Available online at www.sciencedirect.com

SCIENCE DIRECT®

Fisheries Research 72 (2005) 333–345

FISHERIES RESEARCH

www.elsevier.com/locate/fishres

New approaches to the reduction of non-target mortality in beam trawling

B. van Marlen*, M.J.N. Bergman, S. Groenewold, M. Fonds

Department of Biology and Ecology, Netherlands Institute for Fisheries Research RIVO, P.O. Box 68, 1970 AB IJmuiden, The Netherlands

Received 12 November 2003; received in revised form 10 September 2004; accepted 13 October 2004

Abstract

This paper presents experiments with modified beam trawls aimed at reducing discard rates and direct mortality of benthic in-fauna and epi-fauna without affecting the level of landings. Drop-out panels made of large meshes in the belly of the net were effective in reducing by-catch, but the penalty was a loss in landings (particularly sole, plaice, dab). Effective release of heavy invertebrates (quahog, prickly cockle) seems possible. An alternative parabolic tickler chain arrangement did not reduce landings nor by-catch. Parallel chains seemed to offer more potential in reducing by-catch, particularly shellfish, but significant losses in landings also occurred. The configuration used here, with ticklers fitted on the ground rope, caused an increase in direct mortality of benthic invertebrates and is therefore not recommended.

Keywords: Beam trawl; Alternative chains; Bottom impact reduction; Flat fish

1. Introduction

The impact of trawling on the ecosystem has been the subject of many recent studies (ICES, 1988, 1995, 2000, 2001, 2002; Jennings and Kaiser, 1998; Lindeboom and De Groot, 1998; Kaiser and De Groot, 2000; Paschen et al., 2000; Piet et al., 2000; Fonteyne and Polet, 2002). Trawling affects marine species living in and on the sea-bed both by capture (thus removed from the population) or by injury (which may cause them to die or make them more vulnerable to predation (Groenewold and Fonds, 2000)). Trawling, in the Dutch sector, has been estimated to cause annual mortality (in 1994) of larger invertebrates ranging from 7 to 48% (with values over 25% for half of all species measured). This mortality was higher in beam trawls with a width of 12 m than in a 4 m variant or in an ottertrawl (Lindeboom and De Groot, 1998). The beam trawl, usually fitted with heavy ground gear to chase flatfish out of the sea-bed is, therefore, a particular case of interest. The relatively greater mortality rate is related to gear penetration depth and spatial distribution of trawling effort (ICES, 2000, 2002). Species diversity can also be lessened by intensive trawling, as by the average

* Corresponding author. Tel.: +31 255 564780; fax: +31 255 564644.
E-mail address: bob.vanmarlen@wur.nl (B. van Marlen).

0165-7836/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2004.10.019

maximum length and age at maturity of individuals; growth rates increase (ICES, 2001). Fisheries management is now focusing more on preserving eco-systems rather than simply on conserving fish stocks. Two possible ways to diminish adverse effects on benthic fauna by fishing gear are to install panels that help sort out invertebrates while fishing (Van Marlen, 2000), and to design gear components that have less contact with the sea-bed (ICES, 2000, 2002).

The gear modifications we studied were drop-out panels made of large meshes in the lower panel of the net, ranging in size, and alternative rigging of tickler chains in parabolic or parallel configuration. These chains are not the same as tickler chains fitted on the ground rope (sometimes referred to as 'net' ticklers). The catch composition of the modified gear on commercial fish species and non-commercial by-catches was recorded and compared with conventional, non-modified gears. In addition, the direct mortalities of benthic organisms (retained in the cod-end and left behind in the path of the trawl) were compared.

2. Materials and methods

The experiments were carried out in 1999, each consisting of a number of gear tests with the same test configuration. Each gear test contained a number of comparative hauls or tows with a modified and a conventional gear for which no changes in net or rigging were made (Table 1). The trials were conducted on the research vessels "Isis" (28.0 m $L_{o.a.}$, 181 GT, 588 kW engine power), and "Tridens" (73.54 m $L_{o.a.}$, 2199 GT, 2 × 1600 kW engine power). In addition, a comparative study on the direct mortality of invertebrates was carried out in June 2000 on trawl tracks made on the sea-bed.

Table 1
Summary of experiments

Exp	Gear test	Topic of experiment	Configuration	Vessel	Beam width (m)	Period	No. hauls (valid)
1	1a	Comparison of large mesh drop-out panels with conventional gear	19 large meshes of 720 mm mesh size	"Isis"	8	January 1999	18
	1b		19 meshes + sheet underneath 120 mm mesh size				14
2	2a	Comparison of large mesh drop-out panels with conventional gear	19 large meshes of 500 mm mesh size	"Tridens"	12	March 1999	5
	2b		19 meshes + sheet underneath 100 mm				12
	2c		16 meshes + sheet underneath 100 mm				7
	2d		12 meshes + sheet underneath 100 mm				12
3	3a	Comparison of parabolic chains with conventional chains	25 cm spacing, beam width 12 m	"Tridens"	12	March–April 1999	13
	3b		40 cm spacing, beam width 12 m				17
	3c		25 cm spacing, centre chain 35 cm, beam width 12 m				5
4	4a	Comparison of parallel chains with conventional chains	21 chains, 50 cm spacing, beam width 12 m	"Tridens"	12	October 1999	19
	4b		29 chains, 35 cm spacing, beam width 12 m				42
	4c		29 chains, 35 cm spacing, ten pairs of chain connected, beam width 12 m				11

Table 2
Main particulars of gears used

Experiments	Drop-out panels	Drop-out panels and alternative chain riggings	Direct mortality study
Vessel	ISIS	TRIDENS	TRIDENS
Gear component			
Beam length (m)	8	12	7
Headline length (m)	7.8	11.20	
Gear weight (kg)	1500	5500	∼2500
No. ticklers	4	10	–
No. net ticklers	4	10	7
No. and link diameter (mm)	16	24	2 × 16 5 × 14
Footrope length (m)	19 Wings 14 Rollers 5	38 Wings 15 Rollers 8	28 Chains 24 Rollers 4
Footrope chain Ø (mm)	18	22	18
Cod-end depth in meshes	75	70	70
Cod-end circumference in meshes	100	150	120
Cod-end mesh size (mm)	75.3	80	80
Cod-end material	PES	PES	PES
Cod-end thickness (mm)	2.5	2.5	2.5
Cod-end twine construction	Double twine	Double twine	Double twine

The gears differed in overall size and weight as well as dimensions of components (Table 2). To create drop-out panels in the beam trawls, larger meshes were cut in varying numbers (See Fig. 1). In some cases a sheet of netting was fitted underneath.

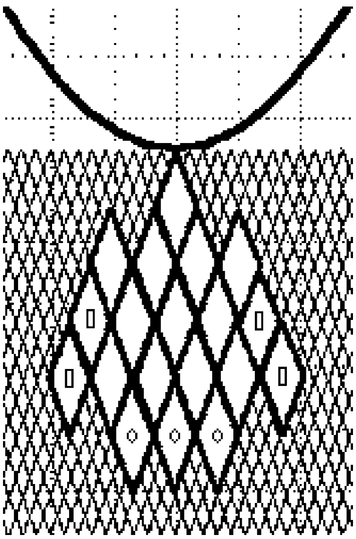

Fig. 1. Drop-out panel of large meshes behind the ground rope. Initially 19 meshes were open, then three covered leaving 16 open (◊), then four covered leaving 12 open (▯).

In the conventional tickler chain rigging many of the chains are connected to the shoes plates on both sides of the gear (Fig. 2) while, in the alternatives, the attachment points were distributed along the beam. (Fig. 3—parabolic chain arrangement, and Fig. 4—example with a total of 21 parallel chains, with tickler chains rigged on the footrope).

The direct mortality of invertebrates caused by a conventional 7 m wide beam trawl was compared to that of a trawl with 15 parallel chains, by taking bottom samples from positions before and after passage of these gears. Both trawls in this study had a beam length of 7 m. The area chosen for this study was the Oyster Ground in the North Sea (between 54.13°–54.17°N and 05.03°–04.57°E). In addition to being a representative fishing ground, the area fulfilled two main conditions: (a) a homogenous (uniform) distribution of benthic fauna and minor environmental gradients, and (b) a high abundance of faunal species that are well known from previous studies to give a clear response (i.e. direct mortality) to trawling, including the sea potato (*Echinocardium cordatum*), various bivalves and the helmet crab (*Corystes cassivelaunus*) (Lindeboom and

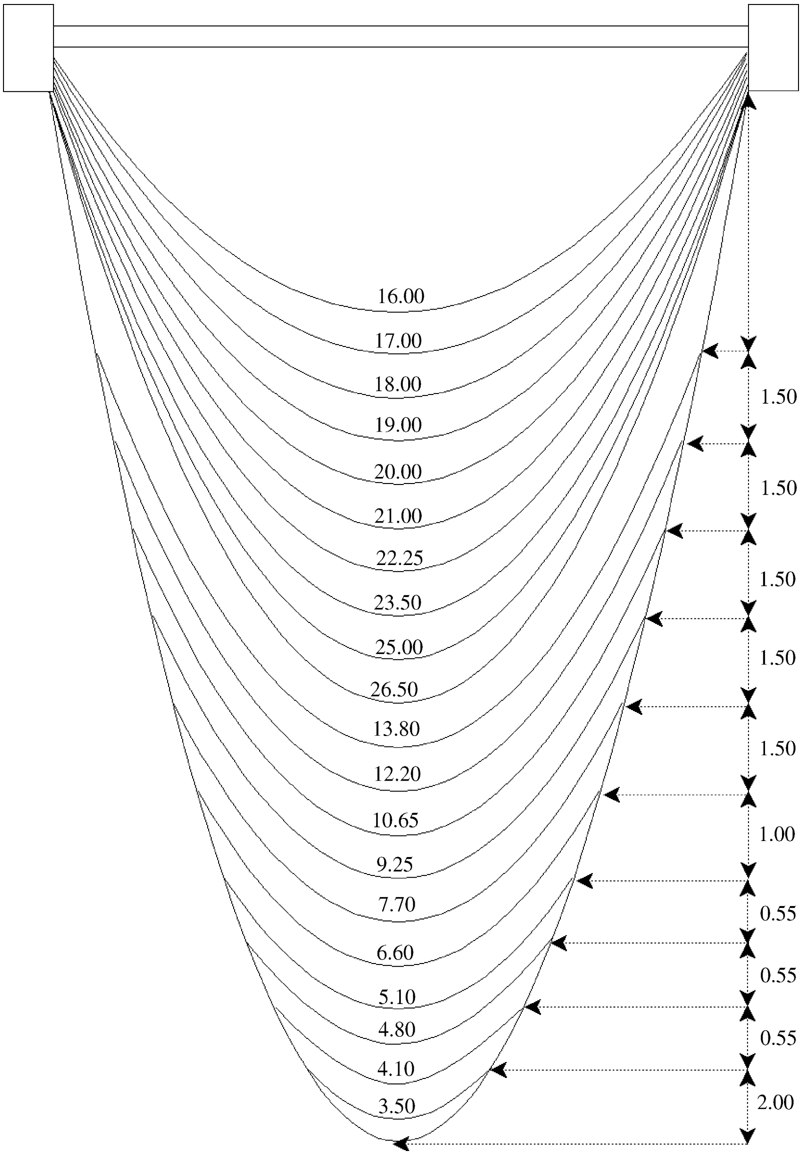

Fig. 2. Conventional 12 m beam trawl tickler chain rigging.

De Groot, 1998). Six parallel strips (three replicates) on the sea-bed were fished from RV "Tridens", each with a particular beam trawl (conventional or its alternative). The strips were about 2000 m long and some 30 m wide, and were fished 12 times to ensure adequate coverage. Prior to fishing, the initial densities of benthic species were estimated by dredging sampling tracks with the Triple-D Deep-Digging benthos Dredge (t_0, $n = 10$) from RV "Zirfaea". Similar benthos samples (t_1, $n = 10$) were taken from 2 to 6 days after trawling, after fish and mobile epi-benthos had scavenged the damaged or dislodged organisms to obtain a reliable mortality estimate (Bergman and van Santbrink, 2000). The sampling tracks were positioned within 3 m of (and parallel to) the t_0-tracks (paired samples) in order to reduce bias caused by small-scale patchy distribution of species, and were about 100 m long, 18 cm deep, and 20 cm wide. They were taken from various

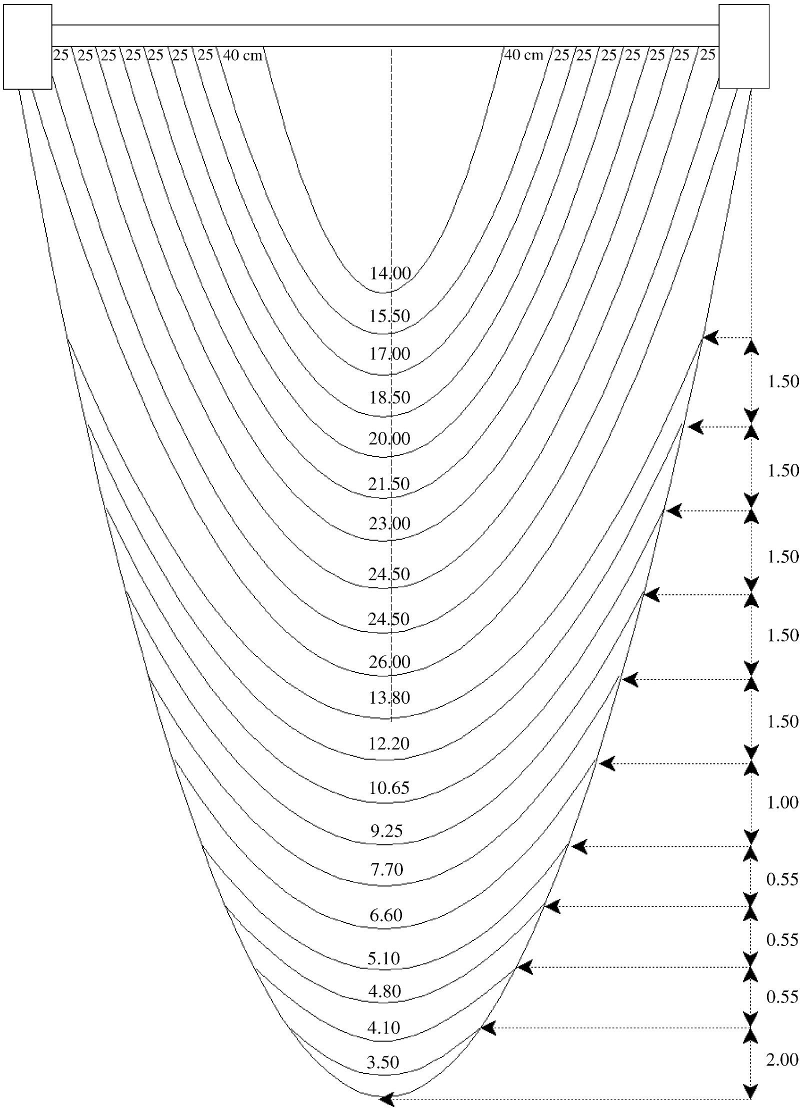

Fig. 3. Parabolic chain rigging alternative for 12 m beam trawl.

positions along the trawled strips. The Triple-D sampler was equipped with a video camera to record the impact of the different types of trawls on the seabed.

Invertebrate catches from the first three hauls with each beam trawl in two replicate strips were compared with the catches of 20 Triple-D samples (t_0) from the same strips. The catch efficiency of the trawls was expressed as percentage of the initial density, as estimated from the Triple-D catches. The direct mortality for a particular type of trawl was calculated using the difference between the initial density of a species and the residual (after trawling) density in a strip, e.g. the sum of individuals caught in 20 hauls on two replicate strips (ca. 400 m^2 in total). Mortality calculated in this way includes both animals killed in the trawl track but not retained by the net, and those caught in the net. The calculations assume that all animals damaged and exposed in the trawl track have been consumed by predators, during the interval between trawling and (t_1) sampling.

Fig. 4. Parallel chain configuration with 21 chains on 12 m beam. The ticklers fitted on the ground rope were kept.

Test species to compare the median direct mortality caused by different types of trawl were only sessile and low-mobility species, to avoid the confounding effects of migration into and from the strip in the interval between trawling and (t_1) sampling. Test species also had to be present in all six strips. The median mortalities of the selected species were checked for the presence of statistically significant differences due to different gears using the non-parametric Wilcoxon's sign-ranks test.

2.1. Catch comparison—data collection and analysis

In all gear tests, both the modified gear and the conventional gear were towed simultaneously resulting in paired series of data. The catches of both nets were stored in separate compartments on board. Target species belonging to the landings category (Table 3) were removed from the catch, and the length of each individual was measured. Fish by-catch species were also measured, and in the case of large numbers, taken from sub-samples of the entire catch. The total weight of by-catch (discard fish and benthos) was either measured using the balance in the conveyor belt on the fish processing deck or estimated from the number of baskets. The SAS™ (SAS Institute, Cary, NC, USA, 1992) statistical package was used to analyse the data. The mean weights in kg per hour fishing over the range of hauls for each gear test were extracted for the categories 'landings' and 'by-catch'.

Table 3
Catch categories with species composition used in the analysis

Category	Species
Landings	Target species: sole (*Solea vulgaris* L.), plaice (*Pleuronectes platessa* L.), dab (*Limanda limanda* L.), brill (*Scophthalmus rhombus* L.), turbot (*Psetta maxima* L.), whiting (*Merlangius merlangus* L.), cod (*Gadus morhua* L.), larger than the minimum landing sizes
By-catch	Discard fish: all target species smaller than the minimum landing size plus all other non-target fish species, plus *benthos*: invertebrates such as swimming crab (*Liocarcinus spp*. L.), masked crab (*Corystes cassivelaunus* L.), common starfish (*Asterias rubens* L.), starfish species, (*Astropecten irregularis* L.), brittle star (*Ophiura spp*. L.), hermit crab (*Pagurus bernhardus* L.)

A more detailed benthos sampling procedure aimed at determining species composition was followed in November 1999. Larger and less abundant invertebrates (e.g. shellfish, whelks, edible crab, etc.) were sorted out from each catch, sub-sampled and their numbers and weight measured and raised to the total catch by multiplying with the sampling factor. The numbers and weights of smaller and abundant invertebrates, such as starfish, swimming crabs, hermits and sea mouse, were determined from sub-samples of 1/4 or 1/16 of the catch taken after proper mixing, and the total numbers and weight in the whole catch calculated using raising factors.

The short term discard mortality of invertebrates was estimated by taking randomly selected abundant invertebrate species from the catch on the conveyor belt on board, storing them in troughs with a continuous supply of sea water and monitoring the numbers alive and dead after 2 h. Bivalves and edible crabs (*Cancer pagurus* L.) were immediately separated in the categories 'dead' or 'alive'. Mortality is expressed as the percentage of individuals caught. Differences in mortality rates were tested pair-wise for significance using Pearson's χ^2-test. The ratio of total by-catch weight (fish and invertebrates) for the alternative and conventional gears was calculated.

3. Results

The mean weights in kg/h and the standard deviation as well as the *p*-values of the paired *t*-tests for the

Table 4
Comparison of landings and by-catch in kg/h for each gear test

Gear modificaton test		No of hauls	Landings (kg/h)						By-catch = benthos + discardfish (kg/h)					
			Mean			Standard deviation		*p*-value	Mean			Standard deviation		*p*-value
			MOD	CON	MOD/CON (%)	MOD	CON		MOD	CON	MOD/CON (%)	MOD	CON	
1a	19 large meshes (720 mm mesh size)	18	16.72	15.32	109.1	7.32	7.41	0.449	**74.65**	**86.49**	**86.3**	**79.15**	**88.12**	**0.001**
1b	19 meshes + sheet (720 mm)	14	15.15	13.97	108.4	5.41	4.25	0.352	32.52	33.65	96.6	11.21	10.77	0.142
2a	19 large meshes (500 mm mesh size)	5	29.80	46.01	64.8	5.75	24.16	0.188	**94.43**	**127.53**	**74.0**	**26.84**	**14.60**	**0.013**
2b	19 meshes (500 mm) + sheet	12	36.89	46.54	79.3	8.44	18.74	0.150	**96.67**	**122.22**	**79.1**	**26.74**	**27.17**	**0.000**
2c	16 meshes (500 mm) + sheet	7	33.10	47.69	69.4	11.63	22.29	0.069	101.90	135.71	75.1	47.29	82.43	0.060
2d	12 meshes (500 mm) + sheet	12	43.75	44.83	97.6	12.95	13.08	0.858	**110.33**	**122.50**	**90.1**	**25.83**	**23.53**	**0.003**
3a	Parabolic 25 cm spacing, 12 m beam trawl	13	37.07	35.63	104.0	8.27	10.85	0.542	**122.73**	**111.75**	**109.8**	**20.45**	**21.65**	**0.023**
3b	Parabolic 40 cm spacing, 12 m beam trawl	16	50.35	32.72	153.9	89.62	11.98	0.431	152.85	145.01	105.4	29.01	31.80	0.119
3c	Parabolic 25 cm spacing, centre chain −35 cm, 12 m	5	35.09	35.73	98.2	15.09	9.64	0.925	174.67	166.67	104.8	14.45	14.91	0.178
4a	21 parallel chains, 50 cm spacing, 12 m width	19	**48.52**	**54.72**	**88.7**	**20.92**	**25.66**	**0.022**	**70.46**	**79.75**	**88.4**	**18.91**	**27.40**	**0.018**
4b	29 parallel chains, 35 cm spacing, 12 m width	41	**44.22**	**57.67**	**76.7**	**14.02**	**21.69**	**0.000**	**79.15**	**116.55**	**67.9**	**53.65**	**115.59**	**0.010**
4c	As 4b, 10 pairs of chain connected, 12 m	11	**43.46**	**52.38**	**83.0**	**12.4**	**12.48**	**0.029**	**45.85**	**84.48**	**54.3**	**17.87**	**47.04**	**0.014**

Bold face is significant, $p \leq 0.05$.

categories landings, and by-catch for the modified and the conventional nets as well as the ratio between the two are given in Table 4.

3.1. Drop-out panels

There was no significant difference in landings between the conventional and modified 8 m gears. Lower landings were found in the 12 m gear, except in gear test 2d, but the comparisons failed to reach statistical significance. The major contribution to this decrease was the smaller catch of sole, plaice, and dab, particularly in gear test 2a. Adding a sheet of netting underneath did not seem to have a noticeable effect. Closing the last four meshes did seem to improve the landings (gear test 2d, Fig. 1).

Significantly less by-catch was found in gear test 1a in the modified gear as well as in gear tests 2a, b, and d varying from 10 to 26%. On looking at the benthic species composition, some reductions appeared only for *Echinocardium*sp., sea mouse (*Aphrodita aculeata* L.*)*, whelks (*Buccinum undatum* L.), the brittle star (*Ophiura* L.) and hermit crabs (*Pagurus bernhardus* L.), but the numbers were relatively small.

3.2. Alternative chain arrangements

By-catches with the parabolic chain configuration in gear test 3a were significantly larger. Benthic species caught more effectively by this configuration were mainly shellfish (i.e. quahogs (*Arctica islandica* L.), prickly cockles (*Acanthocardia echinata* L.) and whelks (*Buccinum undatum* L.)). A small increase in catches of quahogs and whelks was also found in gear test 3b.

The landings were about the same with the parabolic chain configuration in gear tests 3a and 3c, and larger in gear test 3b, although the difference was not statistically significant. Except for small whiting of which fewer were caught by the modified gear, the other fish species showed no difference. For all the three gear tests with the parallel chain configuration the landings ratio was less than 100%, ranging from 77 to 89%. Most noticeable was the reduction in sole catches for the modified gear, particularly the marketable size, to about half of those of the conventional gear.

3.3. Gear performance

Reduced landings do not mean that a gear performs worse in terms of preserving ecosystem values. When this is accompanied by a larger reduction in catches of discard fish and invertebrates, the effect can be positive. To determine whether this was the case, a performance indicator was calculated for each gear test based on the landings/by-catch ratio. Values between 0.27 and 0.54 were found for the performance indicator for the drop-out panels, while for the parabolic chain configuration they reached 0.19–0.33. Higher values (between 0.69 and 1.09) were found for the parallel chain configuration caused by lower by-catches (Table 5).

3.4. Effects on benthic species composition

In general, the gears with parallel chains caught fewer molluscs and fewer in-faunal species, such as sand star (*Astropecten*), but more crustaceans (Tables 6 and 7). Due to the large between-haul variations most differences were not statistically significant, but the lower catches of molluscs were highly significant (except for the epi-benthic active swimming queen scallop), while higher catches of swimming crabs and starfish in week 41 were also statistically significant. Most remarkable were the higher catches (+39%) of Norway lobster (*Nephrops norvegicus* L.) in the gears with parallel chains. A larger number of parallel tickler chains in week 41 (29 instead of 21) did not result in marked differences with the results obtained in week 40. However, some differences were in this case statistically significant, such as the lower catches of whelks in the alternative gear and the higher catches of swimming crabs.

3.5. Catch efficiencies

Only a small fraction of the invertebrate fauna is caught by both the conventional and the parallel chain trawls (Table 8). The highest catch efficiencies were found for epi-benthic or shallow-burrowing species like sand star (up to 7%), sea mouse (up to 9%), large bivalves (up to 8%), and for the Norway lobster (up to 6%). The catch efficiencies for more deeply burrowing species (e.g.

Table 5
Comparison of performance (= landings/by-catch) for each gear test

Gear modificaton test		No of hauls	Performance					
			Mean			Standard deviation		p-value
			MOD	CON	MOD/CON (%)	MOD	CON	
1a	19 large meshes (720 mm mesh size)	18	0.35	0.27	129.6	0.24	0.19	0.093
1b	19 meshes + sheet (720 mm)	14	0.54	0.46	117.4	0.34	0.20	0.216
2a	19 large meshes (500 mm mesh size)	5	0.32	0.35	91.4	0.04	0.15	0.740
2b	19 meshes (500 mm) + sheet	12	0.41	0.40	102.5	0.14	0.17	0.901
2c	16 meshes (500 mm) + sheet	7	0.39	0.44	88.6	0.18	0.21	0.472
2d	12 meshes (500 mm) + sheet	12	0.42	0.37	113.5	0.19	0.10	0.354
3a	Parabolic 25 cm spacing, 12 m beam trawl	13	0.31	0.33	93.9	0.08	0.11	0.441
3b	Parabolic 40 cm spacing, 12 m beam trawl	16	**0.19**	**0.23**	**82.6**	**0.04**	**0.07**	**0.040**
3c	Parabolic 25 cm spacing, centre chain-35 cm, 12 m	5	0.21	0.22	95.5	0.10	0.07	0.740
4a	21 parallel chains, 50 cm spacing, 12 m width	19	0.69	0.70	98.6	0.22	0.27	0.896
4b	29 parallel chains, 35 cm spacing, 12 m width	41	0.79	0.84	94.0	0.91	0.84	0.390
4c	As 4b, 10 pairs of chain connected, 12 m	11	**1.09**	**0.76**	**143.4**	**0.50**	**0.38**	**0.025**

Bold face is significant, $p \leq 0.05$.

Table 6
Species composition of benthic catches of 12 m beam trawl with 21 parallel chains compared to conventional 12 m beam trawl with 20 ticklers (wk 40)

T9910: hauls 1–19, gear test 4a catch in numbers per hour category	MOD		CON		MOD/CON (%)	p-value
	Mean	S.D.	Mean	S.D.		
Benthos	164.7	203.57	231.79	300.16	71.1	0.115
Detailed species						
Whelks (*Buccinum undatum*)	3.1	8.69	3.9	6.92	79.5	0.404
Sea mouse (*Aphrodyta aculeate*)	1.74	1.74	1.75	1.46	99.2	0.964
Edible crab (*Cancer pagurus*)	0.11	0.07	0.11	0.1	96.6	0.857
Norway lobster (*Nephrops norvegicus*)	4.34	4.57	3.2	3.52	135.8	0.137
Prickly cockle (*Acanthocardia*)	**0.26**	**0.28**	**3.31**	**2.43**	**7.9**	**0**
Quahog (*Arctica islandica*)	**0.19**	**0.16**	**2.7**	**1.93**	**7.0**	**0**
Swimming crabs (*Liocarcinus* sp.)	10.34	6.73	7.17	2.82	144.3	0.058
Masked crab (*Corystes cassivelaunus*)	4.51	7.36	3.39	6.27	133.0	0.17
Starfish (*Asterias rubens*)	**11.03**	**10.94**	**8.15**	**10.21**	**135.3**	**0.03**
Sand star (*Astropecten irregularis*)	125.05	189.36	192.5	287.13	65.0	0.113
Hermits (*Pagurus* sp.)	4.02	3.53	5.61	3.89	71.7	0.161

Table 7
Species composition of benthic catches of 12 m beam trawl with 29 parallel chains compared to conventional 12 m beam trawl with 20 ticklers (weeks 41)

T9910: hauls 20–36, gear test 4b catch in numbers per hour category	MOD		CON		MOD/CON (%)	*p*-value
	Mean	S.D.	Mean	S.D.		
Benthos detailed species	124.97	116.72	127.5	119.54	98.0	0.801
Whelks (*Buccinum*)	**0.65**	**1.05**	**1.29**	**1.9**	**50.5**	**0.011**
Sea mouse (*Aphrodyta aculeate*)	0.75	0.36	0.95	0.88	78.8	0.249
Edible crab (*Cancer pagurus*)	0.09	0.08	0.12	0.11	80.6	0.449
Norway lobster (*Nephrops norvegicus*)	**3.15**	**3.42**	**2.27**	**2.55**	**138.8**	**0.019**
Prickly cockle (*Acanthocardia*)	**0.19**	**0.17**	**1.29**	**0.73**	**14.5**	**0**
Quahog (*Arctica islandica*)	**0.24**	**0.25**	**1.37**	**0.81**	**17.4**	**0**
Queen scallop (*Aequipecten opercularis*)	0.18	0.29	0.19	0.36	91.7	0.728
Swimming crabs (*Liocarcinus* sp.)	**18.69**	**10.47**	**12.43**	**9.55**	**150.4**	**0.003**
Masked crab (*Corystes cassivelaunus*)	0.21	0.18	0.36	0.46	58.2	0.173
Starfish (*Asterias rubens*)	**18.75**	**23.99**	**11.88**	**15.72**	**157.8**	**0.006**
Sand star (*Astropecten irregularis*)	81.89	112.99	95.02	120.32	86.2	0.177
Hermits (*Pagurus* sp.)	2.16	1.39	2.24	2.86	96.2	0.9

sea potatoes, blunt gapers *Mya arenaria*), and small species (e.g. sea cucumbers, small bivalve species) were low (less than 0.3%) or even zero. Fewer large bivalves (quahog, prickly cockle), sea mouse, sand star, and helmet crabs, but more Norway lobsters were caught by the parallel chain beam trawl.

3.6. Mortality of invertebrate species

Significantly lower discard mortalities were found for swimming crab, Norway lobster, and quahog in the parallel chain beam trawl, but no difference for masked crab and edible crab (see Table 9). A significantly higher median direct mortality of 15 species

Table 8
Catch efficiency of benthic invertebrates in a 7 m conventional and parallel chain beam trawl, expressed as percentage of initial densities estimated from 20 t_0 catches with the Triple-D sampler

Taxa	Conventional	Parallel
Molluscs		
Artemis shell (*Dosinia lupina*)	0.0	0.0
Basket shell (*Gorbula gibba*)	0.0	0.0
Prickly cockle (*Acanthocardia echinata*)	1.1	0.6
Quahog (*Arctica islandica*)	8.4	0.7
Tower shell (*Turritella communis*)	0.0	0.0
Crustaceans		
Hermit crab (*Pagurus bernhardus*)	1.0	1.2
Norway lobster (*Nephrops norwegicus*)	1.5	6.0
Helmet crab (*Corystes cassivelaunus*)	1.9	0.8
Echinoderms		
Sand star (*Astropecten irregularis*)	7.0	2.2
Sea potato (*Echinocardium cordatum*)	0.0	0.3
Sea cucumber (*Cucumaria elongata*)	0.0	0.0
Polychaetes		
Sea mouse (*Aphrodite aculeata*)	8.6	3.3

Table 9
Short term discard mortality of invertebrates and fish retained from 1 h hauls with conventional and parallel 12 m tickler chain gears

Species	No. of chains	Mortality (%)		Total number	p (χ^2-test)
		Conventional	Parallel		
Masked crab (*Corystes* sp.)	21	66	65	198	n.s.
Swimming crab (*Liocarcinus* sp.)	21	39	31	870	<0.05
Swimming crab (*Liocarcinus* sp.)	29	49	45	247	n.s.
Norway lobster (*Nephrops* sp.)	21	54	27	200	<0.01
Norway lobster (*Nephrops* sp.)	29	68	35	76	<0.05
Edible crab (*Cancer* sp.)	21	19	19	116	n.s.
Edible crab (*Cancer* sp.)	29	42	40	94	n.s.
Quahog (*Arctica* sp.)	21	78	60	1322	<0.01
Quahog (*Arctica* sp.)	29	80	48	655	<0.01
Prickly cockle (*Acanthocardia* sp.)	21	49	52	1741	n.s.
Prickly cockle (*Acanthocardia* sp.)	29	35	29	591	n.s.

(i.e. 54%) was found in the 7 m parallel chain beam trawl compared to the conventional beam trawl (36%).

4. Discussion

4.1. Drop-out panels (experiments 1 and 2)

A vast volume of literature describes by-catch reduction devices for fish, but little considers reducing the capture of benthos. Comparable gear tests on a chain-mat beam trawl were carried out in Belgium, in 1999 and 2000. Catches of benthos could be reduced by 13% with a large diamond mesh escape panel, but there were considerable losses in target flatfish catches ranging from 6 to 26% (Fonteyne and Polet, 2002). As expected, the panel showed similar results as in the Belgian experiments, having similar dimensions extending 1.5 m behind the footrope and a mesh size of 400 mm (Table 4).

Whether benthic organisms sink down rapidly in the region behind the footrope, or are carried away further aft in the net by the water flow, would affect the optimal position of a drop-out panel. A panel position, further aft in the gear, where sand particles stirred up by the chains pass through the netting was suggested by Fonteyne and Polet (2002), based on species composition of the catch and their relative weight. They suggested square mesh windows placed in the belly just in front of the cod-end to release benthic organisms, and a mesh size of 150 mm seemed adequate without loss of target fish. A panel placed just behind the footrope also significantly reduced benthos catches (Table 4). The heavier shellfish especially (such as quahogs) seem to drop through the panel, which indicates that they sink faster in the water flow. In our experiments, however, the larger mesh sizes used in the panel also caused a considerable loss in landings.

Crucial for acceptance of the new gears by the fishing industry is to maintain the catch level of target species. Although the results were not statistically significant, some 25–35% loss in landings was recorded in experiment 2. When looking at species composition, the largest contribution to these losses came from sole, followed by plaice and dab. Large meshes in the lower panel apparently offer better escape opportunities for these fishes. The losses of flatfish could only be diminished by closing the big meshes, thus reducing the size of the drop-out panel.

4.2. Alternative chain arrangements (experiments 3 and 4)

Increasing the number of tickler chains in beam trawling not only improves the catch rate of sole (Creutzberg et al., 1987) but also produces a high catch and mortality of benthic invertebrates (Lindeboom and De Groot, 1998). In the conventional rigging of the tickler chains the attachment points are on the beam trawl shoes with little intermediate spacing (Fig. 2). The parabolic design tested here was based on the idea of creating more space between the attachment points, thus creating the opportunity for heavier organisms to drop-out (Fig. 3). However, this arrangement did not result in lower catches of discardable fish and benthos. Apparently a stronger stimulus on the sea-bed is created. The angle of the chain relative to the direction of tow (incidence angle) determines the pressure on the bottom (Paschen et al., 2000). Smaller angles give higher pressure and deeper penetration. This could be an explanation for the higher catch levels of the parabolic chain arrangement as these angles are smaller along longer lengths of chain compared to chains attached to the shoe plates on the conventional beam trawl.

The philosophy behind the parallel chain design was to create a stimulus with minimal area coverage. This configuration seemed to reduce the landings, in particular the sole catches, whereas the effect on plaice was marginal. There seemed to be potential for substantially reducing benthos catches (Table 4). Considering species composition, significant reductions in numbers per hour were found for prickly cockle (*Acanthocardia*), quahog (*Arctica islandica*), and starfish (*Asterias rubens*) (Tables 6 and 7). In addition the larger catches (+35%) of Norway lobster (*Nephrops norvegicus* L.), a species living in deeper burrows in the sediment, were noticeable.

The parallel configuration used was a combination of parallel chains and net ticklers fitted on the ground rope in the conventional way. In retrospect this was not a fortunate choice, as the direct mortality study revealed that this configuration caused a higher mortality of invertebrates than the conventional tickler chain gear. Apparently chains digging parallel with chains running across do not diminish impact. Further trials are, therefore, recommended with the chains running parallel from the beam to the ground rope but leaving off the net ticklers.

The performance indicators did not show a consistent pattern, making it difficult to draw definite conclusions. Most obvious were the highest values for the parallel chain configuration (Table 5).

5. Conclusions

5.1. Drop-out panels

A considerable reduction in by-catch ranging from 10–25% in weight can be achieved with the drop-out panels, but the penalty is a loss in landings, particularly sole, and to a lesser extent plaice and dab.

5.2. Alternative chain arrangements

The use of parabolic chains did not reduce the by-catches (discard fish and benthos). The gear with parallel chains (and net ticklers) resulted in significantly smaller landings (12–24%, particularly less sole), but also significantly smaller benthos catches (12–46%). If sole catches could be enhanced this configuration might be promising, at least from the catch point of view. The final judgement for both came from the direct mortality study. The alternative arrangement with the parallel chains (and net ticklers) resulted in a higher direct mortality of invertebrates than the conventional tickler chain arrangement; thus rendering this option unacceptable in the form tested. The question remains open, whether parallel chains without net ticklers would be a suitable alternative.

Acknowledgements

The authors would like to express their gratitude for financial support of this work by the European Commission (EU-funded project "reduction of environmental impact of demersal trawls" (REDUCE) (FAIR-CT97-3809)), the Ministry of Agriculture, Nature Management and Fisheries as co-financer through research programme 324 "Eco-system effects of fishing". In addition, the authors feel indebted to the skippers and crews of the research vessels "Tridens" and "Zirfaea" as well as all the other contributors for their co-operation. This paper does not necessarily reflect the views of the European Commission and in no way anticipates any future opinion of the Commission.

References

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

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

ICES, 2000. Report of the Working Group on Ecosystem Effects of Fishing Activities. ICES CM 2000/ACME:02.

ICES, 2001. Report of the Working Group on Ecosystem Effects of Fishing Activities. ICES CM 2001/ACME:09.

ICES, 2002. Report of the Working Group on Ecosystem Effects of Fishing Activities. ICES CM 2002/ACE:03.

Bergman, M.J.N., van Santbrink, J., 1994. Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea. ICES J. Mar. Sci. 57 (5), 1321–1331.

Creutzberg, F., Duineveld, G.C.A., Van Noort, G.A., 1987. The effect of different numbers of tickler chains on beam trawl catches. J. Cons. Int. Explor. Mer., 43.

Fonteyne, R., Polet, H., 2002. Reducing the benthos by-catch in flatfish beam trawling by means of technical modifications. Fish. Res. 55, 219–230.

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

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34, 221–233.

Marlen, B. van, 2000. Technical modifications to reduce the by-catches and impacts of bottom gears on non-target species and habitats. In: Kaiser, De Groot (Eds.), 2000. Effects of Fishing on Non-target Species and Habitats: Biological, Conservation and Socio-economic Issues. ISBN 0-632-05355-0, pp. 253–268.

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

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

Piet, G.J., Rijnsdorp, A.D., Bergman, M.J.N., van Santbrink, J., 2000. A quantitative evaluation of the impact of beam trawling on benthic fauna in the southern North sea. ICES J. Mar. Sci. 57 (5), 1332–1339.