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On electrical fishing for brown shrimp (*Crangon crangon*) II. Sea trials

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Abstract

To find ways of reducing the by-catch in the North Sea brown shrimp (*Crangon crangon*) fishery, experiments were carried out with electric pulses. The basic idea was to selectively invoke a startle response in shrimp without stimulating any by-catch species. A selective groundrope could then be used in combination with electric pulses to obtain catch separation.

Sea trials with the electro-net showed that the raised groundrope created an escape route for most fish species regularly caught in shrimp trawls, while the electric field made the shrimps tail-flip high enough to be caught. The electro-net with raised groundrope and small meshes in the top panel gave satisfactory results. The losses of commercial shrimp catches were negligible. Part of the undersized commercial fish catch could escape and non-commercial fish and invertebrates were caught in lower numbers compared to the standard gear. Electric fishing can be a practical alternative to the standard shrimp trawl and could be an acceptable balance between the economic interests of the fishermen and the ecological demands of the marine ecosystem.

Keywords: Brown shrimp; Beam trawl; North Sea; Discard reduction; Electric pulses

1. Introduction

Laboratory experiments with electric pulses on the behavioural responses of fish and invertebrates typical in brown shrimp (*Crangon crangon*) fishery catches gave promising results (Polet and Delanghe, 2004). Brown shrimp displayed a pronounced startle response in the electric field and the majority of the animals jumped into the watercolumn, over 10 cm and up to 50 cm. Most of the other invertebrate and commercial and non-commercial fish species did not react to the pulses or, if a reaction was observed, the animals kept close to the bottom. These results suggested the possibility for selective fishing by altering the groundrope

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and using the electric pulses as an alternative stimulation.

While most selectivity-enhancing measures concentrate on the net part of the trawl (Walsh et al., 2000), the area of alternative stimulation with electric pulses is in the net mouth. Thus catch separation takes place before the animals have entered the net. This prevents escapees being exposed to net meshes before they can escape, reducing the damage incurred by contact or stress during the capture and escape process. This would reduce the mortality amongst escapees.

The traditional way to stimulate brown shrimp in a trawl is mechanical, i.e. by the bobbin rope. According to Berghahn et al. (1995), it is mainly the turbulence in the water that causes brown shrimps to tail flip. This stimulus, together with vibrations in the sediment and direct contact with the bobbins, indiscriminately affects all animals contacted and offers little opportunity to alter the selectivity of the net. By applying electric pulses, the mechanical stimulation by the bobbin rope becomes redundant. The basic idea is to raise the groundrope and stimulate shrimps to jump into the net. Animals not stimulated could then escape underneath the net. If effective, this could improve the species selectivity of the groundrope of a towed fishing gear. In addition, sea floor contact would be minimised thus reducing damage to the habitat.

A project was set up which consisted of two phases, (1) laboratory experiments to study behaviour; (2) sea trials to test a preliminary design of an electro-shrimp trawl. This report focuses on the sea trials.

2. Materials and methods

2.1. Plan of the field experiments

For the field experiments, the standard shrimp trawl was adapted to allow electrodes to be fitted and the groundrope to fish selectively. Financial and time constraints did not allow designing and building a purpose-made electro-trawl. In the traditional shrimp trawl, the groundrope fishes rather close to the seafloor and lies about 40 cm behind the centre of the bobbins (Fig. 1). According to fishermen, it is the tickler effect of the bobbins that stirs up animals from the seafloor. Once stimulated, the distance between the bobbins and the groundrope gives the animals sufficient time to reach a height above the groundrope. For the electro-fishing trials, the groundrope was raised leaving a vertical gap of 10–15 cm, and was shortened so it would lie against the bobbins (Fig. 1). The vertical gap provides an escape route below the net and the contact between bobbins and groundrope eliminates the stimulation effect of the bobbins. To prevent shrimps from escaping underneath the net, an electric pulse field was generated in the net opening, sufficient to initiate a startle response allowing the shrimps to be caught. Two electrode arrays were tested: (1) parallel anodes and cathodes, gliding over the seafloor and (2) cathodes gliding over the bottom and anodes rigged perpendicularly in the top panel of the net (Fig. 1). The latter gave a slightly better startle response for shrimps during the laboratory observation tests (Polet and Delanghe, 2004) but had the disadvantage of being more difficult to fit into the net.

The pulse generators used are of the type LWY because of their relatively high capacity (Polet and Delanghe, 2004). The control unit aboard the vessel has an input voltage of 24 V and is linked with the pulse generator on the trawl by a cable connection. The pulse amplitude is 123 V (at low load), the frequency is 5 Hz and the pulse duration is 0.6 ms. When applied at full scale, the pulse amplitude drops to 44 V. Therefore, two pulse generators were used together, generating a 65 V pulse in the net mouth.

2.2. Vessels, fishing gear and fishing grounds

An exploratory sea trip was carried out on RV Belgica between 22 and 26 November 1999. The purpose of this trip was to test the pulse generators and the rig of the electrodes and groundrope to check for any practical problems. To compare the experimental catch with a normal commercial catch, it was arranged that a commercial shrimp trawler would fish alongside RV Belgica. Two members of the DvZ team embarked on this vessel (Z.582–Asanat) to analyse the catches.

Experimental electro-fishing in commercial conditions was carried out in the year 2000, on the chartered vessel O.700, “Bisiti”. This vessel was fitted for catching shrimps (rotating shrimp riddle, cooker, etc.) and has a three man crew. In contrast to the research vessel, the commercial boat towed two beam trawls

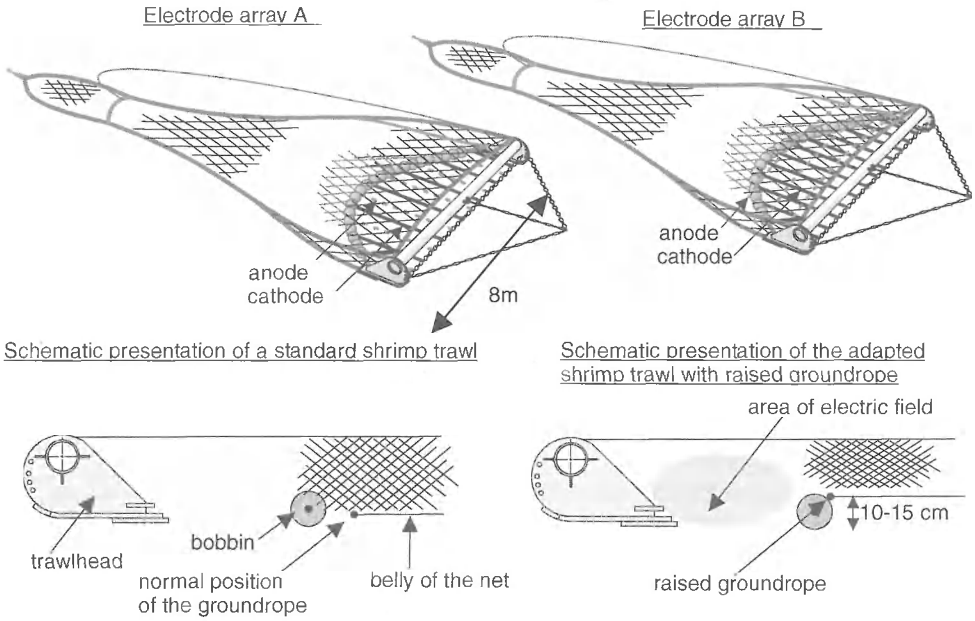

Fig. 1. A shrimp beam trawl altered for electro fishing.

simultaneously, one at each side of the vessel. For the sea trials, the choice of fishing grounds and fishing practices was left to the skipper to ensure commercial conditions. The traditional fishing grounds on the Flemish Banks off the Belgian coast were fished (ICES sub-division IVc). A total of 12 sea trips and 90 hauls were carried out; 57 hauls were analysed. The experimental trawl was towed at one side of the vessel and the standard trawl at the other side, allowing comparison of catches obtained under the same conditions.

The pulse generators were fitted to the beam of the trawl and connected to the electrodes rigged into the net mouth. The two electrode arrays shown in Fig. 1 were tested. A chain was rigged for the connection of the electrodes, lying 50 cm apart, between the two beam trawl shoes. The electrodes were partly loaded with light chains to assure moderate bottom contact. At sea, the bottom contact was regularly checked by inspecting the abrasion of the chains. The electrodes in the top panel were woven through the net meshes and lay 50 cm apart. The principle outlined in Fig. 1 for a selective groundrope was used. The groundrope was shortened to raise it closer to the bobbins. At first, the connectors between the groundrope and the bobbins were shortened but were still long enough to allow some movement of the groundrope. According to the skipper, and as became clear from the catches, this resulted in a rather unstable groundrope often rising too high above the bobbins. Therefore, later in the project, these connectors were further shortened, pulling the groundrope tight to the bobbins. During most of the trials, the net itself was not altered, except for three trials when an 11 mm mesh piece of netting was rigged to the front part of the top panel (28 mm meshes).

2.3. Data collection and analysis

On board, the fishermen processed the catch through a rotating shrimp riddle. After sorting, the catch was split into three fractions:

- the main by-catch containing the larger fishes, crabs, starfish, debris, etc.,
- the commercial shrimps containing also 0-and 1-group flatfish together with occasional juvenile roundfish and

- the non-commercial shrimps also with the smallest flatfish.

The volume of each catch fraction was recorded. This allowed a preliminary assessment of the functioning of the electro-net. Further analysis was done on numbers of individuals by species.

The fish in the catch were sorted out and measured immediately after the haul. The fish were measured for total length (TL) to the cm below, from the tip of the nose to the tip of the stretched tail fin. This method was preferred over standard length (i.e. from the tip of the nose to the fork of the tail fin), to be in accordance with the method used to measure fish for their compliance with minimum landing size regulations.

For shrimp, samples were taken for later analysis in the laboratory. There, the total length of the shrimps was measured to the mm below from the tip of the scaphocerite to the distal margin of the fans on the stretched uropods. An image analysis method (developed by the Bundesforschungs Anstalt für Fisherei, Hamburg, D) was used to measure the shrimps. Following the results of a theoretical study on the effect of sample sizes on the estimation of selection parameters for shrimp trawl cod-ends (Polet and Redant, 1999), it was decided to measure at least 250 shrimps per catch fraction.

A sample was taken to estimate the amount of non-commercial fish and invertebrates from each haul. In the laboratory the animals were weighed and counted.

To evaluate the efficiency of the electro-net, the catches of this net were expressed as a percentage relative to the standard net, by species. The significance of differences was assessed with t-tests. For brown shrimps, length frequency distributions were calculated together with the percentage difference in catch by length class. For commercial fish species, fish below and above MLS were distinguished. For non-commercial fish and invertebrates, total numbers were used to evaluate the differences in catch.

3. Results

The sea trips carried out and the configurations tested are given in Table 1. The catch results for the different series of sea trials are given in Tables 2–4. For each series and each species, the table presents: (1) the total numbers of animals caught in the standard net, (2) the percentage animals caught in the experimental net relative to the standard net indicating the catch loss (or increase) due to gear modifications, (3) the 95% confidence limits for this difference and (4) the p-value of the t-test indicating whether the catch difference was significant or not. A graphic representation of the length frequency distributions of the shrimp catches in both nets and the percentages shrimps caught in the experimental net relative to the standard net by length class is given in Fig. 2.

Table 1
Overview of the sea trips and the configurations tested with the electro-trawl

Series	Vessel	Pulses	No. of generators	Electrode array	Groundrope	Connectors	Small meshes in top panel	Number of hauls
1	Belgica	No	2	A/B	Shortened	Short	No	6
2	Belgica	Yes	2	A	Shortened	Short	No	6
3	Belgica	Yes	2	B	Shortened	Short	No	6
4	O.700	No	–	A/B	Standard	Standard	No	3
5	O.700	No	–	A/B	Shortened	Long	No	3
6	O.700	No	–	A/B	Shortened	Short	No	3
7	O.700	Yes	1	A	Standard	Standard	No	3
8	O.700	Yes	2	A	Standard	Standard	No	6
9	O.700	Yes	2	A	Standard	Standard	Yes	3
10	O.700	Yes	2	A	Shortened	Long	No	2
11	O.700	Yes	2	A	Shortened	Short	No	1
12	O.700	Yes	2	A	Shortened	Short	Yes	6
13	O.700	Yes	1	B	Standard	Standard	No	3
14	O.700	Yes	2	B	Standard	Standard	Yes	3
15	O.700	Yes	2	B	Shortened	Short	No	3

Table 2
Results of the sea trials for brown shrimp—total numbers in standard net (*); percentage animals in experimental relative to the standard net (**); 95% confidence limits for the percentage difference (***); p-value for the difference in catch between the standard net and the experimental net (****)

	Series							
	1	2	3	4	5	6	7	8
Brown shrimp <MLS	18556*	18556	18556	189513	40596	172535	23442	499735
	10%**	24%	50%	94%	31%	54%	48%	53%
	(−4 to 24)***	(−5 to 53)	(31–69)	(85–104)	(15–48)	(47–60)	(2–93)	(42–63)
	0.000****	0.002	0.000	0.467	0.003	0.002	0.039	0.001
Brown shrimp >MLS	15503	15503	15503	47526	47711	38386	29934	143947
	24%	69%	76%	100%	31%	57%	79%	86%
	(−8 to 55)	(39–99)	(56–96)	(89–110)	(14–48)	(46–67)	(70–87)	(72–100)
	0.004	0.047	0.025	0.410	0.003	0.003	0.008	0.056

	9	10	11	12	13	14	15
Brown shrimp <MLS	25445	60978	48825	129883	30534	211612	58875
	99%	52%	81%	116%	74%	110%	72%
	(70–128)	(46–58)	–	(102–130)	(72–75)	(80–139)	(54–91)
	0.673	0.001		0.032	0.000	0.355	0.022
Brown shrimp >MLS	25380	61208	19888	56038	40956	55798	29314
	112%	73%	92%	88%	91%	98%	96%
	(69–155)	(59–88)	–	(74–103)	(74–108)	(91–105)	(82–110)
	0.330	0.015		0.096	0.303	0.762	0.323

During the first three series of experiments on RV Belgica, the shrimp trawl with shortened groundrope was used, i.e.:

- *Series 1: without pulses*
  The loss of shrimps was 90% for small and 76% for large shrimps. This demonstrates that the raised groundrope creates an escape route through which most of the shrimps escape when no pulses are used. From Fig. 2 (Series 1) a clear length effect was observed, i.e. an increasing escape rate with decreasing length.
- *Series 2: with pulses and electrode array A*
  By switching the pulse generator on in the same configuration as in Series 1, the loss is reduced. This is especially the case for the larger shrimps with 31% shrimp loss relative to the standard net. This was significantly more ($p = 0.019$) than in Series 1. For the smaller shrimps, the catch loss was 76%, which was not significantly higher than in Series 1. Fig. 2 (Series 2) again shows a length effect, indicating that for shrimps larger than 60 mm there was no catch loss and even a slight catch increase.
- *Series 3: with pulses and array B*
  By using electrode array B, the catch losses were further decreased. The catches for small and large shrimps were 50 and 76%, respectively relative to the standard net, both significantly higher compared to Series 1 (respective p-values 0.008 and 0.004). Again the losses of larger animals were less compared to the smaller shrimps.
  The first three series of trials on the commercial vessel were used to identify the effect of fishing gear alterations without electric pulses although the electrodes were rigged into the net opening for each series.
- *Series 4: standard shrimp trawl*
  During these trials, the experimental net was identical to the standard net, with the exception of the presence of electrodes in the net opening (not generating pulses). In this Series, the tickler effect of the electrodes could be evaluated. The shrimp catches in the standard and the experimental net were comparable. For the smaller shrimps a small reduction was observed, although it was not significant. For most of the fish and invertebrates, a catch

Table 3

Results of the sea trials for commercial fish species–total numbers in standard net; percentage animals in experimental relative to the standard net; 95% confidence limits for the percentage difference; *p*-value for the difference in catch between the standard net and the experimental net

Series:	4	5	6	7	8	9	10	11	12	13	14	15
Whiting	154	584	120	863	799	588	862	198	962	2834	210	329
< MLS	104%	69%	66%	93%	67%	86%	65%	85%	85%	90%	58%	90%
	(0_208)	(49_90)	(25_107)	(42_144)	(47_87)	(77_94)	(32_97)	(-)	(46_124)	(1_180)	(46_70)	(-25_205)
	0.985	0.023	0.165	0.614	0.007	0.051	0.043		0.888	0.42	0.021	0.903
Whiting		11		22						20		
> MLS		100%		32%						144%		
		(-136_336)		(28_36)						(57_231)		
		0.678		0.009						0.206		
Poor cod	2368	8	1081	56	615	2972		70	3567	36	99	1030
< MLS	130%	80%	102%	111%	97%	98%		103%	104%	207%	93%	92%
	(62_198)	(-193_353)	(62_143)	(2_221)	(83_112)	(63_132)		(-)	(89_119)	(-63_478)	(83_103)	(66_118)
	0.291	0.717	0.45	0.292	0.61	0.425			0.421	0.301	0.881	0.988
Sole	259	138	110	211	394	271	92	14	977	392	106	84
< MLS	104%	41%	47%	103%	76%	76%	60%	81%	87%	74%	88%	78%
	(15_193)	(37_46)	(-41_135)	(92_114)	(55_98)	(-10_162)	(41_80)	(-)	(64_110)	(31_116)	(26_150)	(-3_160)
	0.537	0.001	0.283	0.51	0.11	0.213	0.012		0.842	0.096	0.903	0.363
Sole	6			17	8	12	2		24		2	9
> MLS	286%			112%	375%	208%	0%		142%		250%	100%
	(-)			(41_182)	(-)	(-)	(-)		(48_235)		(-)	(-)
	0.238			0.547		0.315			0.421		0.5	
Plaice	214	62	124	35	236	140	97	22	309	1004	66	23
< MLS	155%	54%	66%	92%	94%	89%	40%	65%	81%	70%	74%	41%
	(-2_312)	(8_100)	(52_79)	(37_147)	(57_131)	(-33_210)	(38_41)	(-)	(63_99)	(57_83)	(52_95)	(4_78)
	0.333	0.218	0.042	0.438	0.236	0.675	0.003		0.009	0.013	0.739	0.045
Plaice		12		29			26	2		32		
> MLS		25%		153%			62%	50%		173%		
		(-200_250)		(13_294)			(-43_167)	(-)		(131_216)		
		0.17		0.244			0.263			0.023		
Dab	321	131	459	15	530	9	79	13	84	1584	255	
< MLS	103%	49%	100%	67%	61%	282%	61%	38%	157%	65%	135%	
	(51_155)	(-12_109)	(-223_424)	(-16_149)	(32_89)	(-54_618)	(59_63)	(-)	(78_235)	(57_73)	(106_163)	
	0.778	0.079	0.544	0.225	0.704	0.175	0.003		0.867	0.005	0.176	
Dab		27	6		10		18		32	547		
> MLS		17%	0%		130%		29%		79%	83%		
		(1_33)	(-)		(-)		(21_38)		(-197_356)	(31_135)		
		0.005			0.691		0.184		0.721	0.186		
Flounder	7	26		32			27		36	179		
> MLS	57%	29%		120%			30%		69%	37%		
	(-228_341)	(-26_84)		(-59_299)			(10_50)		(-37_176)	(10_65)		
	0.288	0.042		0.678			0.543		0.824	0.01		

Table 4

Results of the sea trials for invertebrates and non-commercial fish species–total numbers in standard net; percentage animals in experimental relative to the standard net; 95% confidence limits for the percentage difference; p-value for the difference in catch between the standard net and the experimental net

Series:	4	5	6	7	8	9	10	11	12	13	14	15
Anemones		0 0% (-)								16 58% (-)	10 420% (-) 0.687	
Pagurus spp.		43 42% (-63_148) 0.432	37 65% (-256_385) 0.338	449 181% (77_286) 0.079	77 105% (-) 0.248	26 115% (-) 0.025	123 1% (1_2) 0	50 30% (-)	105 38% (-) 0.405	79 237% (136_338) 0.023	65 113% (99_128) 0.249	43 50% (-4_104) 0.074
Liocarcinus holsatus	18013 116% (90_142) 0.081	3660 33% (37_38) 0	10937 87% (28_147) 0.464	1202 102% (82_123) 0.269	23391 127% (120_134) 0.023	10456 180% (99_261) 0.066	8477 33% (5_60) 0.009	6493 56% (-)	20210 160% (30_290) 0.183	3365 47% (-47_141) 0.135	8756 110% (73_148) 0.531	10724 59% (56_63) 0
Spisula subtruncata	47 167% (-565_900) 0.458	56 35% (-11_81) 0.025	14 81% (-)	3735 142% (94_190) 0.083	335 101% (66_135) 0.412			22 69% (-)	56 17% (-) 0.124			15 0% (-)
Abra spp. + Angulus spp.		39 21% (-)	131 39% (-103_181) 0.165		995 91% (40_141) 0.996	14 105% (-)		0 12% (-)	214 77% (-) 0.344		109 161% (-) 0.863	
Ensis	465 102% (67_136) 0.456	10 53% (-)	87 69% (-361_499) 0.728	4082 131% (126_135) 0.031	202 80% (12_149) 0.389	219 113% (61_165) 0.186			1151 44% (3_86) 0.052	710 112% (82_143) 0.22	79 38% (-)	162 51% (18_83) 0.029
Sepiola atlantica	84 98% (-911_1107) 0.602	0 0% (-)	70 25% (4_46) 0.014			106 117% (77_156) 0.706			245 63% (5_122) 0.041			125 34% (-25_94) 0.042
Allotheutis subulata		0 0% (-)				40 0% (-)					69 128% (-)	21 0% (-)
Asterias	14 121% (-)	83 36% (-18_89) 0.046	2 50% (-)	59 128% (126_130) 0.014	26 123% (-)		91 25% (-2_52) 0.007		13 61% (-)			451 1% (-)
Ophiura spp.	4788 99% (14_183) 0.728	2137 32% (25_38) 0.001	675 86% (-22_194) 0.715	32035 96% (74_117) 0.429	9937 96% (72_120) 0.396	1063 106% (43_169) 0.725	4141 12% (2_23) 0.001	90 71% (-)	4805 79% (6_152) 0.724	1259 108% (73_142) 0.435	2489 119% (116_121) 0.038	1472 79% (37_121) 0.197

Table 4 (*Continued*)

Series:	4	5	6	7	8	9	10	11	12	13	14	15
Ciliata mustela		17 63% (10_116) 0.093					8 66% (-) 0.329					
Eutrigla		0 0% (-)									92 0% (-)	
Trigla lucerna		0 0% (-)			50 0% (0_0)						141 7% (-4_18) 0.003	
Myoxocephalus scorpius		8 0% (-)		2 133% (-)								
Agonus cataphractus	2623 150% (0_299) 0.214	58 41% (7_75) 0.018	534 62% (-39_164) 0.312	22 9% (-30_48) 0.982	3138 68% (44_91) 0.041	4603 82% (68_97) 0.062	10 54% (33_75) 0.105	136 51% (-)	1938 72% (59_84) 0.006	5 0% (-)	1591 128% (-)	493 87% (-18_192) 0.762
Liparis liparis		27 0% (-)		2 0% (-)							10 0% (-)	
Trachinus vipera	261 60% (-238_359) 0.301	0 0% (-)	81 13% (-)		68 44% (-) 0.406	395 45% (-122_212) 0.633			569 51% (18_84) 0.028			666 57% (47_67) 0.003
Callionymus spp.	105 106% (-) 0.521	181 46% (-1_94) 0.05		179 99% (48_149) 0.914	287 133% (90_177) 0.764	7 505% (176_834) 0.034	97 46% (0_93) 0.667			186 205% (137_274) 0.48	204 242% (153_330) 0.207	19 117% (-)
smelt		66 2% (-5_8) 0.015	203 0% (-)	55 0% (-)	21 0% (-)				31 69% (-) 0.242			6 0% (-)
Pomatoschistus spp.	13366 105% (77_133) 0.293	885 38% (17_60) 0.008	6259 74% (53_96) 0.074	242 38% (28_47) 0.001	35689 60% (40_79) 0.001	4381 52% (8_95) 0.059	456 38% (-36_112) 0.068	4504 54% (-)	3330 67% (41_94) 0.046	950 61% (59_63) 0.001	11223 65% (58_73) 0.005	1711 28% (22_33) 0

increase was observed which was, however, never significant.

- *Series 5: shortened groundrope with long connectors* The fishing gear in this set of trials was identical to the previous Series with the exception of a raised groundrope with long connectors. The losses of shrimps were substantial and significant for small as well as large shrimp. No clear length effect was observed. The losses of fish and invertebrates were also substantial. It is clear that the raised groundrope creates a good escape route for all animal species caught by shrimp trawlers.
- *Series 6: shortened groundrope with short connectors* The only difference between this Series and the previous one was the short connectors, resulting in a more stable groundrope held close to the bobbins. The catch reduction for shrimps was significant for

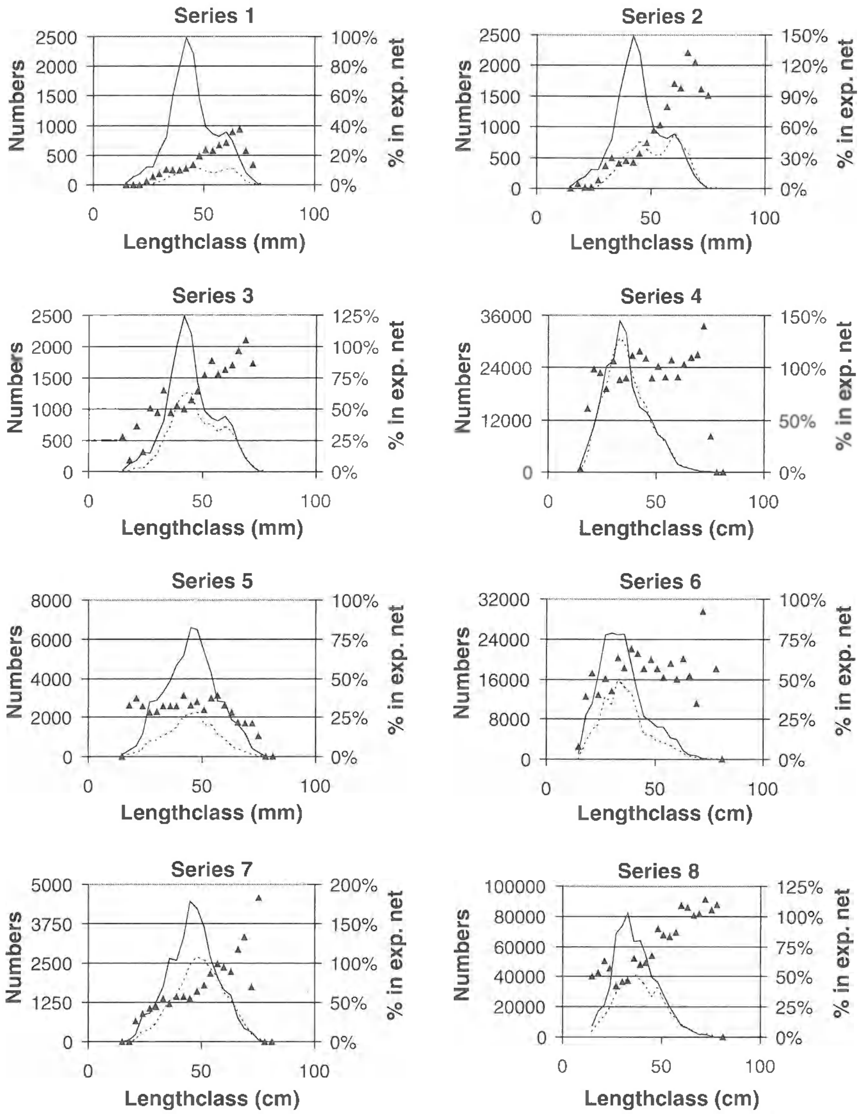

Fig. 2. The length frequency distributions for brown shrimp caught in the standard and the experimental net and the percentage in the experimental net catch relative to the standard net catch.

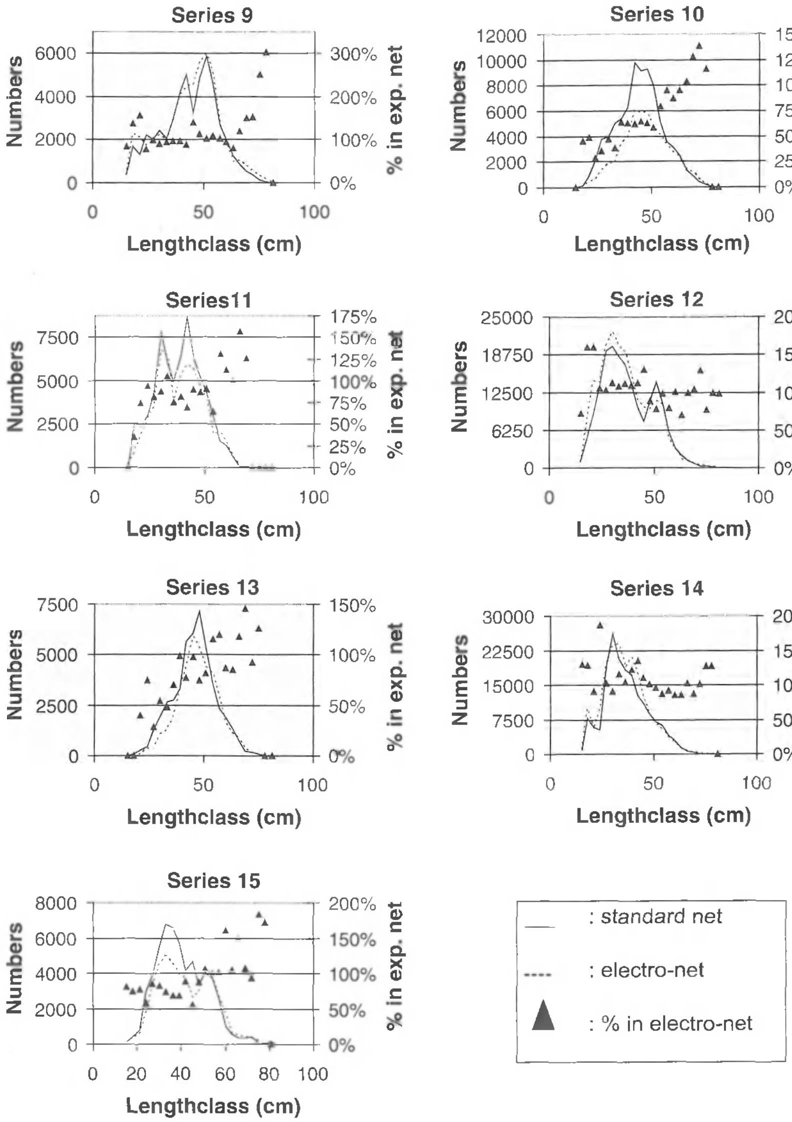

Fig. 2. (*Continued*).

both small and large animals, although the losses were significantly less ($p = 0.004$) compared to Series 5. For all fish and invertebrate species, large catch reductions were observed but for many species the reductions were not significant.

The following six series of trials were carried out to evaluate electrode array A, i.e.:

- *Series 7: standard shrimp trawl, with pulses generated by 1 pulse generator*

It was originally planned to carry out trials with two generators, but due to a breakdown, the sea trip was continued with only one functioning generator. A notable loss of shrimp catch was observed, with small shrimps about 50% and large only 80% compared to the standard net. The length effect was quite clear, with high losses of small shrimps and for the largest animals (>70 mm) a slight tendency of a catch increase. Since the trials were carried out with a standard net, the catch loss must have been caused by the electric pulses. For the commercial fish species, the only significant difference was the catch reduction for large whiting. For the other species, a significant catch increase was found for non-mobile species like the common starfish (*Asterias rubens*) and *Ensis directus*. For gobies (*Pomatoschistus* spp.) a significant catch reduction was obtained. For other species, the results were variable.

- *Series 8: the same as the previous one but with 2 pulse generators operating in parallel*
  Again, important catch reductions were obtained for brown shrimps, although less pronounced compared to the previous Series. A concurrent length effect was observed. For commercial fish, the results were again rather inconclusive. The catch reduction for undersized whiting was significant. For large sole, the catch was higher in the electro-net although the significance could not be tested since this species was only caught in one haul. The results for the non-commercial fish and invertebrates were quite species dependent. The significant catch reduction for pogge (*Agonus cataphractus*) and gobies may suggest a repellent effect of the pulses for these animals. The significant increase in catch of the common swimming crab (*Liocarcinus holsatus*) may, however, point to a stimulating effect of the pulses for crabs.
- *Series 9: the same as the previous one but with small meshes in the top panel*
  Because it was not expected that the shrimp catches would decrease with electric pulses (Series 7 and 8), it was suspected that shrimp escaped by another route. It might be that due to the extra stimulation, shrimp would tail-flip up to the top panel where the larger meshes (28 mm) would allow escape. Therefore, the front part of the top panel was shielded with a small mesh panel (10 mm mesh opening). The catch of undersized shrimps was almost identical in both nets. The catch of large shrimps was 12% higher in the electro-net, although the difference was not significant. A clear length effect was not observed.
  The catch differences for the other species were again species dependent and to a great extent the same as in Series 8.
- *Series 10: shortened groundrope with long connectors, no small meshes in the top and pulses generated by 2 generators*
  The configuration used here was identical to Series 5, but with pulses. High shrimp losses were observed, although not as high as in Series 5. The catch losses were significantly less compared to Series 5 ($p = 0.007$ and 0.001 for small and large shrimps respectively). Strong reductions in fish and invertebrate catches were also observed.
- *Series 11: the same as the previous one but with short connectors*
  The catches of small and large shrimps were, respectively, 81 and 92% relative to the standard net. The catch losses were somewhat higher for the small shrimps but any length effect was weak. For almost all fish and invertebrate species, important catch reductions were observed. The results for this Series are less reliable since only one valid haul was carried out.
- *Series 12: the same as the previous one but with small meshes in the top panel*
  A catch loss of 12% for large shrimps was observed, although not significant. For small shrimps, a significantly higher catch was obtained in the electro-net (116% relative to the standard). The length effect observed in the trials without small meshes in the top was absent and had reversed to some extent. The catch differences for commercial fish were quite variable and a significant reduction was noted only for undersized plaice. Catch reductions were seen for most of the non-commercial fish and invertebrate species. Only for the common swimming crab (*L. holsatus*) and *Callionymus* spp. was the catch higher in the electro-net.

The last three series of trials were carried out to evaluate electrode array B. The configurations tested were not as complete as for electrode array A due to time restrictions.

- *Series 13: standard shrimp trawl, with pulses from 1 pulse generator*
  A significant catch reduction was observed for small shrimps and as for the other trials without small meshes in the top, the length frequency distribution showed a clear length effect. For large shrimps the catch reduction was small and non-significant. The catch differences for the other species were quite variable and species dependent.
- *Series 14: same as the previous one but with small meshes in the top panel and 2 generators*

The shrimp catches in the electro-net were not significantly different from those in the standard net. The length effect seen in the trials without small meshes in the top panel was absent. For most of the commercial fish species, a catch reduction was seen, although only significant for undersized whiting. For sole and dab the catches were higher in the electro-net but the differences were not significant. The results for non-commercial fish and invertebrates were quite variable and species dependent.

- *Series 15: shortened groundrope with short connectors, no small meshes in the top and pulses generated by 2 generators*
  A significant catch reduction was seen for small shrimps, but for large shrimps the catches remained the same. For almost all commercial fish the catches were lower in the electro-net, but only significant for undersized plaice.
  With the exception of *Callionymus* spp. all non-commercial fish and invertebrate species were caught in lower numbers in the electro-net.

4. Discussion

A disadvantage of the generators MJX-50 and LWY, in sea-going applications, was the cables connecting the onboard power supply and control unit to the generator rigged on the fishing gear. This made shooting and hauling the gear difficult. The high electric voltage in the cable was also a safety risk for the crew. An advantage of the cable connection was the ability to check the functioning of the generator while fishing. The generator Tongfa-98, fed by batteries, solved the problem of a cable connection, but had the disadvantage of not being sufficiently powerful to feed the full electrode array.

4.1. Brown shrimp

From the preliminary experiments on RV Belgica (Series 1–3), it was clear that the pulses had an effect on the shrimp catches. A catch loss for large shrimps of 76% was reduced to a loss of 31 and 24% for electrode arrays A and B respectively. Other trials demonstrated the same effect of the pulses, e.g. comparing Series 6 (no pulses) with a catch loss of 43% and Series 12 (with pulses) showing a non-significant catch loss of 12%. Apparently, the stimulation of the electric pulses was strong enough to bring the majority of the shrimps into the net. In a number of experiments, however, a clear length effect was observed when pulses were used, i.e. the catch reduction of small shrimps was higher compared to large shrimps. At first, it was thought that the larger shrimps showed a stronger startle response compared to the small ones. The observation tests in the laboratory, though, only indicated a rather small difference (10% or less) in startle response. The length effect was not observed when a small mesh panel was rigged into the top panel. This indicated that some of the shrimps were tail-flipping as high as the top panel and, in the absence of small meshes, could escape through the top panel meshes. Clear length selectivity occurred in that area, with more small shrimps escaping than large ones.

De Groot and Boonstra (1974) obtained 39 and 20% higher commercial and undersized shrimp catches with an electro-net (i.e. standard shrimp trawl with pulses as extra stimulation). They found a length effect in the shrimp catches, although not as pronounced as in this study. Shrimp nets then were usually made of smaller meshes. Due to the lower selectivity, it is logical that the length effect is less clear. The relative catch increase for commercial shrimps of 39% is markedly higher compared to the 12% observed in Series 9 of this study. It may be that electric pulses enhance the escapement of shrimps through the meshes of the net body. Smaller meshes will release less shrimps, leading to a stronger relative catch increase, as observed by De Groot and Boonstra. It may also be that different environmental conditions during the sea trials caused this difference in relative catch increase, but due to a lack of data, no decisive answer can be given. Similar catch increases were observed by Delanghe et al. (1988) fishing with an electrified shrimp beam trawl.

A possible disadvantage of the electro-net as used in this study was the tickler effect of the electrodes gliding over the seafloor. The impact of this tickler effect on the catches when fishing with raised groundrope is difficult to estimate with the available data. An alternative electrode array with electrodes not touching the seafloor might further decrease the unwanted by-catches. Future experiments should pay attention to this issue.

4.2. Commercial fish species

Reductions of the whiting catch were obtained for most of the Series, although only significant in four trials. Escapes were recorded with the raised groundrope, but also when the standard net was fished with pulses. Apparently, the electric field had a scaring effect on this species inducing their escape from the net. Published data on by-catches in electro-trawls are scarce, but for whiting and also for cod the same effect was reported by Vanden Broucke and Van Hee (1977). For poor cod, on the other hand, no significant reductions were recorded, indicating that this species was not scared out of the net and did not even escape underneath the raised groundrope.

For sole, the results were quite variable and inconclusive. Undersized plaice, on the other hand, clearly used the escape route underneath the raised groundrope. There was even a slight indication of catch reduction due to the electric field when fishing with the standard groundrope. For undersized dab, catch reduction was obtained when fishing with electric pulses, both with the raised and the standard groundrope. This might indicate that these fishes did not use the escape route underneath the net. The catches were not lower in the electro net, only when small meshes were rigged in the top panel of the net. This indicates that this species had a similar behaviour to shrimps, i.e. an upwards movement in the electric field. The fishes that were small enough could escape through the larger net meshes in the top panel. This is supported by the observation tests that showed that dab swam straight up after the electric field was switched on.

4.3. Non-commercial fish and invertebrate species

Heavier animals like hermit crabs clearly benefited from the escape route underneath the net, reaching catch reductions from 35% up to almost 100%. Similar good catch reductions were obtained for shellfish species like *Spisula subtruncata*, *Abra* spp., *Angulus* spp. and *E. directus*. Also for the other invertebrate species, strong catch reductions were observed with the electro-net. Often, these were not significant due to the rather low numbers of observations per Series. For *L. holsatus* the same behaviour was recorded with one exception. In Series 12, despite the raised groundrope, higher catches were found in the electro-net. In these hauls, very high numbers of small crabs (about 1 cm carapace width) were caught. Apparently, these small animals did not show the same behaviour as the larger animals of the same species that are more usual in the catches. The small crabs did seem to react to the pulses.

The results for the non-commercial fish species were similar. Species like *A. cataphractus* and especially *Pomatoschistus* spp. also showed catch reductions in the electro-net rigged with a standard groundrope. For these two species, the pulses seemed to have a scaring effect resulting in lower catches.

4.4. Comparison with the other selective devices

In Polet (2003), it was already concluded that the sieve net would be the better choice for the Belgian shrimp fishery compared to a sorting grid. Comparing electric fishing with the sieve net is difficult. Electric fishing is a method still further to be developed. Some problems with the rigging have already been identified and it is probable that future research and commercial testing will lead to improved selectivity. The sieve net, on the other hand, has long past the development phase and has been in commercial use for several years. The design as it stands now is close to optimal for commercial application.

For the sake of completeness, a comparison is given below and some general conclusions can be drawn. The results should be interpreted with the remarks of the previous paragraph in mind. The principle of electric fishing, i.e. selection of animals before entering the net, has clear advantages compared to the filtering principle of the sieve net. The contact of escapees with the electro-net is minimal since they escape underneath the net, so escapee mortality is likely to be lower.

For commercial shrimps, the electro-net (Series 12) outperforms the sieve net (Table 5, All CV-Trials).

Table 5
The p-values of the t-tests (and Mann–Whitney U-tests between brackets) indicating the significance of the differences between commercial shrimps lost comparing the sieve net and the electro-net (only commercial vessel trials) (details in Polet, 2003)

Sieve net	Electro-net–Series 12
CV-Spring	0.75 (0.72)
CV-Summer	0.42 (0.42)
CV-Autumn-Winter	<0.01 (<0.01)
All CV-trials	0.02 (0.03)

The catch loss was not different when comparing the electro-net with the CV-Spring and CV-Summer trials. So, if the technical problems with the sieve net observed in the CV-Autumn-Winter trials could be resolved or if a seasonal enforcement of the sieve net would be implemented, the catch loss of the sieve and the electro-net would be comparable. It is expected, however, that further optimisation of the electro-net could improve the performance for commercial shrimps. So, it is likely that in the future, electric fishing would be the better choice for the fisherman.

The good catch reductions for commercial fish <MLS observed with the sieve net were not found to the same degree with the electro-net. For non-commercial fish and invertebrates, on the other hand, both selective trawls showed comparable catch reductions.

4.5. *The future of electric fishing*

The results of this study indicate that electric fishing has good potential to improve the selectivity of the shrimp beam trawl. The sea trials have been carried out, though, in a limited variation of circumstances like seasons, vessels and fishing grounds. Therefore, the potential for a wider applicability in brown shrimp trawling should be further studied.

Since the electric pulses have a clear selective effect on different fish and invertebrate species, other applications should be possible as well. Any trawl fishery with a mixed catch, facing problems with discards, could apply the method to prevent certain species from entering the trawl, on the condition that the target species have a different response compared to the by-catch species. Catch separation within the net is also feasible. An electric field could enhance the effectiveness of selective devices like a separator panel in the net. Another application could be the reduction of catches, losses of target species in an outlet of, e.g. a sorting grid. A recent example is the problem of losses of penaeid shrimps through the outlet of a sorting grid aiming at the reduction of fish by-catch (Foster and Watson, 2003). The grid appears to be very effective in releasing finfish but also allows shrimps to escape. A small electric field could prevent this. The effectiveness of square mesh windows could be improved with electric pulses. A problem with these devices is that they offer an escape route to fish but the animals sometimes do not use the opportunity because of lack of stimulus. Pulses could offer this stimulus in some cases. This list is not exhaustive.

An acute problem with electric fishing is legislation. Council Regulation 850/98 prohibits the use of electricity in any fishery in EU waters. The reason is that electricity can be (mis) used in different ways to catch fish, often quite detrimental. Before the method can be applied, it is inevitable that steps will have to be taken to alter the regulation. A consensus on the merits of the method should therefore be achieved amongst fishermen, managers and scientists before a realistic attempt can be made to do so. DG XIV (fisheries) of the European Commission has already expressed a positive attitude towards electric fishing and stated that legislation can be altered on condition that a substantial report with sufficient supportive arguments can be presented.

5. Conclusions

The selective electro-net seems to be feasible. The sea trials indicated that the raised groundrope created an escape route for most of the species regularly caught in shrimp trawls, and also for brown shrimps. The electric field made the shrimps tail-flip high enough to be caught. The response was even strong enough to make the shrimps jump as high as the top panel, leading to catch losses. To prevent this, the insertion of a small mesh piece of netting into the top panel was necessary.

It can be concluded that the electro-net with raised groundrope and small meshes in the top panel gave satisfactory results. The losses of commercial shrimp catches were small or even non-existent. Part of the undersized commercial fish catch could escape and non-commercial fish and invertebrates were caught in lower numbers compared to the standard net. Future work should pay attention to the design of an electro-trawl with a larger net opening, allowing long electrodes and a new type of bobbin rope with less bottom contact. Bearing this in mind, electric fishing should be a feasible alternative to the standard shrimp trawl and could be an acceptable alternative balancing the economic interests of the fishermen and the ecological demands of the marine ecosystem. Future trials should done out with a newly designed modern pulse generator.

It should, however, be borne in mind that the sea trials in this project only covered a short time span and a narrow range of conditions such as water temperature, currents, degree of activity of the shrimps etc. An extensive range of sea trials on commercial vessels in different conditions should precede commercial application.

The final obstacle on the way to a possible commercial application is Council Regulation 850/98 that prohibits the use of electricity in any fishery in EU waters. Before the method can be applied, steps must be taken to alter this regulation. A consensus on the merits of the method should therefore be achieved amongst fishermen, managers and scientists before a realistic attempt can be made to do so.

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References

Berghahn, R., Wiese, K., Lüdemann, K., 1995. Physical and physiological aspects of gear efficiency in North Sea brown shrimp fisheries. Helgoländer Meeresun 49, 507–518.

De Groot, S.J., Boonstra, G.P., 1974. Notes on the further development of an electrified shrimp trawl in The Netherlands. ICES C.M. 1974/B:5.

Delanghe, F., Vanden Broucke, G., Deschacht, W., 1988. Elektrische visserij op garnalen en platvis. Mededelingen van het Rijksstation voor Zeevisserij (no. 224).

Foster, D.G., Watson, J.W., 2003. The response of finfish to side opening grids. In: ICES Symposium on Fish Behaviour in Exploited Ecosystems, Bergen, Norway, June 23–26, 2003.

Polet, H., Redant, F., 1999. Effect of population structure, sampling strategy and sample size on the estimates of selection parameters for shrimp (*Crangon crangon*) trawls. Fish. Res. 40, 213–225.

Polet, H., 2003. Evaluation of the technical means to reduce discarding in the belgian brown shrimp (*Crangon crangon*) fishery. Ph.D. Thesis at the Ghent University, Belgium.

Polet, H., Delanghe, F., 2004. Assessment of the feasibility of electric pulses as an alternative stimulation for brown shrimp (*Crangon crangon*)–laboratory experiments. Fish. Res, in press.

Vanden Broucke, G., Van Hee, J., 1977. Verder onderzoek over de elektrische visserij op garnalen. Mededelingen van het Rijksstation voor Zeevisserij, 133-TZ/82/1977.

Walsh, S.J., Engas, A., Ferro, R.S.T., Fonteyne, R., Van Marlen, B., 2000. To catch or conserve more fish: the evolution of the fishing technology in fisheries science. In 100 years of science under ICES. In: ICES Marine Science Symposia, vol. 215, A Symposium held August 1–4, 2000. Helsinki, Finland.