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Technical Report

Sustainable brown shrimp fishery - is pulse fishing a promising option?

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1. Summary

Pulse trawling is an alternative fishing technique aimed at the reduction of intensive seabed contact and poor selectivity (high bycatch rates) as major shortcomings of standard shrimp beam trawling.

In standard trawl fisheries, beam trawls with bobbin ropes are used to target brown shrimp. This fishing technique negatively impacts the marine environment and thus conflicts with protection requirements in marine protected areas, especially in the Wadden Sea national parks. A significant aspect in developing ecologically sustainable fisheries is therefore the development of measures to reduce the adverse environmental impacts of shrimp fisheries. Pulse fishing with electro-trawls is currently being discussed as a promising option to mitigate the disadvantages of traditional beam trawling by reducing seabed contact and enhancing selectivity. However, fishing by means of electric currents in the ocean is principally prohibited. Only since 2009 does an exemption permit the HOVERCRAN's use as a commercially applicable system by 5 % of a country's beam trawl fleet (in terms of flatfish and shrimp vessels).

Mode of operation: In pulse fisheries, the mechanical stimulation by traditional bobbins is (partially) replaced by electrical stimulation with electrodes. The electric pulses provoke a flight response (tail-flip) in brown shrimp which forces the animals to jump into the water column and makes them accessible to the fishing net. Short electric pulses with a low frequency (0.25 ms and 4.5 Hz) are used to selectively provoke a reaction from shrimp without stimulating unwanted bycatch organisms such as other invertebrates or fish.

Impact on the seabed: Compared to flatfish beam trawls, shrimp beam trawls are lighter, which lessens their negative impact on the seabed. However, animals living in and on the seabed are not affected by the penetration depth of the gear alone, but among other things also by the direct removal of organisms. Sensitive habitat-forming biotic communities such as *Sabellaria* reefs or sea cypress populations are almost extinct in some of their original habitats, e.g. the Wadden Sea, where much of the shrimp fishery takes place. The reason for this decline is discussed controversially, in particular with regard to the impact of multiple trawling and the mechanical destruction of benthic species.

Shrimp catches: Shrimp fishery with electrical trawls is less dependent on abiotic factors such as light intensity and water turbidity than the fishery with standard beam trawls. Fishing efficiency strongly depends on the configuration of the gear. In its original hovering configuration with raised ground rope (HOVERCRAN), the pulse trawl caught fewer large shrimp than the conventional beam trawl. This loss was compensated by reducing mesh sizes in the top panel as this prevented the tail-flipping shrimp from escaping through the meshes of the top panel. With this setting, a similar catch weight of shrimp was obtained as with standard beam trawls. In configurations where the electrical pulse was combined with additional bobbins in the ground rope, catches of large shrimp were even higher than with standard beam trawls. Set-ups using 9 or 11 bobbins (compared to 36 bobbins in a conventional beam trawl) caught 10 % more shrimp. A combination of a standard beam trawl with electrical pulses resulted in a 50 % increase in shrimp catches.

Bycatch: Ideally electrical stimulation as applied in the pulse fishery selectively provokes a flight response in shrimp without affecting other benthic species. However, for most of the typical bycatch fish (e.g. dab, plaice, sole[1]), a substitution of the mechanical stimulus of commercial beam trawls by an electrical stimulus alone did not result in reduced bycatch rates. But electrical pulses in combination with a ground rope that was raised by 10-15 cm achieved the desired results. In the original HOVERCRAN configuration (without bobbins), bycatch (fish and invertebrate species) was reduced by 35 %. But in a setting of a pulse trawl in combination with 11 bobbins, the bycatch rate was only reduced by 15 %. In addition, preliminary results of investigation on various settings of shrimp pulse trawls (without sieve net[2]) in Belgium and the Netherlands revealed considerably higher bycatch rates for some species, compared to traditional beam trawls with sieve nets. As these results only cover part of the investigation period, it is advisable to wait for the final results to become available before the technique is subjected to a final evaluation. In another investigation, bycatch rates of a pulse trawls equipped with 10 bobbins were reduced by 15 % compared to a standard beam trawl without sieve net.

Comparison with flatfish pulse trawls: The basic principle of a pulse trawl for shrimp differs significantly from that for flatfish, as pulses are low in voltage and frequency. While theses pulses are sufficient to induce muscle contractions in shrimp, they induce only general behavioral reactions (flight response) of fish. Ideally, this flight reflex enables the fish to escape underneath the net. Pulses as applied in flatfish trawls have higher electric field strengths, higher pulse frequencies (40-45 Hz) and a longer duration of exposure. They lead to muscle cramps that make the flatfish contort upwards in a U-shape, which makes the animal easily accessible to the approaching fishing net.

No injuries of fish and invertebrates have been observed in bycatch organisms of shrimp pulse trawls, contrary to findings in flatfish pulse trawls. No mortality was observed in typical bycatch species after exposure to electric fields such as those used by shrimp pulse trawls. Some on-going studies further investigate whether or not non-target fish and invertebrates suffer injuries from exposure to shrimp pulses.

Opportunities and risks: Ecological opportunities of shrimp pulse trawls (depending on the setting) are reduced bycatch rates and less damage to the seabed and the associated benthic organisms. Savings in fuel consumption that lead to substantially increased profits in flatfish pulse fishery are of minor importance for shrimp pulse trawling as towing speed and towing resistance are small compared to flatfish trawls.

On the other hand, this technology entails considerable risks to the environment. It is only a small step from an increased efficiency in capturing brown shrimp to overfishing of the entire stock if a large-scale introduction of pulse fishery is not accompanied by the implementation of effective management measures (such as effort limitation, e.g. by means of fleet reduction), scientific monitoring as well as measures of surveillance and control. Especially a combined use of pulse trawls with standard bobbins in the ground rope requires clear rules, provided that pulse fishery will be allowed for more than 5 % of a nation's beam trawl fleet.

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[1] Common sole, Dover sole (Solea solea)

[2] Sieve nets are also called veil nets. See also chapter 5.3.1.

As a **preliminary conclusion**, based on today's knowledge, the use of pulse trawls in shrimp fisheries should only be allowed in settings with raised ground rope and without the application of additional bobbins. Moreover, a comprehensive legislative framework is strictly necessary in order to regulate the admissible technical settings of pulse trawls. Measures of surveillance and control have to be unequivocally defined in order to offset any possible increase in efficiency by means of effort limitations.

The regional coastal fishery belongs to the North Sea coast. However, it needs to find ways in future aiming for better nature protection. For a better protection of the nature under water in the Wadden Sea, WWF wants to find solutions together with the fishery. Foto: H.-U. Rösner/WWF.

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2. Introduction, scope of work

Fishing with standard beam trawls has major shortcomings and is therefore not in accordance with the requirements of nature conservation or with the demands of ecologically sustainable fisheries. Beam trawls have a significant impact on the seabed (in shrimp trawls by runners and bobbins, in flatfish beam trawls by heavy tickler chains or chain mats that penetrate deeply into the seabed) and destroy benthic communities. Moreover, despite the use of sieve nets (which is not obligatory in most cases) and other bycatch reducing devices, shrimp trawls are a non-selective fishing technique. The North Sea shrimp fishery targets brown shrimp (*Crangon crangon*) and, due to the small size of the species, uses small mesh sizes of about 20-25 mm. This results in high bycatch rates of organisms which are non-marketable and will thus be discarded. The common bycatch comprises large numbers of juveniles of commercial and non-commercial species, other crustaceans and juvenile shrimp (see also compilation of Fischer 2009). Many fish species, e.g. plaice and sole, have their nursery grounds in the vulnerable Wadden Sea, which is at the same time one of the main harvesting areas of the shrimp fishery. The Wadden Sea is highly protected area because of its unique biogeophysical properties. It is designated as a national park, as an element of the Natura 2000 network of protected areas, as an internationally important wetland according to the Ramsar Convention and as an UNESCO biosphere reserve. The high natural value of the area led to its recognition as a UNESCO natural world heritage site in 2009.

The Wadden Sea, the main harvesting area of shrimp fisheries, is a nursery ground e.g. for plaice and sole and is of high ecological value.

Efforts to mitigate the negative impacts of commercial beam trawl fisheries have existed for almost as long as the fishing technique itself has been applied in the North Sea. Considerations and investigations to replace the bobbins as used in standard shrimp beam trawls by electrical stimulation are being made since the 1960s. However, electrical fishing in the ocean is principally prohibited (chapter 3). It is only since 2009 that the HOVERCRAN as a commercially applicable system may be used by 5 % of a country's beam trawl fleet (in terms of flatfish and shrimp vessels) due to an exemption (chapter 4).

The aim of this study is to evaluate the ecosystem compatibility of shrimp pulse trawling based on the available literature and on results of the latest scientific research. Apart from describing the effects on bycatch organisms and the seabed, the impact analysis also includes an evaluation of the impact on the shrimp stocks themselves (chapter 5). This may result from catching undersized shrimp or from higher catches as a result of enhanced efficiency. Finally the feasibility of protective policy objectives in protected areas where shrimp fishing takes place is evaluated.

Currently, investigations are under way in Germany, the Netherlands and Belgium[3] that aim at improving opportunities to evaluate the gear's ecosystem compatibility. As final results are not yet available, the assessment presented in this report can only be preliminary in many important respects. It is required nonetheless because currently important changes are conceivable concerning the management of shrimp fisheries, and the relevant decisions by a competent body need to be underpinned by the essential elements of evidence, especially with regard to environmental compatibility of the technology. Investigations of pulse trawls in flatfish fisheries are only presented in exceptional cases when information on shrimp trawls is lacking and investigations on flatfish trawls are used in theas an alternative for evaluation, or when they are important for a comparative analysis.

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[3] At Thuenen-Institute (D), IMARES (NL), and ILVO (B).

Furthermore, this report identifies future needs for research and knowledge gaps and considers specific features of the legal regulation that should provide comprehensive control and ensure that adverse side-effects will be reduced (chapter 6).

Based on a literature study the following questions shall be answered in this report:

A. What technical aspects characterize shrimp pulse fisheries and what are the differences compared to flatfish pulse fisheries?

B. What is the catch efficiency of pulse trawls, compared to standard shrimp beam trawls, and what are the ecological risks with regard to the sustainable use of the resource?

C. What impacts result from the use of pulse trawls on the seabed, compared to standard shrimp beam trawls?

D. What are the bycatch rates of undersized shrimp, fish and invertebrates in pulse trawl fisheries, compared to standard shrimp beam trawl fisheries?

E. What impacts result from the use of pulse trawls on vertebrate and invertebrate organisms? What is the level of current knowledge and which future needs for research exist?

3. Legal framework

Shrimp fishery in the North Sea

The United Nations Convention on the Law of the Sea (UNCLOS) provides the overall legal framework for all activities with respect to the use of the world's seas. With respect to shrimp fisheries: in the German territorial seas of the North Sea, between the 3- and the 12-nautical mile lines, also Danish and Dutch fishing vessels have fishing rights with the legal framework being provided by the Common Fisheries Policy (CFP) of the European Union (EC no. 1380/2013). Based on the CFP, shrimp fishery is not regulated by catch quotas. However, shrimp stocks are regularly assessed by a working group of the International Council of the Exploration of the Sea (ICES) (Working Group on Crangon Fisheries and Life History, WGCRAN), based on investigations of the national fishery research institutes (Aviat et al. 2011).

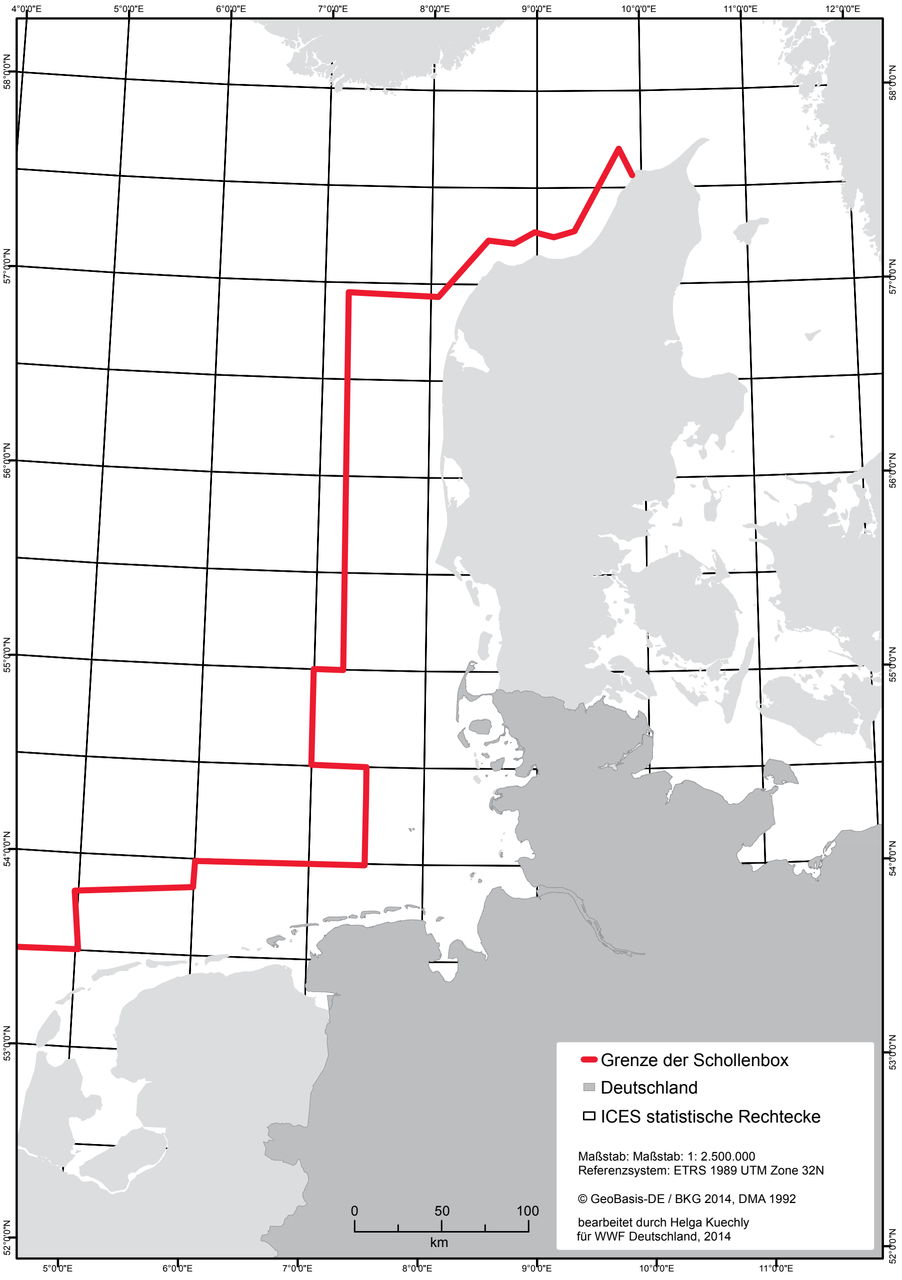

Figure 1: Position of the plaice box in the North Sea.
Source: European Commission, in: Aviat et al. 2011.

Pursuant to Council Regulations 3094/86 and 55/87, the area known as the "**plaice box**" in the south-eastern North Sea (Figure 1), is closed for beam trawling by large fishing vessels (>300 hp/221 kW) in order to protect undersized plaice from ending up as discard. As a result the engine power of most shrimp trawlers no longer exceeds this value. Fishing by smaller vessels (total length 8-24 m) is permitted provided they are on an authorized list and their engine power does not exceed 221 kW (Aviat et al. 2011).

Pulse fishery

In 1987, the German authorities banned electrical fishing on a commercial scale because they feared that catch efficiency of the beam trawl fleet would further increase and shrimp stocks would be at risk of overfishing. One year later the Dutch government also issued a national ban. Following these national restrictions, the European Commission prohibited the use of electricity to catch marine organisms (EC no. 850/98, article 31, paragraph 1: "The catching of marine organisms using methods incorporating the use of explosives, poisonous or stupefying substances or electric current shall be prohibited.")

Fishing by means of electric currents in the ocean is in principal prohibited, but an exemption allows 5 % of a country's beam trawl fleet to use pulse trawls.

In March 2006, the European Commission commissioned ICES to evaluate and review the state-of-the-art concerning the use of electrical stimulation for beam trawling. The ecosystem impacts of a widespread introduction of pulse fisheries were of special interest to the Commission (ICES 2006). The recommendations of the "ICES-FAO Working Group on Fishing Technology and Fish" of May 2006 conclude that the pulse trawls had some preferable properties compared to standard beam trawls, but the potential for inflicting an increased unwanted mortality on target and non-target species required additional experiments before any final conclusion could be drawn on the possible ecosystem effects of this gear (ICES WGFTFB 2006). The advantages include reduced bycatch rates of undersized fish and non-target invertebrates, reduced fuel consumption and a lower swept-area per hour. On the other hand, the fact that the gear might inflict increased mortality on target and non-target species that contact the gear without being retained was identified as a major disadvantage. If the pulse trawl were to be introduced into commercial fisheries, there would be a need to closely monitor fisheries with a focus on the technological development and bycatch properties (ICES 2006). The working group specifically demanded investigations of potential spinal damage of cod exposed to electrical stimulation, potential effects on invertebrates and possible disruption of the electric sensory systems of elasmobranchs (ICES 2009).

Subsequently, the European Commission granted an exemption that is laid down in Regulation EC no. 43/2009, Annex III: No more than 5 % of the beam trawler fleet of any Member State shall be allowed to use the electric pulse trawl in the southern North Sea, provided that the maximum electric power in kW for each beam trawl is no more than the length in meter of the beam multiplied by 1.25 and the effective voltage between the electrodes does not exceed 15 V. In addition, the vessel has to be equipped with an automatic computer management system which records the maximum power used per beam and the effective voltage between electrodes. This exemption has been granted every year since 2007 (EC no. 1288/2009 and 579/2011). There is no requirement to perform additional accompanying research of the impacts of pulse fisheries. It is not specified whether the term beam trawl fleet relates to shrimp beam trawls or flatfish beam trawls. 5 % of the **German fleet** amounts to a total of 13 licenses, all of which have already been allocated. 12 licenses are designated to be used in the flatfish fishery and one in the shrimp fishery. As of December 2012, only two flatfish trawlers and one shrimp trawler were equipped with pulse trawl gears (German Bundestag 2012). The common practice of obtaining a license without using it hinders the scientific investigation of pulse trawling in Germany.

More investigations at the Netherlands Institute for Marine Resources & Ecosystem Studies (IMARES) between 2007 and 2009 (chapter 5) provided the basis for updated ICES recommendations (ICES 2009) that were requested by the European Commission and the Dutch ministry. ICES (2009) concluded that the pulse fishery may offer advantages over standard beam trawl fishery, but that there were indications of unwanted side effects on target and non-target species. Thus further research was needed to draw firm conclusions on the potential to further relax the ban on electro fishing (ICES 2009).

In 2012, the Scientific, Technical and Economic Committee for Fisheries (**STECF**) of the European Commission was also requested to give its opinion on whether the concerns expressed by ICES in 2006 and 2009 regarding the ecosystem and other effects (in particular control and enforcement issues) of this gear had been adequately addressed. STECF recommended that the control and enforcement issues be resolved before the proportion of the beam trawl fleet using pulse trawls was increased. Any extension of the fishing area as well as any application of pulse technology in other gear types should be considered only after an impact assessment on the effects of the pulse trawl on the ecosystem was performed, in particular when species not subject to a prior impact study could be affected by the gear (STECF 2012).

The Demersal Working Group of the North Sea Regional Advisory Council (**NSRAC**) also addressed issues of the pulse fishery at its September 2012 meeting and reached the following conclusions: The remaining ecological concerns should be continuously addressed by the commercial vessels through monitoring programs. Only then would enough information become available. NSRAC believes that the pulse trawl is a major step towards more sustainable fishing. The NSRAC agreed with STECF that comprehensive monitoring regarding the use of pulse gear should be established. The certification system being developed in the Netherlands, reversing the burden of proof (known as “results based management”), should provide the necessary basis for this (NSRAC 2012).

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4. Pulse beam trawls

4.1 Glossary of technical terms as they relate to pulse trawls

Scientific reports describe the technical settings of pulse trawls in some detail. Hence, some physical parameters are explained focusing on the mode of operation in electro trawling with regard to the target species (see also chapter 4.4). Relevant features of the pulse trawl are: voltage (amplitude in volts), electric field strength (in volt per meter), pulse frequency (in hertz), pulse duration (in microseconds or milliseconds), pulse shape, pulse characteristics (continuous or interrupted), towing speed and the electrode configuration (diameter, length, arrangement of conductor and insulator components, etc.). On the “biological” side, important features are the impacted species, the length of the organism, the position and orientation in the electric field, conductivity of the sea water (depending on temperature and salinity) and the organism as well as sediment properties.

Pulse duration and pulse frequency

The relevant signal of a pulse trawl consists of singular electrical pulses of comparatively low intensity and short duration. In the affected organism, they induce muscle contractions (comparable to electrical signals transmitted by the nerves). When repeated at low frequencies, the muscle relaxes and subsequently contracts again. The typical frequency (rhythm of the pulses) of a shrimp pulse trawl is about 5 Hz (5 pulses per second). This means that the phase between two pulses is 166 ms. Pulse duration is in the order of 0.2 ms (ICES 2011). Experiments with frequencies as low as this revealed that they trigger a continuous sequence of tail flips (by contraction and relaxation) which makes the animal jump from the seabed into the water column (Polet et al. 2005a,b). This makes the shrimp accessible for the fishing net that is towed close to the seabed.

Once the frequency exceeds a certain threshold value, the muscle contractions occur in such short succession and without a relaxation phase in between that the muscles are continuously stimulated and remain contracted (cramp). In combination with higher voltages and pulse durations, such as those applied in flatfish pulse trawls, this makes flatfish like plaice and sole bend in a U-form as a result of their powerful dorsal muscles. This makes it easy to collect the fish with the ground rope of the trawl (van Stralen 2005) (see also chapter 4.6).

Electric field strength

Electric field strength, measured in volts per meter, describes the intensity and directivity of an electric field. The definition is based on the force that an electric field applies to charged objects in its vicinity. A visual presentation shows field lines that run from the positive electrode (cathode) to the negative one (anode) (Figure 2). The line density indicates the field strength at a certain point. As the risk of injury to fish does not result from the field strength alone, but also depends on the size and orientation of the animal, high field strengths do not necessarily stand for a high risk of injury. For example no spinal injuries were induced in small cod by field strengths of 250–300 V/m, whereas large cod often suffered injuries at significantly lower field strengths of 40–100 V/m (De Haan et al. 2011).

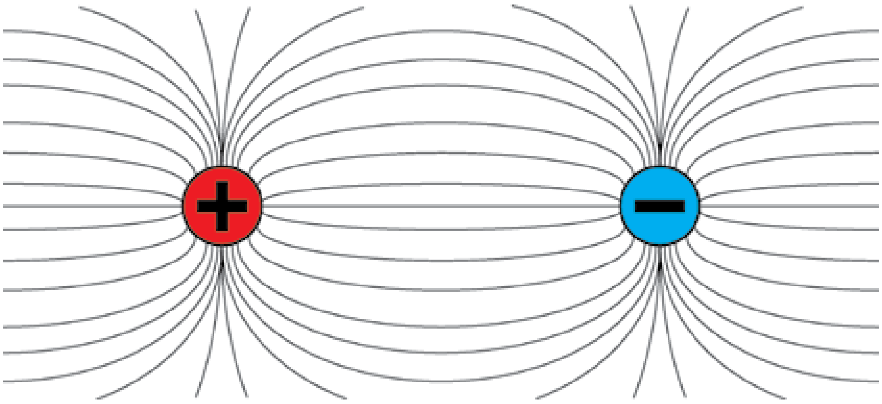


Figure 2: Cross-sectional view of a heterogeneous field between two wire-shaped electrodes (+) and (-). The field lines (purple) run from + to -. Areas of equal potential (equipotential lines) are in pink. Electric field strength is highest close to the electrodes and lowest midway between the two electrodes. Moreover, the field strength depends on the distance of the electrodes and the voltage. Source: ICES (2012).

Electric potential and voltage

The electric potential is the work (energy per time or the product of load and voltage) required to carry a charge in an electric field from one point to another. Like voltage, the electric potential is measured in volts. Important for the effect of an electric field is the potential difference. For a fish in an electric field this means: The larger the difference between the head and the tail of a fish, the more lines of equal field strength (equipotential lines) are covered, and the higher the potential difference along its body the more strongly it experiences the electric field. Therefore, a large cod with a larger potential difference over its body will show greater reaction than a small cod (Figure 3). This effect may influence the susceptibility of an organism to injuries. The orientation of the fish in the electric field also has a significant influence on the potential difference over its body (Soetart et al. 2013).

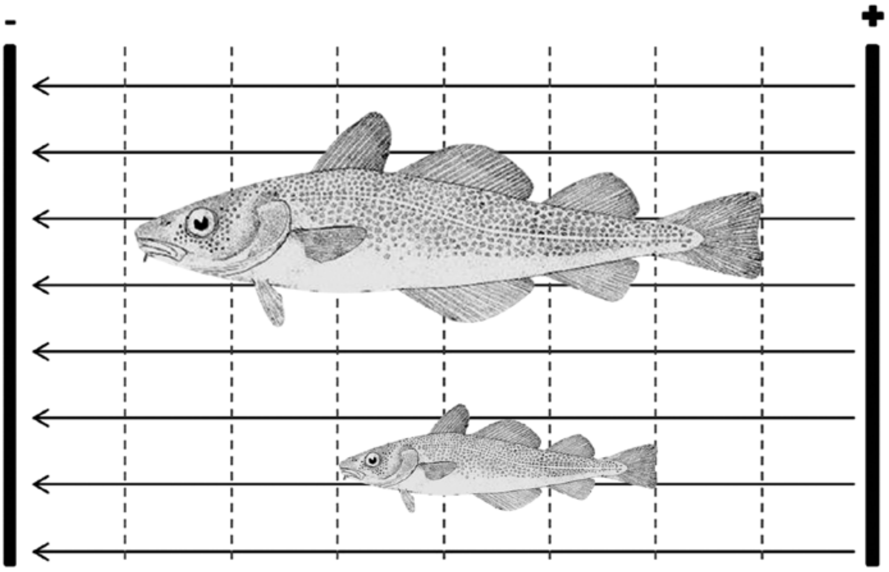


Figure 3: Correlation between body size and potential difference. Both cod are orientated at right angles to the electrodes (bold lines; Left: cathode; Right: anode) in an idealized (homogenous) electric field. The arrows are the field lines, the dashed lines are zones with the same potential (equipotentials). Source: Soetaert et al. (2013)

4.2 Development of pulse trawling in shrimp fisheries

First speculations on the **effectiveness of electricity for catching shrimp** probably date back to 1765 (Baster 1765). First field trials of pulse trawls in shrimp fisheries were performed as early as the 1950s in order to open the “bad bottom” areas (from a fisher’s perspective) at the west-coast of Florida to commercial shrimp fishing. At the time, due to widespread coral growth and large sponge beds which restricted trawling, the area was only partially exploited by fisheries. However, the resulting calculations of the power needed to electrify a shrimp trawl showed that the size and costs of the required pulse generator (32.5 kW) would be economically impractical (Higman 1956). Then the prototype of a pulse trawl was developed in the Gulf of Mexico in 1967, aiming to catch nocturnally active species of shrimp during the day and thus increase the catch efficiency in shrimp fisheries (Pease & Seidel 1967). Seidel & Watson (1978) describe a separator trawl designed to selectively capture shrimp and eliminate the incidental capture of bottom fish and other marine organisms. The gear was not towed from a beam trawl, but most probably from an otter trawl. Fish bycatch was eliminated by closing the entrance to the net completely with a fish barrier made of webbing. Shrimp passed into the trawl through the bottom of the net which was constructed of large mesh webbing (30-45 cm) and towed at 30-60 cm from the bottom. Shrimp were forced up through the bottom mesh of the net by the electric field (field strength 30 V/m, pulse frequency 4–5 Hz) located under the net, while the fish were frightened away from the path of the net by the shrimp-specific electric pulses. The electrode array was attached to the footrope of the trawl and trailed back under the net to create an electric field (Seidel & Watson 1978). In contrast to the frightening effect on fish, previous experiments had demonstrated that higher pulse frequencies of 20–35 Hz (at a minimum field strength of 15V/m) induced electrotaxis (swimming to the positive electrode) in fish (i.e. five coastal pelagic fish species with total lengths about 10 cm) (Seidel & Klima 1974).

Targeted investigations of electrified shrimp trawls in the North Sea shrimp fishery started in the 1960s in the Netherlands (Boonstra & de Groot 1970, 1974a,b). In the 1970s, further investigations on electrical fishing for shrimp and sole were undertaken in Belgium (Vanden Broucke 1972, 1973). The objectives of the experiments were to some extent different for flatfish and for shrimp. With regard to flatfish, a selective fishery and a simplification of the gear by replacing the heavy chains by lighter electrodes were aimed at. With respect to shrimp fishery it was endeavored to develop a switch-over from the traditional night-time fishery to a day-time fishery (Vanden Broucke 1973). In the same period, investigations of flatfish pulse trawls were performed in England (Stewart 1975, 1977, 1978) and Germany (Horn 1976a). Most European investigations were carried out in the Netherlands (IMARES, formerly RIVO-DLO), Belgium, (ILVO, formerly RvZ), England (SEAFISH), Germany (TI, formerly BFA-Fi,) and France (Ifremer). However, many of the results were not officially released but solely published in internal reports.

From 1972–1988, Russia/Lithuania had an institute with 140 staff member (40 of whom were electrical engineers and 20 fisheries biologists) in Klaipėda. The institute aimed specifically at the development of electrical fishing (ICES 2011). In a comprehensive literature review in the course of the EU ALTSTIM project (van Marlen 1997), three phases within the investigations of electrical fishing were distinguished as follows:

1. The shrimp period: 1966–1979

2. The flatfish- (sole-) period: 1979–1985

3. Commercialization attempts: 1986–1988

Investigations focused on the reduction of fuel consumption and increased catch efficiency, but the reduced habitat impact and the increased selectivity, leading to reduced mortalities of juvenile flatfish, were used as an argument in favor of this technique from the very beginning (Boonstra & de Groot 1970, Stewart 1978, Horn 1976b). As mentioned by van Marlen in his literature review in ICES (2011), the technologies developed along similar lines in the early studies. From today's perspective it might be asked why all these valuable investigations did not result in the development of commercially applicable fishing gear. In spite of much interest expressed by the fishing industry and much cooperation that took place, market introduction was hampered by high investment costs in combination with the high vulnerability of any electro-fishing device. In summary, the development was driven very much by science and attempts for a market introduction were not made before the end of the projects (ICES 2011). Investigations of pulse trawls continued until the 1980s when they stopped in all North Sea coastal States because of national bans on electrical fishing that were driven by the fear of overfishing (Polet 2005a) (chapter 3).

The following years saw experimental investigations of pulse trawls in the USA (Holt 1992, quoted in Polet et al. 2005a) and in India (van Marlen 1997). In the 1990s, pulse trawls were introduced in the shrimp fishery in the inshore waters of the East China Sea on a large commercial scale. However, due to the lack of effective management, the utilization of the new technology resulted in a massive overfishing of shrimp stocks. Consequently, in 2001 pulse trawling was banned completely from the East China Sea (Yu et al. 2007) (chapter 5.2.1). In 1997 a Belgian fishing vessel owner discovered pulse trawling in China, where at that time more than 2,000 vessels applied this technology. He brought a pulse generator back to Belgium and this renewed the European interest in pulse trawling (Polet et al. 2005a). Finally, under the pressure of rising fuel prices, pulse trawls once again came into focus at the beginning of the 21st century due to their reduced towing resistance. Despite high investment costs, an economically efficient operation now seemed possible. This resulted in new developmental activities that led to the introduction of the first commercial system in 2009 (Soetaert et al. 2013) (see also chapter 4.5).

4.3 Mode of operation of standard shrimp beam trawls

In conventional beam trawl fisheries, shrimp are mechanically stimulated by bobbin ropes, in pulse trawl fisheries by electrical stimulation with electrodes.

In conventional North Sea fisheries, beam trawls with bobbin ropes are used to target brown shrimp (Figure 4). The mouth of the net is held open by two solid metal bars, the beams, usually of 8-9 m length (12 m is permissible), and a ground rope with bobbins, hard rubber rollers that keep the trawl in contact with the bottom. At the sides, the beam is fixed to two skids or beam shoes, made of steel, which travel along the seabed. The nets are towed from outriggers on both sides of the fishing vessel. As the gear is towed over the seabed, the ground rope stimulates the shrimp to jump into the water column so that they can be scooped up by the net.

The traditional way to stimulate brown shrimp in beam trawls is mechanical, i.e. by the bobbin rope. The bobbins induce rapidly rising water currents which, in combination with vibrations of the sediment, cause startle reactions in buried and emerged brown shrimp. The tail flip (Figure 5) makes the animals jump into the water column even before they are actually touched by bobbins (Berghahn et al. 1995).

Figure 4: Schematic drawing of a beam trawl (Tischer 2014). The beam is towed and travels on the shoes along the seabed. Bobbins are fixed to the ground rope to induce mechanical stimulation that make the shrimp jump into the water column.

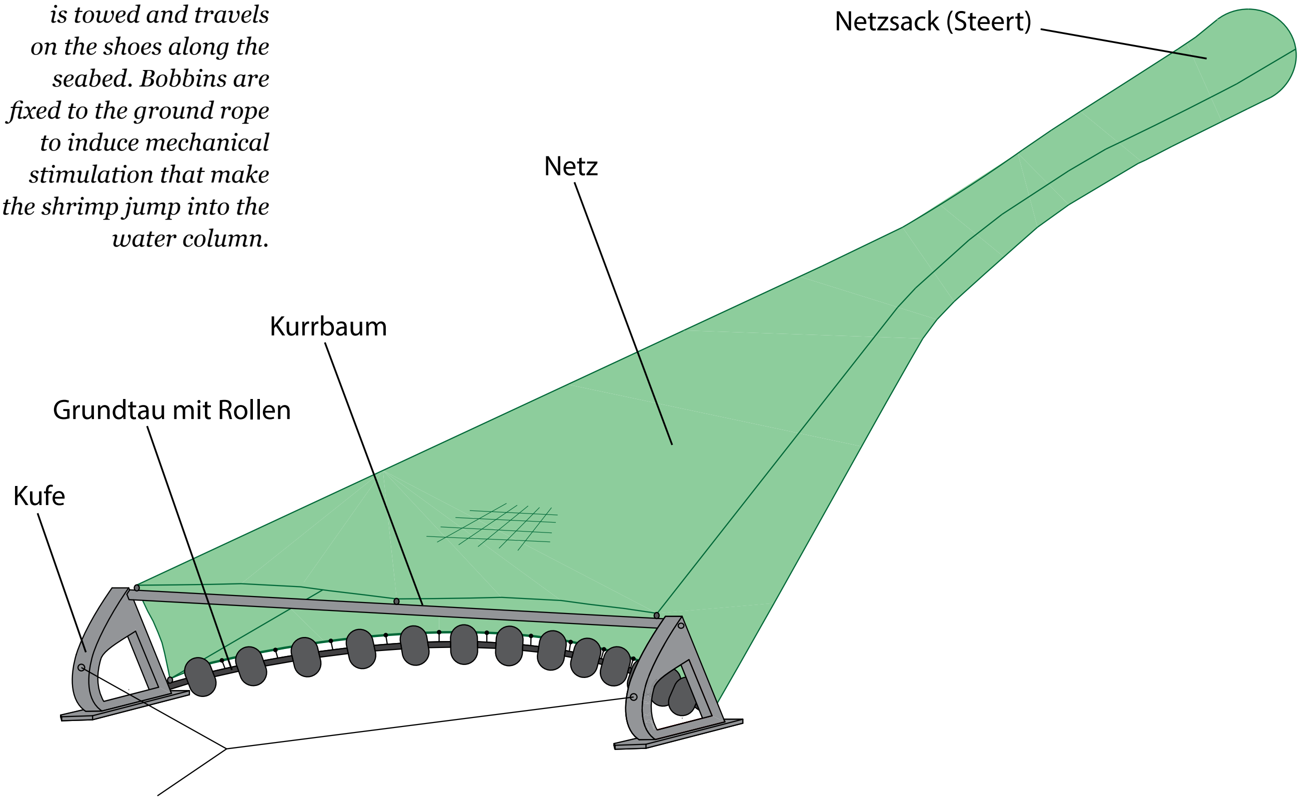


Figure 5: Typical startle reaction in brown shrimp. Tischer 2014 after: Verschueren & Polet 2009.

The typical mesh size in the codend of a shrimp trawl is 16-26 mm, in the German fleet sometimes even smaller. Compared to a flatfish trawl with a total weight of up to 12 t (Rauck 1985, FAO 2013), a shrimp trawl is much lighter. The trawl, the shoes and the bobbin ropes together have a total weight of about 550–750 kg (Verschueren et al. 2012).

The ground rope of a shrimp trawl is typically equipped with 24 to 40 (in Germany usually 36) bobbins. The ground rope is longer than the beam and thus, when towed over the ground, forms a U-shaped curve. As a result, the bobbins are towed over the ground in a skewed position, which, in turn, leads to a high towing resistance with resultant high fuel consumption. With regard to bycatch it is unfavorable that the bobbins are arranged close to one another so that larger fish which are not targeted by the fishery cannot escape between the bobbins and underneath the net.

4.4 Mode of operation of pulse trawls

The construction principle of a pulse shrimp trawl does not differ much from a conventional beam trawl (Figure 6). The shrimp pulse trawl aims at reduced bycatch rates and seabed contact. The basic idea is to replace the mechanical stimulation of a standard beam trawl (chapter 4.3) by (additional) electrical stimulation. The use of a specific electric field close to the seabed ideally induces an upward flight response in shrimp, while not affecting most of the typical bycatch species such as fish and invertebrates (Figure 7) (chapter 5.3).

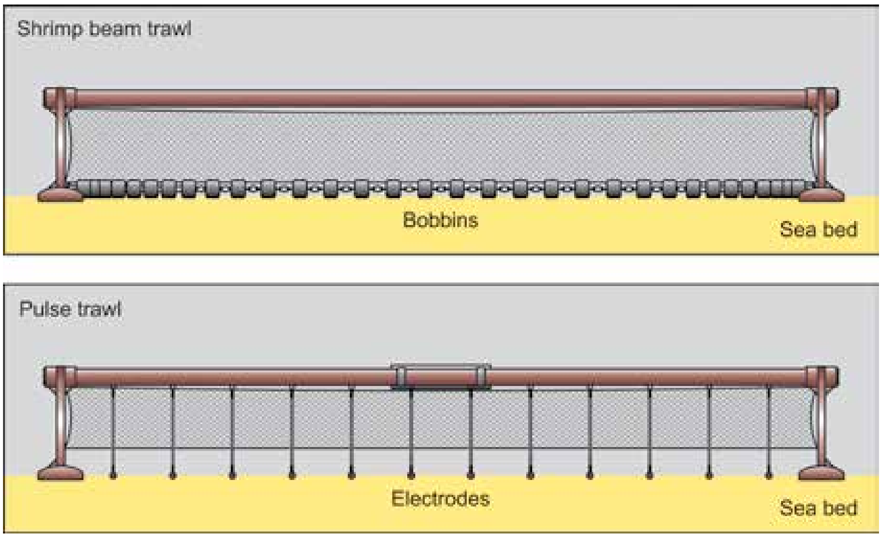
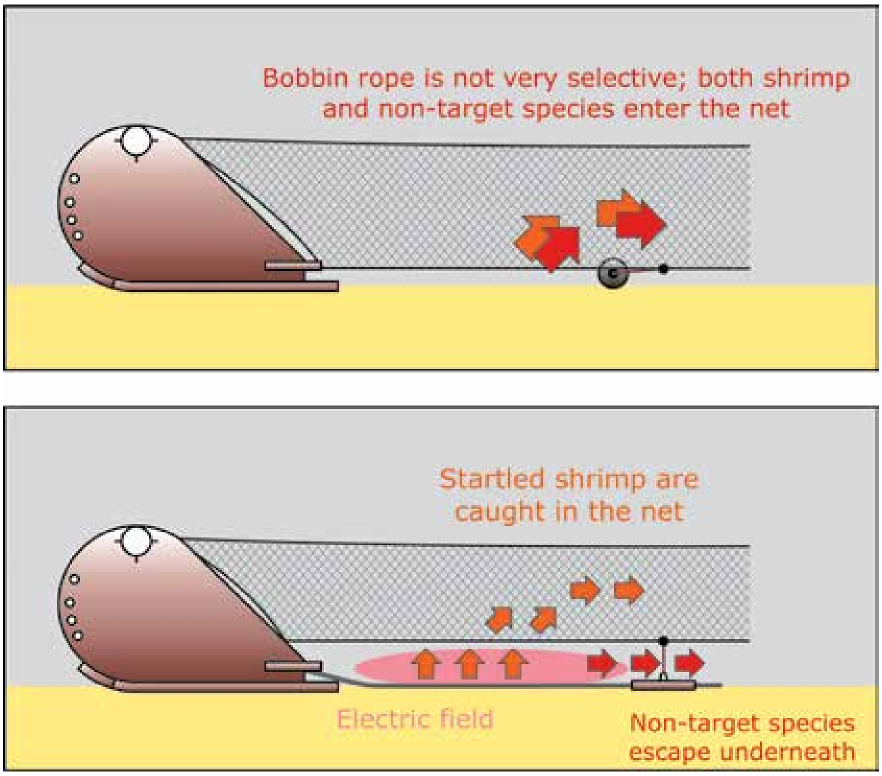


Figure 6: Schematic drawing of a standard beam trawl with bobbin rope (above) and the HOVERCRAN (below) with 12 electrodes at the seabed. Source: Verschueren & Polet 2009.

Figure 7: Schematic drawing of the operating mode of a shrimp pulse trawl. Above: standard beam trawl, below: further developed shrimp pulse trawl with raised ground rope designed to let fish escape underneath the trawl. Source: Verschueren & Polet 2009.



The basic principle of a shrimp pulse trawl is the application of a shrimp-specific pulse that does not stimulate other species. In combination with a raised ground rope and smaller meshes in the top panel than in the lower panel, the pulse makes the shrimp jump over the ground rope into the net. Animals not stimulated could then escape underneath the net (Polet et al. 2005a,b). The available results of the investigations of the HOVERCRAN (chapter 4.5) demonstrate that the achievable bycatch reduction depends strongly on the height of the ground rope. The higher the ground rope was raised, the less bycatch occurred (ICES 2011). In field trials by Polet et al. (2005b), the ground rope was raised leaving a vertical gap of 10-15 cm, in the trials performed by ILVO with beam trawler TX-25, the ground rope was raised by 15 cm (Verschueren & Polet 2009). The combination of these two basic principles of the shrimp pulse trawl – a shrimp specific pulse and a raised ground rope– resulted in reduced bycatch rates (chapter 5.3). Moreover, bottom contact can be reduced considerably by total omission of the bobbin rope (van Stralen 2005) (chapter 5.1).

4.4.1 Optimum pulse form

Investigations of the effect of pulse trawls on shrimp often started with experiments on the optimal pulse parameters (Table 1). A startle response in shrimp could be induced by very short square wave pulses[4] of only 0.25-0.6 ms duration (Polet et al. 2005a, b). Experiments with low pulse frequencies of 5-6 Hz revealed that they trigger a continuous sequence of tail flips that maintain the animal swimming in the water column. The pulse frequency of 4.5 Hz applied by the HOVERCRAN therefore corresponds to the experimentally determined tail flip rate of brown shrimp. At lower frequencies the animals sank to the ground as a result of a short rest between two subsequent contractions. At higher frequencies they swam more slowly because the contractions were incomplete. After 15 s, the so-called pulse fatigue set in. The tail flips weakened and the animals slowly sank to the bottom. However, this period is much longer that the stimulation time[5] applied in pulse trawls (Polet et al. 2005a). Throughout the experiments, the best results were achieved with electric field strengths of 30 V/m. The low frequency and the very short pulse duration permit an energy input of only 1 kWh for a single trawl, which is considered very low by the authors of the report (Verschueren & Polet 2009).

A shrimp-specific electric pulse of low frequency and low duration (4.5 Hz and 0.25 ms) is used to provoke selectively a reaction from shrimp without stimulating unwanted bycatch organisms such as other invertebrates and fish.

Experiments were carried out on beam trawler TX-25 with outputs of the pulse generator between 70 % and 100 %. A total of 23 hauls was investigated. The results showed that 100 % output did not increase the catch efficiency when compared to an output of 80 % (which resulted in smaller amplitudes and thus a weaker electric field). Moreover, all other adjustments (70, 90 and 100 %) led to higher bycatch rates of fish and invertebrates in the catch (Verschueren et al. 2012). These findings would imply that the optimum pulse strength is 80 %, and a further increase does not result in a further increase in shrimp catches.

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[4] The steep increase and decrease of the signal are important for the reaction (Verschueren et al. 2012).

[5] At a towing speed of about 2.5 nm/h.

source	voltage	signal duration	pulsefre-quency	result
Higman 1956	relatively low	n/a	5 Hz	» jump height of pink grooved shrimp (Penaeus duoarum): 30–40 cm » pulsed direct current, 60-periods, periods of less than 4 s, current density 15 mA*2,5 cm-^{2} » maximum response 87%, with 1:3 current ratio (phase control factor = 25%) » calculated theoretical optimum electrical conditions: 15,15 mA/2,5 cm, 5,3 Hz, phase control factor 33% » reaction of shrimp inversely proportional to length of the shrimp » no difference in reactions under various temperature regimes
Pease & Seidel 1967	3 V	n/a	4–5 Hz	» direct diver observations to investigate the stimulation of burrowed pink shrimp (Penaeus duoarum) and brown shrimp (P. aztecus) » under optimum electrical conditions, average time to jump 8 cm into the water column was 2.0 s » optimum towing speed: 2.5 kts
Boonstra & de Groot 1974a	2.5-60 V	0.2 ms	1-50 Hz	» optimum pulse duration 0.2 ms, although the shrimp (Crangon crangon) still react with 0.1 ms » maximum pulse frequency to make a completely bur-rowed shrimp jump 20 cm up was 5 Hz
Klima 1968 (quoted in Seidel & Watson 1978)	n/a	n/a	4-5 Hz	» optimum pulse frequency to induce a startle response was 4-5 Hz with a field strength of 30 V/m
Polet et al. 2005a	0-200 V	0.4-0.6 ms	5 Hz	» 100% flight reaction at field strengths of 8 V/m (head to tail) in case of large shrimp perpendicular to the elec-trodes, 12 V/m in case of small shrimp. Parallel to the electrodes, 18 resp. 24 V/m for large and small shrimp was needed » lowest head-tail voltage that invoked a response was 4 V/m » pulse frequency: 1-3 Hz discontinuous tail-flip; 5-6 Hz continuous and complete contraction; 7-9 Hz continuous tail-flip but incomplete contractions » after 15 s exposition: pulse fatigue (tail-flip weakened)
De Haan et al. 2011	53-66 V 1)	50-220 µs	30, 40, 45, 80 & 180 Hz	» experimentally determined field strengths and voltages differ for electrodes hanging vertically beside the ship and under normal fishing conditions with horizontally towed electrodes (error in the order of magnitude of 8-10%, possibly even larger in harbors) » electrode voltage at the surface about 8% lower and field strength 31% lower than at the bottom.

1) field strength 255-311 V/m.

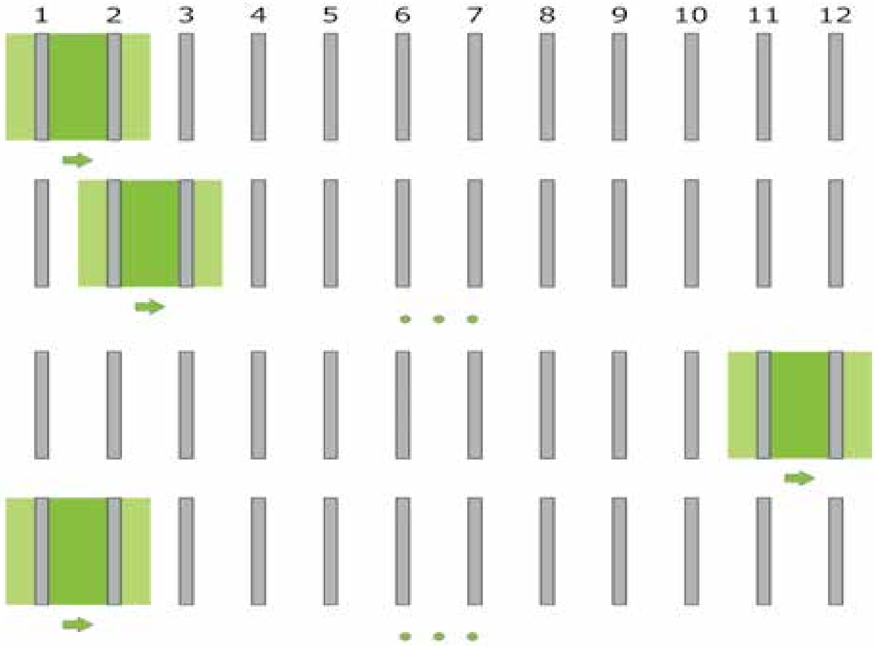
4.5 Current development status of shrimp pulse trawls: HOVERCRAN

At the end of the 1990s the Belgian Institute for Agricultural and Fisheries Research (ILVO) started the development of a commercial pulse trawl based on a Chinese prototype that was imported by the Belgian ship owner Willy Versluys. In 2008 the 8 m commercial shrimp pulse trawl HOVERCRAN was developed in cooperation with the University of Ghent and the Belgian company *Marelec NV* (Figure 8). The name is a synonym for "Hovering Pulse Trawl for a Selective Crangon Fishery" and refers to the hovering movement of the gear over the seabed. In 2009 the HOVERCRAN won WWF's international *Smart Gear*-competition.

Figure 8: The HOVERCRAN with 8 m beams, trawl shoes and 12 electrodes of 3 m length each. Source: Soetaert et al. 2013.

The development of a selective shrimp fishing gear aimed to increase species- and size-selectivity, reduce bycatch and discard rates, reduce impact on the environment and promote a higher quality of the commercial catch (Verschueren & Polet 2009).

Figure 9: Schematic illustration of the electrode pairs that are alternatively driven by the pulse generator in the HOVERCRAN. Source: Verschueren & Polet 2009.



The control unit of the HOVERCRAN on deck of the vessel is fitted by a supply cable with the pulse generator which converts common alternating current into low-frequency pulsed direct current. The generator, is screwed to the beam of the beam trawl. The supply cable of 100 m length and the fishing gear cable have to be driven together by a specific winch (Verschueren & Polet 2009). In the experiments carried out so far, two types of pulse generators were used. The prototype lost more power than originally planned via generator and cable, therefore an optimized device was applied in subsequent investigations. In 2008 a pulse generator with a maximum voltage of 50 V_{peak} was used on vessel O-191, while in 2011 the distance between electrodes was increased from 60 cm to 70 cm and a generator of 65 V_{peak} was used on vessel TX-25. This increased the electric field induced between the electrodes on the seabed from 35 to 50 V/m. Pulse frequencies differed only marginally (4.5 vs. 5 Hz) (Verschueren et al. 2012). 12 electrodes (6 anodes and 6 cathodes) form eleven electrode pairs that are alternatively driven by the new pulse generator (Figure 9). Further differences between the experiments were related to the number of bobbins and the height of the ground rope (Table 2).

Table 2: Specifications of pulse trawls as applied in various investigations (n/a = not available)

vessel	**number of bobbins**	**level of ground rope**	**arrangement**	**source**
O-191	0	5 cm, 10 cm and 15 cm	» combined application of pulse trawl and standard beam trawl (without sieve net) » pulse generator in the middle of the beam » 12 electrode at 60-70 cm distance » pulse trawl with raised and shortened ground rope » 35 different configurations of ground rope, mounting, net and weights	ICES 2012, Verschueren et al. 2012
TX-25	10	15 cm	» combined application of pulse trawl and standard beam trawl (comparison of pulse trawl vs. standard beam trawl with and without 60 mm sieve net) » prototype HOVERCRAN » winches located on outriggers » straight ground rope	ICES 2011, 2012, Verschueren et al. 2012
HA-31	24	n/a	» beam length 9 m » straight ground rope with 24 instead of 36 bobbins » strain relief cable between electrodes	ICES 2012
WR-40 „Jogina“	12, each 12 cm diameter	5 cm	» beam length 9 m » wheels instead of beam shoes » electrode length 1.5 m » distance between electrodes 65-70 cm » towing speed 3 kts	ICES 2012
SD-33 „Marlies“	11	n/a	» beam length 8.4 m » straight ground rope of about 8 m length » steel sleeves as spacers between bobbins and electrodes	Kratzer 2012

The electrodes consist of stainless steel, cables of about 3 m length (Ø 12 mm) are with the central strand removed and replaced by a copper conductor (cross section 10 mm²). The electrodes are fixed to the 8 m beam of the beam trawl and towed horizontally over the seabed in the towing direction. The front half of the electrode is isolated (since 2011) (Verschueren & Polet 2009). In contrast to the electrodes of a flatfish pulse trawl with an alternating conductor, the back half of the electrodes of a shrimp pulse trawl are uninterrupted. In the HOVERCRAN system, pulse amplitude is the only parameter that is variably adjustable. All other parameters, such as pulse form, pulse duration or pulse frequency of 4.5 Hz (2008) and 5 Hz respectively (since 2011) are fixed default values. ICES (2011) report on ideas of the companies *DELMECO* and *Marelec* (chapter 4.6) to develop a trawl for the combined catch of shrimp and flatfish.

4.6 Differences between shrimp pulse trawls and flatfish pulse trawls

In 1992, the Dutch ***DELMECO** Group B.V.* (formerly *Verburg Holland B.V.*) started to develop a flatfish pulse trawl. Following tests of various prototypes (1995: 4 m beam trawl, 1997: 7 m beam trawl) finally a commercially applicable 12m beam trawl was invented in 2004 (van Stralen 2005). The pulse generator delivers electric power to the 25 electrodes attached to the beam with 0.42 m spacing. An electrode itself consists of 6 different copper conductors (Ø 26 mm, 0.18 m length) alternated with isolators. The total length of the electrode is about 6 m (van Marlen et al. 2011, quoted in Soetaert et al. 2013).

Another Dutch company, *HFK engineering*, invented a different type of flatfish pulse trawl, the so-called **"PulseWing"**. Because of the use of a wing-shaped foil ("SumWing") the standard trawl shoes could be omitted, resulting in reduced bottom contact. Only a runner at the center of the SumWing is required. The pulse wing is rigged with 28 parallel electrodes of 6 m length, placed at a distance of 0.415 m from each other. Each electrode is composed of 12 copper conductors (Ø 33 mm, 0.125 m length) alternated with polyurethane isolators (van Marlen et al. 2011, quoted in Soetaert et al 2013). The alternating arrangement of conductor- and isolator components along the towed electrodes of the pulse flatfish trawl results in interrupted pulse sequences (which are only produced along the conductors) (De Haan et al. 2009a). Depending on the lengths of the conductor components, the resulting pulse "packets" have durations of about 100 ms (PulseWing) or 140 ms (*DELMECO*) at towing speeds of about 5.5 kts.

Table 3: Selected electric parameters of the flatfish pulse trawls of DELMECO Group B.V. and HFK engineering and the shrimp pulse trawl HOVERCRAN of Marelec NV. Sources: De Haan et al. 2011, Verschueren et al. 2012.

pulse system	electric output (kW/m)	distance of electrodes (m)	peak voltage (V)	frequency (Hz)	pulse duration (ms)
DELMECO	0.46	0.42	50	40	0.22
HFK	0.58	0.41	45	45	0.38
HOVERCRAN	0.13	0.67	60	4.5	0.25

The shrimp pulse trawl's mode of operation differs from that of the flatfish pulse trawl which is only described, but not evaluated in this report. The pulses used in shrimp pulse trawls are of low pulse frequency (4.5 Hz) (Table 3) and do not induce an attraction reaction (electrotaxis) in fish, but, on the contrary, a flight reaction (Seidel & Watson 1978). The pulses in flatfish pulse trawls are characterized by higher voltage, pulse frequencies and pulse durations and induce a cramp reaction in flatfish like e.g. plaice and sole. The electric field makes the muscles contract. When the pulse frequency exceeds a certain threshold value, the muscles have no time to relax before the next pulse is applied and remain contracted. This summation of many individual contractions may lead to a muscle cramp and immobility of the animal. The threshold frequency for plaice is about 15-20 Hz (Steward 1977).

Pulsed electricity induces cramps of the strong dorsal muscles of flatfish. This reaction makes the fish bend upward in a U-shaped movement so that they are easily scooped up by the ground rope of the beam trawl. The duration of exposure required to induce such a cramp reaction is about 1 s, corresponding to a towing distance of the beam trawl of about 3 m (van Stralen 2005).

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5 Environmental impact

5.1 Impact on the seabed

Standard beam trawl

Sabellaria reefs and sea cypress colonies once formed hard substrates within the soft Wadden Sea grounds but have now largely disappeared, possibly as a long-term effect of intensive bottom trawling.

There is a debate on the contribution of extensive beam trawling to the decline of sensitive benthic communities that were once widespread but are now almost extinct in some of their original habitats. Habitat-forming species such as reef-building *Sabellaria* or sea cypress (*Sertularia cupressina*) were formerly key species of the diverse and species-rich communities (Michaelis & Reise 1994). Due to their decline, experimental investigations are hardly possible these days and so the contribution of beam trawling cannot be conclusively examined or proven (see below).

Pulse trawl

The HOVERCRAN pulse trawl replaces the bobbin ropes by lighter electrodes and mechanical stimulation of the shrimp by electrical stimulation (chapter 4.5). By refraining from the use a bobbin rope the seafloor contact can theoretically be minimized by 75 % (Verschueren & Polet 2009) and the impact on fine-sandy and muddy sediments can be reduced (ICES 2011). In a conventional beam trawl with bobbin rope, 61 % of the fished surface is actually "touched" by trawl shoes or bobbins. Without bobbin rope only 14 % of the fished surface is "touched" (by trawl shoes or electrodes) (Verschueren & Polet 2009) (Figure 11). These calculations are based on the original configuration of the HOVERCRAN without bobbin rope and with the ground rope raised by 10-15 cm (chapter 4.5). When a modified configuration with 10 bobbins was used on the Dutch vessel TX-25, the ground contact was only reduced by about 50 % (Verschueren et al. 2012).

Figure 10: Sand mason worm, Lanice conchilega (Picture: V. Liebich/WWF)

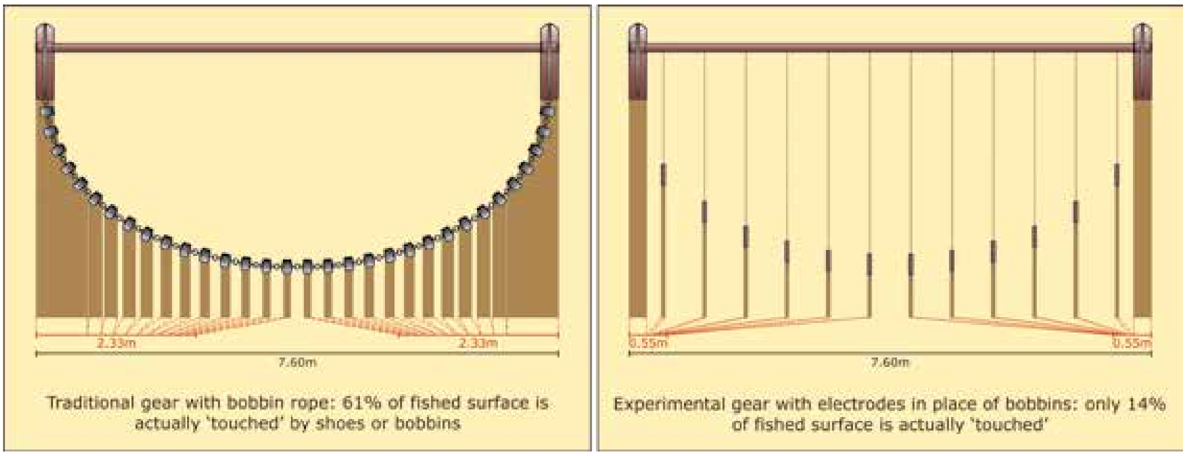

Figure 11: Schematic top view of a standard beam trawl (left) and a HOVERCRAN (right) (netting is not drawn). The comparison illustrates that the shrimp pulse trawl reduced the bottom contact by 75%. Source: Verschueren & Polet 2009.

Modified configurations of the pulse trawl: Fishermen using shrimp pulse trawls in commercial applications mostly combine the original HOVERCRAN configuration that solely uses electrodes with an additional bobbin rope (Table 2). Only some of the bobbins are replaced by electrodes in order to guarantee that the fishing grounds which are often uneven may be fished evenly. Instead of the usual 36 bobbins, 24 bobbins on a straight ground rope were used on vessel HA-31, in combination with 12 additional electrodes. One of the Dutch vessels, TX-25 and HA-31, currently uses 9 bobbins (ICES 2012). During the investigations in the German Wadden Sea, the vessel "Marlies" (SD-33) fished with 11 bobbins (Kratzer 2012). Additional investigations were carried out with a traditional beam trawl with 36 bobbins that was combined with 12 electrodes (ICES 2012). However, information on the ground contact of this configuration is currently not available.

Fishermen using shrimp pulse trawls in commercial applications mostly combine the original HOVERCRAN configuration (solely with electrodes) with additional bobbins.

5.2 Efficiency and size selectivity of pulse trawls vs. standard beam trawls

The total catch of a shrimp trawler consists of marketable shrimp that are landed and sold and possibly a smaller share of marketable fish. In addition, there are small undersized shrimp and the bycatch of fish and invertebrates (see also chapters 5.3 for the definition of bycatch used in this report). Currently there is no legal minimum landing size for shrimp in the EU, but in practice the market size is 4.5 cm (corresponding to a carapax width of 6.5 cm) (Campos 2009, Verschueren et al. 2012). In some of the earlier studies analyzed in this report the separation between "small" and "large" or "marketable" and "not-marketable" shrimp was based on other size classes or is not explicitly stated. Therefore no uniform size classes can be used to characterize shrimp catches throughout this report.

For the evaluation of different fishing methods, the gear's selectivity with regard to target species and unwanted bycatch species is of major importance. Therefore only these parameters will be discussed in the following sections. Catch efficiency and size selectivity regarding shrimp catches are presented in this chapter (5.2) and bycatch of fish and invertebrates (except brown shrimp) is discussed in chapter 5.3. Some reports dealing with the efficiency of capture methods also investigate the differences in the total catch. However, this parameter only allows limited conclusions on the sustainability of a fishing gear and will therefore not be analyzed and discussed in this report.
Comparative analyses of pulse trawls and conventional beam trawls mostly found

higher catch rates of shrimp in pulse trawls (Table 4). Differences among studies may result from the fact that both gears were tested either on the same vessel (port and starboard side) or on different vessel, or by variations in catch conditions (most importantly spatial or temporal differences), or by differences in the gears themselves (e.g. arrangement of the ground rope, additional application of bobbins, mesh size in the top panel).

Correlation of catch rate and water turbidity: During daytime, brown shrimp burry in the sediment and leave this shelter at night or when water turbidity is high. In clear offshore waters this behavior leads to higher catch rates in shrimp fisheries at night than during daytime. However, in the Wadden Sea, high catch rates can also be achieved during daytime due to higher water turbidity. Pulse trawling allows for more continuous shrimp catches than can usually be achieved under varying conditions caused by clear or turbid waters or day- or nighttime. This was demonstrated e.g. by fishing trials on the mud bottom in the **Gulf of Mexico.** During daylight, when catch efficiency is normally low, pulse trawls could catch 96-109 % of the shrimp caught at night by a conventional trawl. By contrast on a calcerous sand-shell bottom, the catch rate was only 50 % as pulse trawls are most efficient on mud substrate. Nighttime catches with pulse trawls were consistently smaller than the catches with standard gear, which was explained by the behavior of shrimp: at night they come out of their burrows to forage on the bottom. The electric pulse that makes burrowed shrimp jump into the water column during daylight allows them to swim out of the electric field at night and gives them time to escape from the net (Pease & Seidel 1967). Investigation in the Dutch **Scheldt estuary** also revealed lower catches in pulse trawls during daytime in turbid waters compared to non-electrical trawls. It was assumed that under such conditions the shrimp are already out of the sand and can therefore escape the pulse trawl more easily with their jumps (escape reaction). The advantages of the pulse trawl were thus expected to be of larger importance in clear offshore waters (Boonstra & de Groot 1970). The catch efficiency of the HOVERCRAN in **Belgian waters** was not much affected by environmental conditions: catch rates during day- und nighttime, in clear or turbid waters and when the weather was good or bad were relatively constant (ICES 2011). Recent investigations in the **German Wadden Sea** demonstrated that catch efficiency of the pulse trawl at daytime or at dawn was higher than that of a conventional beam trawl. By contrast, at night-time catch efficiency was identical in both gears (Kratzer 2012).

Correlation of pulses and size selectivity: One of the major shortcomings of shrimp trawling is the large amount of undersized, non-marketable shrimp. This fraction can account for up to two thirds of the individuals in the catch (von Marlen et al. 1998) (see also chapter 5.3). Based on results of the available investigations, no final conclusion can be drawn as to whether pulse trawls would improve the gear selectivity for shrimp and thereby reduce the bycatch of non-marketable shrimp. It is conceivable that the effect of an electric pulse on shrimp is similar to the size-specific potential difference that has been observed for fish (see also Figure 3). This would imply that the effect of electric pulses on shrimp depends on the size of the individual. However, orientation in the electric field is also important for the effectiveness of the pulses. Laboratory experiments demonstrated only little size effect in the escape reaction that was induced by the electric pulse. In experimental fisheries with various constellations of net, electrodes and pulse generator, size-selective effects have been observed but they were attributable to the mesh size in the top panel of the net rather than the electric pulses (Polet et al. 2005b).

Shrimp catches in early experiments with pulse trawls: Early experiments with commercial beam trawl vessels in Belgium revealed that shrimp catches in pulse trawls were 44-48 % higher than in standard beam trawls (Vanden Broucke 1973). Comparative analyses on a research vessel equipped with a 3 m beam trawl (towing speed 1.0-1.8 m/s) in the Dutch Scheldt estuary resulted in average catches of marketable shrimp that were twice as high as in conventional beam trawls (+116 %). However, the catches of undersized shrimp were also higher (+84 %). When pulse frequency was increased[6], catches of small shrimp were markedly lower than in a preliminary investigation in a former oyster basin (Boonstra & De Groot 1974a). In subsequent full-scale experiments with a commercial 8 m-beam trawler, on average 33 % more commercial size shrimp were caught with the pulse trawl (Boonstra & De Groot 1974b) (Table 4).

Shrimp catches in experiments with the HOVERCRAN: During the development of the HOVERCRAN, a variety of constellations of net, electrodes and pulse generator were tested by Polet et al. (2005b). A raised ground rope without electrical stimulation led to considerably reduced bycatch rates (Table 5). However, catch efficiency for the target species also decreased (Table 4). Catch rates for large shrimp (>4.5 cm) were 76 % lower. However, it was possible to compensate the reduced catch efficiency by the pulse trawl: with electrodes that were arranged parallel in the towing direction and a raised ground rope, catches of large shrimp were only reduced by 31 % compared to catches with a conventional beam trawl. A significant length effect was apparent in these experiments. Catches of small shrimp were reduced more (-76 %) than catches of large shrimp. It was possible to further minimize the catch loss by a ground rope that was arranged closer to the bobbin rope (number of bobbins not given in the report). With a conventional net (low ground rope), catches were also reduced, which was explained by the behavior of the electrically stimulated shrimp that jumped through the meshes of the top panel. **Smaller meshes in the top panel resulted in catch rates that were not significantly reduced compared to control catches. However, pulse trawls caught more small shrimp (<4.5 cm) than standard beam trawls.** The authors assume that some of the shrimp jump higher than the top panel. Smaller meshes generally increase catch efficiency, but at the same time the percentage of small, non-marketable shrimp also increases (Polet et al. 2005b). Several constellations of a modified arrangement of the electrodes (anode and cathode perpendicular to each other) showed no differences in the catches of large shrimp (Polet et al. 2005b).

Further experiments have been carried out since 2008 on the commercial shrimp trawler O-191 in the Belgian North Sea. Aim of these investigation was an advancement of the gear so that the desired properties and technical characteristics (no jumping of the net when applied without bobbins, defined level of the ground rope over the seabed, even distribution of the electric field within the mouth of the net) could be achieved (Verschueren et al. 2012). The following design characteristics proved most beneficial: a square mouth of the net, a shortened or raised ground rope and plastic wings fixed by strain reliefs to the ground rope. Moreover the catches of marketable shrimp in pulse trawls should be at least as high as in standard beam trawls. In 9 of the 35 tested configurations this was achieved together with reduced bycatch rates (see also chapter 5.3). Best results were achieved with a standard gear that was equipped with electrodes, a raised ground rope that 10 cm higher and a special attachment of the electrodes that were

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[6] In these trials, a pulse rate between 7 and 50 Hz was applied which was much higher than in the HOVERCRAN.

positioned close to the ground. With this configuration, the catch of large shrimp was 64 % higher, but the bycatch of small non-marketable shrimp (<4.5 cm) was also 111 % higher. **Trials with a non-electrified pulse trawl demonstrated that the higher catches of shrimp in this configuration were achieved by the electric pulses, while the reduced bycatch of fish** (see also chapter 5.3) **was a result of the raised ground rope**. Various constellations of a ground rope that was raised by 15 cm caught 0-46 % more large shrimp. The bycatch of small non-marketable shrimp (<4.5 cm) differed not significantly from a conventional trawl. With a square net mouth and a ground rope that was raised by 5 cm and a specific attachment, 48 % more large shrimp were caught with 52 % more bycatch of small shrimp (Verschueren et al. 2012).

In spring 2012, further trials of ILVO and IMARES started in cooperation with Dutch shrimp fishermen (Verschueren et al. 2012). The commercial vessel TX-25 was equipped with an improved version of the HOVERCRAN and in spring 2011 another vessel (HA-31) was to succeed (ICES 2011, Verschueren et al. 2012). **As fishing grounds might also contain stones, a constellation entirely without bobbins was not feasible because the bobbins are also protecting the net. Therefore the final constellation of the pulse trawl was with 10 instead of the usual 36 bobbins**. In addition, the square net mouth and the raised ground rope were applied. In the course of this study a complete season was to be investigated in comparative trials in the Wadden Sea (ICES 2011). First results were presented by Verschueren et al. (2012) (in Dutch). In a first series (14 hauls in comparison to a standard beam trawl with sieve net), the pulse trawl caught on average 26 % more large shrimp, but the bycatch (fish and invertebrates) was also considerably higher (see also chapter 5.3). In a second series (10 hauls in comparison to a standard beam trawl without sieve net), the pulse trawl caught 14 % more large shrimp and the bycatch (fish and invertebrates) was slightly reduced compared to the conventional gear (Verschueren et al. 2012).

The results available so far indicate that the catch rates of large shrimp are correlated with the level of the ground rope and the number of bobbins (ICES 2012). The additional application of a standard beam trawl (39 bobbins) with 12 electrodes increased the catch rate by up to 54 % compared to a conventional beam trawl without electric pulses. However, these investigations were performed under experimental conditions with a gear setting that was considered poorly suitable for practical application (ICES 2012). Pulse trawls with 9 and 12 additional bobbins caught about 10 % more shrimp than conventional beam trawls (ICES 2012).

A direct comparison of a commercial beam trawl (beam length 8.4 m) and a shrimp pulse trawl based on the HOVERCRAN concept with a straight ground rope and 11 bobbins in the ground rope (instead of the usual 36) was carried out between summer 2012 and summer 2013 in the German Wadden Sea. In this gear the ground rope was fixed directly behind the axis of the bobbin rope (diameter of bobbins: 220 mm). The ground rope in this constellation was raised by about 10 cm, depending on the penetration depth of the bobbins (D. Stepputtis, TI, pers. comm.). Results of the first project phase between June and August 2012 were presented by Kratzer (2012). Data were collected via self-sampling conducted by the crew of the vessel, complemented by a phase of scientific sampling. For the evaluation undertaken in this report the results under strictly commercial conditions are considered more meaningful than the scientific sampling which was carried out using a more experimental approach. Thus only the results of the self-sampling are taken into consideration here[7].The results demonstrated again that the electric field between the electrodes replaces the bobbins as a stimulus to trigger an escape reaction in shrimp. **On average, shrimp catches in pulse trawls were 10 % higher than in conventional beam trawls. Catches of large marketable A-shrimp were 8 % higher in the pulse trawl and catches of small non-marketable B-shrimp 14 % higher.** In some of the trials the pulse trawl caught more small shrimp, in other trials there were no significant differences between the gears. Variations of towing speed between 2.5 and 3.5 kts had no marked effect on the catch rates of pulse and standard trawl (Kratzer 2012).

Table 4: Environmental impact of pulse trawls in comparative studies with conventional beam trawls with regard to catch efficiency for shrimp (n/a = not available)

source	voltage	signal duration	pulse frequency	result
Pease & Seidel 1967	3 V	n/a	4–5 Hz	» pulse trawls on mud substrate during daylight caught 96–109% of the normal night catch » pulse trawls on calcerous sand-shell bottom during daylight caught only 50% of the normal night catch » at night pulse trawls caught 61–80% of the normal night catch
Boonstra & de Groot 1970 1)	50–60 V	0.2 ms	5 Hz	» catch rate of pulse trawl increased by 50% (results preliminary)
Vanden Broucke 1973 2)	100 V	n/a	2 Hz	» shrimp catches of pulse trawls 44% higher (total 65 kg)
			10 Hz	» shrimp catches of pulse trawls 48% higher (total 43 kg)
Boonstra & de Groot 1974a 3)	2,5–60 V	0.2 ms	5 Hz (in one exp. 7–50 Hz)	» pulse trawl caught 116% more marketable shrimp (>54 mm) » 81% more undersized shrimp
Boonstra & De Groot 1974b	60 V	n/a	1–50 Hz	» pulse trawl caught 33% more marketable shrimp
De Groot & Boonstra 1974	n/a	0.2 ms	n/a	commercial vessel TH-6, 9 m beam trawl: » pulse trawl caught 26% more marketable shrimp » 49% % more undersized shrimp
Polet et al. 2005b	123 V	0.6 ms	5 Hz	» pulse trawl with raised ground rope and electrical stimulation caught 24–31% less large shrimp, depending on arrangement of electrodes » marked length effect: with electrical stimulation catch reduc-tion of the pulse trawl (compared to standard beam trawl) was higher for large shrimp than for small shrimp » in configurations with raised ground rope and small mesh size in the top panel, this effect was inversed: the pulse trawl caught 16% more small shrimp
ICES 2012	4)	0.25 ms	4.5 Hz	» shrimp pulse trawl based on the HOVERCRAN configuration combined with 9 bobbins in a Dutch commercial vessel caught 10% more shrimp than the conventional gear

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[7] In the scientific sampling the pulse trawl caught on average 33 % less bycatch and shrimp catches were not statistically significant different (Kratzer 2012).

Kratzer 2012	4)	0.25 ms	4.5 Hz	» shrimp pulse trawl based on the HOVERCRAN configuration combined with 11 bobbins caught 10% more shrimp (B-shrimp +14%, A-shrimp+ 8%) » variations of towing speed between 2.5 and 3.5 kts had no marked effect on catch rates
Verschueren et al. 2012	5)	0.25 ms	4.5 Hz	commercial vessel O-191 » catches of marketable shrimp were at least as high in 9 of 35 tested configurations with reduced bycatch rates » standard gear with electrodes close to the ground and a ground rope raised by 10 cm caught 64% more large shrimp and 111% more non-marketable small bycatch » pulse trawl ground rope raised by 15 cm in various configurations caught 0-46% more large shrimp, no significant difference of catches of small shrimp compared to standard gear » square net mouth with ground rope raised by 5 cm resulted in 48% more large shrimp and 52% more small shrimp commercial vessel TX-25 (results preliminary, only 14 hauls) » on average, 26% more large shrimp compared to standard beam trawl with sieve net » on average, 14% more large shrimp compared to standard beam trawl without sieve net

¹) Distance between the 3 electrodes 0.5 m, arranged in parallel to the ground rope (transverse to towing direction)

²) Pulse generator of 2.5 kVA with alternating currents of 220 V

³) Pulse generator P.G. 6820; distance between electrodes 0.35 m in towing direction, alternating positive and negative; towing speed 1.0-1.8 m/s

⁴) Field strength 30 V/m

⁵) Setting of pulse generator: max. 50 or 65 V peak, field strengths max. 35 or 50 V/m

5.2.1 Increased efficiency as a risk

At the end of the 1990s the shrimp stocks in the East China Sea became drastically overfished due to the widespread use of pulse trawls. This example demonstrates the severe risk posed by electro-trawling. The depletion of several major commercial fish species in the East China Sea gave rise to high fishing pressure on shrimp as a new target species (Yu et al. 2007). There were 96 species of shrimp, of which ten or more had commercial value. Unlike those used in the German North Sea, typical Chinese shrimp beam trawls had beam lengths of 24-36 m. The beam trawl fleet increased from about 5,500 vessels in the beginning of the 1990s to an estimated 10,000 vessels in 2000. In 1992 pulse trawls were introduced to the fishery and in 2000 the technology was used by about 3,000 vessels. This increased the shrimp catches by more than 100 %. Due to illegal upgrading of pulse parameters, greater numbers of small shrimp <50 mm were caught. As a consequence the shrimp biomass declined drastically, for example the biomass in 1995 was 34 % less than that estimated in 1994. Management measures included licensing the use and limiting power output, and other output parameter settings of pulse trawls. Management had however no certification process for device manufacturers to control development, and there was no suitable equipment to monitor and enforce regulations on pulse trawl output parameters in the fishery. As a result of economic pressure and the immediate effect of an increase in catch when higher output parameters of the pulse generator were used, many manufacturers produced devices that exceeded the permitted output values. The pulse trawls were becoming electrical "killing apparatus", rather than the intended stimulus device. As fishery management authorities were not able to control and regulate the use of the technology, pulse trawls were banned from the East China Sea in 2001. The ban included the manufacture, sale, repair, transport, and use of any pulse trawls (Yu et al. 2007).

Higher catch efficiencies due to the application of pulse trawls require the definition of a comprehensive legislative framework which is outlined in chapter 6.3. Opportunities and risk associated with the increased catch efficiency are discussed in chapter 6.4.

5.3 Bycatch

There are several approaches for the **definition of bycatch** and this may cause confusion when different studies are compared. According to the definition commonly used in fisheries science, undersized individuals of the target species do not belong to the category bycatch (Ehrich & Neudecker 1996). However, shrimp fisheries have very high discard rates. They account for about half (Lancaster & Frid 2002) to two thirds (Von Marlen et al. 1998) of the individuals in the catch. In the shrimp fishery in Lower Saxony, Germany, the share of marketable shrimp (>50 mm total length corresponding to a carapax width of 8 mm) has been shown to be only 11 % (by weight) of the catch (Walter 1997). As up to 23 % of the discard of undersized shrimp die (due to injuries the animals suffer during the catch or sorting process, or because they are eaten by seabirds) (Lancaster & Frid 2002), the discarded fraction is taken from the stock without being commercially utilized. This fulfills the definition of bycatch. In accordance with former WWF reports (e.g. Fischer 2009), in this report the following definition is set: **Bycatch is defined as any catch of species (commercial or non-commercial fish, invertebrates, marine mammals, seabirds, plants, etc.) other than the target species, but also undersized individuals of the target species. Bycatch may be either discarded or landed/retained.** As the bycatch of undersized shrimp also affects catch efficiency, it has already been discussed in chapter 5.2.

Figure 12: Shrimp and bycatch in the catch of a pulse trawl before sorting (picture: V. Liebich/WWF 2014)

5.3.1 Bycatch of fish

In shrimp fisheries, small mesh sizes of about 16–26 mm are used due to the small size of the tar-get species, therefore many more organisms are caught as unwanted bycatch and subsequently discarded.

Conventional shrimp fishery: In shrimp fisheries the mesh size of about 16–26 mm is small due to the small size of the target species, therefore many other organisms are caught as unwanted bycatch and subsequently discarded. The ratio of marketable shrimp and fish bycatch has improved during the last decades by further developing the fishing technology (Neudecker & Damm 2010). Some of the measures to enhance selectivity[8] are sieve nets of larger mesh size that separate fish from the catch and let them escape through an exit window (funnel) in the top panel before they enter the codend. These developments significantly reduced the bycatch of 0-group and older fish (Verschueren et al. 2012). However, sieve nets, which are in principal obligatory under EU law, often do not need to be deployed, especially in the Wadden Sea, because of existing exemptions (Fischer 2009). In addition the filtering process in the sieve net may induce stress and increase mortality for the escapees. Bycatch of fish still occurs with regional and seasonal differences and this may have consequences for the ecosystem, the stock and fisheries ecology. The species with the largest economic importance is plaice. The sieve net cannot keep 0-group plaice and smaller individuals (<10 cm length) from entering the codend where they are caught together with the shrimp fraction. Especially in the nursery areas of juvenile plaice, this adversely impacts the stocks (Verschueren et al. 2012). Because of these shortcomings, further bycatch reduction devices are needed for shrimp fisheries.

Bycatch rates can differ considerably by region and season. As an example, fish bycatch off the coast of Lower Saxony, Germany, was much lower in the summer months July and August than in spring (Aviat et al. 2011). Sampling of the commercial German beam trawl shrimp fishery in the period 2002-2008 (only six

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[8] Further measures to increase gear selectivity by separating fish before they enter the net are described by Röckmann et al. (2011).

trips with 38 hauls[9]) revealed that 30 % of the total catch were non-target fish and invertebrates. A further 35 % of the total catch were undersized shrimp which were also discarded, and only the remaining 35 % were marketable brown shrimp (Ulleweit et al. 2010). Overall, the discard proportion of small fish (no size classes given in the report) was more than 10 %, consisting of dab, plaice, whiting, herring, sandeel, hooknose and sand gobies (in the order of occurrence in the bycatch) (Ulleweit et al. 2010). In addition, Verschueren et al. (2012) also name flounder, sole, cod and pouting as important bycatch species in shrimp fisheries. The time between hauling and discarding can be reduced by using effective rotary drum sieve with a lot of rinsing water. This is assumed to enhance some species' survival rates. Depending on parameters like haul duration, catch processing conditions and ambient temperature, mortality rates of 0-83 % have been observed in flatfish. Mortalities were about 10 % for sculpin, hooknose and eelpout and about 100 % for whiting and other roundfish (Berghahn et al. 1992, Lancaster 1999, quoted in Verschueren et al. 2012). Mortality of sole has been estimated at 30-50 % (Dahm et al. 2002, Revill et al. 1999, both quoted in Verschueren et al. 2012).

Based on the data of Ulleweit et al (2010), Neudecker & Damm (2010) calculated the total bycatch of plaice in the German shrimp fishery as 112 million individuals. This value was much lower than former calculations (EU RESCUE study) of 774 million plaice, which were, however, based on an exceptionally good recruitment year for plaice. The large variation combined with the application of different methods does not permit a quantitative evaluation in the framework of this report. In the light of generally high recruitment and low mortality rates of juvenile plaice compared to flatfish beam trawl fisheries, Neudecker & Damm (2010) assume no significant impact of the shrimp fishery on plaice spawning stocks. By contrast, Revill et al. (1999, quoted in Verschueren et al. 2012) estimate the possible loss in plaice yield as a result of bycatches in the shrimp fishery at 7,000-19,000 t. Besides plaice, there are other species of which considerable numbers are lost for stock recruitment. The EU RESCUE study estimated annual bycatches in the North Sea shrimp fishery (prior to the introduction of sieve nets regulated by Regulation EC no. 850/98, implemented by 2003) at 55 million individuals of whiting, 42 million cod and 16 million soles (van Marlen 1997, quoted in Verschueren et al. 2012). The effect of these takes, which may have declined as a result of the obligatory use of sieve nets, on the fish stocks and subsequently on the economic situation of fisheries targeting these species, remains unclear.

HOVERCRAN pulse trawl: Shrimp pulse trawls combined with adjustments of the ground rope and net have the potential to reduce the bycatch of fish. Ideally, the applied pulses selectively provoke a startle reaction in shrimp that makes the shrimp jump into the water, without affecting fish species that are usually caught as unwanted bycatch. In test fisheries during the development of the pulse trawl, Polet et al. (2005b) tested a variety of constellations of nets, electrodes and pulse generator (see also chapter 5.2). A focus was on the mode of action of the pulses themselves, of a raised ground rope and other ways of attaching, and a top panel with smaller meshes than a conventional net, which might affect the volume of the bycatch. **In most cases, no bycatch reduction was achieved by means of electrical stimulation alone.** Only the bycatch rates of whiting (in pulse trawls 32-93 % of the catches with conventional beam trawls), hooknose (9-68 %) and gobies (38-60 %) were significantly reduced in pulse trawl catches

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[9] Only 0.01 % of all hauls in the shrimp fishery (in total about 500,000 per year) are investigated in the framework of the EU data collection (Verschueren et al. 2012).

without further modifications. With standard gear rigging electric pulses resulted in slightly reduced bycatch rates of undersized plaice (70-94 %, not all differences significant) and dab (61-67 %, %, not all differences significant). **Additional raising of the ground rope resulted in significantly reduced bycatch rates of many fish species, e.g. plaice and dab.** Still, bycatch rates of poor cod and sole were not reduced in a combination of pulse trawl and raised ground rope, and catches of dragonet were even higher than in the conventional trawl. The bycatch of plaice (50-65 %, not all differences significant) and dab (29-61 %, not all differences significant) was further reduced in this constellation. These species use the escape path under the ground rope. Undersized dab were also caught in smaller numbers in pulse trawls than in standard beam trawls (61-67 %). Catches were further reduced with a raised ground rope (38-61 %), but with small meshes in the top panel the bycatch rates were higher (135-282 %). Dab probably have a different escape behavior than plaice, which has also been demonstrated in laboratory experiments. Dab escape upwards into the water column, similar to shrimp (Polet et al. 2005b).

In most cases, electrical stimulation alone did not result in bycatch reduction, but in combination with a raised ground rope bycatch rates were significantly reduced.

Experiments with the HOVERCRAN pulse trawl on the commercial Belgian vessel O-191 (Verschueren et al. 2012) resulted in bycatch rates of fish that were reduced on average by 35 %. However, these field experiments were only carried out over a relatively short time span of six months in summer and only in Belgian waters (Verschueren & Polet 2009, ICES 2011). In total, 35 different net configurations were tested (Verschueren et al. 2012). A standard beam trawl with additional electrodes, the ground rope raised by 10 cm and electrodes close to the seabed resulted in 37 % less bycatch of fish. Reduced bycatches of commercial species were achieved for whiting and cod. Trials without electric pulses in this configuration revealed that bycatch reduction was primarily a result of the raised ground rope, while higher shrimp catches (chapter 5.2) were an effect of the electric pulses. Raising the ground rope by 15 cm in different configurations resulted in bycatch reductions of 23-40 % (predominantly flounder, dab, plaice, sole and sprat. For whiting, one configuration resulted in increased bycatch rates, while 3 other configurations resulted in reductions). A square net opening in combination with a ground rope raised by 5 cm and a specific way of attaching the gear led to 39 % less bycatch (dab, pouting, whiting).

A subsequent test fishery on the Dutch vessel TX-25 in the Wadden Sea resulted in surprising findings. First preliminary results of 14 hauls, fished in direct comparison to a standard beam trawl with sieve net, showed higher bycatch rates of fish and invertebrates (+244 %) in the pulse trawl (Verschueren et al. 2012). Commercial fish species in the bycatch were predominantly undersized plaice (+82 %) and whiting (+56 %) and a smaller share of sole and pouting. However, values had very high variability among hauls and were therefore not statistically significant. Yet, significant differences were found for some invertebrates (chapter 5.3.2) and for sea sculpin (+1.216 %), but absolute numbers are not given in the report. Maybe these results indicate that some species react especially sensitively to the “shrimp pulse”. Moreover, they are based on a very small number of trials. Interpretation is further complicated as sea trials have a very large variation fluctuation range (standard deviation of the results is extremely high).

In a second test series, 10 pulse trawl hauls were compared to catches of a standard beam trawl without sieve net. Bycatches in the electrical trawl were slightly lower than in the standard trawl (-15 %). Differences, like those observed when both test series were compared, were to be expected because the conventional trawl without sieve net is considerably less selective than the configuration with sieve net. The information value gained by the experiment depends on the legal framework. Which of the test series is relevant depends on whether or not sieve nets are mandatory.

Investigations by Kratzer (2012) demonstrated that a smaller number of bobbins in the modified ground rope allows fish to escape underneath the ground rope and leads to lower bycatch. Bycatch rates were on average 15 % lower in the pulse trawl than in the standard beam trawl. The median of the fish bycatch was 6 % in conventional trawls and 4 % in pulse trawls (maximum values 30 % resp. 20 %). When interpreting these results, catch processing on board has to be taken into account. A non-specified share of the catch is not discarded until after cooking of the shrimp (Kratzer 2012). On the species level, pulse trawls primarily caught fewer flatfish (individuals) (plaice [5–12 cm]: -28 %, sole [5.5–10 cm]: -43 %, dab [4–6 cm]: -50 %), but also bycatch of sand goby (4.5–8.5 cm: -75 %) and hooknose (4–10 cm: -44 %) was considerably reduced compared to conventional beam trawls.

Table 5: Bycatch volume of shrimp pulse trawls compared to standard beam trawl in experimental fisheries (n/a = not available)

source	voltage	signal duration	pulse frequency	result
Vanden Broucke 1973 1)	100 V	n/a	2 Hz	» 250% more marketable sole (only 45 individuals in total) » 24% less undersized sole (76 individuals in total)
			10 Hz	» 200% more sole (only 39 individuals in total)
De Groot & Boonstra 1974a	60 V	0,2 ms	10 Hz	» 12% more marketable sole » 30% more undersized sole
Seidel & Watson 1978 2)	n/a.	n/a	4–5 Hz	» specific pulses trigger shrimp to jump into the net that is towed 30-60 cm over the ground, but make fish escape horizontally in front of the net
Polet et al. 2005b	123 V	0.6 ms	5 Hz	» bycatch of whiting, hooknose and shrimp significantly re-duced by electrical stimulation alone. Bycatch of undersized plaice slightly reduced, but more starfish, swimming crab and razor shells caught » additional raising of ground rope significantly reduced by-catch of several fish and invertebrate species, heavy organ-isms like bivalves or hermit crab by 35–100%. Bycatch of un-dersized plaice considerably reduced. Bycatch of pouting and sole not reduced. Dragonet even caught in higher numbers » less undersized dab caught in pulse trawls with conventional and raised ground rope » additional application of top panel with smaller mesh size did not reduce dab bycatch. Swimming crab escaping upwards were caught by the smaller meshes in the top panel, hence bycatch rates were even higher
Kratzer 2012 3)	30 m/s	0.25 ms	4.5 Hz	» bycatch rates of pulse trawls reduced by 15%. » bycatch reduction predominantly achieved by less flatfish in the catch (plaice, sole, dab).

Verschueren et al. 2012	4)	0.25 ms	4.5 Hz	commercial vessel O-191 » bycatch reduced by 37% in a standard trawl with additional electrodes and ground rope that was raised by 10 cm and electrodes close to the seabed. Reduced rates in commercial fish species: whiting and cod » bycatch reduction between 23 and 40% when ground rope was raised by 15 cm (most importantly flounder, plaice, dab, sole and sprat. Results ambiguous for whiting) » bycatch reduction of 39% when ground rope was raised by 5 cm and square mouth of the net (da, pouting, shiting) commercial vessel TX-25 (results preliminary, only 14 hauls) » Bycatch of fish and invertebrates increased by 244% com-pared to conventional beam trawl with sieve net » Bycatch of sea sculpin increased by 1.216%,results not statis-tically significant for other species

1) Pulse generator of 2.5 kVA with alternating currents of 220 V. Investigations were aiming at a mixed fishery for shrimp and sole.
2) Field strength 30 V/m.
3) Shrimp pulse trawl (based on the HOVERCRAN), combined with 11 bobbins
4) Setting of pulse generator: max. 50 or 65 V peak, field strengths max. 35 or 50 V/m

5.3.2 Bycatch of invertebrates (other than brown shrimp)

Standard beam trawl: Sampling of the commercial German beam trawl shrimp fishery in the period 2002-2008 (only six trips with 38 hauls[10]) demonstrated that the invertebrate bycatch was 20 % (by weight) of the total catch[11] (Ulleweit et al. 2010). Looking at the species composition this bycatch consisted predominantly of shore crab, swimming crab, crab, sea star and brittle star. The proportion of marketable shrimp was 35 % (by weight) of the total catch. With a total landing weight of 13,000 t brown shrimp in the German shrimp fisheries (Anonymus 2013a, b), this corresponds to a total weight of 7,500 t of invertebrates that are annually discarded. The report of Ulleweit et al. (2010) mentions no survival rates for invertebrate species.

Pulse trawl: The shrimp pulse trawl in combination with modifications of the gear and net may help to reduce the bycatch of invertebrates. Polet et al. (2005b) tested a variety of constellations of net, electrodes and pulse generator (see also chapter 5.2 and 5.3.1).

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[10] Only 0.01 % of all hauls in the shrimp fishery (in total about 500,000 per year) are investigated in the framework of the EU data collection (Verschueren et al. 2012).

[11] Moreover, about 35 % of the total catch were undersized shrimp, see chapter 5.2.

» **Electrical stimulation:** More sea stars, swimming crab and razor clams were caught.

» **Raising of the ground rope** reduced the bycatch of many invertebrate species. 35-100 % less heavy organisms like bivalves or hermit crab were caught when the ground rope was raised.

» **Small mesh size in the top panel**: Swimming crabs that were escaping upwards were retained by the small meshes, leading to increased bycatch rates of these species.

Preliminary findings of experimental fisheries with the commercial vessel TX-25 did not yet prove unambiguous results. Bycatch rates of sea stars in pulse trawls increased by 373 % compared to standard beam trawls with sieve net. In addition, 504 % more swimming crab[12] were caught. The largest share (by weight) of the bycatch consisted of swimming crab (Verschueren et al. 2012). One possible explanation mentioned by ICES (2011) is that they might be stirred up in the wake of the trawl shoes. The swimming crab were probably electrically stimulated and therefore swam up in the water column (see also results of Polet et al. 2005a, b above).

5.4 Injuries in fish and invertebrates

5.4.1 Flatfish pulse trawl

Sharks and rays

Injuries of fish have been documented as a result of overdoses in freshwater electro fishing and in flatfish beam trawling. Results of investigations of shrimp pulse trawls available so far do not indicate the occurrence of severe injuries.

Sharks and rays are among the most electro-sensitive organisms because they have their own body cells for the perception of electricity produced by any other living creature. Among other things, these receptors serve to identify the low electric fields produced by prey organisms. As a result of this ability, sharks and rays may react particularly sensitive to electric pulses and may be specifically sensitive to pulse trawling. Bycatch rates of sharks and rays in conventional trawls or in pulse trawls have not been documented so far. In some areas like the Wadden Sea, sharks and rays are virtually extinct, among others because of too much pressure on fisheries. Management aims at a reintroduction and adverse effects on this species complex have to be avoided. At IMARES not only investigations on cod, but also on lesser spotted dogfish (*Scyliorhinus canicula*) were undertaken. This electrosensitive species perceives field strengths as low as 10 µV/m and reacts by avoidance to field strengths of about 1 mV/m (Mulder & Bos 2006). The field strength of a pulse trawl is higher by a factor of 108 resp. 106 and might lead to overstimulation of the sensory cells. The circumstances under which field strengths of this magnitude trigger an escape reaction are not known. De Haan et al. (2009b) studied the exposure of lesser spotted dogfish to stimulated electric pulses under laboratory conditions. 3 groups of 16 fish (0.3–0.65 m total length) were exposed to electric stimulation at different distances, each animal 4 times for 1 s (de Haan et al. 2009a). The treatment did not result in mortalities, macroscopic injuries or aberrant feeding behavior (De Haan et al. 2009b). Although the experiments had been primarily designed to investigate feeding behavior, other direct behavioral reactions of fish were monitored during the observation period

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[12] Information on species (shore crab (Gewone Strandkrabben) or swimming carb (Gewone Zwemkrabben) are contradictious.

of 9 months. Typical escape reactions were seldom observed in dogfish that were exposed to electric field strengths corresponding to those right next to the fished area of the pulse trawl. Individuals exposed to the near field of the electrodes often accelerated towards the water surface. In field situations, this behavior might increase the risk of being entangled in the meshes of the top panel of the pulse trawl (De Haan et al. 2009b). More investigations, also with other shark and ray species (see also chapters 6.1 and 6.2), need to be performed in order to solidify these results

Invertebrates

First investigations of the impact of electric pulses on invertebrates living on the seafloor were undertaken by Smaal & Brummelhuis (2005). The authors exposed 19 different species (gastropods, echinoderms, crustaceans and polychaetes) to electric fields with pulses of twice the voltage of a commercial flatfish pulse trawl. The duration of exposure of 10 seconds was 8 times the time of a usual exposure. Some of the animals investigated were exposed to the electric field 3 times in a row and others 3 times on consecutive days. Due to the higher pulse frequency, the energy content was considerably higher than that of a shrimp pulse trawl. In addition, the pulse was bipolar (consisting of a positive and a negative component similar to a sinusoidal pulse). During exposition, no reaction was discernible in echinoderms and polychaetes. Gastropods retreated into their shells, bivalves closed their shells and crustaceans cramped. During the time period following exposure, there was no marked difference in behavior or mortality rates between test and control animals (Smaal & Brummelhuis 2005).

Van Marlen et al. (2009) exposed a range of benthic invertebrates to 3 consecutive series of pulses at distances of 0.1–0.4 m to the electrodes. Ragworms (*Nereis diversicolor*), European green crab (*Carcinus maenas*) and Atlantic razor clam (*Ensis directus*) showed at maximum a 7 % lower survival rate. For common prawn (*Palaemon serratus*), subtruncate surfclam (*Spisula subtruncata*) and common starfish (*Asterias rubens*), no statistically significant effects of electrical exposure on survival were found. Food intake was significantly lower (10-13 % less) for European green crab. All other species showed no differences in food intake or behavior after exposure compared to the control group. The authors concluded that it was plausible that the effects of pulse beam trawling on invertebrates might be far smaller than the effects of conventional beam trawling (van Marlen et al. 2009), provided that their bycatch is avoided by means of a raised ground rope.

In summary, there are only few investigations allowing only limited conclusions on the impact of the introduction of a large scale pulse fishery on invertebrates, but the available results of short term studies indicate that the impact might be minor compared to the impact of conventional beam trawling.

5.4.2 Shrimp pulse trawl

Fish and invertebrates

Currently no information on the impact of low intensity pulses (such as those used in shrimp pulse trawls) on sensitive species like sharks and rays or polychaetes are available.

Polet et al. (2005a) executed tank experiments to investigate behavioral reactions and survival rates of a number of fish and invertebrates. They used 2 different settings of a pulse generator that was derived from commercial shrimp fisheries in China. The behavioral reactions were investigated at dusk conditions and water temperature of 12°C to pulses of 6 Hz and 65 V amplitude (see also Table 4). Except for brown shrimp, only 2 of the 9 fish species tested in observation tests, plaice and dab, reacted to the pulse by leaving the sediment where they burrowed when the experiment started. Of the 6 examined invertebrate species, only shore crab and swimming crab showed a behavioral response by leaving the sediment where they were dug in before and walked around agitatedly on the bottom. In survival experiments, the animals were exposed to the electric field for 15 s. Survival rates of all species investigated (11 fish and 5 invertebrate species) were around 100 % (observation period 10-30 days). These findings indicate that the impact of electric pulses on the survival of fish and invertebrate species was small. Behavior and food intake were not affected by exposure either. Histological investigations 24 hours after exposure to electric pulses revealed only minimal impacts in both control and exposed animals (Polet et al. 2005a, ICES 2011, 2012).

However, based on a report of Bart Verschueren (ICES 2011), behavioral reactions were more pronounced in some species. Dragonet showed strong irregular muscular contractions and moved over very short distances close to the bottom during exposure. Five-beard rockling that rested on the bottom or swam slowly over the sand before the pulse started agitatedly swimming close to the bottom during electric stimulation. After the pulses were switched off, the fish soon resumed their initial behavior. Atlantic cod that were relatively motionless during the setting period, started swimming agitatedly in random directions, regularly bumping against the walls of the tank when the electric field was switched on. During the full 10 seconds of exposure, the fish body showed small jerks to the frequency of the pulses (ICES 2011).

Currently, the impact of typical pulses of a shrimp pulse trawl on cod, sole, polychaetes and shrimp are being investigated (see also chapter 6.1) under special consideration of different life stages (eggs, larvae, juveniles and adults).

6. Outlook

6.1 Current studies aiming at increased selectivity in shrimp fisheries

The following paragraph outlines some recent investigations aiming to increase selectivity in shrimp fisheries (conventional and pulse trawls). The list does not claim to be exhaustive.

German HOVERCRAN project: A comparative analysis of a conventional and a pulse-trawl was undertaken in the German Wadden Sea in Schleswig-Holstein on vessel SD-33 over the entire season 2012/2013 to cover seasonal effects. The study was based on funding by the European Fisheries Fund (EFF). One masters thesis (Kratzer 2012) was performed in the framework of this project. During some periods, a second pulse gear was used to compare certain technical improvements (ICES 2012). At the time of writing, no results other than the masters thesis by Isabella Kratzer (2012) were publically available.

A major goal of the **PhD-work of Maarten Soetaert** at ILVO is to find a safe startle pulse to catch sole as an alternative for the currently used cramp pulse in flatfish fisheries with high risk of causing injuries (see also chapters 4.6 and 5.4.1). A possible alternative might be to use pulses of lower frequency that might also be applied in a combined system of a pulse trawl to catch shrimp and flatfish simultaneously. Previous studies found that a total of 25 % of sole jumped out of the sediment when exposed to the HOVERCRAN pulse. The idea was to increase this to 60-70 %. Tests will also be done to determine the injury dose (ID50) and the lethal dose (LD10) for sole, cod, shrimp and sandworm (*Nereis virens*), at 50 and 100 V/m field strength and frequencies between 5–180 Hz using the HOVERCRAN pulse (ICES 2012). Practical investigations were meant to be terminated in autumn 2013. At the time of writing, no final results are available (Maarten Soetaert, ILVO, pers. comm.).

Subject of the **PhD-work of Marieke Desender** at ILVO are possible behavioral reactions and injuries in various organism groups (see also chapter 5.4). Species under investigation in tank experiments are sharks, rays and invertebrates. In addition, the impact of electric fields (75 and 150 V/m) on various life stages (eggs, larvae, juveniles) of cod, sole, brown shrimp and sandworm is to be investigated. At the time of writing, no results are publically available.

Recent investigations of pulse trawling are ongoing (2012-2017) in the framework of the **EU BENTHIS project** coordinated by IMARES. In the Dutch Voordelta in the fieldwork compaign of the North Sea case study, standard beam trawls and pulse trawls were directly compared in June 2013 with regard to mortalities of benthic organisms (vessel SCH-18) (BENTHIS 2013).

In the **Dutch MSC Management plan for shrimp fishermen** it is mentioned that certain areas will be closed for trawling in the future in order to investigate the impact of beam trawling for shrimp on the seabed (MSC 2010).

CRANNET: The CRANNET project aims at increasing the selectivity by means of modifications in the codend. Shrimp with a total length of 4.5 cm are commercially marketable but smaller individuals as small as 2 cm are also regularly caught (Verschueren et al. 2012). Shrimp beam trawling takes too many undersized shrimp that are not marketable. A large share of this fraction is discarded after the first sieving procedure in the rotary drum sieve and a smaller share is marketed as crushed shrimp. Based on various investigations the survival rate of the discarded shrimp fraction is estimated at 75–85 % (Verschueren et al. 2012). Still, the interpretation of numbers like these is difficult because long-term effects are not considered and a certain percentage of the discarded animals will be eaten, e.g. by sea birds. After cooking a second sieving takes place on a shaking sieve and the smallest fraction is discarded. The third sieving procedure takes place after landing and the smallest shrimp are used for feeding purposes. Neudecker et al. (2006) tried to make up a balance of this without being able to account for regional and seasonal differences. Under consideration of the estimated survival rates of the discarded shrimp fraction they calculated that for every tonne of marketed shrimp, the same amount (by weight) is permanently taken from the stock as moribund discard. This waste of valuable resources has economic and ecological consequences and a declared aim of fishery and science is the reduction of bycatch of undersized shrimp. In this context the research project CRANNET is currently investigating modifications to optimize the codend of shrimp trawls (Thuenen Institute 2013). Larger meshes or other modifications like meshes that are turned by 45 or 90° are being investigated. Another aim of the study is to find out if catch efficiency will be increased or decreased by escape windows for small shrimp in the codend.

6.2 Future needs for research and knowledge gaps

Chapter 4.5 outlines the current development status of the shrimp pulse trawl and chapter 5 summarizes current knowledge on the environmental impact of the technology. It may be concluded that some aspects cannot be finally evaluated yet and knowledge gaps remain even though investigations have been performed for several years. Other aspects are being investigated in current research projects and PhD work (chapter 6.1). The following paragraph summarizes some open questions and fundamental aspects that have to be further investigated in order to come to an adequate assessment of pulse trawling in shrimp fisheries.

For a proper assessment of pulse trawling vs. conventional shrimp trawling, information should be gathered on facts such as the mesh size applied on commercial vessels or the use of sieve nets vs. making use of the exemption to fish without in the course of **a recent fleet recording**. The last inventory of the shrimp fleet was taken in 1996 in the framework of the EU study 94/044 *RESCUE*[13].

Environmental impact by discard and bycatch: The amount of fish and bycatch taken permanently from the stock as bycatch in the shrimp fishery is currently unclear. The same applies to the resulting impact on the stocks, the ecosystem and on the fisheries economy. The most recent evaluations were performed prior to the introduction of sieve nets. Data collected via the *Data Collection Framework* are presumably not suitable for drawing usable conclusions due to the small sampling size. An evaluation of current bycatch volumes in combination with modeling of the possible measures to enhance selectivity like e.g. the introduction of pulse trawls would be desirable. In case of a potential permission, intensive accompanying research will be strictly necessary in order to verify the former assumptions.

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[13] Research into Crangon Fisheries Unerring Effects

In addition to increasing the selectivity by means of electrical stimulation, other measures are required to reduce bycatch rates. **Sieve nets and sorting grids** like they are mandatory according to EU Regulation (EC) no. 850/98, article 25(2), contribute to this target. In Germany they do not need to be applied in summer (May 1 to September 30) on account of an exemption. Other factors like large numbers of algae or jellyfish which obstruct the meshes of the net may also be used as a reason to fish without sieve nets (Catchpole et al. 2008). No exemptions are granted in Dutch waters any more since 2013 (Verschueren et al. 2012). This is meant to motivate the development of technical measures that avoid the obstruction of sieve nets or to shift to other fishing areas with fewer algae and jellyfish. This justifies further research needs for sieve nets, sorting grids or escape windows (e.g. *letter box*; Steenbergen et al. 2011) which are more versatile in use.

In connection with the application of pulse trawls, **a combined use of several measures to enhance selectivity** has not yet been adequately investigated. It remains to be seen to what extent the combined use of sieve nets and pulse trawls is possible or if a reduced mesh size of >20 mm in the codend has the potential to reduce the total bycatch or the bycatch of some species. Verschueren et al. (2012) propose to investigate especially the combination of pulse trawls and sieve nets in comparison to a standard beam trawl with sieve net.

Technical development of pulse trawls

Investigations of **various constellations of shrimp pulse trawls (based on the HOVERCRAN concept)** with regard to the number of bobbins and the height of the ground rope indicate that both, catch rates of commercial-sized shrimp and bycatch, strongly depend on the combination of these parameters. While major improvements of the pulse trawl from a perspective of nature conservation are reduced bycatch rates and less seabed contact, the interest of fisheries are predominantly increased catch rates of commercial-sized shrimp and reduced fuel consumption. Future research should focus on the optimum combination of both targets. In addition, questions of technical measures of surveillance and control need to be further elucidated by specialists (see also chapter 6.3).

Another option to reduce bycatch rates might be a vertical arrangement of the electrodes instead of the (usual) horizontal orientation in shrimp pulse trawls, with the **anode in the top panel above the cathode**. This arrangement might enhance the jumping effect in shrimp by anodic attraction. However, it might also lead to higher electrical corrosion if the polarity is not alternated (ICES 2011). A reversal of polarity between the electrodes might limit the problem of corrosion (Verschueren et al. 2012).

Further investigations of the required exposure time to the electric field are also needed. Shrimp that react very fast to the electric field (Polet et al. 205a) might be separated from other species with slower reactions when the electric field is applied at optimum exposure time. This might be technically achieved by **variations of the length of the electrode** in relation to towing speed.

Pulse characteristics: As a result of the investigations carried out so far to develop the pulse trawl further, the HOVERCRAN is equipped with 12 electrodes with pre-set output parameters like pulse shape, pulse duration and pulse frequency. The only variable parameter is the pulse amplitude which is freely adjustable on a scale of 0-100 %. As a result of the different pulse shapes and the large variety of possible combinations of output parameters, combined with the number of affected bycatch species, modifications of the pulse characteristics provide great potential to minimize the undesirable side-effects of the technology.

Mesh size in the top panel: The amount of unwanted fish or undersized shrimp in the bycatch might be reduced by variations of the mesh size in the top panel. Investigations of Polet et al. (2005a) demonstrated that smaller meshes resulted in higher numbers of small shrimp in the catch. Therefore, modifications of the mesh size offer additional means to influence the balance between desired shrimp catch and unwanted bycatch positively. Maybe the mesh size in the top panel acts as an important corrective factor for the amount of shrimp bycatch. The selective properties of a raised ground rope might be further optimized **by modifications of the height of the ground rope** in combination with bobbins of different size or weight. In addition, the electrodes should ideally be attached in such a way as to hover directly over the ground and do not drag on the floor (Verschueren et al. 2012). Further research and development work is still needed here.

Impact on the seabed

The impact of conventional beam trawling on the seabed cannot be fully assessed at this stage, among other things because the occurrence of sensitive benthic communities like *Sabellaria* reefs or sea cypress populations have declined to very low levels in areas where much shrimp beam trawling has traditionally been taking place (see also chapter 5.1). In no-take zones in the framework of marine protected areas it could be investigated if and how the recovery or a reintroduction of these communities could be achieved. The contribution of shrimp beam trawling and other demersal fisheries to their decline should also be investigated.

Impact on fish and invertebrates

Based on today's knowledge **spinal injuries and other damage like they are known from flatfish pulse trawling** (chapter 5.4) are not induced by pulses like they are used in shrimp pulse trawling. All species investigated by Polet et al. (2005a) (11 fish and 5 invertebrate species) had survival rates of 100 % after being exposed to a shrimp-specific pulse for 15 seconds. The passage of a pair of electrodes with a towing speed of 2.5 kts over the animals took about 1.1 s, resulting in a dose during the experiments that exceeded the dose during the passage of a typical shrimp pulse trawl over an organism considerably (Polet et al. 2005a). However, the results of Polet et al. (2005a) also indicate that the impact of electricity acts species-specific. Electric pulses induced minor behavioral reactions in sole, dab, dragonet, five-beared rockling and cod as well as shore and swimming crab (Polet et al. 2005a). Field trials also indicated species-specific reactions: a (preliminary) comparison of a pulse trawl to a standard beam trawl with sieve net revealed much higher bycatch rates in the pulse trawl compared to the reference hauls (Verschueren et al. 2012). Bycatch rates of some species were significantly higher in the pulse trawl (Verschueren et al. 2012) (see also chapter 5.3). The results suggest that more species than shrimp alone react to the "shrimp pulse".

Therefore a need for further research of the impact of the HOVERCRAN with regard to injuries and behavior of fish and invertebrate species exists, especially electro-sensitive species like e.g. sharks and rays. Investigations with sharks, rays, sole, cod, brown shrimp and sandworm are currently undertaken in the framework of 2 PhD-studies at the Belgian research institute ILVO (see also chapter 6.1). Other aspects to be investigated in these studies are the risk of injuries in cod or sole depending on the life stage, or the impact of low field strengths and frequencies on electro-sensitive species (sharks and rays) in order to better assess the bycatch risk by means of behavioral studies.

6.3 Specific features of shrimp pulse trawling legislation

A comprehensive legislative framework is strictly necessary for the combined use of bobbin rope and electrodes if pulse fishery is allowed.

Pulse fishing with electro-trawls is currently being discussed as a promising option for mitigating the disadvantages of traditional beam trawling. Pulse trawling has some features due to which the marine environment would be affected to a lesser extent than by conventional beam trawling. This includes reduced seabed contact (chapter 5.1) and reduced bycatch rates resulting from a raised ground rope (chapter 5.3). However, with rocky substrates, the additional use of bobbins to protect the net cannot be completely excluded (Verschueren et al. 2012).

There is considerable variation of the electric parameters such as pulse shape, pulse amplitude and pulse frequency in the pulse unit, but also in the gear itself, like height of the ground rope above seafloor, number and arrangement of bobbins, design of trawl shoes, weight, mesh size, use of sieve nets or other deflectors, etc. So there is some concern that fishermen will independently change the setting of the pulse trawl in order to enhance effectivity, which might result in impacts of the gear that are even more harmful than those of a conventional trawl. Therefore, it is necessary to ensure that the pulse settings cannot be modified freely in case of a controlled introduction of pulse fishing. It is strictly necessary to define which parameters remain variable. ICES (2012) asserts that the existing legal regulations (no difference is made between flatfish and shrimp pulse trawls), which only limit electric power and voltage, are not sufficient to avoid any misuse of systems. Hope was expressed of finding simple limits physically reducing the output energy of the system. But possibly other relevant parameters such as pulse shape, pulse duration and pulse frequency also need to be controlled. In this context, a Dutch working group is currently drawing up concrete proposals.

The conductivity of sea water varies among others with temperature and salinity, therefore values are different e.g. in summer or winter and in estuaries or offshore. This might require a variety of different settings of pulse trawls to achieve the desired effects. The only commercial system available at present in Europe, the HOVERCRAN of *MARELEC NV*, offers only little variability of the settings of the electric parameters. The pulse shape of the applied direct current of 250 µs duration and a pulse frequency of 4.5 Hz are fixed default values. Only the pulse amplitude is variably adjustable on a scale of 0-100 %. Investigations have shown best results at 80 % output (ICES 2011, Verschueren et al. 2012).

Currently appendix III of **Regulation EC no. 43/2009** limits the maximum electric power [in kW] (beam length [in m] multiplied by 1.25) and the maximum effective voltage between the electrodes (15 V). Values as high as those defined here are not met by shrimp pulse trawls. The vessel must also be equipped with an automatic computer management system which records power and voltage and it must be impossible for non-authorized persons to modify this automatic computer management system.

Regulation EC no. 43/2009 also specifies that no more than 5 % of the beam trawl fleet by member state shall be allowed to use electric pulse trawls. No differentiation is made between shrimp beam trawlers and flatfish beam trawlers. Such a distinction would be hindered by the fact that some beam trawlers target both, shrimp and flatfish.

From a professional point of view, the approval of shrimp pulse trawls is less critical compared to flatfish pulse trawls because they offer fewer opportunities to change the settings (see above). A possible controlled approval of shrimp pulse trawls is facilitated by the development of a specific shrimp pulse that does not affect other species. Thus, it seems possible that a pulse trawl of a specific manufacturer with fixed pulses and pulse frequency might be approved by the relevant authorities and this might be documented with a certificate. Such a controlled approval of specific systems also needs to include regular controls to ascertain that the device has not been changed. It has to be controllable on board the vessels by the surveillance authority, e.g. by means of a certificate in combination with a sealing of the device. If a manufacturer wanted to use different electric parameters, the sustainability of the system would have to be re-assessed. This would require the definition of minimum standards for investigations to be performed in this context.

Besides limiting electric parameters, it should also be regulated which additional measures to enhance the selectivity of the fishery have to be applied. The use of shrimp pulse trawls should only be approved in combination with a raised ground rope in order to fully exploit the advantage of the gear's increased selectivity that has been proven in several investigations. This would require a legal definition of the allowable height of the ground rope over the seabed and the distance to the trawl which, however, seems to be hard to implement and control in praxis.

In case the use of shrimp pulse trawls should be allowed in the future, it would be necessary to review at regular intervals if the aim declared by the legislative authority, which is to protect the marine environment, is really being achieved. A step-by-step introduction of the pulse trawl is considered a good option, by a successive increase of the share of the fleet using the system (e.g. by extending the exemption from 5 % of a country's beam trawl fleet to 10 %). If, by contrast, an approval for the entire fleet should be considered, then a regional restriction is suggested. A confinement of the application to certain areas would be desirable in order to investigate the impact compared to areas without pulse trawling, prior to a general approval. In general, the application of shrimp trawling - with or without electricity - in sensitive areas should be excluded in order to allow for the protection and/or recovery of valuable benthic communities and species.

The HOVERCRAN does not have an automatic monitoring system as stipulated by law already today. Still, the reporting requirement is a fundamental aspect of auditability in statutory obligations and this should be categorically demanded.

The possible increase in efficiency by application of pulse trawls (see chapter 5.2.1) could be used to reduce fishing effort in order to relieve the pressure on the marine environment. This would, however, require the knowledge of the current fishing effort in order to develop appropriate measures and control their implementation. Prior to any increase in fishing effort, scientific impact assessments are necessary to evaluate if this would negatively impact the environment. Effort limitations could be implemented e.g. by further reductions of fishing days or by fleet reductions.

6.4 Opportunities, risks and perspectives

Opportunities

Ecological opportunities of shrimp pulse trawls are reduced bycatch rates and less damage to the seabed, including the associated benthic organisms. This might address some of the criticism relating to the sustainability of conventional shrimp trawling.

Reduced impact on the seabed: In the HOVERCRAN pulse trawl, the bobbin rope and its mechanical stimulation is replaced by electrodes and electrical stimulation. By refraining from the use of bobbins, seafloor contact can theoretically be minimized by 75 % and the impact on benthic communities can be reduced (ICES 2011). These calculations are, however, based on the original configuration of the HOVERCRAN that is completely without bobbins. But in Germany, full omission of bobbins in the ground rope has been has been rated as unrealistic so far. Fishermen using shrimp pulse trawls in commercial applications combine the original HOVERCRAN configuration with an additional bobbin rope (Table 2). Information on the ground contact of these configurations is currently not available.

Bycatch reduction: in most cases no bycatch reduction was achieved in the application of pulse trawls by means of electrical stimulation alone. Additional raising of the ground rope by 10-15 cm and total omission of bobbins seem to be the key factors in order to separate the desired shrimp catch from the unwanted bycatch. The higher the ground rope was raised the less bycatch occurred because individuals not startled by the electric pulse could escape underneath the net. As more shrimp can escape via this path as well, the **optimum height of the ground rope is a compromise between acceptable catches for the fishermen and sufficiently reduced bycatch rates.** The available results are not yet sufficient to formulate general demands with regard to the way the ground rope is attached or a possible combination of pulse trawls with a (smaller) number of bobbins based on this correlation. This might increase efficiency at the expense of selectivity. Based on today's knowledge, spinal injuries and other damages such as those observed in flatfish pulse trawls are not induced by the characteristic pulse used for shrimp.

Savings in fuel consumption are desirable but can hardly be achieved by the use of pulse trawls in shrimp fisheries alone because the standard towing speed of about 2.5 kts is comparably low and cannot be further reduced by the replacement of standard trawls by pulse trawls (ICES 2012).

Should it emerge that the application of pulse trawls reduces the impact of shrimp trawling on the ecosystem considerably and verifiably, this would be a strong argument in favor of a certification of shrimp fisheries by the Marine Stewardship Council, MSC. It is also important to underline here that the general need for nature conservation of large unfished areas where demersal trawling is banned, especially in the Wadden Sea national parks, will not be rendered obsolete by the introduction of pulse trawling. This need exists independently of the fishing technology because there are other effects of pulse trawling which contradict to the target of a natural and undisturbed development within the national parks. These include the take of target species, the remaining bycatch, the remaining impact to the seabed and disturbance by fishing vessels. The importance of developing low-bycatch fishing technologies is so high because this might contribute to the ecological and sustainable performance of shrimp fisheries outside the no-trawling zones way.

Risks

The introduction of pulse trawling to shrimp fisheries also entails considerable risks to the environment. With regard to the impact of pulse trawling on the environment it is especially the increased efficiency that might turn out to entail risks for the sustainable use of the target species. As can be seen from the example of the unregulated pulse fishery in the East China Sea, there is a severe risk related to the application of electro trawling. The introduction pf pulse trawling led to drastic overfishing of the shrimp stocks in the East China Sea which could not be addressed other than by a complete ban of pulse trawling (Yu et al. 2007) (see also chapter 5.2.1).

Many of the investigations carried out on pulse trawling demonstrate increased efficiency in catching large marketable shrimp, while often also higher numbers of small non-marketable shrimp were caught. Catch efficiency for shrimp seems to be highest in a combination of conventional bobbins in the ground rope with additional electrodes and electrical stimulation. The effect on large and small shrimp probably has to be evaluated differently. The unwanted effect of increased bycatches of small shrimp seems to be impossible to counteract by the use of electrical stimulation to trigger a flight response in shrimp alone. Other measures to increase gear selectivity, such as e.g. larger meshes, are necessary to achieve this aim.

Even the fishermen themselves are drawing different and differentiated conclusions on the use of pulse trawls. In a discussion among Dutch and German fisherman described by ICES (2012), many voiced their fear that the use of pulse trawling might increase shrimp catches. An intensive debate developed concerning questions such as: should the application of pulse trawls be restricted by law, or should the additional application of bobbins in a pulse trawl be forbidden? Should shrimp fishery be regulated by TACs/quota in future (currently there is not such regulation, see chapter 3), or should other seasonal, regional or technical regulation be introduced (ICES 2012)? The fact that even some fishermen consider the increased efficiency a risk also underlines the requirement of a comprehensive legal framework, among others with regard to effort limitation, e.g. by fleet reductions. Potential disadvantages from the perspective of fishermen are the high costs of purchasing and maintaining the technology and for the conversion of a standard vessel to a pulse trawler. The price of a complete system including 2 beams, pulse generator, cables etc. are currently estimated at about 70 000 Euro (ICES 2012).

Conclusion

Currently no final conclusion on the sustainability of pulse trawling in shrimp fisheries can be drawn due to the multitude of effects which can be rated as opportunities or risks from a perspective of nature conservation. Moreover, some of the investigations dealing with questions raised on the basis of earlier studies are not yet completed. A greater understanding is expected from these results (especially the German HOVERCRAN project and the PhD-work of M. Desender and M. Soetaert at ILVO, see chapter 6.1). Moreover the overall evaluation of the results achieved during investigations on the Dutch vessel TX-25 is still pending (only preliminary results available in Verschueren et al. 2012).

In case the use of shrimp pulse trawls should be allowed on a wider scale in future in the North Sea, an adequate legal framework, the definition of a comprehensive management system and measures of enforcement are urgently needed. This includes, among other things, effort limitations, e.g. by reducing the fleet size, temporal or spatial fishing limitations and the introduction of a shrimp quota. Especially for the combined use of pulse trawls and bobbins, clear rules are strictly required. In addition, accompanying scientific monitoring is essential.

Pulse trawls have the potential to contribute to the mitigation of negative impacts of conventional shrimp beam trawling, but they are by no means an appropriate gear to be used in marine protected areas whose conservation target is the restoration of sensitive benthic communities.

As a preliminary conclusion, based on today's knowledge, the use of pulse trawls in shrimp fisheries should only be allowed in settings with raised ground rope and without the application of additional bobbins. Moreover, a comprehensive legislative framework is strictly necessary in order to regulate the admissible technical settings of pulse trawls. Measures of surveillance and control have to be unequivocally defined in order to mitigate any possible increase in efficiency by means of effort limitations.

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Glossary

O-group	Age group of fish in a stock in their first year of life
1-group	Age group of fish in a stock in their second year of life
A-shrimp	Large marketable shrimp
B-shrimp	Small non-marketable shrimp
bycatch	Any catch of species (commercial or non-commercial fish, invertebrates, marine mammals, seabirds, plants, etc.) other than the target species. According to the definition used in this report, the bycatch also includes the non-marketable share of the target species, shrimp. In the specific case of the shrimp fishery the term „shrimp bycatch“ is used. Bycatch may be either discarded or landed/retained.
C-shrimp	Small non-marketable shrimp (shrimp bycatch, discard) (size about <4.5 cm, see also chapter 5.3).
discard	Anything that is caught and not landed but thrown back (discarded). Discard may be dead or alive. Discards may be of target or non-target species.
duty cycle	The product of the pulse duration and pulse repetition frequency (see chapter 4.1), equal to the time per second that the signal is active
EIA	Environmental impact assessment
EEZ	Exclusive Economic Zone
electro trawl	See pulse trawl
HOVERCRAN	*HOVERing pulse trawl for selective CRANgon fishery*. A specific development of the Belgian ILVO (see below): a pulse trawl to catch shrimp
Hz	Hertz (pulses per second)
ICES	International Council for the Exploration of the Sea
IMARES	Netherland’s Institute for Marine Resources & Ecosystem Studies
ILVO	Belgian Institute for Agricultural and Fisheries Research
kts (knots)	Speed of 1 nautical mile (nm) (= 1.852 km) per hour
ms	Milli-seconds (1/1.000 s)
µs	Micro-seconds (1/1.000.000 s)
µS/cm	Microsiemens per cm, unit of electric conductivity in water which depends i.a. on temperature and salinity
nm	Nautical mile(s) (1 nm = 1.852 km)
non-target species (of a fishery)	Any species of fish that is not being targeted during a particular tow, haul or set. In the specific case of the shrimp fishery, all species except shrimp are non-target species. Non-target species may be retained or discarded. They belong to the bycatch (see above).
pers. comm.	Personal communication
pulse trawl	The pulse trawl is an electrified beam trawl equipped with electrodes. Depending on the target species, they are either triggered to execute flight reactions (shrimp) or muscle cramps are induced (flatfish) by means of electric currents of varying intensity, duration and pulse repetition. These reactions make the target species easily accessible to the fishing net.

results based management **(ResBM)**	Results-based management is a strategic management approach based on formulated targets. It is up to the fishermen to decide on the means to reach these targets. The concept relies on the fishermen’s innovative skills instead of setting rigid specifications. Incentives are provided to meet the objectives gradually. The only requirement is that results have to be documented in order to use the achieved knowledge within the terms of the management standards.
shrimp, brown shrimp	*Crangon crangon*
TAC	Total Allowable Catch, catch quota
target species (of a fishery)	Those species that are primarily sought by the fishermen in a particular tow, haul or set, or the subject of directed fishing effort in a fishery. In the specific case of shrimp fishery, only shrimp (of all size classes) are the target species. Target species may be landed (marketable shrimp) or discarded (small undersized shrimp), or later sieved out on land as „crushed shrimp“
TI	Thuenen-Institute, formerly von Thuenen-Institute resp. *Bundesforschungsanstalt für Fischerei*. German fisheries research institute.
undersized	Fish and other marine organism which are smaller than their (species- or area specific) minimum landing size

Better protection for the Wadden Sea, coastal fishery compatible with nature protection goals - how is that achievable?

Shrimp fishery

The regional coastal fishery belongs to the North Sea coast. However, it needs to find ways in future aiming for better nature protection.

Wadden Sea

This unique ecosystem at the coast of the North Sea is protected as National Parks and other marine protected areas with the aim, that natural processes should proceed in an undisturbed way. It has been inscribed as World Heritage Site by the UNESCO since 2009.

Problems

Damage and loss of, among other things, sand coral reefs and fishes such as catsharks and thornback rays by bottom trawling. Also, too many marine organisms are wasted when being caught as bycatch.

Solutions

Establishing part of the marine protected areas as no-take-zones, decreasing gear impact on the sea bottom and minimizing bycatch.

Cooperation

For a better protection of the nature under water in the Wadden Sea, WWF wants to find solutions together with the fishery.

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