ECOREGION **General advice**
SUBJECT **Request from France to review the work of SGELECTRA and to provide an updated advice on electric pulse trawl**

Request

France requested ICES to review the work of SGELECTRA and to provide an updated advice on the ecosystem effects of pulse trawl, and especially on the amount of injury and mortality for targeted and non-targeted species that contact the gear but are not retained.

Response

Based on the expert reviews, ICES concludes that:

1. Current scientific knowledge indicates that the introduction of electric pulse systems could significantly reduce fishing mortality of target and non-target species, including benthic organisms, assuming there is no corresponding increase in unaccounted (avoidance) mortality.

2. Recent developments have resulted in pulse trawl systems requiring less power and new trawl designs that reduce the pressure on the seabed. However, operational issues such as the determination of critical pulse characteristics (power, shape, frequency, etc.) to determine maximum acceptable thresholds, still remain unresolved.

3. Questions remain regarding delayed mortality, long-term population effects, and sub-lethal and reproductive effects on target and not-target species. ICES notes that in freshwater fish, the effects from electric trawls are generally sub-lethal. However, no information is available on whether the effects in freshwater are transferable to the marine environment. Further work on marine effects is needed to resolve these issues.

4. It is unclear whether the current legislative framework is sufficient to avoid the deployment of systems that are potentially harmful. While the systems currently under development do not appear to have major negative impacts, ICES considers that the existing regulatory framework is not sufficient to prevent the introduction of potentially damaging systems. Guidelines and procedures for Control and Enforcement are being formulated by a Dutch project group and should be of help in preventing potential damage.

5. Many of these issues will be addressed in the future research proposed by SGELECTRA, and ICES supports these proposals. ICES furthermore supports research into the potential use of the startle pulse as an alternative to the currently used cramp pulse response, as well as research into lighter trawls with the net raised off the bottom and gears with no bobbins or tickler chains disturbing the seabed. The determination of critical pulse characteristics also requires further investigation.

6. ICES considers that the available data are insufficient to recommend the large-scale use of the electric pulse trawl in fisheries. Consideration could be given to experimental increases, beyond 5% in the beam trawler fleet, in selected areas to further investigate the outstanding issues mentioned above.

7. ICES recognises that conventional beam trawling has significant and well demonstrated negative ecosystem impacts, and if properly understood and adequately controlled, electric pulse stimulation may offer a more ecologically benign alternative.

Background

Since the advice provided by ICES in 2009 a Workshop to Assess the Ecosystem Effects of Electric Pulse Trawls (ICES, 2010) has been convened in 2010 and a Study Group on Electrical Trawling (SGELECTRA) met in 2011 and 2012 (ICES, 2011, 2012). SGELECTRA (ICES, 2012) provides an update and a synthesis of recent work undertaken in the area of electrical fishing. Research has focussed on the use of electrical stimulation systems for beam trawl fisheries for plaice and sole, beam trawl fisheries targeting brown shrimp (*Crangon crangon*), and to a very small extent for a fishery on razor clams (*Ensis* spp.). Considerable work has also been carried out on spinal damage to cod from pulse trawling.

SGELECTRA (ICES, 2012) reports in particular on:

- the results of catch comparison trials between pulse systems, trawl designs, and conventional beam trawls;
- an overview of the findings from tank experiments aimed at assessing the impact of various pulse settings on cod;
- proposed areas of future research.

Below is a summary of the issues raised by reviewers and highlighted by ICES.

1 Catch efficiency

The experimental design discussed by SGELECTRA (ICES, 2012) is sufficient to provide a broad overview of the catch efficiency at a trip or fleet level, but insufficient to provide adequate length-dependent differences between the pulse systems tested and conventional beam trawling because of the different towing speeds used by the different systems. Both pulse systems tested retained less target and non-target species than conventional beam trawls and the amount of discards was also reduced. Results of other research programmes also indicate reductions in both landings and discards and it is concluded that pulse trawls do offer a reduction in fishing mortality, provided that the decrease in catch is not neutralized by a corresponding increase in unaccounted (avoidance) mortality.

The systems presented in the SGELECTRA offer an alternative stimulus method for beam trawls fitted with tickler chains only. Tickler chains are normally deployed on finer substrate and it is unclear if pulse systems are a viable alternative to the chain mats used in rougher substrate.

For shrimp fisheries, it has been demonstrated that a combination of conventional gear with bobbins, but equipped with 12 electrodes, resulted in increased catches of up to 54% when compared to conventional gear without pulses. Catch efficiency is dependent on the number of bobbins and power setting. Increasing the power does not always result in increased catch.

2 Unaccounted avoidance mortality

There is clear evidence from various field, aquarium, and post-mortem studies that the electrical fields generated by the pulse trawls can cause vertebral injuries in large cod. This may happen if cod is in close proximity (10 cm) to the electrodes in a fixed position. Further away from the electrodes (e.g. 40 cm) vertebral injuries did not occur. The pulse characteristics contributing to this impact on cod have not been identified, except that research showed that with higher pulse frequencies (180 Hz) spinal damage did not occur (De Haan *et al*., 2011). The results suggest that the ability of the pulse trawl to catch cod is lower than the conventional gear and that a higher proportion of the cod encountering the pulse trawl may evade capture. It is unclear whether some of these fish are fatally exposed in the process (unaccounted avoidance mortality) and if so, what proportion are killed in this way. Vertebral injuries may only be of concern if they result in unaccounted mortality, i.e. if the cod that are not retained die. It is concluded that further work on this aspect is needed and that this would be aided considerably by a better understanding of specific effects of the pulse characteristics and their interrelationship. The reviews appended below discuss this in more detail and provide evidence from studies on freshwater fishes that while these are affected by electric trawls, the effects are generally not lethal.

In contrast to vertebral injuries in large cod there is no evidence to suggest that targeted plaice and sole caught in the pulse trawls suffer spinal damage.

3 Non-target fish and benthic species

Work has demonstrated general reductions in catch rates of non-target species similar to what has been shown for plaice and sole. Other studies have shown that the catch rate of invertebrates in pulse trawls varies considerably, from less than 5 to 10%, but also that catch rates for some species can be several times larger than by conventional beam trawl.

It is unclear at what level unaccounted avoidance mortality is associated with the conventional tickler beam trawls. It would, however, be fair to assume that the removal of the tickler chains and replacement with a pulse system will have a significant and positive effect, both in terms of reducing the catch of non-target benthos and also in terms of the likely reduction in avoidance mortality.

For elasmobranch fishes, the reviewers raise a particular concern regarding possible effects of strong electric fields generated by the gear upon the highly sensitive electrosensory system of sharks and rays that help them in orientation and food seeking. Research is underway to address this issue.

4 Effects on population level

Although limited information exists for effects on marine species, evidence shows that variation in power, voltage, pulse shape, duration, and frequency of the electric field can modify the incidence and degree of impact on fish. Repeated electrofishing of freshwater systems can result in higher incidences of morphological abnormalities resulting from previous spinal injuries, and such injuries can affect the growth of juveniles and the general body condition in the population. Surprisingly, despite the high incidence of spinal traumas, the abundance of studied salmonids remained stable or even increased, indicating the absence of serious harmful effects at the population level. Freshwater studies have indicated that effects, such as hemorrhages, spinal injuries, and mortality of different species vary greatly and that electrofishing may be harmless for some species and extremely dangerous for others. Whether the effects observed in freshwater are transferable to the marine environment is unknown.

5 Legal regulation of pulse trawls

EU legislation on pulse trawls regulates power and voltage, but there are indications that the pulse shape, duration, and frequency are also of importance. This implies that regulating power and voltage alone may not be sufficient to ensure that negative impacts do not increase when the pulse trawl systems are further developed and used. A Dutch project developed draft guidelines and procedures for control and enforcement in pulse trawl fishery, and new limits for various pulse characteristics and a certification scheme were suggested.

6 Further work

There are still a number of unknown issues related to pulse trawls. These include the question of how different pulse characteristics interact and impact on fish. In Belgium a low energy system that stimulates a startle reaction rather than a cramp response are under investigation for both brown shrimp and sole. Another issue is the unaccounted (avoidance) mortality, which is not fully understood. These issues require further research.

Sources

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Annex(es)

Review 1: A review of SGELECTRA scientific activities (based on the 2010–2012 reports)
Review 2: Potential Ecosystem Impacts of Pulse Trawls. Review of SGELECTRA (2012)

Please note that the reviews in the annexes are supplied for information purposes only. They represent the views of the reviewers, but not necessarily the views of ICES.

Review 1

A review of SGELECTRA scientific activities (based on the 2010–2012 reports)

For the last three years, SGELECTRA has carried out a bulk of research and analytic work. Particularly, the contribution of the IMARES specialists is noteworthy for their large-scale laboratory and field studies conducted in reply to ICES advices. Now these studies that were initially focused on flatfish fishery are well supplemented with the recent data by the experts from Belgium and Germany where the shrimp trawling is being developed, as well as with valuable experience of the researchers from Lithuania and other countries. The new data on spontaneous razor clam fishery in Scotland that could be channeled to safe and controlled forms is also of considerable interest. Every year we learn more and more about the pros and cons of pulse trawling compared to conventional beam-trawl fishery. Currently, numerous advantages of pulse beam-trawling are substantiated, including a significant decrease in discards of undersized target fish, non-target species and benthic invertebrates, as well as less fuel consumption and fished area. An important step was a marked reduction in electric power of the fishing gear relative to heavily-powered regimes used in earlier systems. With the present operation mode, all the listed advantages of the pulse trawl are revealed against the background of its decreased catchability as compared to the conventional gear. However, the difference between the catches of the two gears is much less than the difference between their bycatches. Therefore a possible negative effect of pulse trawling on marine ecosystems is believed to be less severe than that of the tickler chain fishing which is fairly criticized for its negative impact on bottom habitats. In this connection a minor remark could be made regarding the way of data presentation in the last SGELECTRA report. It seems reasonable to provide additional information on the total percentages of discarded organisms (benthos, undersized target fish and non-target fish) in the catches of pulse trawl and conventional gear, along with length and weight means for marketable fish and discards. These simple indices would facilitate selectivity comparisons between the two gears in future reports.

Despite the great deal of research work, some issues, including the points raised in the earlier ICES advices, still remain unclear. One of the vital concerns is the fate of fish exposed to electric current. Currently, the data obtained by IMARES regards only the captured fish and shows that the target objects (plaice and sole) are robust enough to electric pulses. For these species, no spinal damages were reported that are the major concern to ecologists and fishermen today. At the same time, such traumas were found in cod. Previous field studies by the IMARES with the use of X-ray analysis revealed spinal injuries in two out of 25 cod individuals captured by the pulse trawl (i.e. in 10% of fish). Additional data on the injury occurrence in the landings and discards of cod was obtained during the field trials of 2011. These values were as low as 7.4% for TX36 (two fish out of 27 examined) and 11.1% for TX68 (two of 18 fish). In comparison with many electrofishing systems operating in fresh waters, these values appear to be low enough. In freshwater electrofishing, the share of the damaged individuals varies from several percent to 53–67%, depending on species and size of fish, shape, frequency and strength of electric current, and also on water conductivity (Sharber and Carothers, 1988; Snyder, 2003a, b). It is extremely important that vertebral fractures were observed in large cod individuals but not in small fish (12–16 cm), which raises their survival chance. Meanwhile, the damage of marketable fish is not a serious problem (at worst, it would have a negative effect on their appearance and market price).

Fish that were not retained

A problem of great concern is the fate of fish that were exposed to electric field of the gear but not retained. At present, the data obtained by IMARES and the participants of SGELECTRA cannot address this issue. The available information on this problem in the world literature is also extremely poor and mainly regards freshwater electrofishing systems.

Field surveys. For example, during the visual observations on the Gorki reservoir (Russia, the Volga river) no dead fish were seen behind the pair pulse trawl ELU-6M (Izvekov and Aslanov, 2000; Izvekov, 2001). These observations were conducted onboard a plastic boat that was towed over the trawl cod-end. The emerged stunt fish (mostly sabrefish, bleak and medium-sized asp) occurred seldom (approximately 4 fish per hour). Their number and weight accounted for 2.6% and 2.8% of the total catch, respectively. These fish were dip-netted and placed into a plastic tank onboard where they shortly recovered their swimming performance (from several seconds to 5–7 minutes).

Earlier, similar results were obtained on the Rybinsk reservoir (Russia, the Volga river) for the bottom trawl electrified with 50 Hz alternating current (Shentyakova *et al.*, 1970). In addition to visual monitoring of the water surface behind the electric trawl, immediately after its towing, a series of trawlings were performed using a conventional bottom trawl to find the dead and damaged fish that were not retained. During these control trawlings, no dead or damaged fish were collected in the near-bottom water layers. All fish caught behind the electric trawl appeared alive and visually did not differ from the fish captured by conventional gear at the adjacent sites. When released into the cages, all fish from the experimental and control trawlings (bream, zope, burbot and sheatfish) actively moved into deep water, except for the ruff (Shentyakova *et al.*, 1970).

The above observations could indirectly evidence the relatively low rate of serious deviations in the swimming capacity of fish that were not retained by the electric trawl, even using the alternating current that usually has a more severe effect on fish (see Snyder, 2003a, b) compared to pulse stimuli used in flatfish fishing. However, there remains a possibility of hidden damages and electrofishing-induced changes in fish behavior, which may affect their further survival.

Behavioural effects of electrofishing. While the acute effects of electrofishing, such as mortality and injury, are actively studied, little is known about its indirect behavioural effects. Experiments with bluegill *Lepomis macrochirus* have shown that electroshock causes a decrease in feeding intensity (up to 12 h) and only a short-term increase in its susceptibility to predation (up to 10 min) (Wahl *et al.*, 2007). However it is known that predators often follow the trawls, and are ready to consume the fish escaping through the codend meshes (Broadhurst, 1998; Svane, 2005). Therefore, even short-term changes in defensive reactions (predator detection, avoidance, schooling or shelter seeking) can essentially reduce the survival chances for the escapees (Ryer *et al.*, 2004; Suuronen, 2005; Suuronen and Erickson, 2010). In laboratory experiments, the trawl-stressed walleye pollock were more likely consumed by the predators than fish of a control group (Ryer, 2002). Even to a greater extent this may refer to fish escaping from the electric trawl, due to the negative impact of electric field added to all the adverse factors of conventional trawl fishing. Therefore, the numbers of fish that escape pulse trawls, their mortality and injuries rates, changes in behavior and vulnerability to predation are a great concern to be addressed in future studies.

Linking laboratory and field trials. When studying possible harmful effects of electric fields on fish under laboratory conditions, one of the acute problems is the yawning gap between the experimental data obtained and the actual situation in the wild. The IMARES experiments with cod have shown that in a close proximity to the electrodes, serious spinal injuries and some disturbances in feeding behaviour may occur, mainly in large specimens. However, we do not know exactly what share of fish would be subjected to such a strong impact during the sea trawling; it is also unclear what percentage of them would not be retained and how it could influence the overall fishing mortality.

Therefore, it is desirable to track the fish behavior in the operating range of a real pulse trawl. For instance, this could be done with the use of multiple underwater video cameras located in different parts of the gear. Today this method is fairly widespread in the marine trawl-fishery investigations (Piasente *et al.*, 2004). As for electrofishing, this may give us a clear view of fish approaching the electrodes and the specimens escaping under the footrope or through the codend meshes. These observations could also provide a rough estimate of the number of immobilized specimens remaining at the bottom. Comparison of the video-based escape rates with the total catch values would help in determining catchability and overall fishing mortality of the gear. Video records of the flatfish reactions to the moving shrimp electrotrawl were presented by the Belgian researches at the WKPULSE-2010 workshop, which proves the feasibility of such an approach. Another method is direct observation by divers. This method was successfully used in the Scottish experiments with a 3-m electrified beam trawl to investigate the behavioural responses of flatfish (Stewart, 1978).

Also, there exist some methods of sampling the escapees to determine their species, number and survival rates, e.g. using a codend cover, tag and recapture methods, electronic tags, acoustic telemetry etc. Though each method has its pluses and minuses (Breen *et al.*, 2002; Suuronen, 2005; Suuronen and Erickson, 2010) all of them appear to be valuable when studying the escape mortality of electrofishing gears in the wild. We believe the above methodologies will make it possible to build a bridge between the laboratory and field data. Equally important would be to compare the long-term changes in population characteristics for the fish that inhabit electrofishing areas and control areas where only conventional gear is used.

Possible population-level effects of electric fishing

Target fishes. It should be kept in mind that most electrofishing effects were studied at the organism level, while the population-level studies are at their dawn (Kocovsky *et al.*, 1997; Ainslie *et al.*, 1998; Nordwall, 1999; Carline, 2001). The long-term monitoring of populations that experience regular impact of electric fishing gears is of special interest. Currently, such data is scanty and available only for freshwater fish species. For example, in the rivers where electrofishing is regularly carried out, each year many fish are recaptured with morphological abnormalities resulting from previous spinal injuries (McMichael, 1993). Repeated action of electrofishing gears is known to cause more spinal damages than single-pass electric fishing (Ainslie *et al.*, 1998). Pond experiments have shown that such electrofishing-induced injuries can affect the growth of juvenile fish proportionally to the damage severity (Dalbey *et al.*, 1996). Extrapolation of the experimental data suggests approximately 3% or less decrease in mean population growth when 20% or less of the population is electrofished (Ainslie *et al.*, 1998). Also, electrofishing may lead to a subsequent decrease in body condition of recaptured fish (Thompson *et al*., 1997). And finally, electric fishing can provoke short-term emigration of fish from their home sites (Nordwall, 1999; Young and Schmetterling, 2004), including the spawning grounds (Siepker *et al.*, 2006), which can negatively affect the recruitment.

Population studies on three salmonid and one catostomid species (Kocovsky *et al.*, 1997) have shown that after 6–8 years of annual three-pass removal electrofishing, the rates of visible spinal injuries varied from 3.5 to 12.3% at

different locations. In contrast, no damages were found at control sites that had not been previously electrofished. The actual injury rates seem to be even higher because in 44% of X-rayed fish with no externally evident damages, previous injuries were seen. During the observation period, the abundance of longnose sucker *Catostomus catostomus* significantly decreased. Surprisingly, despite the high incidence of spinal traumas, the abundance of studied salmonids remained stable or even increased, indicating the absence of serious harmful effects at the population level. Similar data was obtained during the population studies of brown trout *Salmo trutta* (Carline, 2001). In spite of the high spinal injury rates (38–44%), the influence of high-frequency pulse electrofishing on most population characteristics was insignificant.

Regarding pulse fishing for flatfish, now it is hard to predict possible population-level effects. Apparently, these effects could be estimated only with the lapse of time, when analyzing the population statistics for the fish dwelling in the areas exposed to full-scale electrofishing and in the areas where fish are captured by the conventional gear. Long-term variations in population characteristics in the electrofished areas would also be very informative.

Non-target fishes. It should also be stressed that previous investigations of electrofishing-induced injuries were concentrated on commercially valuable fishes, while little attention was paid to cohabiting small non-target species. In a special study (Miranda and Kidwell, 2010) with non-target fishes (cyprinids, ictalurids and percids), the incidence of hemorrhages averaged 2% (from 0 to 20% for various species), the incidence of spinal injuries averaged 6% (0–30%), and mortality averaged 16% (0–90%). The considerable data spread implies that electrofishing may be harmless for some species and extremely dangerous for others.

In this respect, various non-target species mentioned in the ICES advice are investigated to different extent. According to the latest data by IMARES, whiting hardly seems to suffer any spinal fractures, while dab and turbot remain poorly studied.

Conclusion

Thus, extensive information on the influence of pulse electrofishing on marine organisms has been collected during the recent years. At the same time, some issues related to the ecological safety of pulse trawling remain obscure. Hence, further laboratory and field studies are needed on the effect of repeated stimulation; delayed mortality; long-term effects of the pulse trawling on the electrofished populations; influence on the reproductive success of fishes, their reproductive system and early development; direct and indirect escape mortality; effects on a variety of non-target species. Field studies should be accompanied by X-ray photography of the captured fish (to reveal possible vertebral damages) and their dissection (to count haemorrhage rates in muscles). A particular concern is possible effects of strong electric fields generated by the gear upon the high-sensitive electrosensory systems of elasmobranch fishes (sharks and rays) that help them in orientation and food seeking.

For the near future, SGELECTRA plans a series of urgent studies. Of special importance is the idea to search for a new startle pulse equally suitable for shrimp and flatfish electrofishing. No less promising is the attempt to find low frequency pulses that force sole to jump out of the sediments. Both hypotheses are planned to be tested in Maarten Soetaert's PhD-Thesis. We also hail the development of lighter trawls with the net raised off the bottom, the future gears with no bobbins or tickler chains disturbing the seabed.

Currently, the available data still seems insufficient to recommend the large-scale commercial use of the pulse trawl in fisheries. However, considering the reduced discards and landings of the electrified trawl in its present configuration, ICES may view the question of a partial increase in the proportion of beam trawlers allowed to use the pulse gear in the southern North Sea (as long as its electric parameters and operation mode remain the same). Another solution may be full-scale electric fishing allowed for several years within some limited areas in order to follow the electrofishing-induced changes in marine biota as compared to similar areas fished by conventional gear.

As a whole, the work of the SGELECTRA participants for the last years deserves appreciation. Most concerns expressed by ICES were adequately addressed in the course of well-designed and thoroughly conducted experiments and field trials. Some insufficiently explored issues are planned for the near future. These plans should be approved, amplifying them with studies of the fate of fish escaping the gear.

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Review 2:

Potential Ecosystem Impacts of Pulse Trawls - Review of SGELECTRA (2012)

Introduction

SGELECTRA (ICES, 2012) provides a synthesis of recent work undertaken in the area of electrical fishing. Research has focussed on the use of electrical stimulation systems for beam trawl fisheries for plaice and sole and for beam trawl fisheries targeting brown shrimp (*Crangon crangon*) and a fishery for razor clams (*Ensis* spp.). With respect to beam trawl fisheries SGELECTRA (ICES, 2012) reports mainly on the results of catch comparison trials, brief overview of the findings from tank experiments aimed at assessing the impact of various pulse setting on cod (a review of each is given below and based on the report commissioned by the EC in Spring 2012 which was written by this author). SGELECTRA (ICES, 2012) also reports on proposed areas of future research. These will undoubtedly provide further and important understanding of the impact of electrical pulse simulation in particular the determination of critical pulse characteristics (power, shape, frequency etc) to determine maximum acceptable thresholds, which is currently lacking.

Much of the following text is taken from an EU commissioned study which was prepared by the author of this review. It is noted that SGELECTRA (ICES, 2012) reviewed this study and raised a number of important points for further consideration. The specific points have been considered in the text below.

1 Impact on commercial species

Detailed analysis of catch comparison results from van Marlen (2011 & SGELECTRA 2012)

Catch comparison work undertaken by van Marlen (2011) reported in SGELECTRA (ICES, 2012) tested two pulse system (TX68 and TX36) on two separate commercial vessels. The two systems differed not only in terms of the pulse characteristics (see Table 1.1.1) but also in trawl design. The TX36 system was attached to a new concept for beam trawls, the SumWing, a hydrodynamic design which generates lift during towing to minimise sea bed impact (thus drag) which is also being tested as a replacement to the conventional beam and shoe arrangement. The TX68 system is more akin to the tradition beam trawl, where the pulse system only replaces the conventional tickler array. The catches from the two systems were contrasted with those from a conventional beam trawler (GO4). From the spatial and temporal data presented the experiments were not conducted using the parallel haul technique (Anon., 1996), but fished independently of the other vessels in approximately the same area and time. This approach is sufficient to provide a broad overview of the likely gross effects at a trip or fleet level, but insufficient to provide adequate length dependent differences between the three systems. It is acknowledged that given the different towing speed used by the systems the application of the parallel haul technique would be difficult to apply in practice.

Table 1.1.1 Comparison of the two pulse systems (van Marlen *et al.*, 2011).

	TX68	**TX36**
Power (kW)	5.5	7
Voltage	50	45
Frequency (Hz)	40	45
Duration (μs)	220	380
Nr electrodes	25	28

Catch and landings rates based on a variety of sources are presented by van Marlen *et al.* (2011). LPUE derived from auction data (Table 1.1.2), CPUE data of landings and discard data raised to trip levels (Table 1.1.3) and CPUE estimates derived from sampled hauls only (Table 1.1.4).

Table 1.1.2 Summary of LPUE by species based on auction data.

ship	GO4	TX36	TX68	TX36/GO4	TX68/GO4	TX36/TX68
species	kg/h	kg/h	kg/h	%	%	%
PLE	34.9	24.7	25.2	70.8%	72.1%	98.2%
SOL	17.6	14.8	15.4	84.4%	87.4%	96.6%
DAB	3.4	2.5	4.6	73.9%	135.4%	54.6%
TUR	3.6	3.1	2.8	85.3%	78.4%	108.9%
BLL	2.0	2.1	2.0	103.7%	99.8%	103.9%
COD	1.8	0.8	0.3	42.3%	19.2%	220.8%
WHG	2.7	0.1	1.3	3.2%	47.0%	6.9%
NEP	0.0	0.0	0.0	n/a	n/a	n/a
VAR	24.1	10.4	11.0	43.2%	45.6%	94.6%
Landings (sum)	90.1	58.4	62.5	64.9%	69.4%	93.4%

It is clear from this and the differences in LPUE (Table 1.1.2) and CPUE (Table 1.1.3) that both pulse systems retained considerably less target and non-target species. Landings (Table 1.1.2) and catch (Table 1.1.3) of commercial species (plaice and sole) show marked declines. For the landings of plaice and sole, landings for the TX36 system, landings were 70.8% and 84.4% respectively of that of the vessel equipped with the conventional beam trawl. For the TX68 system, plaice and sole catches were 72.1% and 87.4% respectively of the conventional vessel.

Table 1.1.3 Landings and discards of target species raised to total trip duration. From van Marlen *et al.* (2011).

ship	species	total fishing time (min)	measured (kg)	landings (kg)	landings (kg/h)	landings (#/h)	discards (kg/h)	discards (#/h)	perc_n	perc_w
GO4	Cod	4410				0.4				
GO4	Dab	4410					56.6	1052.0		
GO4	Plaice	4410	287.0	2565.0	34.9	101.7	106.8	1443.9	93	75
GO4	Sole	4410	292.5	1291.0	17.6	72.3	2.8	41.2	36	14
GO4	Whiting	4410					9.9	111.8		
TX36	Cod	4775					0.0	0.1		
TX36	Dab	4775					16.3	290.2		
TX36	Plaice	4775	202.8	1965.0	24.7	71.3	49.6	624.7	90	67
TX36	Sole	4775	188.0	1180.0	14.8	61.4	1.0	10.8	15	6
TX36	Whiting	4775					1.1	14.8		
TX68	Cod	4900					0.2	1.0		
TX68	Dab	4900					24.7	459.9		
TX68	Plaice	4900	112.0	2054.0	25.2	72.3	61.2	833.0	92	71
TX68	Sole	4900	123.0	1254.0	15.4	56.1	1.7	18.7	25	10

For plaice and sole discards, for the TX36 system, these were 46.4% and 35.7% respectively of that of the vessel equipped with the conventional beam trawl. For the TX68 system, plaice and sole catches were 57.3% and 60.7% respectively of the conventional vessel.

Table 1.1.4 Summary of mean CPUE over sampled hauls expressed in numbers and kilogram per hour for both landings and discards for the three vessels using a GLM to test of significance. From van Marlen *et al.* (2011).

Ship			GO4			TX36			TX68			TX36/GO4	TX68/GO4	TX36/TX68	GLM_output		
Variable	species	cat	n	Mean	Stdev	n	Mean	Stdev	n	Mean	Stdev	%	%	%	Diff TX36 vs. GO4	Diff TX68 vs. GO4	Diff TX36 vs. TX68
n_hl_hr	PLE	lan	33	129.7	85.6	27	59.3	44.3	20	65.0	60.0	45.7%	50.1%	91.1%	s	s	ns
w_hl_hr			33	35.9	22.6	27	15.7	13.0	20	16.3	15.3	43.7%	45.4%	96.3%	s	s	ns
n_hl_hr	PLE	dis	33	1502.2	707.2	33	615.7	311.7	33	827.6	340.6	41.0%	55.1%	74.4%	s	s	ns
w_hl_hr			33	111.1	57.4	33	48.9	25.9	33	60.9	25.9	44.0%	54.8%	80.4%	s	s	ns
n_hl_hr	SOL	lan	33	74.1	27.4	18	52.4	15.7	18	41.4	20.4	70.7%	55.9%	126.5%	ns	s	ns
w_hl_hr			33	18.9	6.6	18	15.0	3.7	18	10.9	5.7	79.4%	57.8%	137.2%	ns	s	ns
n_hl_hr	SOL	dis	31	45.6	46.4	27	13.2	10.8	22	28.2	17.1	29.0%	61.9%	46.8%	s	ns	s
w_hl_hr			31	3.1	3.6	27	1.2	0.9	22	2.6	1.5	39.8%	84.5%	47.1%	s	ns	s
n_hl_hr	DAB	lan	23	66.8	40.7	29	32.4	17.9	25	21.9	14.3	48.5%	32.8%	147.8%	s	s	ns
w_hl_hr			23	9.7	5.8	29	4.7	2.8	25	3.1	2.1	49.2%	32.2%	152.6%	s	s	ns
n_hl_hr	DAB	dis	33	1094.6	556.4	33	287.7	152.2	33	450.7	227.6	26.3%	41.2%	63.8%	s	s	s
w_hl_hr			33	58.9	33.4	33	16.2	8.1	33	24.1	13.2	27.5%	40.9%	67.1%	s	s	s
n_hl_hr	BLL	dis	1	24.0	.	6	10.6	6.5	2	9.7	0.5	44.4%	40.5%	109.6%	ns	ns	ns
w_hl_hr			1	4.8	.	6	1.3	0.8	2	1.0	0.2	27.9%	20.5%	136.2%	ns	ns	ns
n_hl_hr	TUR	dis	1	32.0	.	5	7.7	3.0	2	12.0	0.9	24.2%	37.6%	64.3%	s	ns	ns
w_hl_hr			1	5.8	.	5	1.5	0.7	2	1.7	0.3	26.0%	30.1%	86.5%	s	ns	ns
n_hl_hr	WHG	lan	14	51.1	22.6	8	12.9	10.7	7	22.7	16.5	25.2%	44.4%	56.7%	s	s	ns
w_hl_hr			14	8.7	4.2	8	2.0	1.6	7	3.6	2.5	23.2%	41.4%	56.0%	s	s	ns
n_hl_hr	WHG	dis	24	159.9	82.3	15	33.3	27.1	28	93.0	105.9	20.8%	58.1%	35.8%	s	s	s
w_hl_hr			24	14.1	7.8	15	2.5	2.0	28	6.7	7.8	18.0%	47.6%	37.9%	s	s	ns
n_hl_hr	COD	lan	5	4.7	6.6	13	1.0	0.5	10	0.8	0.3	21.7%	17.6%	123.5%	ns	ns	ns
w_hl_hr			5	12.6	13.3	13	2.8	1.9	10	1.8	0.8	21.9%	14.4%	152.1%	s	s	ns
n_hl_hr	COD	dis	0	n/a	n/a	4	0.6	0.0	2	17.5	15.4			3.7%	ns	ns	ns
w_hl_hr			0	n/a	n/a	4	0.1	0.1	2	2.7	2.9			4.6%	ns	ns	ns

However, there appears to be some disagreement between the LPUE estimates derived from landings and raised trip CPUE data and with the modelled CPUE estimates derived from sampled data. It is unclear why or indeed how these differences occur, particularly contrasting the raised and sampled only estimates, but the authors note that sampling levels did not produce reliable results in all cases, particularly for more rarely caught species such as turbot and brill. Therefore care should be taken not to over interpret the results shown in Tables 1.1.2 and 1.1.4. For example, using the LPUE estimate from the auction data (Table 1.1.2), plaice landings associated with the pulse system are ~70% that of the conventional vessel, whereas the modelled estimates (Table 1.1.4) indicate that plaice LPUE of the pulse trawl is 45% that of the conventional vessel. It is not possible to reconcile these differences.

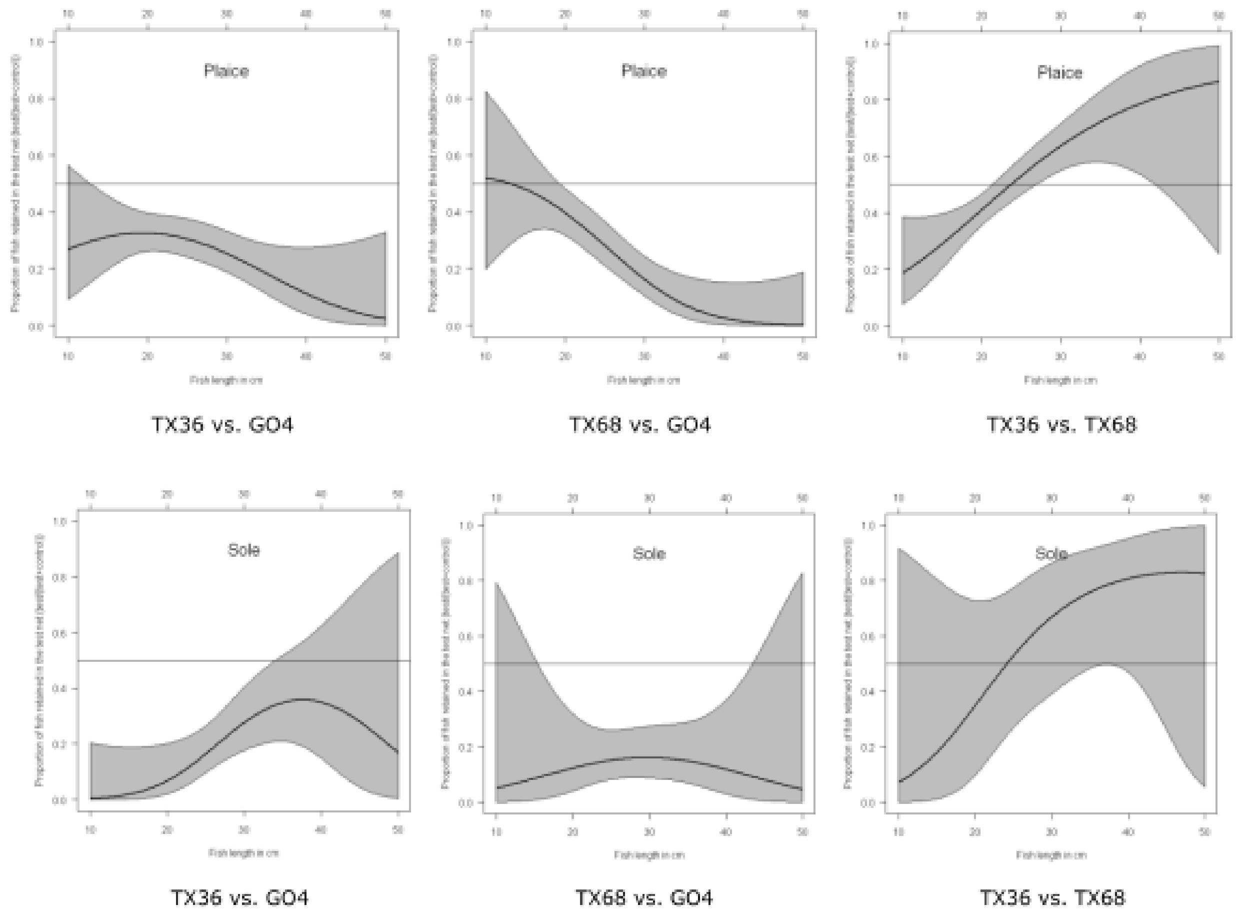

Figure 1.1 Comparison of catches at length of plaice and sole comparing the proportion of fish retained in the test net (test/test+control) from the TX36 (test) and GO4 (control); TX68 (test) and GO4 (control) and a comparison between the two pulse systems TX36 (test) and TX68 (control). From van Marlen *et al.* (2011).

Van Marlen *et al.* (2011) also presents a comparison of catches at length for both plaice and sole. The authors note that the analysis presented in Figure 1.1 should be interpreted more in terms of giving a trend than providing absolute comparative data due to low sampling levels, highlighted by the wide confidence intervals. Due to the uncertainties in the length estimates (and lack of numerical data) and the somewhat variable results presented in Tables 1.1.2–1.1.4, it is not possible to provide a forecast as to the likely impact that the wider introduction that such systems would have on stock development. Secondly, the systems presented offer an alternative stimulus method for beam trawls fitted with tickler chains, normally deployed on finer substrate and are not proposed as an alternative to the chain mat matrix used in rougher substrate. It is unclear what degree of uptake could be expected or how much transfer would occur between chain mat beam trawls to tickler chains.

SGELECTRA (ICES, 2012) also reports on a research programme which has quantified the likely stock impacts of five commercial species (cod, haddock, whiting, plaice and sole). The results are broadly in agreement with the earlier studies presented above and indicate reductions in both landings and discards of all five species under the catchability assumptions made.

Given the levels of reductions in both landings and discards, it can be concluded that the impacts would be positive in reducing the fishing mortality associated with the tickler beam trawl fleet, provided the introduction of the system does not introduce higher levels of avoidance (unaccounted) mortality.

Impact on Cod

There is clear evidence from various field, aquarium and post-mortem studies that the electrical fields generated by the pulse trawls can cause vertebral injuries in large cod. This effect is demonstrated in the recent study (de Hann *et al.,* 2011). The pulse characteristics from three commercial pulse systems were evaluated. Pulse frequency, power, shape and width were adjusted as well as orientation relative to the electrode (0^o and 90^o degrees). Vertebral injuries were observed in 50–70% of the cod. The work demonstrates that even with constant power levels, other variables of the

pulse (shape, frequency etc) can significantly affect the impact on organisms and it therefore difficult to disentangle and identify the key parameters and their thresholds. A multi-variate analysis of the results from de Hann *et al.* (2011) could potentially help identify the critical elements and their interactions.

However, vertebral injury may only be a concern if it results in significant unaccounted mortality i.e. cod (or other organisms) contacting the gear die and are not retained (avoidance mortality). If all of the large cod affected by the pulse are caught in beam trawls they would be destined to die anyway (i.e. from suffocation and barotrauma on deck) and would form a legitimate component of the catch for subsequent landing (assuming quota etc. is available). There may be a market quality issue as cod with vertebral injuries may exhibit internal bleeding which can discolour the flesh and potentially affect its market value.

The catch comparison study reported on by van Marlen *et al.* (2011) reports cod catches (above MLS) in the pulse trawls of around 20–40% of those obtained with the traditional tickler chain beam trawl. However, some uncertainty on cod still remains. The swept area of the pulse trawls amounts to around 80% of a comparable traditional tickler chain beam trawl and can be explained by the slower towing speed of the pulse trawls and reduced swept area. As such, it would not be unreasonable to expect that cod (>MLS) catches in the pulse trawl to be around 80% of the amount caught in the traditional beam trawl. However, cod catches (>MLS) were recorded to be 20–40% of the amount caught in the traditional tickler chain beam trawl. This suggests that cod catchability of the pulse trawl is lower than the conventional gear and a higher proportion of the cod encountering the pulse trawl may be evading capture. It is unclear whether some of these fish are fatally exposed in the process (avoidance mortality) and if so what proportion are killed in this way. It should also be noted that low levels of cod catches were encountered in the catch comparison trials. The statistical comparison of cod catches is not wholly persuasive that the differences observed are significant. It is recognised that field experiments are always problematic when a species of interest are caught at low levels, however further comparative data on cod catches would help to provide more clarity on this particular concern raised by ICES in 2009.

Impact on non-target fish and benthic species

Beam trawling is associated with high by-catch rates of both non-target fish and benthic species. The work presented by van Marlen *et al.* (2011) demonstrates overall reductions in catches of non-target species similar to the levels shown for plaice and sole (Table 1.3.1).

Table 1.3.1 CPUE estimates in numbers per hour raised to total trip duration for non-target fish species for the three vessel with the percentage ratio of catch rates for the pulse gear relative to the conventional beam trawl. From van Marlen *et al.* (2011).

Species	Name (EN)	#/h GO4	#/h TX36	#/h TX68	TX36/GO4	TX68/GO4
Pomatoschistus sp.		1.9	2.56	1.08	137.1%	57.9%
Callionymus lyra	Dragonet	25.2	9.77	50.16	38.8%	199.0%
Hyperoplus lanceolatus	Greater sand-eel	11.1	5.95	3.65	53.5%	32.8%
Clupea harengus	Herring	0.0	0.22	0.00		
Agonus cataphractus	Hooknose	3.3	5.22	4.50	158.2%	136.4%
Trachurus trachurus	Horse mackerel	19.9	1.60	2.53	8.0%	12.7%
Echiichthys vipera	Lesser weever	17.8	3.93	21.02	22.1%	118.2%
Cyclopterus lumpus	Lumpsucker	0.3	0.00	0.26	0.0%	78.9%
Callionymus reticulatus	Reticulated dragonet	0.0	6.47	0.00		
Arnoglossus laterna	Scaldfish	35.1	27.99	20.54	79.6%	58.4%
Taurulus bubalis	Sea scorpion	1.8	0.00	0.00	0.0%	0.0%
Buglossidium luteum	Solenette	55.5	49.00	39.52	88.2%	71.2%
Sprattus sprattus	Sprat	1.6	0.00	0.00	0.0%	0.0%
Trisopterus luscus	bib	0.0	0.00	0.37		
		173.50	**112.69**	**143.63**	**65.0%**	**82.8%**

Table 1.3.2 CPUE estimates in numbers per hour raised to total trip duration for non-target benthic species for the three vessel with the percentage ratio of catch rates for the pulse gear relative to the conventional beam trawl. From van Marlen *et al.* (2011).

Species	Name (EN)	#/h GO4	#/h TX36	#/h TX68	TX36/GO4	TX68/GO4
Ammodytes sp.		15.0	9.61	5.28	64.1%	35.2%
Anthozoa		3.1	0.87	0.37	27.7%	11.8%
Asterias rubens	common star fish	1321.4	683.67	837.32	51.7%	63.4%
Buccinum undatum		3.0	0.00	0.00	0.0%	0.0%
Cancer pagurus		2.3	0.73	0.76	31.6%	33.3%
Corystes cassivelaunus		37.9	58.37	18.38	153.8%	48.4%
Echinidae		5.9	0.00	0.00	0.0%	0.0%
Echinocardium cordatum	sea potato	4.7	89.71	287.26	1893.5%	6063.0%
Ensis sp.		4.5	1.49	0.45	32.7%	9.8%
Hyas coarctatus		0.9	0.29	0.00	33.9%	0.0%
Laevicardium crassum		0.0	0.29	0.00		
Liocarcinus depurator		21.9	10.06	12.91	46.0%	59.1%
Liocarcinus holsatus	swimming crab	1483.7	952.24	1115.83	64.2%	75.2%
Liocarcinus marmoreus		0.0	11.98	11.80		
Loligo sp.		1.9	7.14	0.22	375.3%	11.7%
Loligo subulata		0.0	0.00	0.63		
Necora puber		2.0	0.00	2.98	0.0%	147.4%
Ophiura ophiura	brittle star	1802.3	1538.56	164.99	85.4%	9.2%
Pagurus bernhardus	hermit crab	208.4	369.46	54.96	177.3%	26.4%
Psammechinus miliaris		0.0	5.37	5.62		
Spatangus purpureus		5.6	0.00	0.00	0.0%	0.0%
Spisula sp.		1.5	0.00	0.00	0.0%	0.0%
Myoxocephalus scorpius	Bull-rout	31.4	14.74	28.09	47.0%	89.5%
Mytilus edulis	Common mussel	0.7	0.00	1.49	0.0%	225.4%
Crangon crangon	Common shrimp	14.2	29.15	7.07	205.6%	49.9%
		4972.35	**3783.72**	**2556.41**	**76.1%**	**51.4%**

Lindeboom and de Groot (1998) estimate that for a 12 m beam trawl, fitted with tickler chains, the catch efficiency for invertebrates is less than 10% and for almost half the species encountered much less than 5%. Despite this, the catch of invertebrates can be several times larger than the catch of target species.

It is unclear what the level of avoidance mortality is associated with the conventional tickler bream trawls but it would be fair to assume that the removal of the tickler chains and replacement with a pulse system will have significant and positive effect, firstly in terms of reducing the catch of non-target benthos and also in terms of the likely reduction in avoidance mortality.

Issues surrounding control

The current EU Legislation on Pulse trawls stipulates the following criteria:

3.2. The following measures shall apply in 2009:

- *a) no more than 5 % of the beam trawler fleet by Member State shall be allowed to use the electric pulse trawl;*
- *b) the maximum electrical power in kW for each beam trawl shall be no more than the length in meter of the beam multiplied by 1,25;*
- *c) the effective voltage between the electrodes shall be no more than 15 V;*
- *d) the vessel shall be equipped with an automatic computer management system which records the maximum power used per beam and the effective voltage between electrodes for at least the last 100 tows. It shall be not possible for non authorised person to modify this automatic computer management system;*
- *e) it shall be prohibited to use one or more tickler chains in front of the footrope.*

There are a number of pulse characteristics other than power (article 3.2(b) annex III, EC regulation 42/2009) and voltage (article 3.2(c) annex III, EC regulation 42/2009) that can contribute to the potential negative impacts on organisms, particularly fish. Pulse shape, duration and frequency also contribute to the potential impact e.g. Sharber and Carothers (1988) note that one quarter sine waves resulted in a more significant increase in the incidence of vertebral damage (67% damage rate) compared to 44% for other wave forms. De Hann *et al.* (2011) notes the degree of vertebral damage decreased with increasing pulse frequency. Data presented by de Hann *et al.* (2011) indicates that there is also some degree of inter-dependency between pulse characteristics.

The ICES study group SGELECTRA (ICES, 2011) has acknowledged the need for more clear workable and enforceable limits to be identified, other than the existing two parameters described in the existing EU legislation (3.2 annex III, EC regulation 42/2009) i.e. power per unit of length and maximum voltage. SGELECTRA (ICES, 2011) note that these two will not be sufficient to ensure that fishing efficiency or negative impact with pulse trawls will not increase in future through technical adaptations of the systems. In recognition of the need to identify the impact and relationships between pulse characteristics, further work is scheduled to be reported by SGELECTRA in June 2012. The Dutch National Working Group on Control and Enforcement is also due to produce its recommendations on parameters which can be used for control and enforcement by around June 2012.

It is evident that in its current form, the existing EU derogation allows a range of pulse equipment to be developed for testing under normal fishing conditions. However, the absence of control on other pulse characteristics means that it is possible to deploy electric fishing techniques with negative ecological consequences within the specification in the current derogation. Yu *et al.* (2007) notes that the ability of operators to increase the power output and improper setting of pulse characteristics resulted in injury to both shrimp and other marine life in the eastern China Sea. The authors further note that the desire to increase catching efficiency of the pulse system effectively led to a system that developed into a killing apparatus rather than the intended stimulus device.

It is necessary to expand the current understanding of electric trawling in general with the aim to determine further and appropriate threshold levels. However, it may be necessary to maintain broad regulatory limits so as to allow engineers to develop and optimise their pulse trawl designs. Due to the potential benefits of reduced fuel consumption, swept area and reduced catch rates while maintaining profit levels, there is a need to facilitate technical advancement in the field of pulse trawl technology while avoiding unnecessarily complex and potentially stifling technical legislation, while simultaneously servicing conservation, environmental and fisheries management requirements. This need becomes more acute as industry demands for such technology exceeds the current EU 5% limitations (as has become the case now). Future developments should continue to undertake extensive ecological impact assessments. As requests to expand the user base of the pulse trawl technology beyond the current 5% derogation limit are considered, new legislation will need to be drafted.

Even with a broader understanding of all pulse characteristics, it will be difficult to define effective and detailed technical legislation needed to ensure safe and responsible environmental practice. Such prescriptive legislation will need to encapsulate all the critical technical parameters, thresholds, pulse fields parameters and equipment specifications for a range of pulse trawls. Such legislation will be technically very complex and will require a matrix of pulse characteristics benchmarked against a range of specified ecological indicators. Defining appropriate thresholds will require extensive field and laboratory testing to explore and quantify the impacts of the critical pulse characteristics and selection threshold boundaries.

The Netherlands and Belgium have paralleled technical developments with aquarium and field studies to assess the potential impacts of the pulse systems under development. Regulating a system based on agreed impact thresholds (results based) rather than prescribing highly technical specifications may offer a more tractable approach. Different manufacturers of pulse trawls targeting flatfish are already developing systems with differing pulse fields, and varying effects in the field. We note also that Belgian researchers are at an advanced stage in the development of a low frequency and low energy pulse trawl for use in the brown shrimp (*Crangon crangon*) fisheries. More systems with a variety of pulse field characteristics could develop in the future as knowledge improves making prescriptive legislation more complex.

SGELECTRA (ICES, 2012) further explores the issue of control and enforcement and a Draft procedure for control and enforcement is provided in annex 6 of the report. Clearly, there has been substantial work undertaken by the control authorities with input from scientists and manufacturers. The basis of the control is only to permit the use of pre-certified systems that meet a range of technical specifications and criteria.

Conclusions

Understanding of the various systems available has increased significantly over the past few years with much focus on quantifying the impact on non-target species, both fish and invertebrates and assessing the impact on catch rates of

commercial species, including extensive studies where such systems have been used under commercial conditions for extended periods. It appears that despite the reductions in marketable catch of plaice and sole, the use of these systems are still economically attractive due to reductions in fuel costs due to slower towing speeds and reduced drag. SGELECTRA (ICES, 2012) recognises that there are still a number of unknowns relating to these systems and that a better understanding of how the various pulse characteristics interact and impact on fish is required. PhD studies currently ongoing in Belgium aim to address a number of these issues. SGELECTRA (ICES, 2012) note that there are four basic responses: startle (fright) reaction, followed by cramp, forced swimming and electro-taxis and that understanding of what pulse characteristics and thresholds correspond to these responses is required. Work underway in Belgium is aiming to develop low energy systems that stimulate startle reactions that are sufficient to result in the capture of sole. There are still a number of outstanding issues relating to the use of electrical stimulation systems. It is unclear whether the current legislative framework is sufficient to avoid the deployment of systems that are potentially harmful. While the current systems under development do not appear to have major negative impacts, the current regulatory framework is insufficient to prevent the introduction of potentially damaging systems despite adhering to current regulatory limits. Given the complexity and interactions between pulse characteristics, using a prescriptive legislative approach will result in highly complex and technical regulations. The introduction of electric pulse systems could significantly reduce fishing mortality of target and non-target species including benthic organisms assuming that there is no corresponding increase in unaccounted (avoidance) mortality. The impact on animals that come into contact with the gear but are not retained (this can be either active or passive) is not fully understood, commercial field trials show lower CPUE than conventional beam trawls, this can be due to the lower towing speed (lower swept area) and/or the catchability of the gear is lower e.g. animals contact the gear but are not retained. While the numbers of cod caught in the commercial field trials are low, the CPUE is lower than would have been expected just from the reduction in swept area suggesting that there is an increase in overall avoidance, whether these fish are injured (as demonstrated in tank experiments) or not is unknown. It can be concluded that further work on this aspect is needed and that this would be aided considerably by a better understanding of specific effects of the pulse characteristics and their inter-relationship. Notwithstanding the above, it is also recognised that conventional beam trawling has significant and well demonstrated negative ecosystem impacts, and if properly understood and adequately controlled, electric pulse stimulation may offer a more ecologically benign alternative.

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