Reducing the catch of small shrimps in the Gulf of Maine pink shrimp fishery with a size-sorting grid device

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Since implementation of the Nordmøre grid in the Gulf of Maine pink shrimp (*Pandalus borealis*) trawl fishery in the early 1990s, fish bycatch has been reduced drastically. However, the Nordmøre grid does not reduce the amount of small shrimps landed when the shrimps are on the fishing grounds. This paper reports on two designs of a new size-sorting grid system, one with a funnel and one without. The designs' main feature is the size-sorting grid's position, installed in front of the main Nordmøre grid. They were tested in the flume tank and at sea. Parallel tows involving two vessels and alternating tows using one vessel were made to compare the size-sorting grid system. Both size-sorting designs reduced the number of small shrimps in the catch significantly, by 38 and 45 kg^{-1} of catch, respectively. There was some reduction in shrimp catch rates, presumably from the release of small shrimps. There were no significant differences in the number or quantity of major bycatch species for the commercial grid and the two experimental grid designs. The designs were practical to operate and easy to install. Their application could reduce the catch of small shrimps in the pink shrimp fishery in the Gulf of Maine and in other areas.

Keywords: bycatch reduction, *Pandalus borealis*, pink shrimp, shrimp trawl, size selectivity.

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Introduction

Pink shrimp (*Pandalus borealis*) is widely distributed in the northern portions of the Pacific, Atlantic, and Arctic (Shumway *et al.*, 1985). Because small-mesh codends are used for harvesting the species, bycatch can be considerable (Howell and Langan, 1992). The use of the Nordmøre grid became mandatory in 1992 in the pink shrimp fishery in the Gulf of Maine and has proven to reduce finfish bycatch significantly (Kenny *et al.*, 1992; Clark *et al.*, 2000; Fonseca *et al.*, 2005). However, the Nordmøre grid does not reduce the catch of small fish and small shrimps that pass through the 25-mm spacing between the grid bars (Clark *et al.*, 2000). Landing undersize shrimps wastes resources and reduces landed value. Various projects, therefore, have been carried out to reduce the catch of small shrimps. Increasing mesh size was effective in some fisheries, but not in others. Campos *et al.* (2002) found that codends made from larger mesh size netting or from square meshes had larger 50% selection length (L50) for rose shrimp (*Parapenaeus longirostris*) in Portuguese waters, but increasing mesh size did not seem to increase size selectivity in pink shrimp fisheries in Norway (Valdemarsen, 1989) and in Canada (Tait and Tait, 1993). Square mesh codends demonstrated some reduction of small shrimp catch in some tests in Canada; mesh breakage and loss of market-sized shrimps were reported (Hickey *et al.*, 1993). In a test comparing 45-mm diamond and square mesh in Greenland waters for pink shrimp, Lehmann *et al.* (1993) did not find differences in size selectivity. Valdemarsen (1989) argued that shrimps are carried passively by the flow relative to the net. With the bulbous shape of the codend full of catch, flow inside the codend may be reduced to as little as 5% of the towing speed. The reduction of flow velocity was found to relate to the amount of catch in the codend and the distance from the catch accumulation (Broadhurst *et al.*, 1999). Reduced flow rate in the codend would reduce the probability of small shrimps escaping from the codend. Valdemarsen (1989) proposed that a funnel-shaped design, called radial escape section (RES), be installed in the rear section of the belly to force small shrimps out of the trawl. The device reduced the catch of small shrimps, but wide use of the design was prevented by repeated instances of debris blocking the funnel and complicated rigging. A dual-grid system was tested in Newfoundland and in the Gulf of Maine (DFO, 1995, 1998; Schick *et al.*, 1999). In these systems, the size-sorting grid was installed behind the Nordmøre grid. Success was probably limited by lowered flow rates at the second grid (FTU, 1996). This paper reports on designs that include a size-sorting grid in front of the main Nordmøre grid to avoid flow-reduction problems.

Material and methods

The original design of the grid section included a size-sorting grid with 11-mm bar spacing and an inverted, bottom-opening Nordmøre grid without a funnel. The size-sorting grid acted as a ramp to guide the shrimp to the top of the Nordmøre grid. Flume tank tests were carried out at the Center for Sustainable Aquatic Resource at Memorial University of Newfoundland in St John's, Newfoundland. A full-scale grid section with a codend was tested at the towing speed of 2.4 knots. The test section was

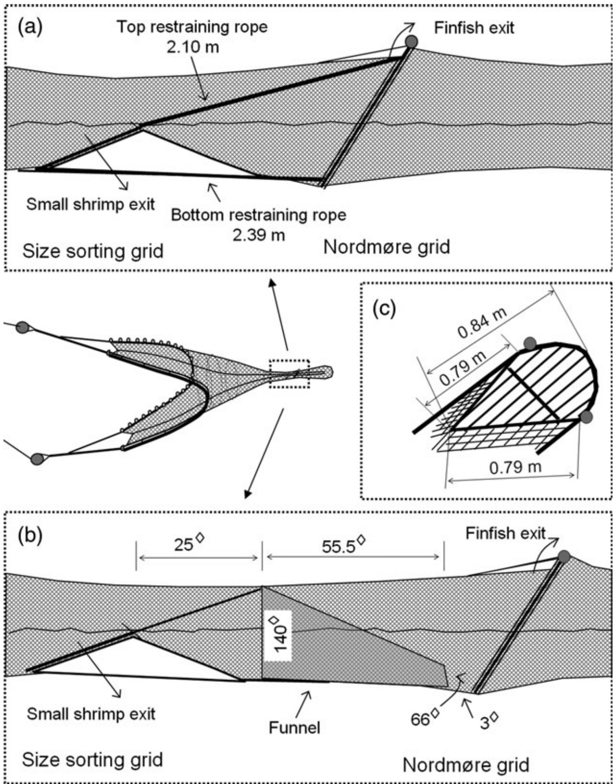

Figure 1. Two size-sorting grid devices tested in the sea. (a) Size-species grid no funnel (SGNF); (b) size-species grid with funnel (SGWF); and (c) details of fish exit opening.

shipped to Portland, Maine, where sea trials were conducted. However, after a few tows, it was concluded that the inverted Nordmøre grid caught more flounder bycatch than the control grid, and the design was modified to a standard top-opening grid (Figure 1). During the second phase of the test, a funnel was added. These two designs are called size-species grid no funnel (SGNF) and size-species grid with funnel (SGWF). Both the size grids and the Nordmøre grid were made of high-density polyethylene (HDPE). The size grid was rectangular and had external dimensions of 0.97×1.27 m, with 11-mm bar spacing and 10-mm bar width. The Nordmøre grid was oval and had external dimensions of 0.97×1.47 m, with 25 mm bar spacing and 12 mm bar width. The size grid was installed at a 35° angle and the Nordmøre grid was $\sim 50^\circ$. The funnel arrangement and the fish exit are shown in Figure 1b and c.

For SGNF trials, FV "North Star", a 13.7 m inshore shrimp trawler, was used with alternating tows through an ECCE and CEEC pattern, where E represents experimental gear and C represents control gear. The control gear used a standard Nordmøre grid with a funnel. The trawl itself and the codend for both experimental and control gears were identical.

For SGWF trials, FV "North Star" and FV "Persistence" (12.6 m) were paired to conduct parallel tows. FV "North Star" fished the experimental grid system and FV "Persistence" fished a trawl with a regular Nordmøre grid. The vessels were within 0.5 nautical miles apart and deployed and retrieved their gears almost simultaneously. The vessels used similar trawls with an identical Nordmøre grid and codend. The gears were not switched between vessels.

For both testing sessions, the codend was made of 50-mm mesh nylon. The Nordmøre grids used in the size-species grid and the stand-alone Nordmøre grid (control) were also identical. The HDPE Nordmøre grid works well in commercial pink shrimp fisheries in Canada and the northeastern US. Experimental fishing was carried out between late March and mid-June 2006 on shrimp fishing grounds off the coast of Maine. The tow duration was 1 h, and the towing speed was 2.4 knots.

The shrimp catch and the finfish bycatch were sorted and measured from each tow. The pink shrimp catch was weighed to the nearest kilogramme. Major bycatch species included whiting or silver hake (*Merluccius bilinearis*), American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), redfish (*Sebastes* spp.), and red hake (*Urophycis chuss*). Other species caught less frequently or caught in small numbers were Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), butterfish (*Peprilus triacanthus*), blueback herring (*Alosa aestivalis*), and alewife (*Alosa pseudoharengus*). Bycatch was sorted by species and measured individually to the nearest centimetre. The total for each species was weighed to the nearest 0.05 kg. When a large number of species was caught, a subsample of ~ 1 kg was taken. Other bycatch species were weighed and counted. Three 1-kg shrimp samples from each tow were kept for size count and carapace length (CL) measurement at the laboratory. CL was measured to the nearest millimetre.

The Kolmogorov–Smirnov test was used to test differences in length distribution. Mean CL was compared using a *t*-test. A linear mixed model was used to compare replicate counts in the experimental and control tows, because variances were not homogenous and the three samples were nested within each tow.

Results

Handling and operation

There were no problems handling the dual-grid size and species sorting system on board FV "North Star" with the usual deck machinery and crew. The grids were durable and maintained shape and integrity during the course of the experiment. During the single-vessel alternating tows, changing from the experimental grid system to the control grid, or vice versa, took about half an hour.

Size-species grid no funnel (SGNF)

Catch and bycatch from 24 tows using the SGNF grid and the control are presented in Table 1. The mean CL of shrimps caught by the new dual-grid system was greater than those caught by the control using the standard Nordmøre grid (Figure 2). The experimental gear reduced smaller shrimps as indicated by count per kilogramme in 10 of the 11 paired tows. Mean counts were 135.5 kg^{-1} (s.e. 6.75) for the experimental tows and 173.6 kg^{-1} (s.e. 7.11) for control tows, which were significantly different ($p < 0.01$). This represents a reduction in count of 38.1 shrimp kg^{-1}. CL frequency distribution indicates that shrimps appear to be lost from the size-sorting grid at lengths of 20-mm CL or below, with the largest number of shrimps belonging to the 19-mm size class (Figure 3). The Kolmogorov–Smirnov test indicated that the size distribution was significantly different ($p < 0.01$; *z*-statistic 5.68). The mean shrimp size was 21.8-mm CL (s.e. = 0.11) for the experimental tows and 21.2-mm CL (s.e. = 0.09) for the control tows, which were also significantly different (independent samples *t*-test: *p*-value < 0.01).

Table 1. Catch weight and size of pink shrimp (*Pandalus borealis*) and bycatch species in numbers from the experimental size-sorting grid (SGNF) and standard grid (control).

Tow number	Pair number	Gear	Shrimp		Bycatch (in numbers)				
			kg h^{-1}	Count kg^{-1}	Whiting	American plaice	Witch flounder	Redfish	Red hake
17	[a]	SGNF	129.1	122.0	170	64	31	0	8
18	[a]	SGNF	175.0	124.9	165	49	14	0	3
19	1	SGNF	157.3	109.7	176	57	10	0	8
20	1	Control	167.3	144.2	270	78	7	0	19
21	2	control	147.3	169.7	96	48	24	0	11
22	2	SGNF	107.7	127.4	80	82	20	0	10
23	3	SGNF	107.7	119.4	110	58	8	0	15
24	3	Control	142.7	182.1	130	91	11	0	8
25	4	Control	175.0	169.5	78	46	16	0	12
26	4	SGNF	175.5	177.2	160	68	19	0	17
27	5	SGNF	97.3	116.6	56	94	8	0	6
28	5	Control	170.5	190.0	124	60	6	0	11
85	6	Control	80.9	170.1	74	77	29	65	4
86	6	SGNF	154.5	128.2	75	58	20	12	5
87	7	SGNF	152.7	129.6	67	70	24	91	6
88	7	Control	165.0	141.8	99	18	11	38	3
89	8	Control	181.4	158.9	338	65	33	46	24
90	8	SGNF	101.8	126.0	284	45	28	36	12
91	9	SGNF	44.1	142.4	78	70	9	140	1
92	9	Control	71.8	165.4	95	52	29	47	4
93	10	SGNF	140.9	195.6	56	173	34	5	9
94	11	SGNF	162.7	144.0	95	73	35	15	11
95	11	Control	208.2	197.4	48	23	40	15	15
96	10	Control	154.5	220.7	63	161	29	11	8

[a]Tows 17 and 18 were excluded from paired analysis.

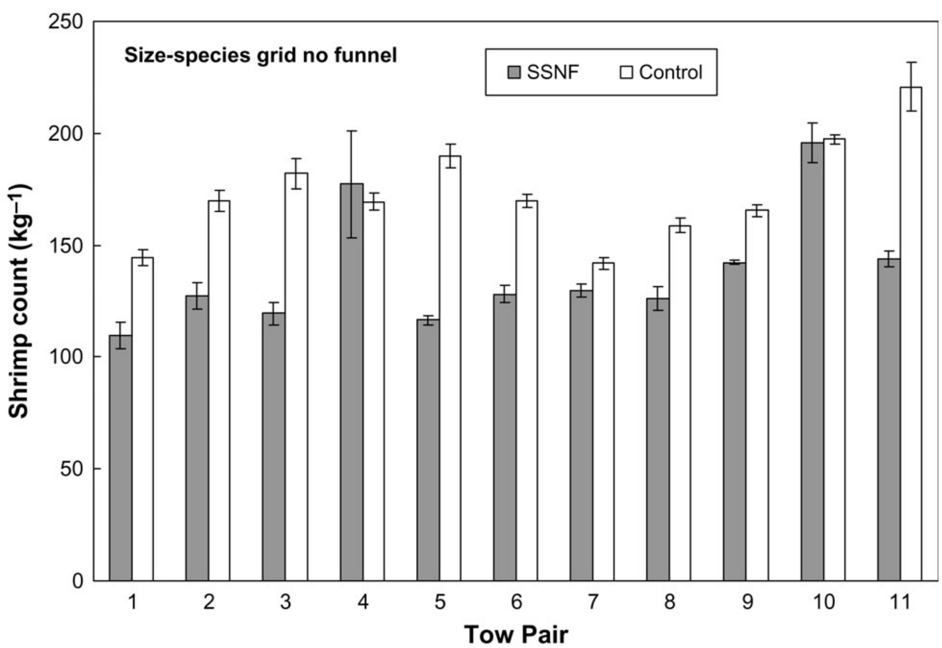

Figure 2. Shrimp sizes, indicated by counts (kg^{-1}), during 11 paired tows. SGNF, size-species grid no funnel, the experimental gear; control, regular Nordmøre grid. Error bars represent ± 1 s.e.

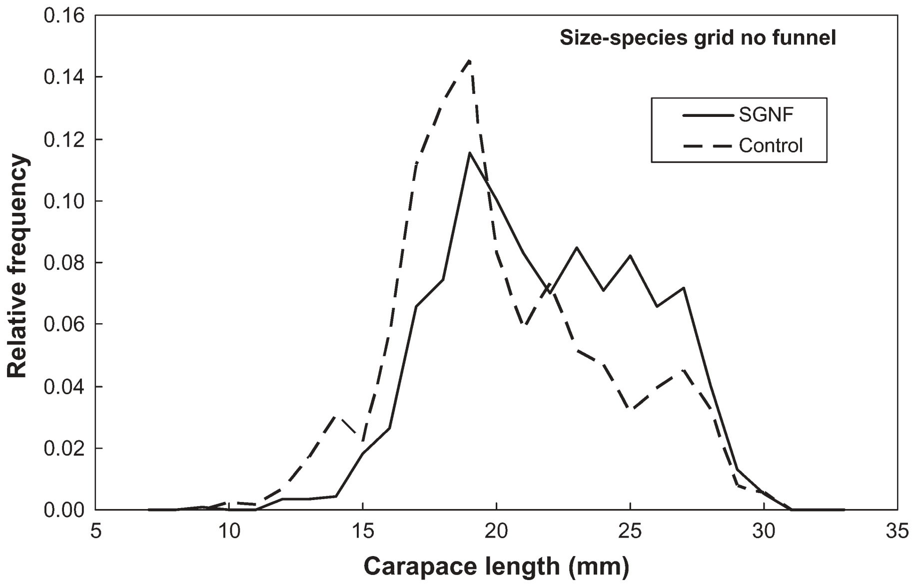

Figure 3. Shrimp CL distribution. SGNF, size-species grid no funnel, the experimental gear; control, regular Nordmøre grid.

The mean catch rate of shrimps was 127.5 kg h^{-1} (s.e. 11.79) for the experimental tows and 151.3 kg h^{-1} (s.e. = 12.4) for the control, an average reduction of 16%. Paired *t*-tests were used to compare experimental and control catch. Mean catch rates were not significantly different ($p = 0.102$), most likely because of the large variation between tows.

Mean numbers of the five main bycatch species (Figure 4) reveal little difference between those caught in the control tows and those in the experimental tows, with large variability in some species (e.g. whiting). Paired *t*-tests indicate no significant differences between the experimental and control tows for any of the five species ($p > 0.05$), indicating that the use of the new size grid would not affect bycatch in the fishery.

Size-species grid with funnel (SGWF)

Catch and bycatch from 24 tows using the SGWF grid and the control are presented in Table 2. The mean CL of shrimps caught by the SGWF dual-grid system was greater than those caught by the control using the regular Nordmøre grid (Figure 5). Overall, the shrimps were smaller during this segment of the experiment than the one described earlier. The experimental size grid caught larger shrimps on 13 of the 14 paired tows. Mean counts were 147.2 kg^{-1} (s.e. = 7.52) for the experimental tows and 192.3 kg^{-1} (s.e. = 7.23) for control tows, which were significantly different ($p < 0.01$). The difference was 45.2 kg^{-1}. CL frequency distribution indicates that shrimps appear to be lost from the size-sorting grid at lengths of 22 mm CL or below, with the largest quantity of shrimps belonging to

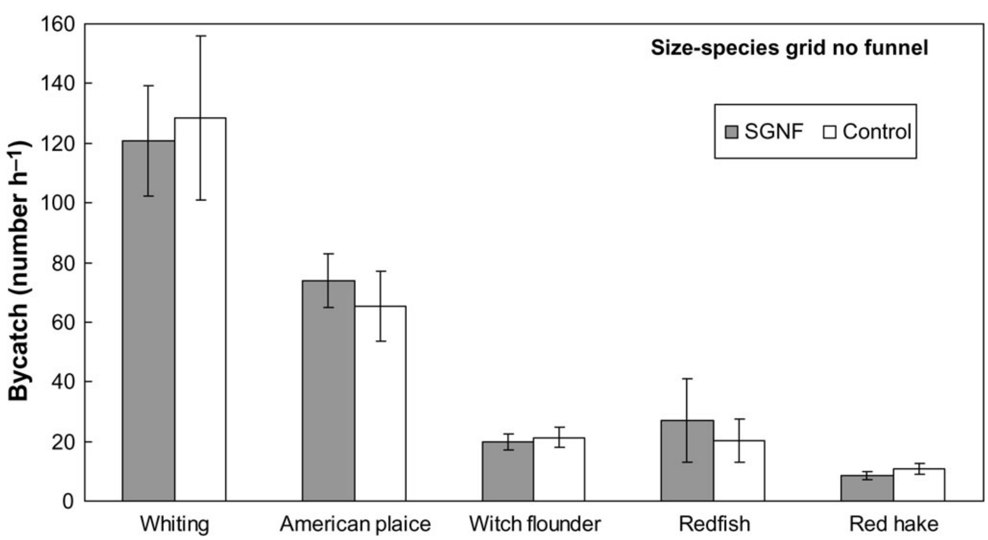

Figure 4. Number of bycatch species caught during 11 paired tows. SGNF, size-species grid no funnel, the experimental gear; control, regular Nordmøre grid. Species include whiting (*Merluccius bilinearis*), American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), redfish (*Sebastes* spp.), and red hake (*Urophycis chuss*). Error bars represent ±1 s.e.

Table 2. Catch weight and size of pink shrimp (*Pandalus borealis*) and bycatch species in numbers from the experimental size-sorting grid (SGWF) and standard grid (control).

Tow number	Shrimp		Bycatch (in numbers)				
	kg h^{-1}	Count kg^{-1}	Whiting	American plaice	Witch flounder	Redfish	Red hake
FV "North Star"—SGWF							
97	95.5	143.9	151	41	0	6	11
98	125.5	129.0	23	31	23	34	5
99	131.8	135.9	19	75	22	20	4
100	76.4	143.5	20	92	19	0	9
101	55.9	168.5	76	139	0	15	0
102	130.0	134.6	26	23	0	42	4
103	134.1	146.2	17	19	22	14	2
105	159.1	141.8	44	22	63	1	5
106	161.8	145.2	79	53	0	2	3
107	118.2	147.8	40	36	21	2	0
108	152.7	146.9	48	32	49	4	5
109	128.2	148.7	71	42	35	6	5
110	143.2	181.5	34	41	53	2	8
111	182.7	145.9	111	35	76	2	4
FV "Persistence"—Control							
97	155.0	198.9	125	38	50	3	9
98	187.0	183.9	18	93	33	45	5
99	190.0	207.4	39	40	52	21	6
100	152.0	241.1	27	140	25	16	10
101	130.0	266.1	72	154	19	15	6
102	12.0	110.3	0	44	15	24	2
103	215.0	184.0	20	50	76	19	7
105	290.0	187.1	52	31	82	18	5
106	327.0	184.3	65	84	59	5	4
107	288.0	180.5	18	34	27	3	1
108	198.0	186.2	32	34	70	3	7
109	239.0	199.7	29	29	78	6	7
110	178.0	201.0	43	23	32	8	2
111	383.0	160.7	66	15	102	4	0

The same tow number from different vessels constitutes a pair.

the 20-mm size class (Figure 6). The Kolmogorov–Smirnov test indicates that the size distribution was significantly different ($p < 0.01$; z-statistic 5.02). Mean size of shrimp was 21.4-mm CL (s.e. = 0.07) for the experimental tows and 20.0-mm CL (s.e. = 0.06) for the control tows, which were also significantly different (independent samples t-test: $p < 0.01$).

Catch rates ranged from 56 to 183 kg h^{-1} for the experimental grid, and from 130 to 383 kg h^{-1} for the control gear. The mean catch rate of shrimps was 128.2 kg h^{-1} (s.e. = 8.71) for the experimental tows and 210.3 kg h^{-1} (s.e. = 22.49) for control tows, an average reduction of 39%. The mean catch rates were significantly different ($p < 0.01$).

Mean numbers of the five main bycatch species caught are shown in Figure 7. With the exception of witch flounder, there are no statistical differences between those caught in the control tows and those caught in the experimental tows ($p > 0.05$). The new size grid caught a small number of witch flounder compared with the control with a regular Nordmøre grid ($p < 0.01$).

Discussion

Catch of small shrimps wastes resources and has a negative impact on the already depressed market. Although there is no minimum landing size for pink shrimp in the US, shrimp buyers have been refusing landings with an excess of shrimps <22-mm CL. In quota-controlled fisheries such as those in eastern Canada, landing of small shrimps represents an economic loss to the vessel because small shrimps usually have very little or no value, but they are counted as a part of the landing quota (Brothers and Boulos, 1995).

Previous efforts on size sorting to reduce small shrimps concentrated on increasing mesh sizes and mesh shapes, square mesh (Hickey *et al.*, 1993; Lehman *et al.*, 1993; Tait and Tait, 1993), and on the installation of the size grid behind the Nordmøre grid (DFO, 1995, 1998; Brothers and Boulos, 1996; FTU, 1996; Schick *et al.*, 1999). Valdemarsen (1989) predicted that merely changing mesh size and shape would not reduce small-shrimp counts, based on behaviour and escape capability of the species. Shrimps passing through meshes may also suffer

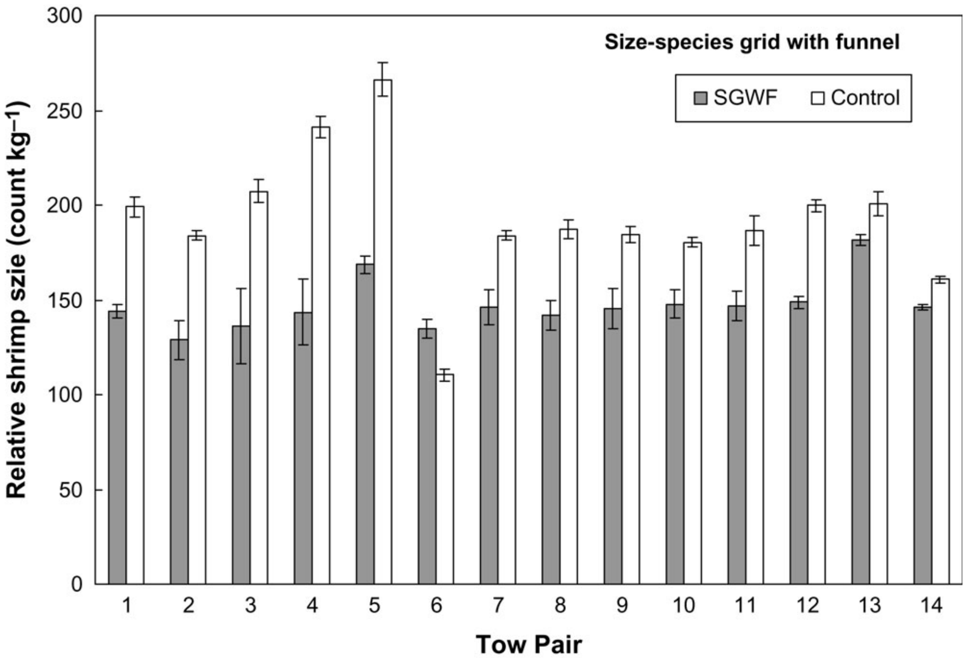

Figure 5. Shrimp sizes, indicated by counts (kg^{-1}), during 11 paired tows. SGWF, size-species grid with funnel, the experimental gear; control, regular Nordmøre grid. Error bars represent ± 1 s.e.

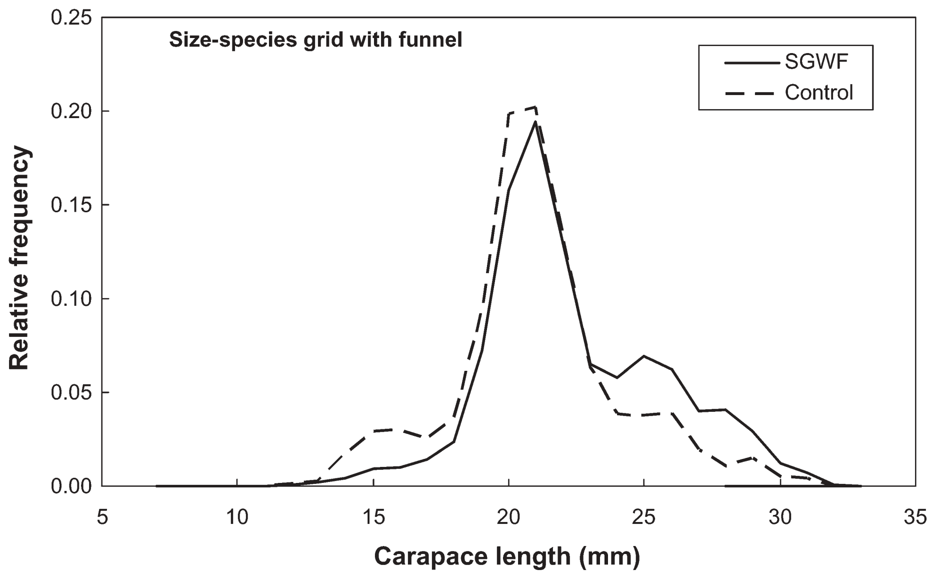

Figure 6. Shrimp CL distribution. SGWF, size-species grid with funnel, the experimental gear; control, regular Nordmøre grid.

damage and mortality, as observed by Ragonese and Bianchini (2006). Small shrimps sliding out of the grid would have a better chance of survival. The rear-installed size grid with small-mesh guiding panels reduced the flow rate at the size grid to as little as 40% of that of the grid system (FTU, 1996). Reduced flow rate can reduce sorting effectiveness.

The current designs have the size-sorting grid in front of the main Nordmøre grid and were effective at improving size selectivity of the shrimp. The increase in size is indicated by large reductions in counts. The SGNF worked very well with a count reduction of 38 shrimp kg^{-1} and an acceptable reduction in shrimp catch (15%). Small shrimps of <20-mm CL may have made up the majority of the reduction in the catch. The size grid seemed not to influence the function of the main Nordmøre grid, as indicated by the small number of fish bycatch in the codend.

Although the SGWF is equally as effective at reducing small-shrimp counts with a reduction of 45 shrimps kg^{-1}, there was also a sizable reduction of 39% in shrimp catch. It should be noted that, during this series of comparative experiments, two different vessels were used, and the experimental and control gears were not switched. Although their trawls were very similar, subtle differences between them could explain some of the differences in catch rates. Further controlled experiments on this design are required.

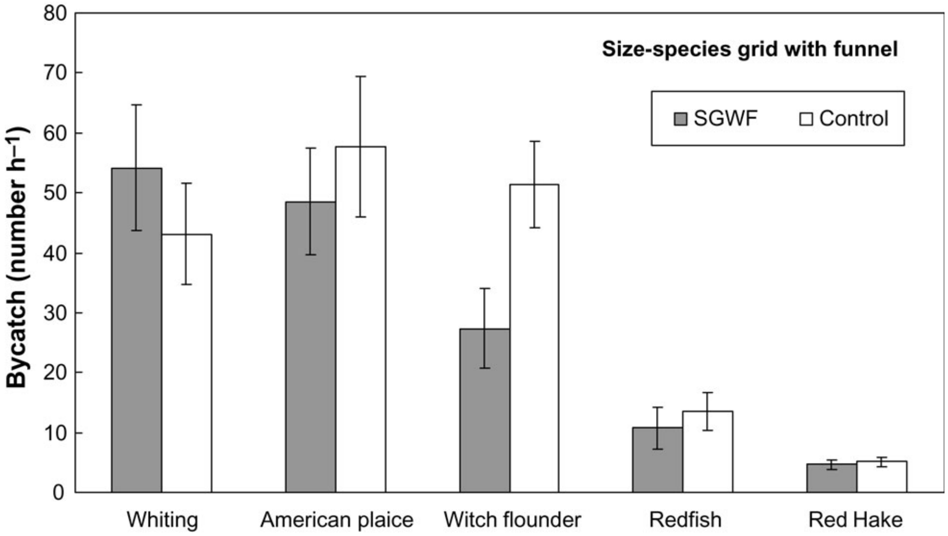

Figure 7. Number of bycatch species caught during 14 paired tows. SGWF, size-species grid with funnel, the experimental gear; control, regular Nordmøre grid. Error bars represent ±1 s.e.

In conclusion, the new size-sorting grid that was installed in front of the Nordmøre grid demonstrated great potential for reducing small shrimps in the pink shrimp fishery in the Gulf of Maine. The technology may also be used in other pink shrimp fisheries with suitable adjustment of the grid spacing to match shrimp size in the area and desirable sizes in the catch. Application to other shrimp and prawn fisheries may also be possible with additional experimentation.

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References

Broadhurst, M. K., Kennelly, S. J., and Eayrs, S. 1999. Use and success of composite square-mesh codends in reducing bycatch and improving size-selectivity of prawns in Gulf of St Vincent, South Australia. Fishery Bulletin US, 97: 434–448.

Brothers, G., and Boulos, D. 1996. Size sorting shrimp with an in-trawl grid system. Report of the ICES–FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB). ICES Document CM 1996/B: 2. 45 pp.

Campos, A., Fonseca, P., and Erzini, K. 2002. Size selectivity of diamond and square mesh cod ends for rose shrimp (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*) off the Portuguese south coast. Fisheries Research, 58: 281–301.

Clark, S. H., Cadrin, S. X., Schick, D. F., Doidati, P. J., Armstrong, M. P., and McCarron, D. 2000. The Gulf of Maine northern shrimp (*Pandalus borealis*) fishery: a review of record. Journal of Northwest Atlantic Fishery Science, 27: 193–226.

DFO. 1995. Shrimp size selectivity. Project summary, CAFID #10. Canadian Department of Fisheries and Oceans.

DFO. 1998. Shrimp size selectivity using an in-trawl sorting system. Project summary, CAFID #57. Canadian Department of Fisheries and Oceans.

Fonseca, P., Campo, A., and Larsen, R. 2005. Using a modified Nordmøre grid for by-catch reduction in the Portuguese crustacean-trawl fishery. Fisheries Research, 71: 223–239.

FTU. 1996. Tests of an experimental size-selective shrimp grate in a Skjervoy shrimp trawl. Fishing Technology Unit Report No. 5/96. Fisheries and Marine Institute, St John's, Newfoundland, 31 pp.

Hickey, W. M., Brothers, G., and Boulos, D. L. 1993. Bycatch reduction in the Northern shrimp fishery. Canadian Technical Report of Fisheries and Aquatic Sciences, 1964. 41 pp.

Howell, W. H., and Langan, R. 1992. Discarding of commercial groundfish species in the Gulf of Maine shrimp fishery. North American Journal of Fisheries Management, 12: 568–580.

Kenny, J. F., Blott, A. J., and Nulk, V. E. 1992. Experiments with a Nordmøre grate in the Gulf of Maine shrimp fishery. A Report of the New England Fishery Management Council to the National Oceanic and Atmospheric Administration.

Lehmann, K., Valdemarsen, J. W., and Riget, F. 1993. Selectivity in shrimp trawl codends tested in a fishery in Greenland. ICES Marine Science Symposia, 196: 80–85.

Ragonese, S., and Bianchini, M. 2006. Trawl selectivity trials on the deep-water rose shrimp (*Parapenaeus longirostris*) in Sicilian waters. Hydrobiologia, 557: 113–119.

Schick, D., Brown, M., Gallagher, D., and Shepard, R. 1999. Reduction of finfish and juvenile shrimp bycatch in the Gulf of Maine northern shrimp fishery through the use of a modified double Nordmøre Grate. Grant Number NA76FD0097. Available from NMFS Northeast Regional Office, Gloucester, MA.

Shumway, S. E., Perkins, H. C., Schick, D. F., and Stickney, A. P. 1985. Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. NOAA Technical Report NMFS Series, 30. 57 pp.

Tait, D., and Tait, W. 1993. Codend mesh experiment conducted on the M/V "Northern Osprey", Shrimp Selectivity Workshop, St John's, Newfoundland, 6–7 July 1993.

Valdemarsen, J. W. 1989. Size selectivity in shrimp trawls. *In* Proceedings of the World Symposium on Fishing Gear and Fishing Vessel Design, pp. 39–41. Ed. by G. J. Fox, and J. Huntington. Institute of Fisheries and Marine Technology, St John's, Newfoundland.

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