributions for different populations, accurate landings data, gear selectivity and discarding practices;
   d) Assess the impact of fishing on target and non-target species (4a above); and

e) Develop survey methods for *Ensis* and sustainable harvesting strategies.

Annex 9: "Once again about electrofishing" by Sarunas Toliusis

The Laboratory of electrofishing was founded in 1958 in Klaipeda, Lithuania. Its purpose was to develop electrofishing methods for practical use in marine fisheries. The research activities took place during several years and resulted in an exhaustive theoretical framework and many experiments were conducted.

The main parameters of the electric stimuli (e.g. pulse duration, pulse form, pulse frequency, electric field strength and duration of their effect) were determined by extended biological laboratory experiments. Corresponding reactions, i.e. primary, anodic electrotaxis and electronarcosis, of various industrial sea fish species were found.

The work of many years in our laboratory cooperating with other institutes in the former USSR-region was completed with creating an electric trawl system that enabled electrical stimulation in bottom and pelagic trawls. The expectations of electrical stimulation in these trawls were met with good results. However, because an official scientifically grounded point of view particularly on ecological consequences of this new application in marine fishery was lacking, we were obliged to carry out complex tests during many years on marine biota under differing doses of electricity. The results of these scientific investigations allowed us to appraise the consequences of applying electrical stimulation and to answer the question of means of using electric fields in fishing gears.

The last aspect of this problem is especially important because many countries do not allow the use of electrical fishery in their waters to avoid adverse effects on the marine environment. In fact, the effect of electric currents can differ, and they depend on the strength of the electrical field, the size of marine biota and the period during which marine biota are affected by the electric current.

The Institute of Zoology and Parasitology of the Lithuanian Academy of Science cooperated with our laboratory and carried out tests during many years (about 20) on the possible effects of electric currents on marine biota.

The researchers investigated effects on stages of reproduction, development and life of fish, crustaceans and invertebrates of typical representative species. As a result, the limits of dangerous and save- electrical doses were determined for different fish species during the exposure to different parameters of the stimulation. It allowed an analysis of the effects of electric fields in a trawl and to find out the dose limits resulting in danger to health of organisms when subjected to electric fields. This analysis showed that the electric dose that marine biota will receive in a trawl is much lower the dose that can be deemed as dangerous. The dose levels of pulse currents bringing fish health in danger were determined as well as the effect of pulse current on different functions of the organism.

Observations were carried out on fish behaviour in electric fields in specific fishing gear. For this purpose towed underwater devices of an open type as well as an aquaplane were used. All visual observations were recorded by camera. At a later stage video techniques and a especially experimental trawl sonar, designed and developed in 1985, were used for observation purposes.

Footage of underwater observations enabled the choice of an optimal configuration of electrodes in a trawl and to establish the values of parameters of pulse current needed for capture with the regime of operation.

Based on these observations and parameter settings of particular electrode configurations, and by using schematic solutions for pulse generators, theoretical analysis and practical calculations, high capacity experimental pulse generators for industrial sea fishing were designed and developed. For energy transmission a cable is used, with a length up to 2000 m. By using pulse transformers, pulses can be transmitted directly, and high energy losses avoided. Another technique is to energy is to transmit energy through discharge condenser packages placed in underwater containers, and in this case the charging current is transferred by the cable.

The electrofishing method was used in practice in 2 applications:

1) For catching African sardinella not using trawlnets, but by light attraction, applying an electric field, and pumping fish up.

2) In electrified trawls of larger fishing vessels:

- in pelagic trawls;
- in bottom trawls, which do not disturb the ecosystem of the bottom.

The possibility of selective fishing on cod and haddock emerged from observations in an electrified bottom trawl. Cod in the electric current field showed a much better anodic electro-taxis, rose high from the bottom and were easily caught in the trawl, whereas haddock rose more slowly and did not get into the trawl. After increasing the distance between electrode - anode and the lower part of the trawl, haddock managed to go up sufficiently high and were successfully caught.

With increasing distance between anode and the bottom, the electric field strength consequently decreases making it insufficient to evoke anodic electro-taxis reactions of small fish. In this way size selectivity is obtained as only big fish usually got into the trawl, whilst small individuals are not caught.

Table 1. Technical parameters of impulse generators.

Parameters	Units	Model 1984 with underwater discharging part	Model 1987 transformer variant
Max. power consumption	kW	90	105
Amplitude of discharge current	A	4,000 ... 6,000	7,000
Duration of impulse	ms	1.5	1.5
Frequency	Hz	100	75
Capacity of capacitor banks	μF	700	3,600
Capacitor bank voltage	V	1,100	830
Max. voltage at the beginning			
of the cable	V	1,700	11,000
Mass of underwater part	kg	100	2 x 35
Mass of side part	kg	1,000	700
Length of cable	m	2,000	2,000

In an electrified pelagic trawl, the electric field that was generated in the critical zone of the trawl was used for electro-narcosis, and it enabled catching more fish in less time. Seen from underwater observations, fish that got into the trawl, when having reached the critical trawl zone, reoriented and swam along with the moving net for a long time. When the electric current was switched on, fish became narcotized between the electrodes fish and then were washed down by water flow into the codend, and after switching off the electric current, the empty space between the electrodes was again filled up with new quantities of fish. By switching on and off the electric current in cycles, large schools of mackerel and horse mackerel were successfully caught in the Atlantic and the Pacific.

As a result the conclusion was drawn, that moderate use of electric fields in fishing gears does not injure marine fauna, but can serve as an effective means for conservation of substrata during trawling, as the electrification of the trawl permits to lift it to 0.5 - 1.0 m over the bottom and to trawl without touching it.

Despite the wide range of investigations carried on the after-effects of electric fields on marine biota, the psychological barrier has not been eliminated among various groups in society that oppose the application of electric fields under natural conditions. It is important to specify the thresholds of danger to health of electric fields and make sure that lower doses are used to limit the effect on vital functions in marine biota. The internal response mechanism of marine biota to electric fields has not been entirely disclosed.

The analysis of experimental - industrial electrofishing gear performance shows that its potential has not been fully exhausted by the results obtained.

Great prospects lie ahead concerning the development of an electrified bottom trawl not harmful to the substrate of the seabed. It is common knowledge of how large the damage can be for bottom organisms and spawners affected by the heavy components of conventional trawl rigging. It would be regrettable not to attempt the preservation of bottom ecosystems by using specially designed electrified bottom trawls enabling the capture of bottom fish while not having bottom contact.

The existence of such possibility may be proved by the results of fishing the bottom trawl designed for heavy grounds as well as by certain experience of fishers who use beam trawls for offshore fishing.

Other advantages of electrified fishing gear are a higher selectivity as well as higher quality of the fish caught. Such electric fishing gear may be used on small fishing boats and enable an economic benefit particularly when any increase in fishing effort can be avoided.

The results of our biological research and experimental work also show the possibility of achieving a good result in using electrified shrimp trawls.

Unfortunately, due to many reasons - economic, organizational, pursued engineering policy and others, research and development on using electrical stimulation has been delayed.

There is some hope that the work will be resumed in the context of general progress of science and technology with the application of new methodological and theoretical techniques.

Annex 10: Evaluation of effect of pulse trawling on cod catches and bycatches

The EU-project FISH/07/2007 LOT3 "Flatnose" dealt with the impact of plaice and sole gears on North Sea fish stocks (Polet *et al.*, 2010), The project gave an overview of all relevant métiers, the status of fish stocks, and changes in the technology of fishing gears targeting plaice and sole. The effect of such changes was evaluated. The sections below summarize the methods used and the main results of this evaluation.

The spatially explicit model given in (Piet *et al.*, 2009) was used combining abundance data for all the main fish species in the demersal North Sea fish community with international effort data and estimates of gear-, species-, and size-dependent catch efficiency to determine the mortality of non-target fish species caused by bottom trawl fisheries and its spatial variation.

Métiers

A total of 73 métiers in demersal fisheries in the North Sea were used based on vessel type and length class, gear type, and mesh size range and grouped in (Table 6):

- Table 6three vessel length classes: <24m; 24–40m; >40m
- eight fishing gear groups: GNS, GTR, OTB, OTT, OTX, PTB, SDN, TBB
- four mesh size groups: 80mm; 90mm; 100mm; 120mm

In the analysis the variable "member state" was not kept and the different nationalities were merged. This is because national management measures were not envisaged in this study and only EU measures were taken into account.

Fishing effort

Fishing effort data were collected from the STECF database. The standard unit to express effort in this project was "kWdays". An alternative unit was "days at sea".

Data sources

i. STECF database 2006

Starting point was the method presented by Piet *et al.* (2009). They used an on survey-catches based spatially explicit (by ICES-rectangle) estimate of the total demersal fish community (total numbers by species and length) (Fraser *et al.*, 2007). On top of these estimates of fish abundance a model was set using realistic effort of beam trawlers and otter bottom trawlers along with gear specific catchabilities. The model calculates spatial explicit catches (landings and discards) of the total demersal fish community.

In the Flatnose project, the model was extended to incorporate more métiers; the otter and beam trawlers are split up in smaller métiers, and static gears are included. The fishing effort of these métiers comes from the data collected in Flatnose. For the estimate of the total fish abundance the same method is used as in Fraser *et al.* (2007), which is done using the haul by haul catches of the Dutch Beam Trawl Survey (DBTS) and the International Bottom Trawl Survey (IBTS). As shown by Fraser *et al.*, 2007, a certain number of hauls per ICES-rectangle is needed, therefore multiple years of survey data (2003–2006) were used to estimate the total fish abundance. The survey catches of these years were compared to the VPA output of the same years based on the assessment reports of 2008 (ICES, 2008).

This study focuses on three roundfish species: cod (*Gadus morhua*), haddock (Melanogrammus aeglefinus), and whiting (Merlangius merlangus), and two flatfish species, plaice (*Pleuronectes platessa*) and sole (*Solea solea*).

For each of the métiers data on mesh size specific codend selectivity was gathered and used in the model. For the trawlnets a logistic curve is used to describe the relationship between the length of a fish and the proportion of fish entering the net that is retained in the codend (Casey, 1996). The values of L50 and L25 are the lengths (cm) at which 50 and 25%, respectively, of the fish entering the net are retained. L50 and L25 are calculated from the selection factor (SF) and selection range (SR), together with the mesh size M (cm) (Wileman, 1991; Wileman, 1992; Wileman *et al*., 1996):

Besides the codend selectivity also factors for the efficiency of each individual gear were used. Those for the trawled gears were loosely based on the values in Piet *et al*. (2009, table 2). We started the modelling with the values as in Piet *et al*., 2009, using the same values for the new métiers. Model parameters were tuned for landings to match actual reported accumulated values from the logbooks. For this purpose, the factors of gear efficiency were changed, within reasonable limits. For example Piet *et al* reported a footrope efficiency of 1 for the beam trawlers, however, here we assume a lower efficiency for the lighter beam trawl of 0.9 for the smaller flatfish. In a similar way the other values are adjusted (Table 9). The values of the static gears are assumed based on best guess and slight adjustment owing to the tuning process.

Data for SDN have not been modelled. For the overall calculation of discards, SDN data have been taken from Method 2 ({Polet, 2010 #455}).

In scenario 2a the métiers Beamhp3 (vessel size >40m, mesh size range 80–90 mm) were replaced by pulse trawls based on the catch efficiencies on plaice, sole and roundfish found in 2006. In scenario 2b Beamhp2 (vessel size 24–40m, mesh size range 80–90 mm) the métiers were added (Table 10, Table 11, Table 12).

A new scenario was run (scenario 2c) with pulse trawling replacing standard beam trawling in the 24–40m (Beamhp2) and >40m (Beamhp3) métiers of 80–90 mm mesh size. New gear efficiencies were given based on anectodal information and proxis. The result is shown in Table 13 and seems to indicate that cod landings and discards will be reduced by introducing pulse trawling in the beam trawl fleet.

References

Casey, J. 1996. Estimating Discards Using Selectivity Data: the Effects of Including Discard Data in Assessments of the Demersal Fisheries in the Irish Sea. J. Northw. Atl. Fish. Sci., 19: 91–102.

Fraser, H. M., Greenstreet, S. P. R., Piet, G. J. 2007. Taking account of catchability in groundfish survey trawls: implications for estimating demersal fish biomass. ICES Journal of Marine Science, Journal du Conseil, 64: 1800–1819.

He, P. 2003. Swimming behaviour of winter flounder (*Pleuronectes americanus*) on natural fishing grounds as observed by an underwater video camera. Fisheries Research, 60: 507–514.

ICES. 2008. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK).

Piet, G. J., van Hal, R., Greenstreet, S. P. R. 2009. Modelling the direct impact of bottom trawling on the North Sea fish community to derive estimates of fishing mortality for non-target fish species. ICES Journal of Marine Science, 66: 14.

Polet, H., Tidd, A., Van Hal, R., Madsen, N., van Marlen, B., Soma, K., Depestele, J., Buisman, E., Sølgaard Andersen, B., Piet, G.J., Catchpole, T. 2010. Scientific advice concerning the impact of the gears used to catch plaice and sole in the North Sea. Final report of the open call for tenders FISH/2007/7, studies and pilot projects for carrying out the common fisheries policy, European Commission June 2010.

van Helmond, A. T. M., and van Overzee, H. M. J. (2007) Discard sampling of the Dutch beam trawl fleet in 2006. CVO Report 07.011. pp.

Wileman, D. 1991. Codend selectivity: An updated review of available data. EC Directorate General for Fisheries.

Wileman, D. 1992. Codend selectivity: updated review of available data.

Wileman, D. Ferro, R.S.T., Fonteyne, R., Millar, R.B. (Eds.), 1996. Manual of methods of measuring the selectivity of towed fishing gears. ISSN 1017-6195. ICES Coop. Res. Rep. No. 215.

Tables

Table 6. Métiers used for North Sea fleet.

Country	Vessel type	Vessel length	Fishing gear	Mesh size
B	Beam Trawl	<24	OTX	70–89
			TBB	80
				120
		>24	OTX	70–89
			TBB	80
				100
				120
	Demersal Trawl	>24	OTX	70–89
	Static Gear	<24	GTR	90–100
D	Beam Trawl	>24	TBB	>=120_0
				90–119_
	Demersal seine	<24	SDN	>=120_0
				90–119_
	Demersal Trawl	<24	OTB	>=120_0
				70–89_0
				90–119_
		>24	OTB	>=120_0
				70–89_0
				90–119_
			OTT	90–119_
	Static Gear	<18	GNS	100–119
				120–219
				90–99_0
			GTR	120–219
		>18	GNS	100–119
				120–219
				90–99_0
			GTR	120–219
NL	Beam Trawl	12–24	TBB	>=120
				70_89
				90_100
		24–40	TBB	>=120

Country	Vessel type	Vessel length	Fishing gear	Mesh size
				70_89
				90_119
		40-XX	TBB	>=120
				70_89
				90_100
				90_119
	Demersal Trawl	12–24	OTB	70_89
				90_100
				90_119
			OTT	70_89
				90_100
		24–40	OTB	70_89
				90_100
				90_119
			OTT	70_89
		40-XX	OTB	70_89
				90_119
			OTT	70_89
	Static Gear	12–24	GNS	100_119
				90_99
UK	Beam Trawl	40+	TBB	100–119
				120+
				80–99
		18–23.99	TBB	80–99
		24–39.99	TBB	100–119
				120+
				80–99
	Demersal seine	18–23.99	SDN	100–119
				120+
	Demersal Trawl	40+	OTB	100–119
				80–99
			TBB	120+
				80–99
		12–17.99	OTB	80–99
			PTB	80–99
		18–23.99	OTB	120+
				80–99
			PTB	80–99
		24–39.99	OTB	100–119
				80–99
			PTB	100–119

Table 7. The different trawl métiers distinguished in the model, with the characteristics of the gear. Width and height are in meters, speed is in nautical miles per hour and fishing day means the actual fishing hours per fishing day.

Gear	Specification	Model name	Width	Speed	Height	Fishing day
Beam trawl	12–24m	BeamHp1	8	4	1	20
Beam trawl	24–40m	BeamHp2	22	5.5	1	20
Beam trawl	>40m	BeamHp3	24	6.5	1	20
Beam trawl	Belgium chain	BeamHp4	22	5.3	1	20
Otter trawl	OTB <24m	OtterFish1	17	3.3	5	18
Otter trawl	OTB >24m	OtterFish2	40	4.5	5	18
Otter trawl	OTT <24m	OtterFish3	60	3.3	5	18
Otter trawl	OTT >24m	OtterFish4	90	3.3	5	18
Otter trawl	OTX <24m	OtterFish5	14	3	5	18
Otter trawl	OTX >24m	OtterFish6	30	3.5	5	18

Table 8. The different static métiers distinguished in the model. Net length in kilometers, surface is in km² and straight is the percentage of the nets set in a straight line. It is assumed that about 50% of GRT >18m are set around wrecks or other objects in that case only half of the Net length is effectively used. The surface is calculated as an oval round the net with a radius of 100meter (the distance assumed the traveled by each fish in an hour. This is freely interpreted from He (2003).

gear	specification	Model name	Net length	Surface	% straight	Fishing day
Static	GNS <18m	Stat1	20	4.031416	100	12
Static	GNS >18m	Stat2	28	4.231416	100	18
Static	GRT <18m	Stat3	14	2.831416	100	21
Static	GRT >18m	Stat4	19	2.881416	50	21

Table 9. Overall factors for the gear efficiency. Start values were the data in Piet *et al.* (2009), which are adjusted by visually tuning the catches to the landings. For all otter trawl métiers the same values are used, which is also the case for all static gear métiers. F are the values for all other flatfish and R are the values for all other roundfish.

		Sole	**Sole**	**Plaice**	**Plaice**	**F**	**F**	**Cod**	**Cod**	**R**	**R**
gear	specification	small	large	small	large	small	large	small	large	small	Large
Beam trawl	12–24m	0.684	0.76	0.684	0.76	0.684	0.76	0.19	0.19	0.19	0.152
Beam trawl	24–40m	0.342	0.4275	0.684	0.76	0.684	0.76	0.19	0.19	0.19	0.152
Beam trawl	>40m	0.72675	0.95	0.72675	0.95	0.72675	0.95	0.25	0.25	0.19	0.152
Beam trawl	Belgium chain	0.342	0.4275	0.72675	0.95	0.72675	0.95	0.25	0.25	0.19	0.152
Otter trawls		0.19	0.323	0.19	0.323	0.19	0.323	0.2166	0.55575	0.2166	0.55575
Static gears		0.35	0.35	0.14	0.14	0.14	0.14	0.2	0.2	0.5	0.5

Table 10. List of scenarios with gear characteristics and catch efficiency multipliers used.

		Gear Characteristics						Catch Efficiency Multipliers				
scenario	description	gear	mesh	width	speed	height	fishing_day	bPLE	sPLE	bSOL	sSOL	RF
0	baseline	BeamHp2	80	22	5.5	1	20	1	1	1	1	1
		BeamHp2	90	22	5.5	1	20	1	1	1	1	1
		BeamHp2	100	22	5.5	1	20	1	1	1	1	1
		BeamHp2	120	22	5.5	1	20	1	1	1	1	1
		BeamHp3	80	24	6.5	1	20	1	1	1	1	1
		BeamHp3	90	24	6.5	1	20	1	1	1	1	1
		BeamHp3	100	24	6.5	1	20	1	1	1	1	1
		BeamHp3	120	24	6.5	1	20	1	1	1	1	1
2a	pulse trawl BeamHp3 (80–90)	BeamHp2	80	22	5.5	1	20	1	1	1	1	1
		BeamHp2	90	22	5.5	1	20	1	1	1	1	1
		BeamHp2	100	22	5.5	1	20	1	1	1	1	1
		BeamHp2	120	22	5.5	1	20	1	1	1	1	1
		BeamHp3	80	24	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp3	90	24	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp3	100	24	6.5	1	20	1	1	1	1	1
		BeamHp3	120	24	6.5	1	20	1	1	1	1	1
2b	pulse trawl BeamHp2 and3 (80–90)	BeamHp2	80	22	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp2	90	22	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp2	100	22	5.5	1	20	1	1	1	1	1
		BeamHp2	120	22	5.5	1	20	1	1	1	1	1
		BeamHp3	80	24	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp3	90	24	5.5	1	20	0.6	1	1.1	0.778	1
		BeamHp3	100	24	6.5	1	20	1	1	1	1	1
		BeamHp3	120	24	6.5	1	20	1	1	1	1	1

		Gear Characteristics						Catch Efficiency Multipliers				
scenario	description	gear	mesh	width	speed	height	fishing_day	bPLE	sPLE	bSOL	sSOL	RF
2c	pulse trawl BeamHp2 and 3 (80–90)	BeamHp2	80	22	5.5	1	20	1	1	1.1	1	1
		BeamHp2	90	22	5.5	1	20	1	1	1.1	1	1
		BeamHp2	100	22	5.5	1	20	1	1	1	1	1
		BeamHp2	120	22	5.5	1	20	1	1	1	1	1
		BeamHp3	80	24	5.5	1	20	1	1	1.1	1	1
		BeamHp3	90	24	5.5	1	20	1	1	1.1	1	1
		BeamHp3	100	24	6.5	1	20	1	1	1	1	1
		BeamHp3	120	24	6.5	1	20	1	1	1	1	1

Table 11. Catches, landings, discards with percentage change for scenario 2a.

species	gear	catch	landings	discards	% change in catch	% change in landings	% change in discards
cod	Beam	-137,220,054	-101,910,164	-35,309,891	-7.3%	-7.0%	-8.8%
	Otter	3,265,999	2,983,024	282,974	0.2%	0.2%	0.2%
	Stat	5,964,491	5,792,432	172,060	0.6%	0.6%	0.8%
haddock	Beam	-53,625,667	-48,126,865	-5,498,801	-9.3%	-10.2%	-5.3%
	Otter	588,958	569,249	19,710	0.0%	0.0%	0.0%
	Stat	11,108	8,312	2,795	0.0%	0.0%	0.0%
plaice	Beam	-7,563,469,095	-4,952,483,402	-2,610,985,692	-11.1%	-16.9%	-6.7%
	Otter	408,371,317	321,583,385	86,787,931	8.6%	10.9%	4.9%
	Stat	383,792,876	290,257,309	93,535,568	6.7%	7.9%	4.5%
sole	Beam	102,234,489	315,029,984	-212,795,495	1.1%	4.1%	-10.6%
	Otter	-18,984,963	-20,303,313	1,318,350	-4.1%	-5.9%	1.1%
	Stat	-32,627,980	-34,629,401	2,001,421	-5.6%	-6.9%	2.6%
whiting	Beam	-335,668,609	-111,762,067	-223,906,541	-8.9%	-9.3%	-8.7%
	Otter	2,006,160	902,873	1,103,288	0.2%	0.1%	0.4%
	Stat	186,228	130,747	55,481	1.4%	1.9%	0.8%

Table 12. Catches, landings, discards with percentage change for scenario 2b.

species	gear	catch	landings	discards	% change in catch	% change in landings	% change in discards
cod	Beam	-137,220,054	-101,910,164	-35,309,891	-7.3%	-7.0%	-8.8%
	Otter	3,265,999	2,983,024	282,974	0.2%	0.2%	0.2%
	Stat	5,964,491	5,792,432	172,060	0.6%	0.6%	0.8%
haddock	Beam	-53,625,667	-48,126,865	-5,498,801	-9.3%	-10.2%	-5.3%
	Otter	588,958	569,249	19,710	0.0%	0.0%	0.0%
	Stat	11,108	8,312	2,795	0.0%	0.0%	0.0%
plaice	Beam	-8,746,825,116	-5,995,241,383	-2,751,583,733	-12.8%	-20.5%	-7.1%
	Otter	476,045,474	381,597,901	94,447,573	10.1%	12.9%	5.4%
	Stat	413,490,248	315,060,650	98,429,599	7.2%	8.6%	4.8%
sole	Beam	-16,319,594	332,405,910	-348,725,504	-0.2%	4.3%	-17.3%
	Otter	-19,593,963	-22,416,960	2,822,997	-4.3%	-6.5%	2.4%
	Stat	-34,148,248	-37,154,255	3,006,007	-5.9%	-7.4%	3.9%
whiting	Beam	-335,668,609	-111,762,067	-223,906,541	-8.9%	-9.3%	-8.7%
	Otter	2,006,160	902,873	1,103,288	0.2%	0.1%	0.4%
	Stat	186,228	130,747	55,481	1.4%	1.9%	0.8%

Table 13. Catches, landings, discards with percentage change for scenario 2c.

species	gear	catch	landings	discards	% change in catch	% change in landings	% change in discards
cod	Beam	-137,220,054	-101,910,164	-35,309,891	-7.3%	-7.0%	-8.8%
	Otter	3,265,999	2,983,024	282,974	0.2%	0.2%	0.2%
	Stat	5,964,491	5,792,432	172,060	0.6%	0.6%	0.8%
haddock	Beam	-53,625,667	-48,126,865	-5,498,801	-9.3%	-10.2%	-5.3%
	Otter	588,958	569,249	19,710	0.0%	0.0%	0.0%
	Stat	11,108	8,312	2,795	0.0%	0.0%	0.0%
plaice	Beam	-3,540,993,870	-1,411,449,101	-2,129,544,769	-5.2%	-4.8%	-5.5%
	Otter	150,003,512	93,481,500	56,522,013	3.2%	3.2%	3.2%
	Stat	215,911,609	144,053,201	71,858,409	3.8%	3.9%	3.5%
sole	Beam	330,562,832	413,474,062	-82,911,231	3.4%	5.4%	-4.1%
	Otter	-22,799,121	-23,216,651	417,530	-5.0%	-6.7%	0.4%
	Stat	-37,535,367	-38,145,874	610,508	-6.5%	-7.6%	0.8%
whiting	Beam	-335,668,609	-111,762,067	-223,906,541	-8.9%	-9.3%	-8.7%
	Otter	2,006,160	902,873	1,103,288	0.2%	0.1%	0.4%
	Stat	186,228	130,747	55,481	1.4%	1.9%	0.8%

Figures

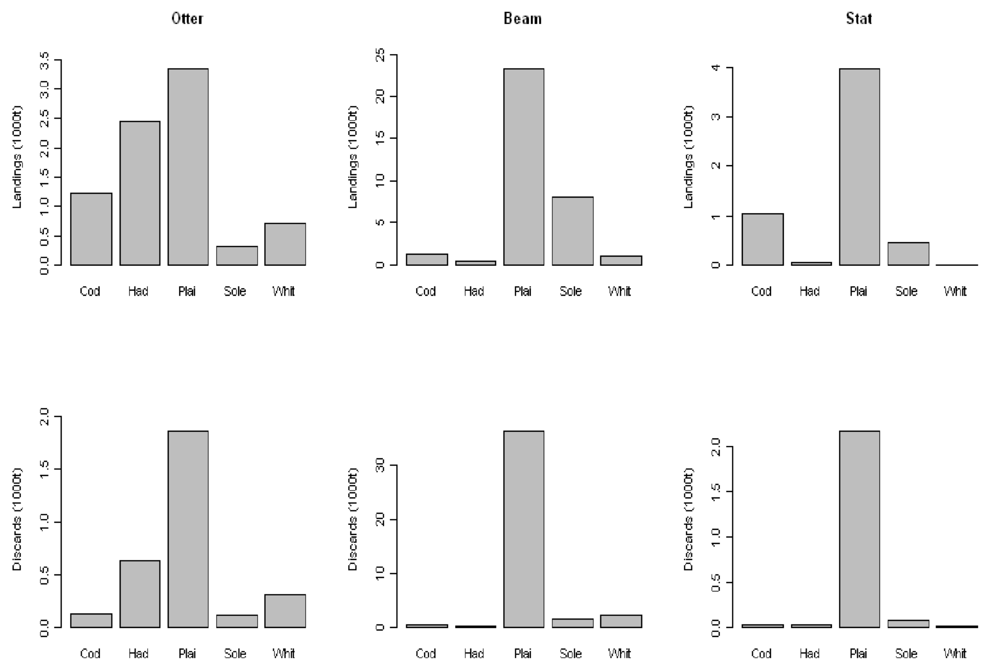


Figure 9. Predicted estimates of landings and discards for the baseline (scenario 0) for the main commercial species for the three categories of gears. "Otter" = otter trawl, "Beam" = beam trawl, and "Stat" = static gear.

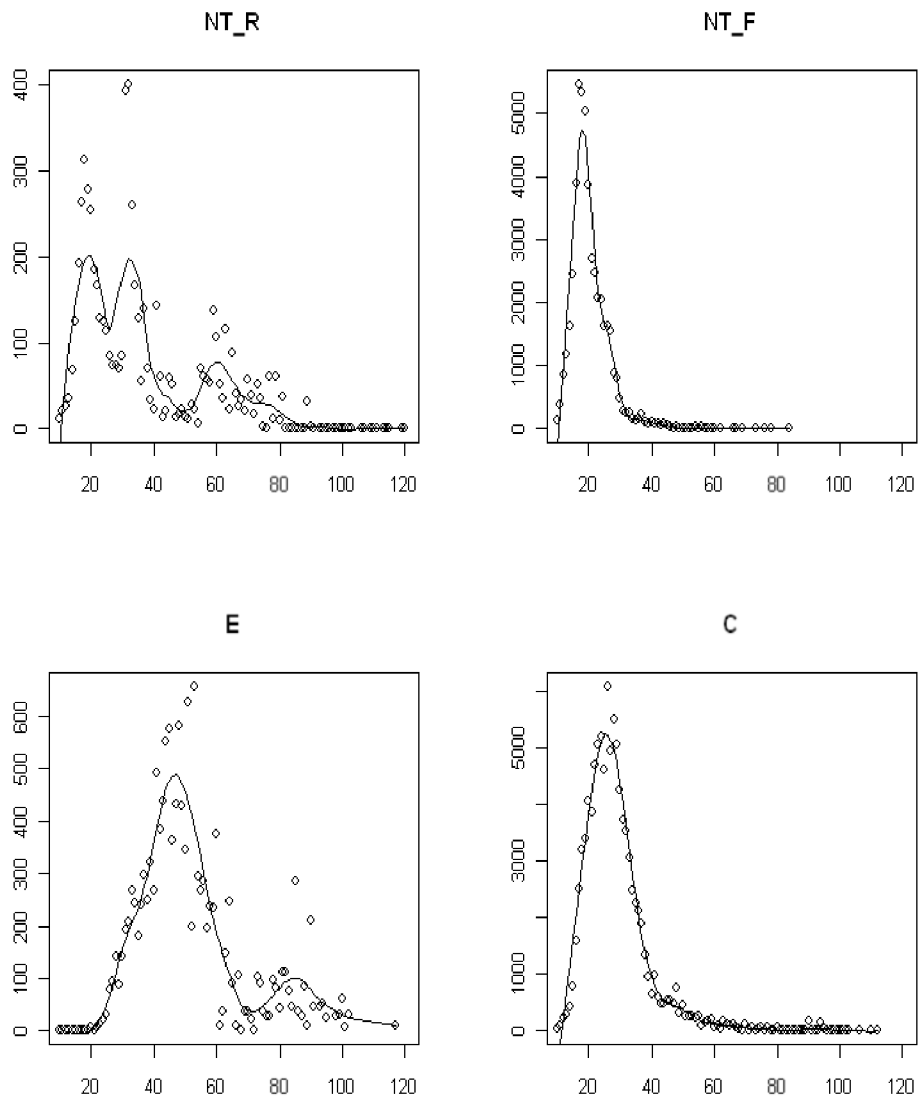


Figure 10. Absolute size-specific removals by fishing (tonnes) in the baseline (scenario 0) of fish assigned to one of the four major groups of fish: (NT_R) non-target roundfish, (NT_F) non-target flatfish, (E) elasmobranchs, and (C) commercial species. Dots are model estimates per 1-cm class, and lines are derived from a loess smoother.