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UNIVERSITY OF NEW HAMPSHIRE
INSTITUTE FOR THE STUDY OF EARTH, OCEANS AND SPACE
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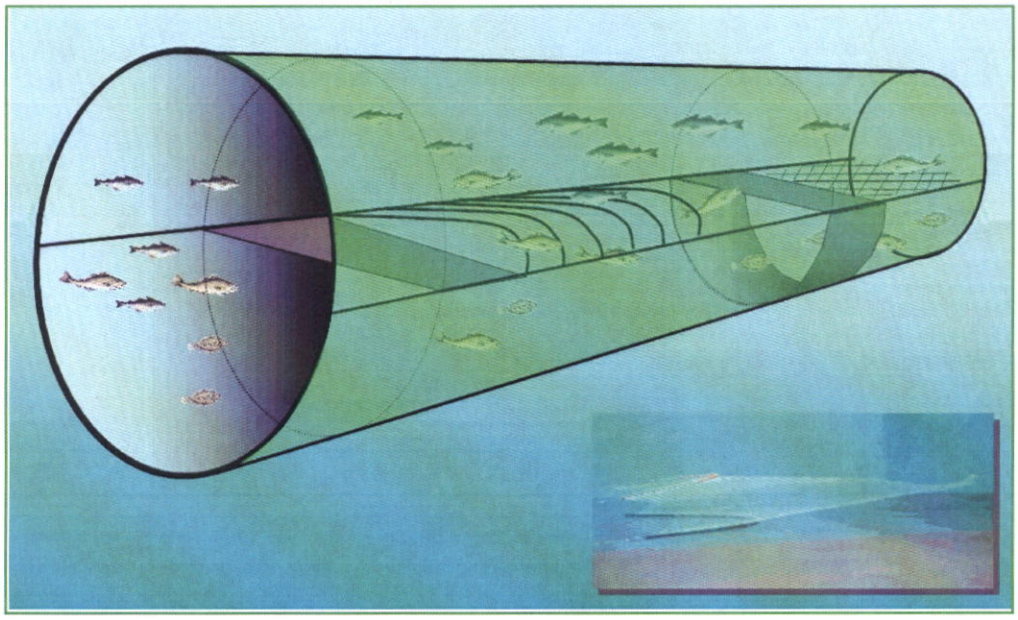
DURHAM, NH 03824

Final Report

Fish Behavior and Species Separation in the Gulf of Maine Multispecies Trawls



Submitted to:

NOAA Fisheries
Cooperative Research Partners Program
One Blackburn Drive
Gloucester, MA 01930

March 2006

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Final Report

Fish Behavior and Species Separation in the Gulf of Maine Multispecies Trawls

by

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Summary

Fish Behavior and Species Separation in the Gulf of Maine Multispecies Trawls

Pingguo He and Carl Bouchard

Successful separation of roundfish from flatfishes during capture processes can lead to gear designs which target certain species or species groups, hereby reducing unnecessary and unaccounted fishing mortality of restricted species. Trawl designs which separate species would allow fishermen to continue to fish for certain species with little or no catch or other species. Beside physical differences in size and shape, behavioral differences between species or species groups are very important in designing fishing gears or modifying operational methods. This project tested various species separation designs to separate roundfish and flatfish in Gulf of Maine mutltispecies trawls. The designs tested include mesh panels, black panels, black tunnels, rope panels, and their combinations. The use of black tunnel resulted in more cod in the upper codend, apparently avoiding the tunnel. However, the black tunnel had minimal effect on flounders. Two design combinations, A) black panel, netting and black tunnel (PNT), and B) black panel, ropes and black tunnel (PRT), both installed at the extension of the trawl and leading to upper and lower codend, showed good promise in separating roundfish and flounders. More than 90% of haddock and about 60% of cod were retained in the upper codend while about 70% of flounders were retained in the lower codend. While separation is possible, both designs have to improve before they can be applied in commercial fisheries. More efficient separation of these species may require installing the separators near the front part of the trawl where more vertical space would provide more natural separation. Behavioral analysis showed distinct behavior among haddock, cod and yellowtail flounder, with haddock more likely to stay in the upper level and more likely to swim up through the rope panel when they are below the panel. Haddock exhibited side to side behavior than other two species. No cod were seen to swim through the rope panel. These behavioral characteristics are utilized in the design of a rope haddock trawl for targeting haddock and pollock, which is also funded by the Cooperative Research Partners Program.

This project natured very close industry/science cooperation between the project partners, and has led to other cooperative projects funded by the Cooperative Research Partners Program and the Northeast Consortium.

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Fish Behavior and Species Separation in the Gulf of Maine Multispecies Trawls

1. INTRODUCTION

Groundfish species are under heavy fishing pressure in New England waters. The stock size Gulf of Maine cod is still well below the recommended Minimum Stock Size Threshold. Management measures have been put into place to reduce fishing mortality of this species. One of the measures was to limit the daily landing to 400 pounds in 2001 fishing year, 500 pounds in 2002, and 800 lbs with Amendment 13 which took effect in May 2004. At times, large quantities of restricted species such as cod are captured in one fishing operation, either as bycatch or as directed fishery at certain locations for some fishing gears. For example, otter trawls and gillnets directing for flatfish species often produce large amount of cod, exceeding daily landing limits.

Species compositions and allowable catch and retention often change as new population assessments become available and new regulations come into effect. For example, the most recent assessment indicates a much lower abundance of yellowtail flounder on Georges Bank (GB), while population of GB haddock remained high. Under these circumstances, separating the flounder and haddock becomes a priority to utilize abundant species while protecting less abundant species. However, the most important strategy for separating species in the multispecies fishery such the one in New England groundfish trawl fishery is to understand behavioral differences between species and how behavior of fish may change due to physical, environmental, biological and operational changes. The National Marine Fisheries Service has recognized the importance of fish behavior in devising conservation-oriented fishing gears which leads to bycatch reduction and improved fishing gear selectivity, and has supported this project to investigate fish behavior and to develop species separating trawls which can be used for controlled harvesting of certain species while reducing discards in the Gulf of Maine.

To understand and to improve species selectivity of fishing gear requires a good understanding of differences in the behavior of fish to be separated. Separator trawls with a horizontal panel was

first designed by Main & Sangster (1982) of Aberdeen Marine Laboratory in Scotland, who tested the trawl with the aid of underwater diver observations. The classical separator trawl (Fig. 1) has inspired new design philosophy for fish separation and new knowledge on species-specific behavior.

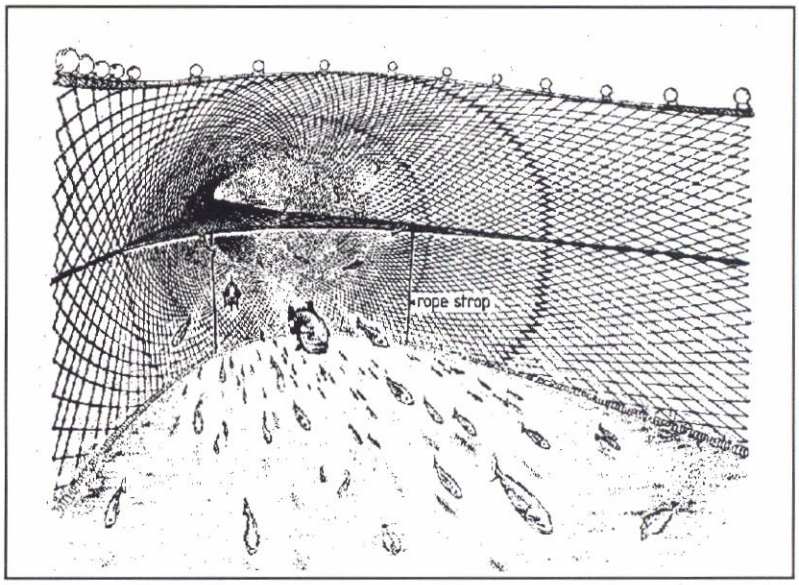


Figure 1. Artist's impression of the classical horizontal separator trawl (from Main & Sangster, 1982).

The Main & Sangster's separator trawl has never been commercialized for separating fish species in Europe though a version the design for separating fish and Nephrops has been used to some degree (Galbraith & Main, 1989). Canadians picked up the idea of separator trawl in early 1990s when there was a need to conserve the depleted cod while harvesting the less depleted haddock (Cooper, 1992). Other versions of separator trawls include that developed by Stone & Bublitz (1995) for separating Pacific cod and halibut, and that by Glass et al (1999) for separating squid and groundfish. Ten years after the Canadians, several separator haddock trawl projects are being conducted in Gulf of Maine and on Georges Bank to harvest haddock while conserving cod. As an alternative to the full size horizontal panel which require precise rigging and usually a new trawl, a rear-end selectivity device fitted to the extension of a trawl may have potential for easier adoption.

At the rear-end of the trawl, the cross-section of the net usually gets smaller toward the codend. And may result in fish becoming more mixed vertically. Behavioral control may be necessary to enhance vertical separation. One area of interest is fish vision and visual illusion. Visual illusion and its possible application in conservation-oriented fishing gear designs was explored by Wardle (1986). Studies in the tank and at sea proved that visual illusion concept can be applied to fishing gears to encourage escape of fish through meshes. The design of "caterpillar codend" and the use of so called "black tunnels" (Fig. 2) are two examples of that principle (Glass & Wardle, 1995;

Glass et al, 1995; Glass, 2000). This project take this principal one step further to apply visual illusion concept to separate species at the rear section of a trawl.

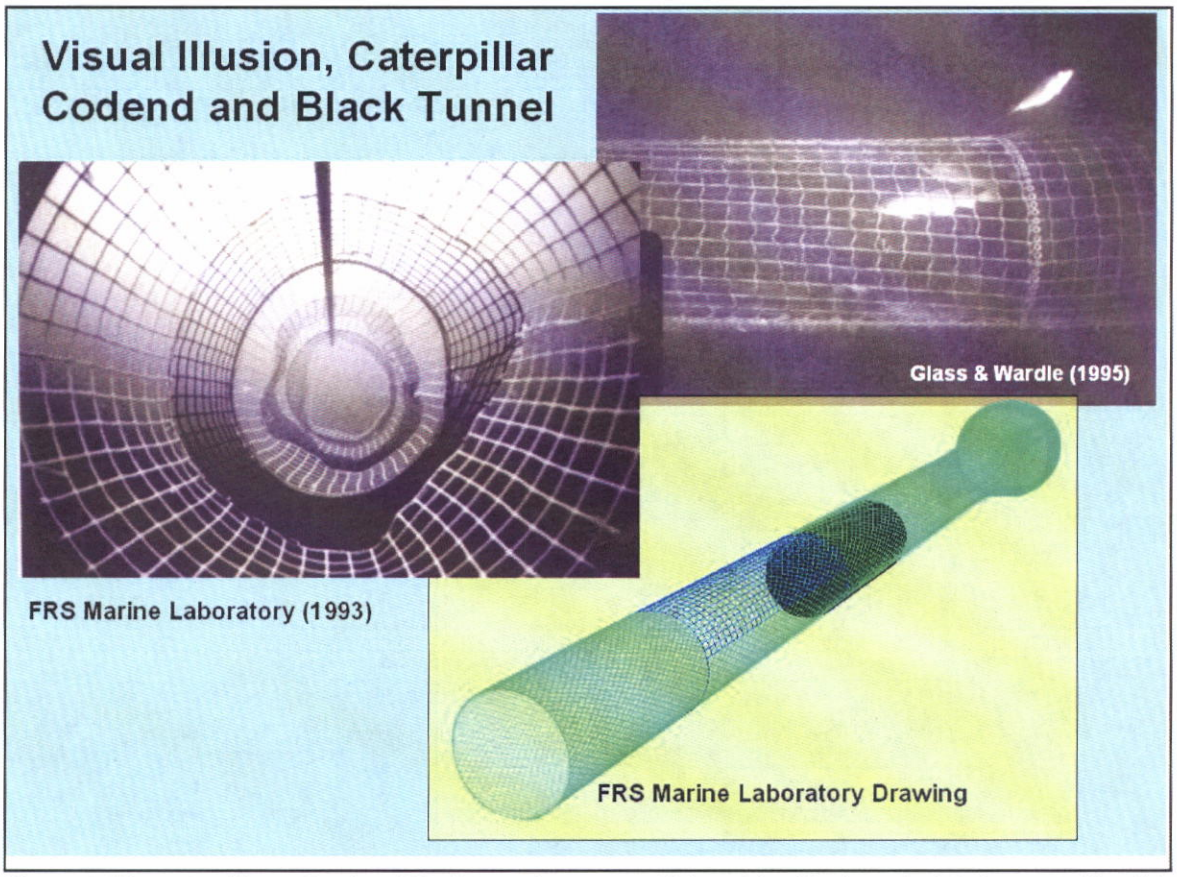


Figure 2. The caterpillar codend and black tunnel concept utilizing vision illusion principle for controlling fish behavior inside a trawl.

The project incorporates designs to suit the condition for the Gulf of Maine multispecies fisheries. One of the objective is to use "soft" material, in contrast to "hard" designs such as metal and plastic grid devices. Soft devices are usually easier to handle and allow the use of conventional net drums in Gulf of Maine inshore trawlers. The project investigates differences in the behavior between flatfish, cod and haddock, to provide knowledge base for species separation, and to design practical separator devices for trawls to separate roundfish and flatfish and thereby to reduce bycatch and discard in the Gulf of Maine multispecies trawl fishery.

Earlier progress reports for this project described flume tank tests of prototype designs and sea

trials comparing the effectiveness of separate panel with or without a black tunnel (He & Bouchard, 2002; 2003; 2004 a; b; 2005a). This final report includes all segments of the project including flume tank tests and four sessions of sea trials.

2. METHODOLOGY

2.1 Fishing gear and design concept

The fishing gear used for tank tests and sea trials was a 286 x 6" balloon trawl, a multispecies trawl used by the inshore fleet in the western Gulf of Maine (Fig. 3 and Fig. 4). The trawl containing an extension piece with a species selection separator leading to two codends. The goal was to have most of the roundfish in the upper codend, and most of flounders in the lower codend. The upper codend may then be left open when the cod daily limit has been exceeded, thus reducing discards of cod. The initial test in Sept. 2002 revealed that the separator section was too narrow. The section was redesigned through further flume tank tests to have a wider separation section. The modified section (Fig. 5) was tested in a flume tank during December 2002. A much wider separation section can be seen in the flume tank photo (Fig. 6). Also seen in Fig. 6 is a "black tunnel" visual stimuli device.

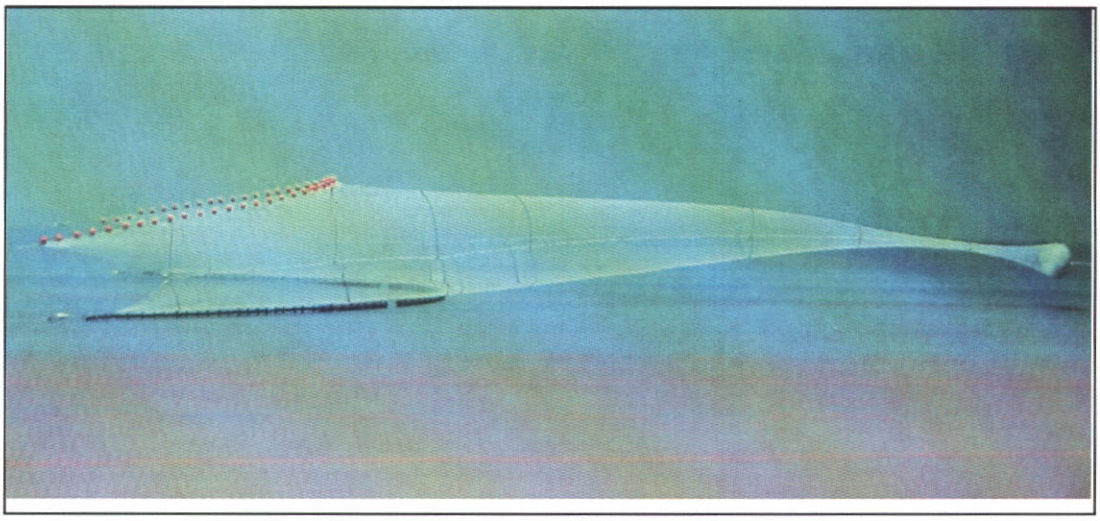


Figure 3. The model of 286x6" balloon trawl as seen in the flume tank.

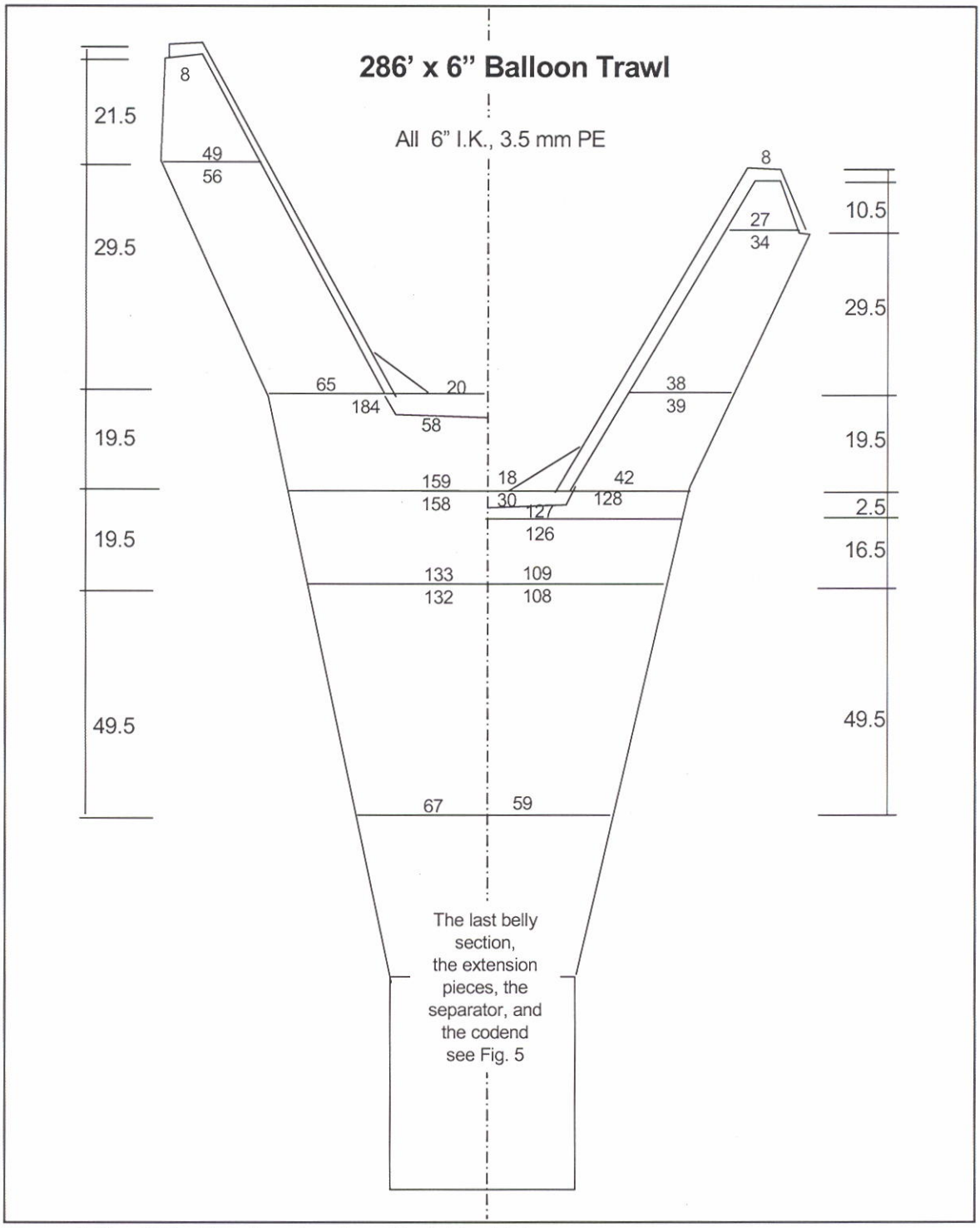


Figure 4. The 286' x 6" Balloon trawl used in fishing trials.

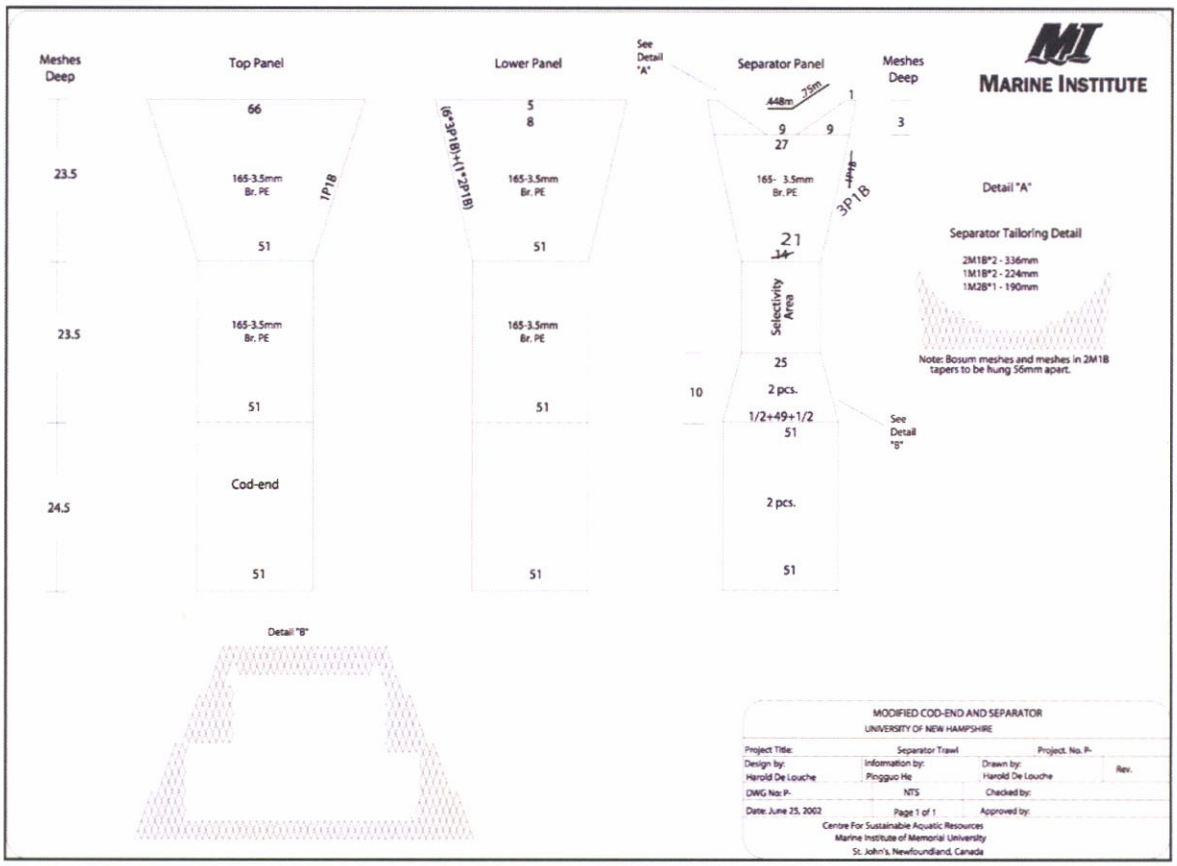


Figure 5. Redesigned species separation section for the 286 Balloon trawl.

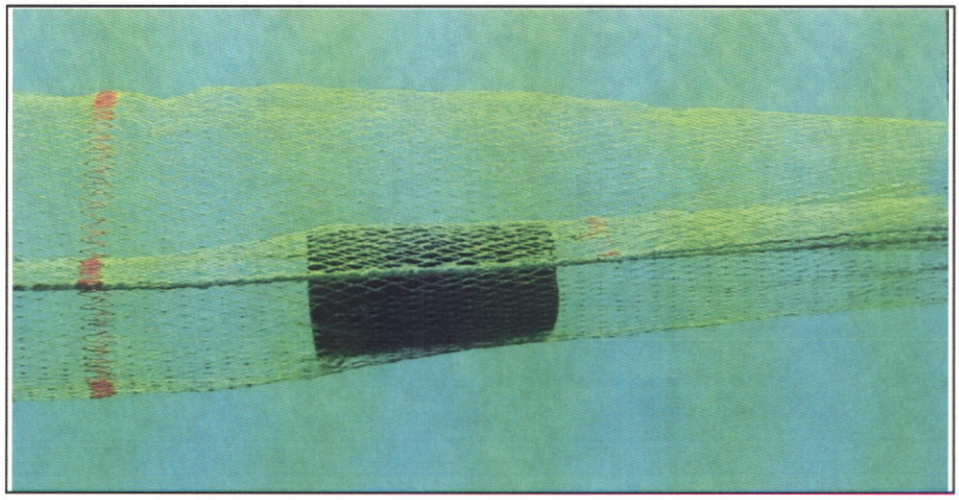


Figure 6. Species separation section with a "black tunnel" as seen in the flume tank.

2.2 Design of the species separation section

Several design concepts and full scale gear were tested in four separate sea trial sessions (Table 1). The original and modified separators were tested in a flume tank before installed in a full scale trawl for sea trials. During the Sept 2002 and April 2003 sea trials, the original and modified separators were tested, along with initial trials on black panels, and the black tunnel (Fig. 7 & 8). The species separation section is installed at the rear part of the body of a trawl and in the extension piece.

Table 1. Summary of sea trials and test designs

Season	Fishing effort	Experimental designs	See illustration
Sept. 2002	8 days 24 tows	Original separator, initial tries of black panel and tunnel	Fig. 7
April 2003	12 days 34 tows	Modified separator, black panels, black tunnel	Fig. 8
April 2004	9 days 28 tows	Black tunnel/panel, rope panel	Fig. 9
April/May 2005	11 days 41 tows	Black panel/tunnel, rope panel	Fig. 10

Three designs were tested in April 2004 (Fig. 9). Design A consisted panel and tunnel as tested in 2002 and 2003 seasons. The black tunnel structure was removed in Design B. In Design C, three parallel ropes of 9/16" diameter were installed in front of the black panel in design B. Both the panel and tunnel were made with rubberized canvas material of black color.

Two designs were rigged and tested in April/May 2005 (Fig. 10). Design A consisted of a black panel at the rear section of the funnel of the net, followed by regular 6" mesh netting panel, an opening, and a black tunnel underneath the horizontal panel. Design B replaced the netting panel with six parallel ropes of ½" diameter. The ropes were 2.5 meshes apart (about 16") with lengths

gradually reduced from 52" to 36". The black panel was trapezoid in shape, measuring 72" on the long side, 39" on the short side and 48" long. The black tunnel measured 28" frontal diameter, 16" rear-end diameter, and 48" long. Also tested was a design with the black tunnel removed from Design B. This design (Design C) only tested for three tows.

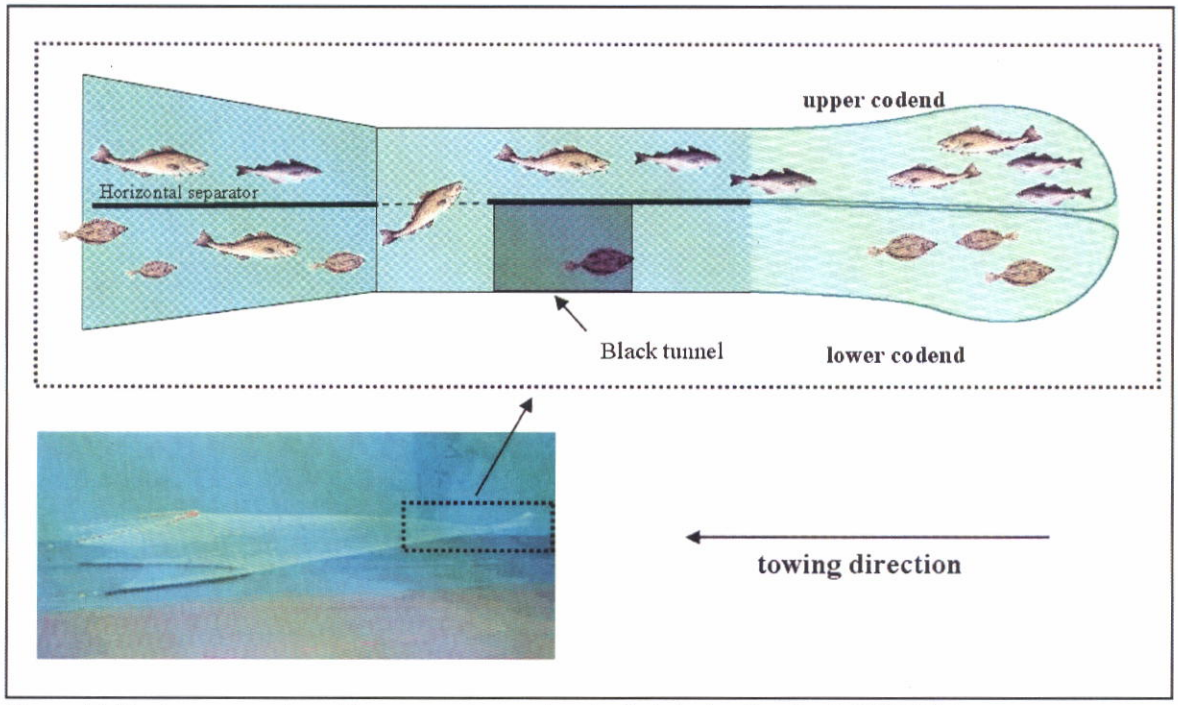


Figure 7. Design concept and the separator system tested during the Sept. 2002 trials.

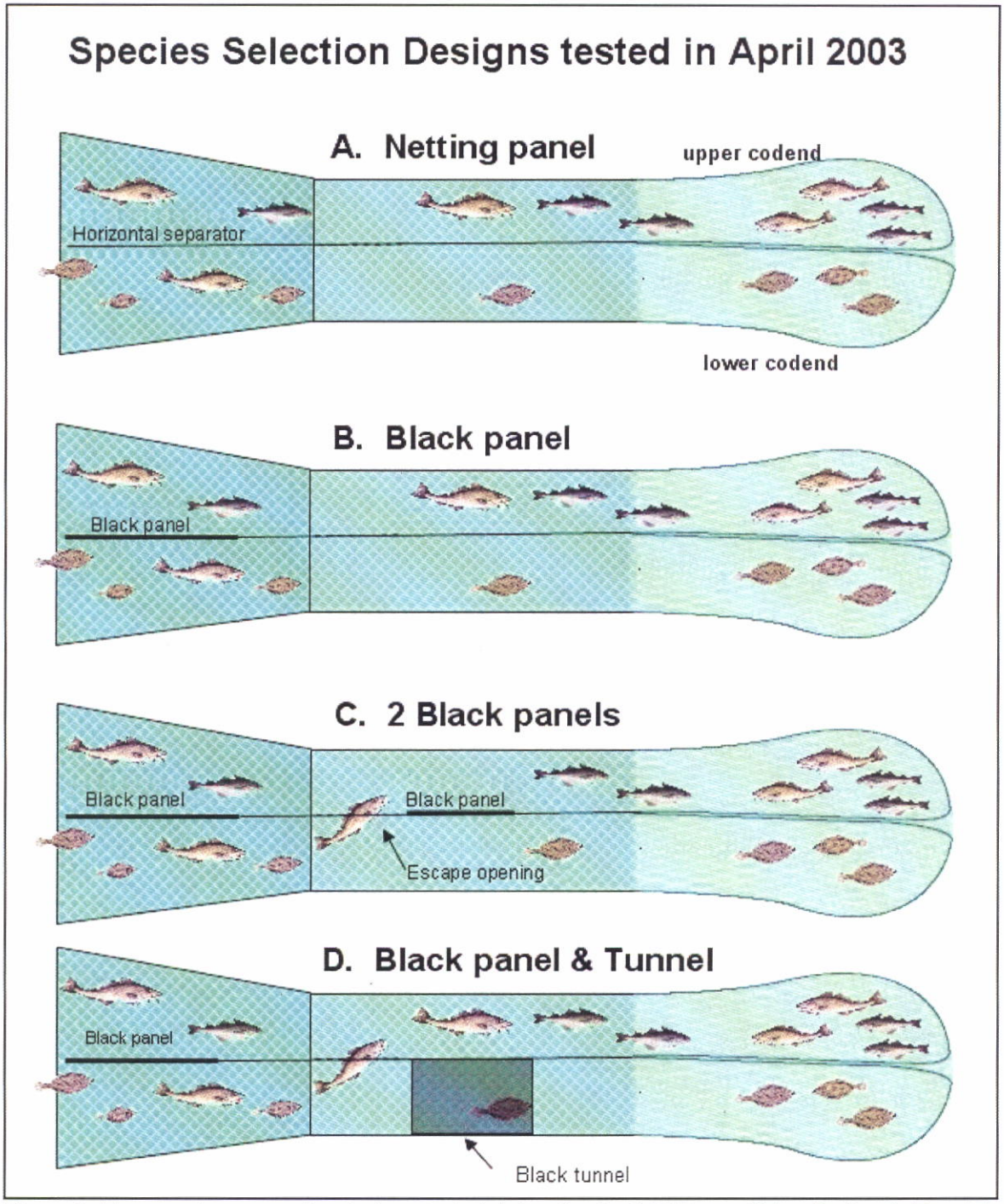


Figure 8. Four species separation designs tested during the April 2003 sea trials. Design A; Tow 1-8; Design B: Tow 9-13; Design C: Tow 14-29; Design D: Tow 30-34.

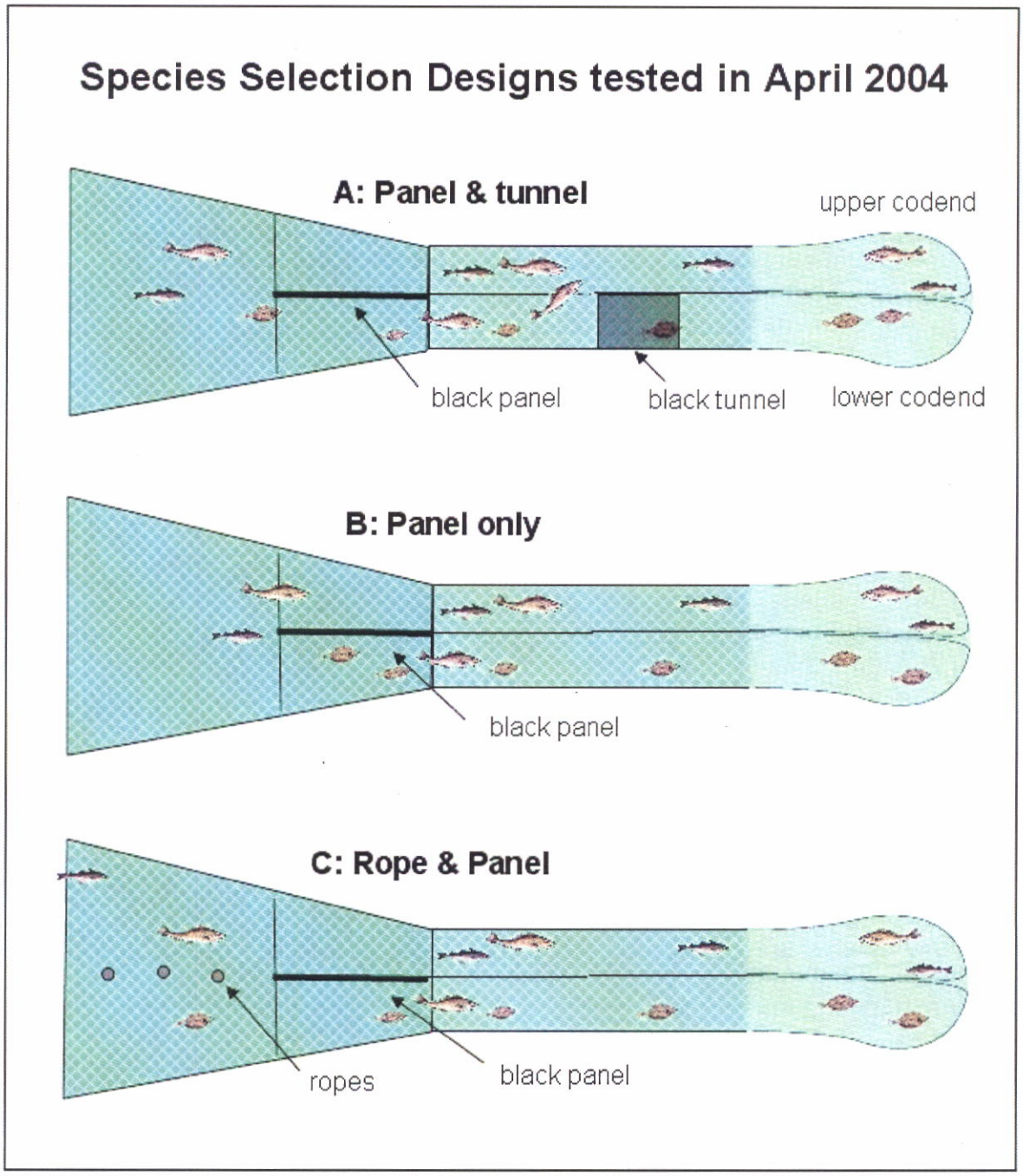


Figure 9. Three species separation designs tested during the April 2004 sea trials.

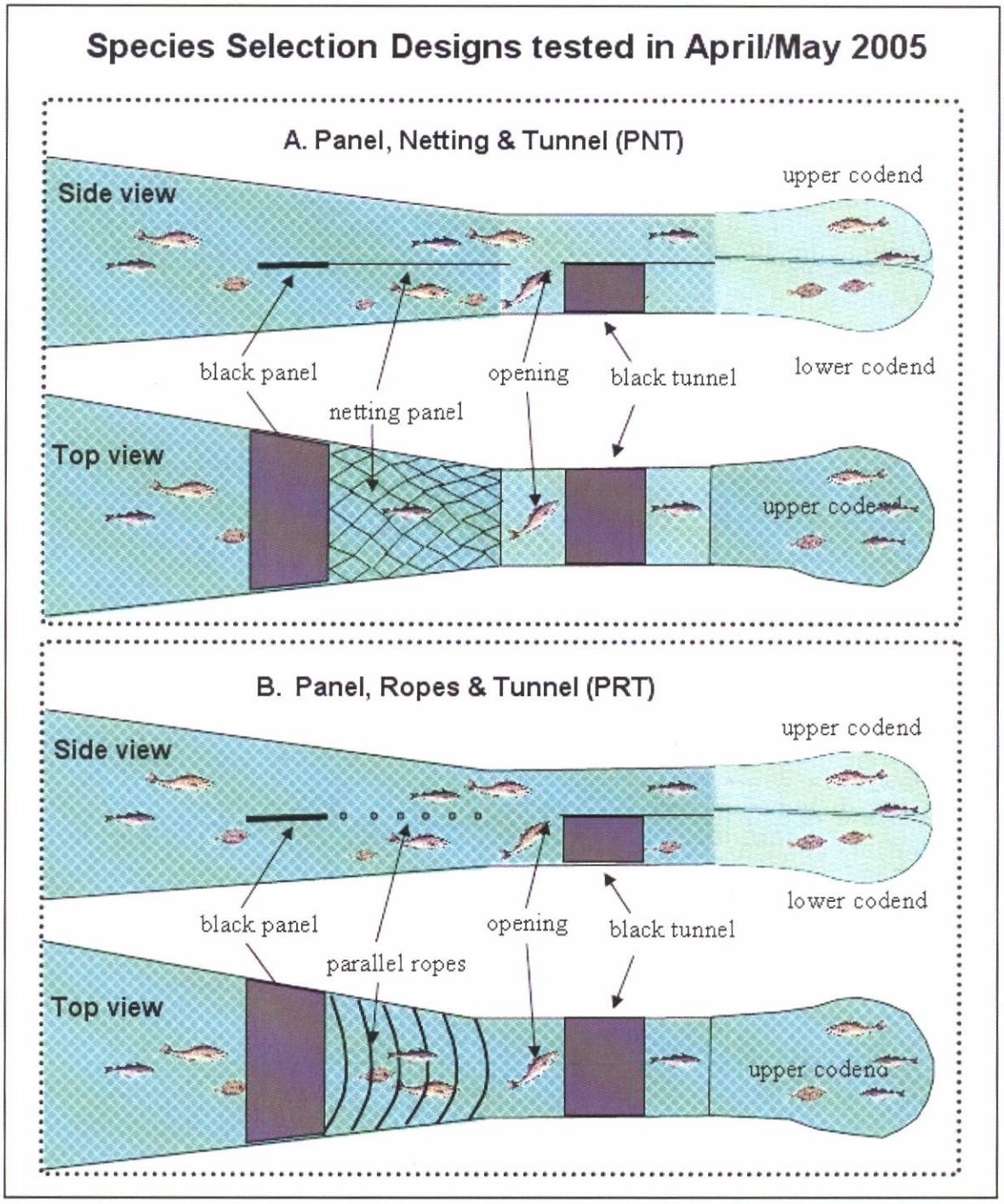


Figure 10. Two species separation designs tested during the April/May 2005 sea trials.

2.3 Sea trials

The vessel used for sea trials was 45' LOA F/V "Stormy Weather" based in Hampton Harbor, NH and operated by the industry partner, Capt. Carl Bouchard (Fig. 11). A two to three member crew and a scientist or technician from the University of New Hampshire were on board the vessel during all sessions of sea trials. The captain and crew were very enthusiastic about the project and were very skillful in gear modification, deployment/retrieval, and assisted in counting and measuring fish/shellfish caught. Each tow lasted for either one or two hours, and towing speed was maintained at 2.8 knots. Fishing trials were as carried out in the western Gulf of Maine of New Hampshire at depths between 22 and 76 fathoms in Scantum Basin and on Jefferys Ledge (Fig. 12).

Figure 11. F/V "Stormy Weather" used for the sea trials.

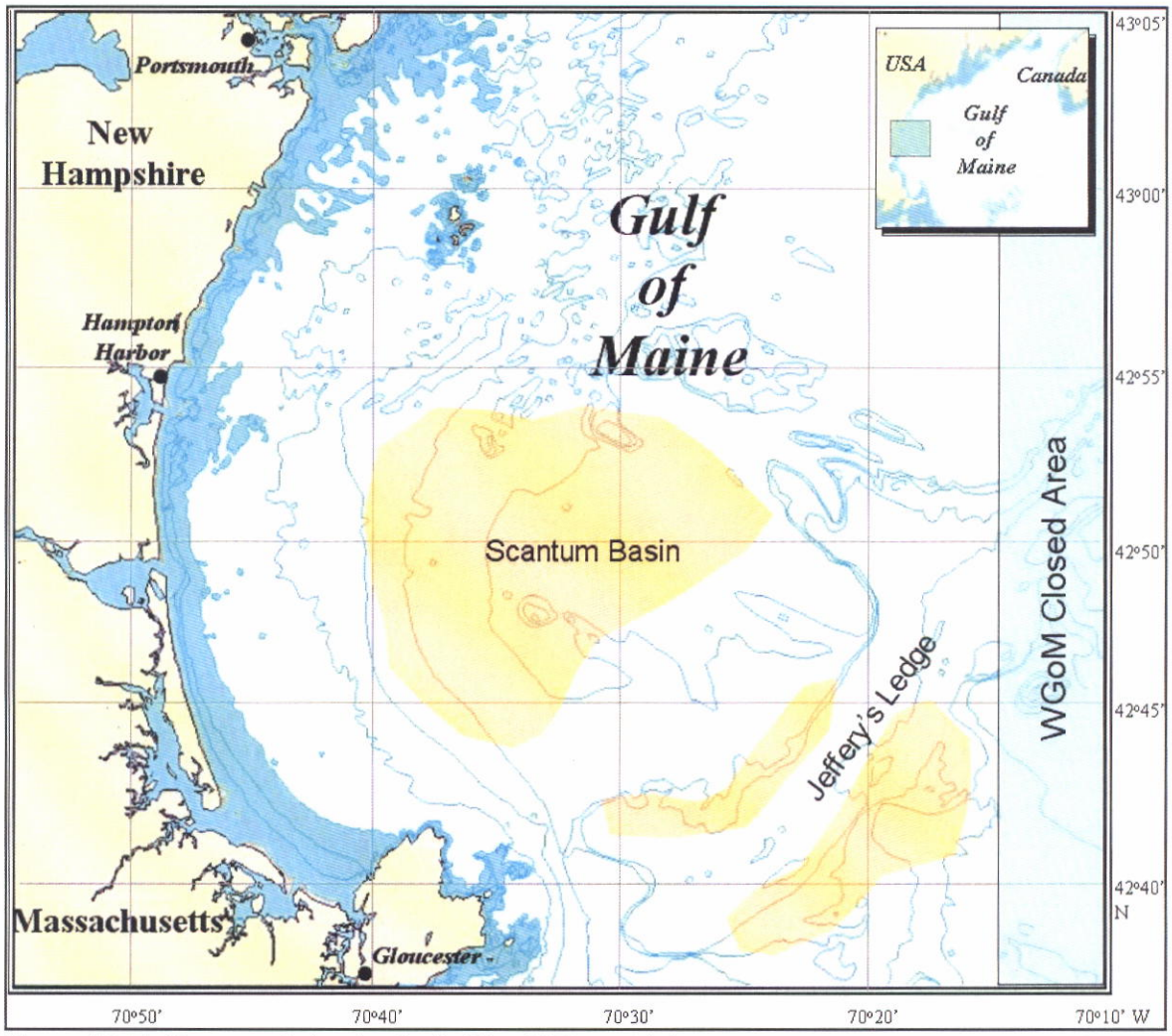


Figure 12. Fishing area during the April - May 2005 sea trials.

2.4 Gear monitoring and underwater observations

NetMind trawl monitoring sensors (Northstar Technical Inc., St. John's Newfoundland) were installed at various points on the trawl and the doors to evaluate geometry of the trawl system during fishing conditions (Fig. 13). A self-contained underwater camera/recorder system (Mac Marine Instruments, Brier, WA; Deepsea Power and Light, San Diego, CA) was installed to

monitor fish behavior near the separation device. The video was taken under natural light conditions in waters less than 40 fathoms to eliminate possible effect of light on the behavior of fish. Most of video tows were on Jefferys Ledge where water depths, seabed type and fishing conditions were ideal for video filming.

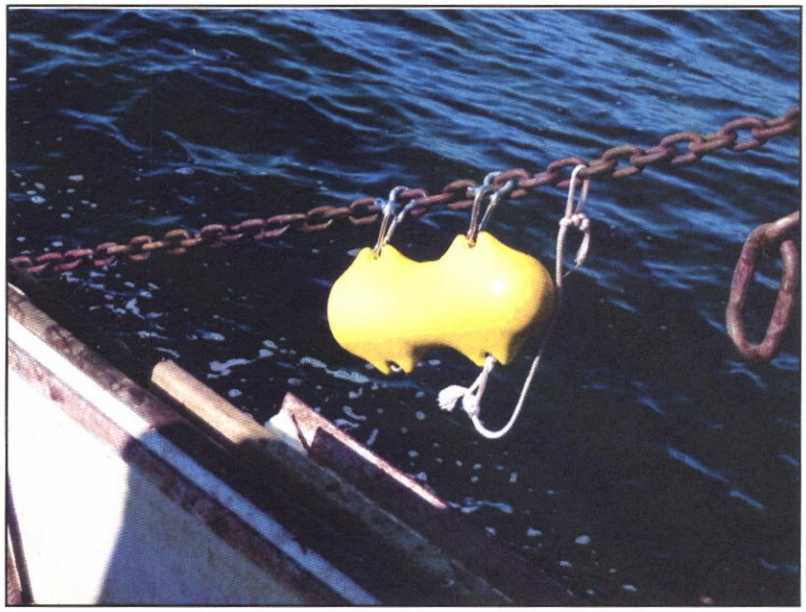


Figure 13. A NetMind sensor installed on the trailing chain of a trawl door.

2.5 Data collection and analysis

Lengths were measured for controlled groundfish species, including six major groundfish and other species. Discard species were counted and noted. Fish from the upper codend and the lower codend were separated and recorded. The ratio of fish in the upper codend and in the lower codendwas calculated for four major fish species: Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), American plaice (dab, *Hippoglossoides platessoides*). Only a small number of witch flounder (gray sole, *Glyptocephalus cynoglossus*) and winter flounder (blackback, *Pleuronectes americanus*) were caught during the sea trials, which usually does not warrant an analysis of separation in individual species basis.

The mean ratios of fish in the upper and lower codend and standard error were calculated for each species and for species groups (flounders: yellowtail, American plaice, witch flounder and winter flounder; and roundfish: cod and haddock). Small numbers in the catch result in large variations in ratios. Tows for the species (or species groups) were excluded from analysis in calculating means and other statistical treatment when the number was less than ten individuals. Comparison of the means for different designs, or between species for the same design were made using t-test

after arcsine transformation of the ratio data as suggested by Zar (1984). This transformation improves normality of the data such as ratios and proportion which usually binomial.

In addition, species separation index (I_{sep}) for major commercial species and species groups are calculated as suggested by Glass *et al.* (2001):

$$I_{sep} = [N_{upper} - N_{lower}]/N_{total}$$

where N_{upper} is the number of fish of a species in the upper codend, N_{lowe} is the number of fish in the lower codend, and N_{total} is the total number of fish of the same species ($N_{upper} + N_{lower}$). The value of I_{sep} will be between -1 and +1. A value of +1 means that all individual of that species is in the upper codend, and a value of -1 means that all individual of that species is in the lower codend, indicating perfect species separation. A value of 0 indicates no separation with 50% of the species caught in both upper and lower codends. Separation Index provide visual comparison and identification whether a large proportion of fish of certain species in the upper or lower codend.

2.6 Behavioral analysis

Video tapes were analyzed using a behavioral analysis software (ObserverPro Plus, Noldus Information Technologies Inc., Leeburg, VA). The major species are recognizable as "haddock", "cod" or "flounder". The individual species of flounder is not recognizable in most cases, but yellowtail flounder, and to a lesser degree, American plaice, dominated the catch during these tows, and presumably most of fish described as "flounder" are yellowtail flounder and American plaice. During the analysis, the following behavior patterns were recognized and recorded (Fig. 14):

Vertical position:	Whether they are "above" the rope panel or "below" the rope panel when the fish first appeared in the video screen.
Change in vertical position	Whether they swim "upwards" when they are below, "downwards" when they are above the rope, or whether their positions remain unchanged

Heading direction	Whether they head "towards" or "away from" the codend when they first appeared in the screen
Change in heading	Whether they turn and result in a change in heading
Other behavior	Whether fish "bang" into the side of the net, or if the fish swims "side to side", and if they do, how many times.

The coded data are reprocessed to provide behavior patterns of each species (species group). The data are compared using χ^2 convergency table between species.

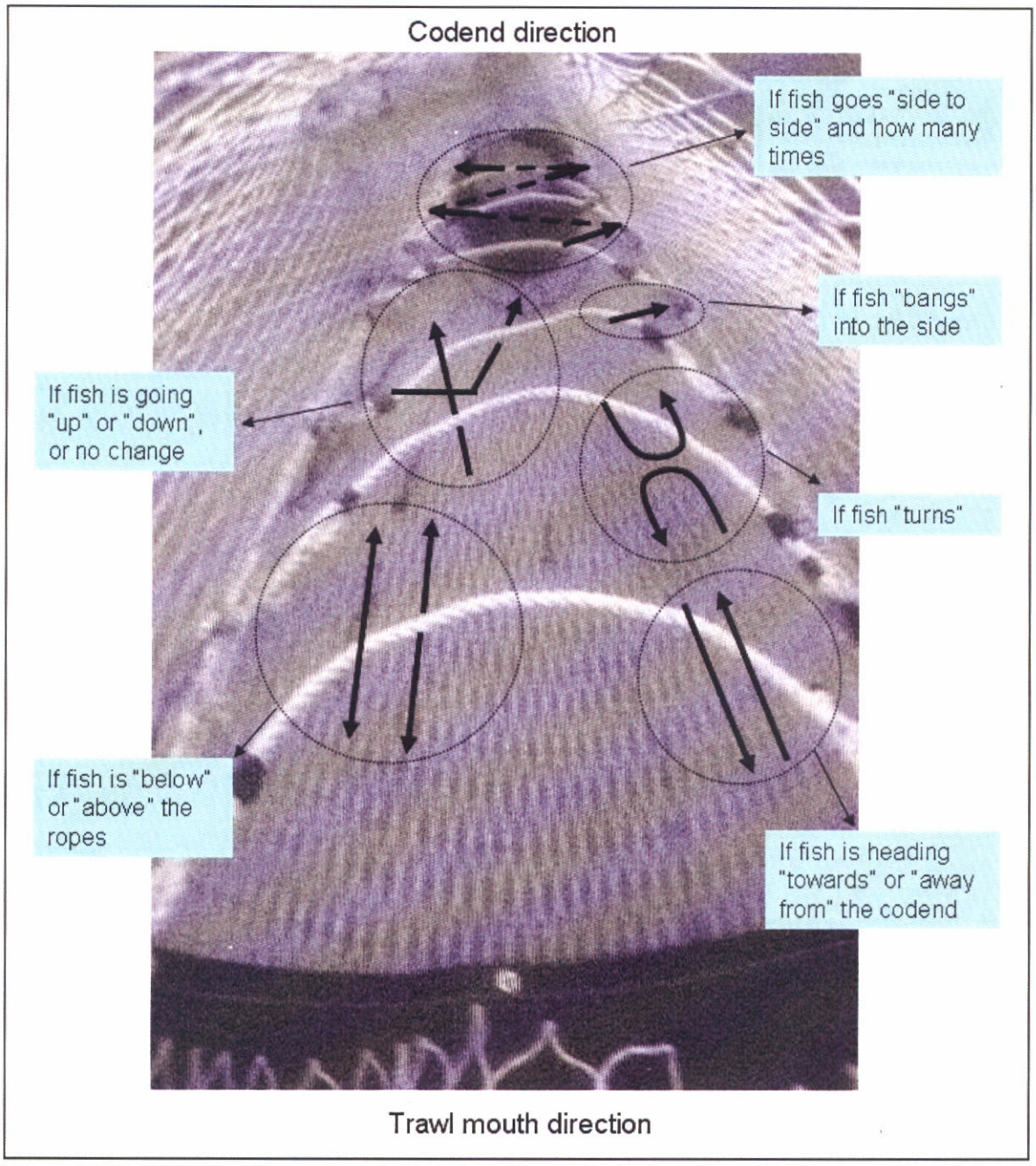


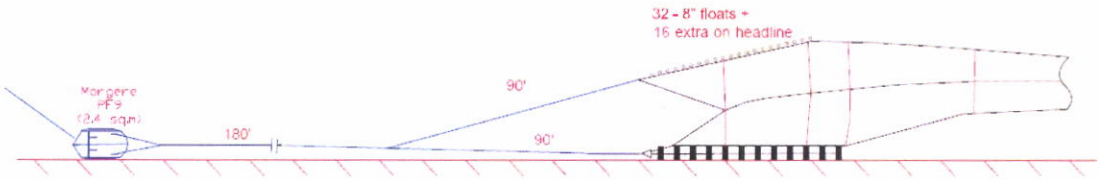
Figure 14. Behavioral patterns recognized during video analysis.

3. RESULTS

3.1 Flume tank test results

Flume tank model tests of the 1:8 model of 286 x 6" Balloon trawl provided good understanding of the gear dynamics and geometry of the trawl system in response to changes in towing speed, adjustment in footgear and addition or reduction of floatation at the headline of wingline. An example of the data collected from flume tank tests is shown in Table 2. Additional test data sheets are attached as Appendix I.

Table 2. Example of flume tank test data. This rig was used as standard rig during sea trials.



MARINE INSTITUTE FLUME TANK
TRAWL MODEL MEASUREMENTS

DATE:	6/12/02	File:	Tank data

Length	scale 1: 8
Sq.speed	scale 1: 8
Area	scale 1: 57.5

Company	University of New Hampshire
Trawl	286 Balloon
Rig 2	50% extra floats on center of headline

FULL SCALE VALUES (Imperial units)
Rig 2

Door type PF9	*Door area (sq.m)*	*Backstr. length (ft.)*
Morgere	2.4	9.0

U.bridle length (ft.)	*L.bridle length (ft.)*	*T.bridle ext. (ft.)*	*L.bridle ext. (ft.)*	*Sweep length (ft.)*	
90	90	0.0	0.0	180	

1 Float bouy. (lbs)	*Float no.*	*Total bouy. (lbs)*	
6.2	48	296.3	

Towing speed (kts)	*SPREAD*				*OPENING*		*TENSION*			*Mouth area (sqft)*	*Mouth drag lbs/sqft*	*Bridle angle (deg)*	*Narrowest dia. across codend (ft)*	
	Door (ft.)	*U.wing (ft.)*	*L.wing (ft.)*	*Mean w/e (ft.)*	*Wing (ft.)*	*Headline (ft.)*	*Port (tonnes)*	*Stbd (tonnes)*	*Total (tonnes)*				*Top*	*Side*
2.00	166.6	37.2	44.4	40.8	6.8	16.0	0.5	0.5	1.0	653.9	3.4	13.0	1.7	0.8
2.50	170.8	38.2	44.4	41.3	6.0	13.4	0.6	0.6	1.3	552.6	5.0	13.3	2.1	0.5
2.80	173.0	38.5	44.2	41.3	6.0	12.1	0.7	0.7	1.5	498.9	6.4	13.6	2.0	0.8
3.00	176.5	38.7	44.0	41.4	5.8	11.5	0.8	0.8	1.6	477.6	7.3	13.9	2.1	0.8

Additional measurement: Diameter at third joining round from codend (2.8kts) - from Top: 5.6 ft
Side 5.2 ft

3.2 Species caught during sea trials

Catch of commercial species varied among different sessions of sea trials, but generally included cod, haddock, yellowtail flounder, American plaice (dab), winter flounder (blackback), witch flounder (gray sole), monkfish, wolffish and pollock. Species names are given in Table 3. Skates (thorny, little and winter) and spiny dogfish were the most abundant discard species. Also caught in small quantities were whiting, redfish, lobsters and crabs.

The original separator design (Sept. 2002 trials) using netting and with a narrow section resulted in large quantities of fish meshed in the separator panel and the extension piece of the net (Fig. 15). Large quantities fish meshing in the separator panel cause distortion of the selectivity section, and diminishes the ability to separate species.

Though the number of fish meshed in the separator panel has been reduced with the re-designed section (April 2003 trials, and thereafter), netting panels used as separator still often resulted in fish meshing in the panel. The rope design (Design B, April/May 2005 trials, Fig. 10) did not mesh any fish.

Figure 15. Large quantities of fish (mainly spiny dogfish) meshed at the separator section during Sept. 2002 trials.

Table 3. Species caught during the 2005 sea trials with the minimum landing size (MLS) for major commercial species. TL- total length, FL – fork length.

Primary target commercial species	MLS
Atlantic cod (*Gadus morhua*)	55.6 cm TL
haddock (*Melanogrammus aeglefinus*)	47.0 cm FL
pollock *(Pollachius virens*)	47.0 cm FL
yellowtail flounders (*Limanda ferruginea*)	33.0 cm TL
American plaice (dab, *Hippoglossoides platessoides*)	35.6 cm TL
witch flounder (gray sole, *Glyptocephalus cynoglossus*)	35.6 cm TL
winter flounder (blackback, *Pleuronectes americanus*)	30.5 cm TL
Other commercial and discarded species	
silver hake (whiting, *Merluccius bilinearis)*	
monkfish (goosefish, *Lophius americanus*)	
white hake (*Urophycis tenuis*)	
red hake (*Urophycis chuss*)	
Atlantic wolffish (*Anarhichas lupus*)	
ocean pout *(Macrozoarces americanus)*	
Atlantic halibut (*Hippoglossus hippoglossus*)	
windowpane (*Scophthalmus aquosus*)	
fourspot flounder *(Paralichthys oblongus*)	
spiny dogfish (*Squalus acanthias*)	
thorny skate (*Amblyraja radiata*)	
little skate (*Leucoraja erinacea*)	
winter skate (*Leucoraja ocellata*)	
sea raven (*Hemitripterus americanus*)	
American lobster *(Homarus americanus*)	
rock crab (*Cancer irroratus*)	
northern stone crab (*Lithodes maja*)	
red crab (*Chaceon quinquedens*)	
snow crab (*Chionoecetes opilio*)	
scallops (*Placopecten magellanicus*)	

3.3 Underwater observation of fish behavior and fishing gear

Underwater videos showed shape of the separator panel, and assisted in rigging modifications during sea trials. Video footage showed how cod, haddock and flounders (yellowtail and dab) behaved differently at the separate device area (Fig. 16). Behavior patterns were coded into

vertical position (**Above** and **Below**), change in vertical position (**Up** or **Down**), **Turns**, and heading (**Towards** the codends or **Away** from codend), and other distinctive behavior (**Bang** into the side of the net and **Side to Side** behavior as the fish drifted or headed toward the codend. Table 4 summarizes each behavior pattern from one of the good video tapes from Tow 27 recorded in April 2005. Table 5 lists the catch (in numbers) of major groundfish species to facilitate comparison between what was observed in the video with what was caught in the upper and lower codend. It should be noted that the 6.5" mesh size codend may have resulted in the escape of a large proportion of fish, especially haddock (He *et al.* 2005).

Table 4. Quantitative results from video analysis of behavioural pattern of cod, haddock and flounders (mainly yellowtail flounder) from Tow 27, April 2005 video recordings.

Species	Number	Above	Below	Up	Down	Towards	Away	Turn	Bang	S to S
Haddock	121	95	26	18	2	51	70	53	23	59
		79%	21%	69%	2%	42%	59%	44%	19%	49%
Flounders	128	21	107	17	1	71	57	3	5	2
		16%	84%	16%	5%	55%	45%	2%	4%	2%
Cod	9	5	4	0	0	2	7	2	2	2
		56%	44%	0%	0%	22%	78%	22%	22%	22%

Haddock	Total observed	Total S to S	1	2	3	4	5	6
	121	59	18	24	11	1	4	1
	% of the total	49%	15%	20%	9%	1%	3%	1%

Above - above the panel, Below - below the panel, Up - swimming from below the panel to the above panel (% of fish Below), Down - swimming from the above panel to below the panel (% of fish Above), Towards - towards the codend, Away - away from codend, turn - change heading, Bang - bang into the side of the net, S to S - side to side swimming pattern. Number 1 to 6: the number of side to side motions in the field of view.

With 121 haddock observed in video recordings, 95 were seen in the upper level and 26 were in lower level. Of the 26 in the lower level, 18 haddock swam up and of 95 in the upper level, only 2 haddock swam down. After the change in vertical position, a total of 111 haddock (or 91.7%) ended up in the upper level toward the upper codend and remaining 10 (8.3%) ended up in the

Table 5. Catch of fish in the upper and lower codend from T27, April 2005.

Species	Codend	Catch	Catch (%)
Haddock	Upper	41	91.1
	Lower	4	8.9
Cod	Upper	3	37.5
	Lower	5	62.5
Yellowtail	Upper	4	28.6
	Lower	10	71.4
American plaice	Upper	3	42.9
	Lower	4	57.1
Flounders	Upper	7	33.3
	Lower	14	66.7

lower level toward the lower codend (Fig. 17) . The upper and lower ratios were strikingly similar to the ratios of catch actually retained in the upper and lower codend (Table 5). Similarly for flounders, the proportion of fish numerated from video recordings (28.9% upper and 71.1% lower) was very similar to that retained in the codends (Table 5 and Fig. 17).

Figure 16. An image from video recording showing a haddock swimming above the rope panel. The black material at the bottom of the photograph is the trailing edge of the black panel, and the black circular shape at the top of the photograph behind the haddock is the black tunnel.

Quantitative analysis of the video recordings showed behavioral differences among different species. In terms of the vertical position when entering the field of view (bottom of Fig. 14), 79% of haddock were above the separator compared with 21% for flounders and 56% for cod. The difference between haddock and flounders was statistically different, χ^2 (1, N=249) = 96.42, P<0.001. So were the differences between cod and flounders, χ^2 (1, N=137) = 8.38, P<0.001. There was no difference between cod and haddock statistically, χ^2 (1, N=130) = 2.49, P>0.1. However, there were very few cod in the sample (9). The result may have been different if there were more cod in the tow.

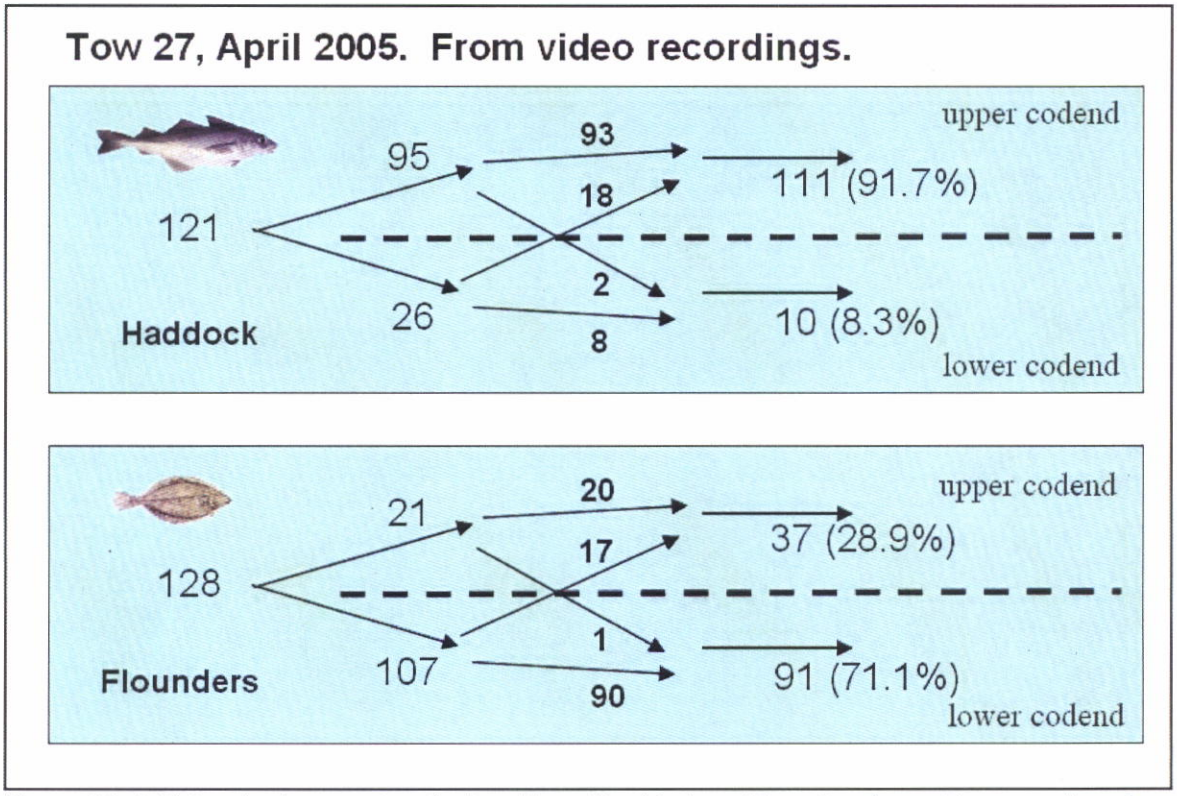


Figure 17. Initial and subsequent vertical position of haddock and flounders from video recordings from Tow 27 during April 2005 trials.

Table 6. Statistical analysis of behavioural patterns of cod, haddock and flounders from April 2005 video recordings. *** P<0.001, ** P<0.01, * P<=0.05, NS, P>0.05.

Vertical position: Above or below the separator

	Above	Below	Total
Haddock	95	26	121
Cod	5	4	9
Total	100	30	130

χ^2 (1, N =130) = 2.487, P > 0.1, NS

	Above	Below	Total
Haddock	95	26	121
Flounders	21	107	128
Total	116	133	249

χ^2 (1, N =249) = 96.417, P<0.001, ***

	Above	Below	Total
Cod	5	4	9
Flounders	21	107	128
Total	26	111	137

χ^2 (1, N =137) =8.382, P<0.001, ***

Side to side behavior

	s-s	no s-s	Total
Haddock	59	62	121
Cod	2	7	9
Total	61	69	130

χ^2 (1, N =130) = 2.369, P > 0.1, NS

	s-s	no s-s	Total
Haddock	59	62	121
Flounders	2	126	128
Total	61	188	249

χ^2 (1, N =249) =74.912, P<0.001, ***

	s-s	no s-s	Total
Cod	2	7	9
Flounders	2	126	128
Total	4	133	137

χ^2 (1, N =137) =12.662, P<0.001, ***

Behavior of fish when below the separator

	go up	stay down	Total
Haddock	18	8	26
Flounders	17	90	107
Total	35	98	133

χ^2 (1, N =133) =30.695, P<0.001, ***

	go up	stay down	Total
Haddock	18	8	26
Cod	0	4	4
Total	18	12	30

χ^2 (1, N =30) =6.923, P<0.01, **

	go up	stay down	Total
Cod	0	4	4
Flounders	17	90	107
Total	17	94	111

χ^2 (1, N = 111) = 0.750, P > 0.1, NS

Heading: Toward or away from codend

	towards	away	Total
Haddock	51	71	122
Cod	2	7	9
Total	53	78	131

χ^2 (1, N =131) =1.334, P > 0.1, NS

	towards	away	Total
Haddock	51	71	122
Flounders	71	56	127
Total	122	127	249

χ^2 (1, N =249) =4.952, P<0.05, *

	towards	away	Total
Cod	2	7	9
Flounders	71	56	127
Total	73	63	136

χ^2 (1, N =136) =3.83487, P =0.05, *

Behavior of fish when above the separator

	go down	stay up	Total
Haddock	2	93	95
Flounders	1	20	21
Total	3	113	116

χ^2 (1, N =116) =0.482, P > 0.1, NS

	go down	stay up	Total
Haddock	2	93	95
Cod	0	5	5
Total	2	98	100

χ^2 (1, N =100) =0.107, P > 0.1, NS

	go down	stay up	Total
Cod	0	5	5
Flounders	1	20	21
Total	1	25	26

χ^2 (1, N =26) =0.248, P > 0.1, NS

Change in heading: Turning or not

	turned	no turn	Total
Haddock	53	68	121
Cod	2	7	9
Total	55	75	130

χ^2 (1, N =130) =1.598, P > 0.1, NS

	turned	no turn	Total
Haddock	53	68	121
Flounders	3	125	128
Total	56	193	249

χ^2 (1, N =249) =61.329, P<0.001, ***

	turned	no turn	Total
Cod	2	7	9
Flounders	3	125	128
Total	5	132	137

χ^2 (1, N =137) =9.45, P <0.001, ***

We also tested other behavioral differences between different species (species groups). Statistical values are presented in Table 6. Summary of findings are:

1) When the fish were below the separator, haddock were more likely to swim up through the ropes than either cod or flounders, but there was no difference between cod and flounders. When they were above the separator, very few individuals swim down through the ropes, and the differences between the species were not statistically different.
2) Haddock and cod were more likely to exhibit "side-to-side" behavior than flounders. Though haddock had larger percentage of individuals showing this behavior (49%) than cod (22%), the difference was not statistically different due to a small number of cod observed. Haddock repeated the side to side behavior as much as six times, though two side-to-side repetitions were most common (Table 4).
3) More haddock and cod headed away from the codend when coming into the field of the view of the camera (haddock 59%, cod 78%) than those headed towards the codend. In contrast, the majority (55%) of flounders headed towards the codend. The differences between haddock and flounders, and between cod and flounders are statistically significant.
4) Cod and haddock are more likely to turn at the selectivity section than flounders. Only 3 flounders out of 128 observed turned in front of camera, while 22% of cod and 44% of haddock turned in the same area. The differences are statistically significant between cod and flounders, and between haddock and flounder. But there is no statical difference between cod and haddock in this respect.

3.4 Species separation

September 2002 trials. During the Sept 2002 trial, a total of 24 tows were made in eight fishing days. Tow 1 through 12 tested a simple netting panel fitted in the last belly section to the codend. Tow 13 to Tow 24 tested a variety of preliminary designs of panels and tunnel. Most fish caught were American plaice, witch flounder and cod. Detailed catch data are attached as Appendix III-1. During the first 12 tows, the netting panel separator was used. The results are presented in Table 7 and Fig. 18. Only a handful haddock were caught during the 12 tows, and its data are not analyzed here.

Table 7. Catch of major commercial species in the upper and lower codend during the September 2002 sea trials. Netting panel separator was used in Tow 1 - 12. Various modification Tow 13 through Tow 24.

Species	Tow #	1	2	3	4	5	6	7	8	9	10	11	12	Total
Dab	Upper	2	19	3	6	42	11	11	18	7	6	24	9	158
	Lower	18	69	83	23	36	27	27	32	46	74	64	48	547
YT	Upper	2	1	0	1	1	0	17	0	0	0	0	0	22
	Lower	6	0	3	7	0	2	50	4	0	0	1	1	74
GS	Upper	15	19	19	15	23	14	3	17	22	18	14	10	189
	Lower	102	224	118	51	175	253	74	112	121	111	156	48	1545
BB	Upper	2	3	0	1	4	0	3	1	0	0	0	0	14
	Lower	4	0	1	2	0	1	7	1	0	0	1	0	17
Total	Upper	21	42	22	23	70	25	34	36	29	24	38	19	383
Flounder	Lower	130	293	205	83	211	283	158	149	167	185	222	97	2183
Cod	Upper	2	1	0	3	3	1	0	4	1	1	2	1	19
	Lower	9	3	0	9	4	6	1	13	2	8	4	4	63

		w/ opening			modified opening			w/ black panel			w/ black tunnel			
Species	Tow #	13	14	15	16	17	18	19	20	21	22	23	24	Total
Dab	Upper	24	12	12	3	5	1	1	1	0	4	2	13	78
	Lower	58	20	9	2	20	7	7	13	6	10	5	24	181
YT	Upper	0	0	0	1	0	0	1	0	0	2	2	0	6
	Lower	1	0	0	0	0	0	0	1	2	2	2	0	8
GS	Upper	40	18	34	20	12	8	27	13	15	22	11	26	246
	Lower	48	46	36	31	44	19	81	38	29	110	53	94	629
BB	Upper	0	0	0	0	0	0	0	0	1	0	0	0	1
	Lower	0	0	0	0	0	1	0	0	0	0	7	0	8
Total	Upper	64	30	46	24	17	9	29	14	16	28	15	39	331
Flounder	Lower	107	66	45	33	64	27	88	52	37	122	67	118	826
Cod	Upper	12	13	10	25	7	7	24	4	9	23	6	7	147
	Lower	12	14	0	17	17	11	33	17	10	30	19	28	208

YT - yellowtail flounder, GS - gray sole (witch flounder) , BB - blackback (winter flounder).

Most flounders (both American plaice and witch flounder) and cod were retained in the lower codend. Separation between cod and flounders was very poor. Subsequent modifications to the separator panel improved separation with more cod retained in the upper codend. A small number of tows did not warrant further analysis. Some of the designs were tested again in April 2003 sea trials.

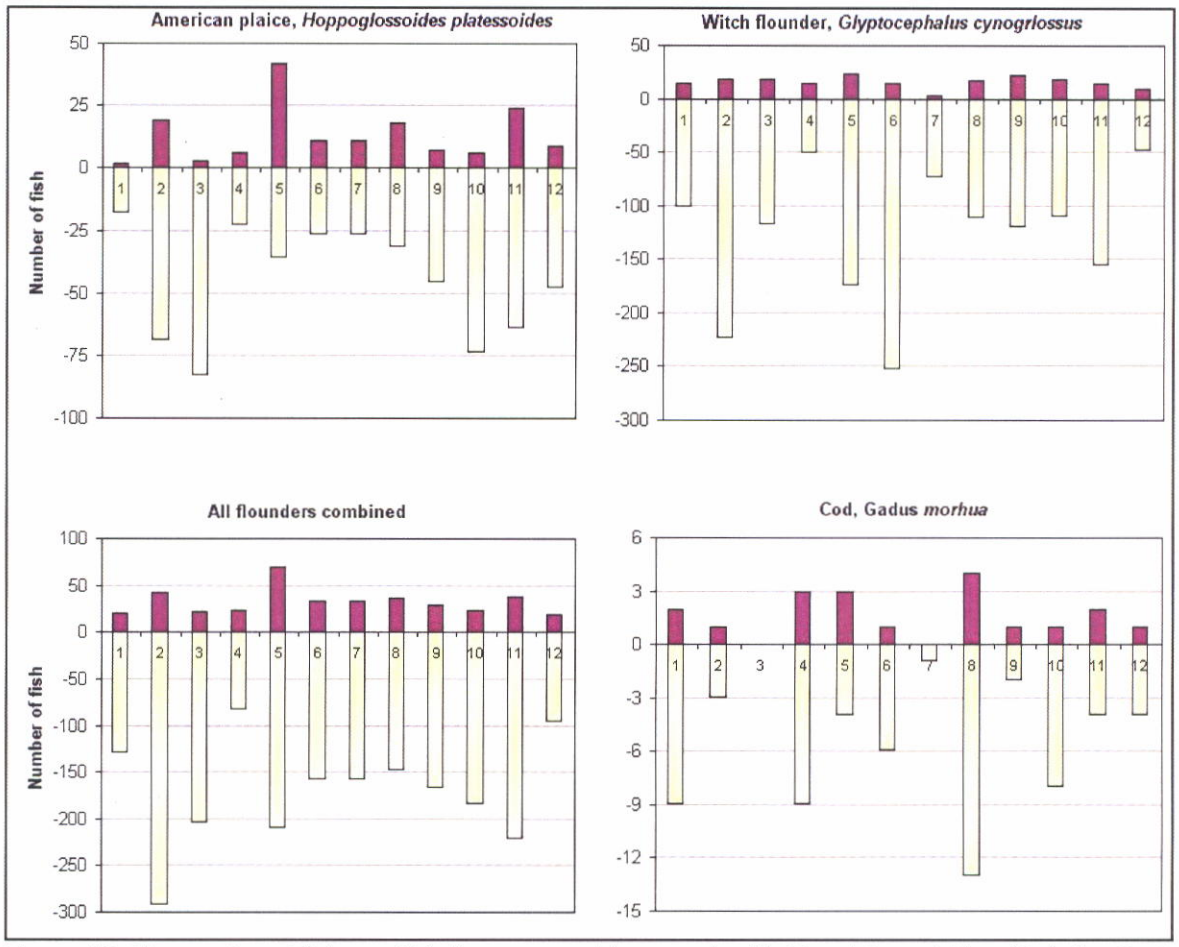


Figure 18. The number of fish caught in the upper and lower codend in Tow 1 through Tow 12 during Sept. 2002 sea trials. A simple netting panel was used as separator.

April 2003 trials. The sea trials following tank tests in the previous December when a new, wide extension piece was designed and tested. Thirty-four tows were made in twelve fishing days during April 2003, concentrating on a black panels and black tunnel designs (Fig. 8). Low water temperature (3.7 °C bottom temperature) delayed arrival of cod and flounders at the traditional fishing grounds off the New Hampshire coast. Catch was generally low and catch composition were inconsistent in early April 2003 when the experiments began. Catch was improved in terms of species and size composition, and amount of catch in later April on Jefferys Ledge. Catch of commercial species included cod, haddock, yellowtail flounder, American plaice, winter flounder, with a few witch flounder, Atlantic wolffish, and pollock. Thorny skates were the most abundant

species discarded both in weight and in numbers. Also caught in small quantities were monkfish, whiting, redfish, lobsters, scallops, four-spot flounder, fluke, juvenile halibut, ocean pout, sculpin, lumpfish, rock crabs, red crabs, snow crabs, and stone crabs. Catch in upper and lower codend for major groundfish species is presented in Table 8. Tow by tow catch and length data for some important groundfish species are attached as Appendix III-2.

Table 8. Catch of major commercial species in the upper and lower codend during the April 2003 sea trials. Tow 1-8: Design A, Tow 9-13: Design B, Tow 14-29: Design C, Tow 30-34: Design D. See Fig. 8.

	Tow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dab	Upper	2	5	4	1	16	14	14	9	11	6	28	10	6	13	17	15	7
	Lower	19	28	35	10	31	35	35	69	81	8	32	25	13	52	50	32	8
YT	Upper	2	5	5	1	9	12	10	8	6	2	0	9	2	15	18	14	7
	Lower	9	23	20	4	27	14	17	33	32	8	18	12	4	24	19	9	4
GS	Upper	0	1	0	0	4	0	0	2	3	0	0	0	0	1	3	2	1
	Lower	1	2	1	0	12	6	0	32	32	0	0	0	0	0	0	3	3
BB	Upper	3	1	2	0	1	1	2	2	2	0	8	4	2	3	3	3	1
	Lower	4	15	5	4	3	8	6	11	5	2	6	3	2	12	8	7	1
Cod	Upper	2	0	0	0	1	2	2	7	14	79	2	2	1	9	5	8	18
	Lower	9	4	4	0	7	5	9	10	12	78	11	5	0	15	10	18	19
HDK	Upper	4	7	11	4	54	125	17	24	18	5	22	9	3	12	21	23	15
	Lower	2	3	10	1	9	30	7	17	3	0	3	0	0	7	1	4	10

	Tow #	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Dab	Upper	6	6	5	4	4	9	2	2	20	11	4	7	2	2	2	2	5
	Lower	9	9	24	4	14	23	13	17	33	18	17	27	3	3	11	6	13
YT	Upper	3	3	3	5	7	5	3	6	33	15	15	6	34	7	23	5	2
	Lower	42	4	8	4	10	16	10	21	198	36	50	52	30	21	64	22	8
GS	Upper	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0
	Lower	0	0	1	0	0	6	1	0	0	0	2	0	0	0	0	0	0
BB	Upper	1	1	1	0	1	3	0	0	6	3	9	4	10	1	5	1	2
	Lower	8	6	5	4	3	5	0	2	23	8	15	15	6	4	8	3	1
Cod	Upper	1	1	1	44	0	1	0	0	5	42	5	17	27	1	11	0	24
	Lower	3	1	6	42	5	6	0	0	7	23	4	9	18	2	10	8	31
HDK	Upper	0	1	6	19	1	1	0	0	77	147	59	183	340	12	150	24	27
	Lower	0	0	1	1	1	1	1	0	11	16	5	19	16	2	9	2	0

YT - yellowtail flounder, GS - gray sole (witch flounder) , BB - blackback (winter flounder), HDK - haddock.

Analysis indicates that most of the haddock were caught in the upper codend, and most of the flounders (including yellowtail and American plaice) were caught in the lower codend (Fig. 19) for all four separator designs (Table 9 and Fig. 20). However, cod seemed to split between the upper and the lower codends. The results indicate that haddock can be successfully separated from other species with some additional rigging changes.

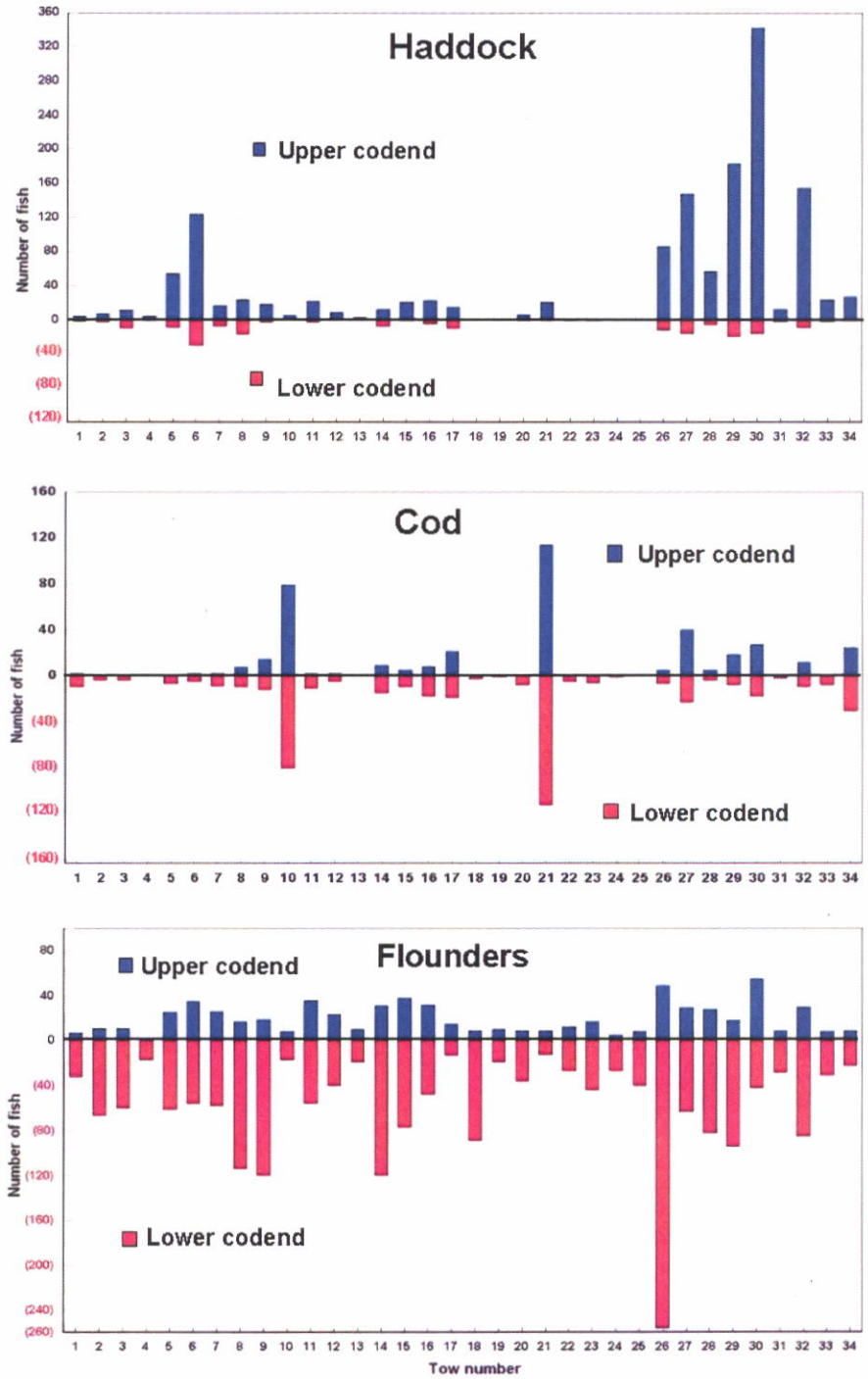


Figure 19. Haddock, cod and flounder (including yellowtail, dab and blackback) caught in the upper and lower codends during April 2003 trials. Tow 1-8: Design A, Tow 9-13: Design B, Tow 14-29: Design C, Tow 30-34: Design D. See Fig. 7.

Table 9. Ratio of catch (in numbers of fish) retained in the upper codend during the April 2003 sea trials.

Species \ Design	Design A			Design B			Design C			Design D		
	Mean	N	SE	Mean	N	SE	Mean	N	SE	Mean	N	SE
American plaice	18.3%	8	3.6%	32.3%	5	6.1%	27.4%	15	2.9%	21.6%	2	6.2%
Yellowtail flounder	26.2%	7	4.2%	19.7%	4	8.8%	30.9%	14	4.7%	28.6%	5	6.3%
Flounders	20.1%	8	3.0%	30.7%	5	4.7%	28.1%	16	2.8%	31.7%	5	5.8%
Cod	29.7%	2	11.5%	39.8%	3	12.3%	46.6%	8	4.7%	52.0%	3	4.7%
Haddock	69.7%	6	5.2%	86.9%	2	1.1%	84.4%	9	4.4%	93.6%	5	2.3%

Design A (Tow 1-8) - Netting only; Design B (Tow 9-13) - Black panel; Design C (Tow 14-29) - Two black panels; Design D (Tow 30-34) - Black panel and tunnel. See Fig. 8. "Flounders" also include witch flounder and winter flounder in addition to the two above.

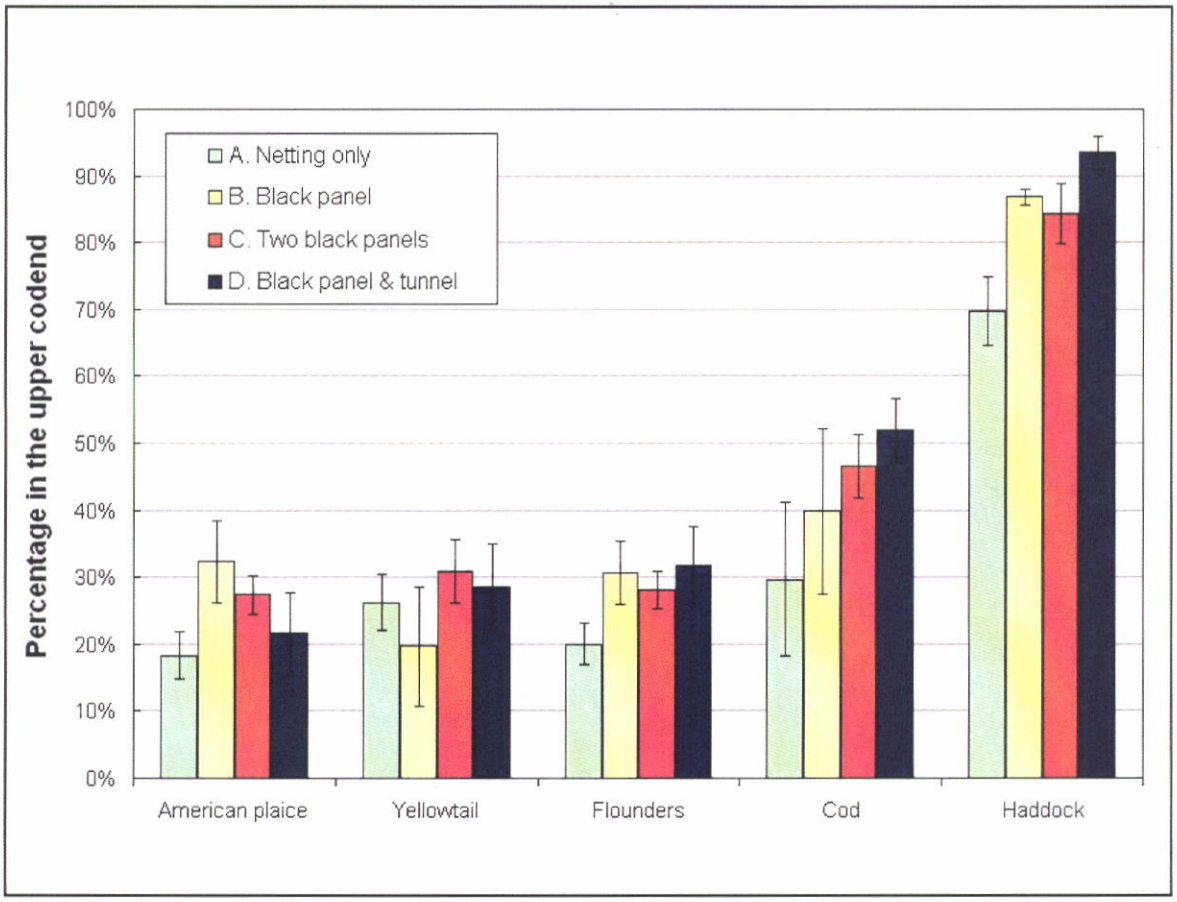


Figure 20. Percentage of fish retained in the upper codend for the four designs tested during April 2003 trials.

Fig. 20 shows that separator designs did not have much effect on yellowtail, American plaice or all four flounder species combined. There are always around 25% of flounder in the upper codend and 75% in the lower codend. Use of the black panel(s) and the black tunnel resulted in more cod in the upper codend from about 30% to 52%, though the increase is not statistically significant due to a small number of tows with more than 10 cod (see Table 10 for the number of tows). The increase in the proportion of haddock in the upper codend was statistically significant when one or two black panels were added to the separator (Design A vs Design B, $t=1.984$, $dof=6$, $p<0.05$; Design A vs Design C, $t=2.299$, $dof=13$, $p<0.02$). Furthermore, replacing the rear black panel with a black tunnel resulted in larger proportion (from 84.4% to 93.6%) of haddock in the upper codend (Design C vs Design D, $t=1.766$, $dof=12$, $P=0.0514$). Compared with the netting only design (Design A), the black panel and tunnel (Design D) resulted in significantly larger proportion of haddock in the upper codend ($t=4.122$, $dof=9$, $P<0.01$).

April 2004 trials. Twenty-seven tows were attempted in nine fishing days in April 2004., with 24 valid tows. Data for Tows 5 and 22 are not available due to large catches mostly of cod, which were not brought up to the deck and no measurement was taken. Tow 8 was a skipped tow (Tow does not exist). Tow 18 was excluded due to a large rock caught in the codend (about 300 lbs) which is deemed to affect the position and geometry of the selectivity device. Catch data for the 24 valid tows are presented in Table 9. Tow by tow catch and length data are attached as Appendix III-3.

Three designs of species separation devices were tested (see Fig. 9). Tow 1 to 18 tested the black panel and the black tunnel (Design A), continuing from the April 2003 trials. The black tunnel was removed in Tow 19 to 22 (Design B). Three parallel ropes were installed (Design C) in Tow 23 to 28. Number of important commercial species in the upper and lower codend is presented in Fig. 21. There were not enough witch flounder and winter flounder in these fishing trials, and they are not analyzed separately. They are included in analysis when data for all flounders are presented.

Design A, the black panel and black tunnel design had good separation between flounders and roundfish. An average of 95% of haddock and 72% of cod were retained in the upper codend, while 80% of dab and 71% of yellowtail flounder were retained in the lower codend.

Table 10. Catch of major commercial species in the upper and lower codend during the April 2004 sea trials. Tow 1-18: Design A , Tow 19-22: Design B, Tow 23-28: Design C. See Fig. 9. No data are available for Tows 5, 8 & 22. Tow 18 is excluded due to a large rock in the catch.

	Tow #	1	2	3	4	6	7	9	10	11	12	13	14
Dab	Upper	0	1	3	2	8	2	2	1	4	20	5	1
	Lower	2	6	8	26	32	8	8	6	37	48	13	5
YT	Upper	3	8	1	10	2	1	7	15	4	3	3	2
	Lower	2	39	4	14	12	5	12	31	19	9	7	7
GS	Upper	0	0	0	0	1	0	0	0	0	0	0	0
	Lower	0	0	0	1	2	0	0	0	0	0	1	0
BB	Upper	0	3	2	3	1	1	4	1	4	2	1	0
	Lower	2	6	2	4	3	3	2	1	1	0	2	1
Cod	Upper	44	0	65	4	2	20	51	6	3	2	27	18
	Lower	8	0	28	0	0	10	8	4	0	1	9	6
HDK	Upper	88	3	14	5	36	0	28	6	12	36	305	28
	Lower	4	0	0	0	0	1	3	0	0	4	6	3

	Tow #	15	16	17	19	20	21	23	24	25	26	27	28
Dab	Upper	2	7	6	0	7	10	1	4	0	13	15	22
	Lower	3	13	10	11	29	28	13	8	13	62	47	87
YT	Upper	8	11	9	0	1	5	4	1	2	13	2	5
	Lower	9	41	25	12	0	10	23	7	40	22	18	21
GS	Upper	0	0	0	0	0	0	0	0	0	0	2	1
	Lower	0	0	0	1	0	0	0	0	1	16	14	2
BB	Upper	4	0	0	2	0	1	0	0	3	1	1	2
	Lower	4	1	1	2	3	3	1	4	19	3	0	4
Cod	Upper	26	5	4	52	0	20	9	7	0	1	0	1
	Lower	16	2	0	102	1	41	10	13	2	4	1	3
HDK	Upper	22	65	28	12	3	11	2	15	3	4	1	19
	Lower	3	3	0	4	0	1	1	16	0	0	1	1

YT - yellowtail flounder, GS - gray sole (witch flounder) , BB - blackback (winter flounder), HDK - haddock.

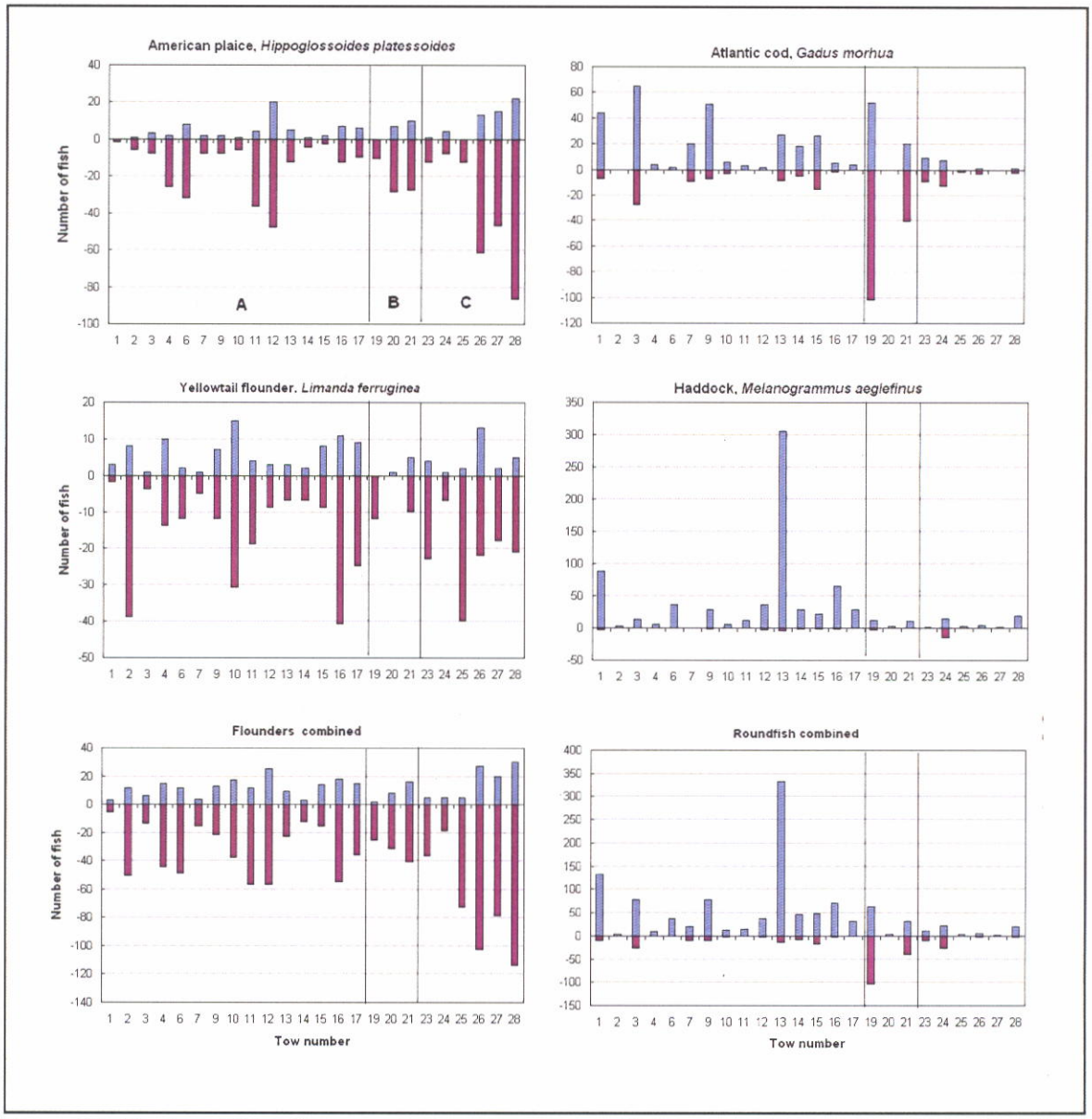


Figure 21. Number of fish of commercial importance caught in upper and lower codend during April 2004 sea trials.

The removal of the black tunnel (Design B) resulted in poorer separation of flounders and roundfish. Percentage of fish was different between Design A and Design B for haddock and cod with decreased proportion in the upper codend from 95% to 83% for haddock and from 72% to 33% for cod (t test, $P<0.05$ for haddock, $P<0.001$ for cod). This indicates that the black tunnel has

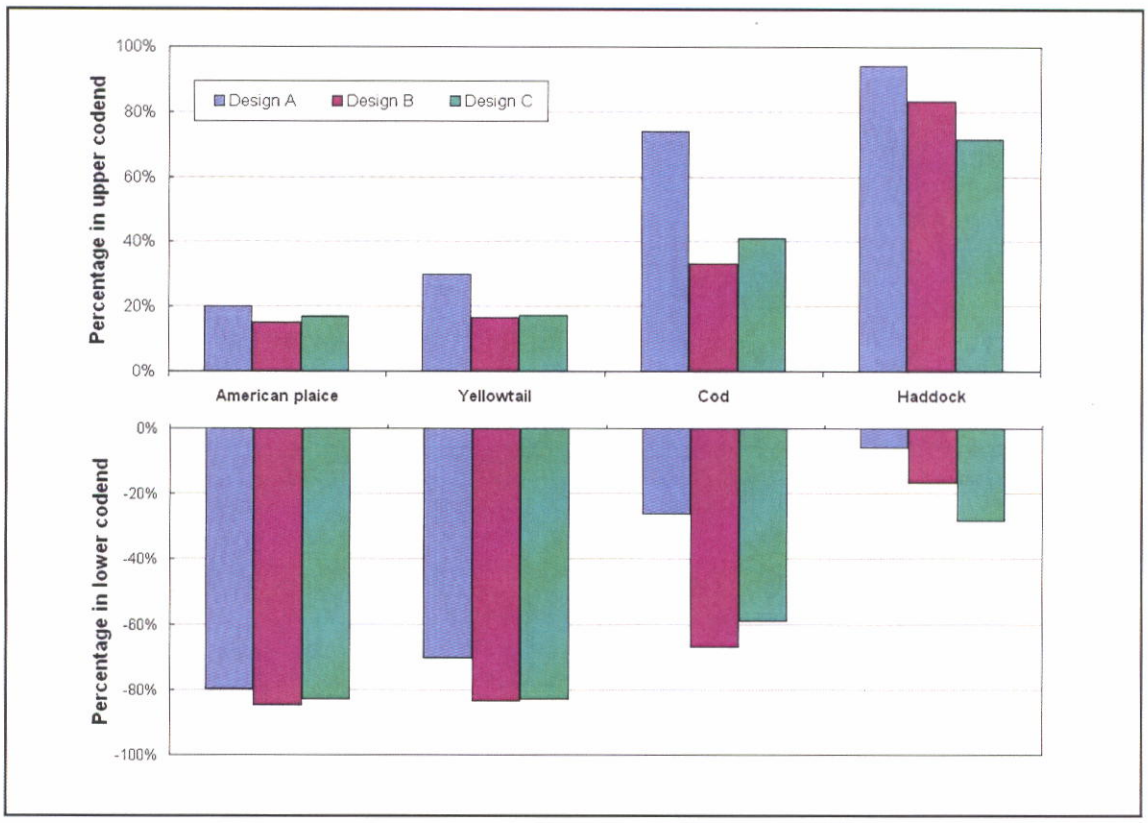


Figure 22. Mean percentage in the upper and lower codend of four species with three designs from April 2004 trials. Design A: Black panel and tunnel, Design B - Black panel only, not tunnel, Design C - black panel and leading ropes (see Fig. 9).

strong effect in encouraging fish to swim up and to avoid the black tunnel which was installed in the lower level of the net. The effect on both flounder species was not statistically significant (t test, $P>0.05$). However, if all four flounder species are combined, the removal of black tunnel resulted in reduced proportion of fish in the upper codend (or increased proportion in the lower codend) (t test, $P<0.05$). The differences in species separation between Design B and Design C are not statistically different, probably due to a small number of tows. The mean proportion of the four species are presented in Fig. 22.

There are significant differences on the proportion in the upper or in the lower codend between flounders and roundfish either combined or individual species, and between cod and haddock (t test, $P<0.001$), but there are no differences between American plaice and yellowtail flounder ($P>0.05$).

April 2005 trials. Forty-one one-hour tows were completed in eleven fishing days in April/May 2005. Only one tow (Tow 6) was excluded as a non-valid tow as the codend was not brought on board and counting and measurement were possible. Three designs were tested. Design A is the black panel, netting and black tunnel (PNT), and Design B replace the netting with parallel ropes, thus called "panel rope and tunnel" (PRT), and Design C had the black tunnel removed from Design B (Panel and rope only). Design A is the same as Design A tested in April 2004 and Design D in 2003 test.

American plaice (dab), yellowtail flounder, cod and haddock again dominated the catch. A very small number of witch flounder and winter flounder were caught. Catch data in numbers in the upper and lower codend is summarized in Table 10. Tow by tow catch and length data are attached as Appendix III-4.

Table 11. Catch of major commercial species in the upper and lower codend during the April 2005 sea trials. Tow 1-22: Design A . Tow 23-27 and Tow 31-41: Design B. Tow 28-30: Design C. See Fig. 10. No data are available for Tow 6.

Species	Tow #	1	2	3	4	5	7	8	9	10	11	12	13	14	15
Dab	Upper	6	4	9	4	3	16	16	1	14	1	4	5	6	0
	Lower	11	14	23	15	31	28	28	5	11	11	10	4	24	12
YT	Upper	3	1	7	7	24	7	30	7	29	8	21	14	41	19
	Lower	1	8	6	39	56	27	72	27	23	37	44	14	159	58
Cod	Upper	1	1	56	3	5	4	2	5	18	6	35	92	6	4
	Lower	1	0	29	1	5	4	11	1	18	5	15	2	2	0
HDK	Upper	0	1	110	18	256	1	51	6	145	5	28	14	7	11
	Lower	3	0	9	0	24	1	16	2	38	0	5	5	1	0

Species	Tow #	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Dab	Upper	1	2	0	7	7	3	12	3	8	1	5	3	2	2
	Lower	26	6	10	4	4	17	3	2	5	2	12	4	3	3
YT	Upper	41	3	3	11	4	5	18	9	13	4	19	4	22	1
	Lower	87	5	12	5	5	51	8	6	17	9	105	10	245	1
Cod	Upper	1	25	2	0	50	19	36	17	4	15	3	3	1	140
	Lower	2	12	2	1	13	5	6	12	15	14	7	5	8	32
HDK	Upper	26	21	6	48	364	317	720	26	163	68	48	41	1	46
	Lower	0	4	0	13	10	22	13	1	10	5	4	4	0	1

Species	Tow #	30	31	32	33	34	35	36	37	38	39	40	41
Dab	Upper	9	3	9	3	26	23	20	20	65	74	63	33
	Lower	45	30	4	5	25	27	37	37	155	86	146	78
YT	Upper	8	5	7	24	9	4	6	8	15	12	15	4
	Lower	1	8	8	112	3	2	6	8	6	12	32	3
Cod	Upper	4	9	78	3	10	27	31	22	15	6	26	11
	Lower	7	2	21	7	15	15	21	13	18	20	25	11
HDK	Upper	8	3	39	64	20	49	33	62	103	46	65	85
	Lower	0	1	0	2	3	2	4	5	34	6	3	2

YT - yellowtail flounder, HDK - haddock.

Fig. 23 plots the four species of fish in number retained in the upper and lower codend for Design A and Design B. Only three tows for Design C did not provide useful data for analysis and comparison. It can be seen from the figure that large portions of haddock and cod were consistently retained in the upper codend while large portions of American plaice and yellowtail flounder were retained in the lower codend.

Analysis on the upper and lower codend retention ratio for those tows with 10 more individuals of a species caught indicate that an average of 90% (N=14, SE 2.4%) of haddock were retained in the upper codend for Design A with the black panel and tunnel (PNT), and 92% (N=15, SE 6.0%) of the same species when the netting was replaced with ropes (Design B). However, the differences are not statistically different (t test, P>0.05). The effect of the design change on cod was more pronounced with decreasing proportion of cod retained in the upper codend when the netting was replaced by ropes (from Design A to Design B). This indicates that cod might have

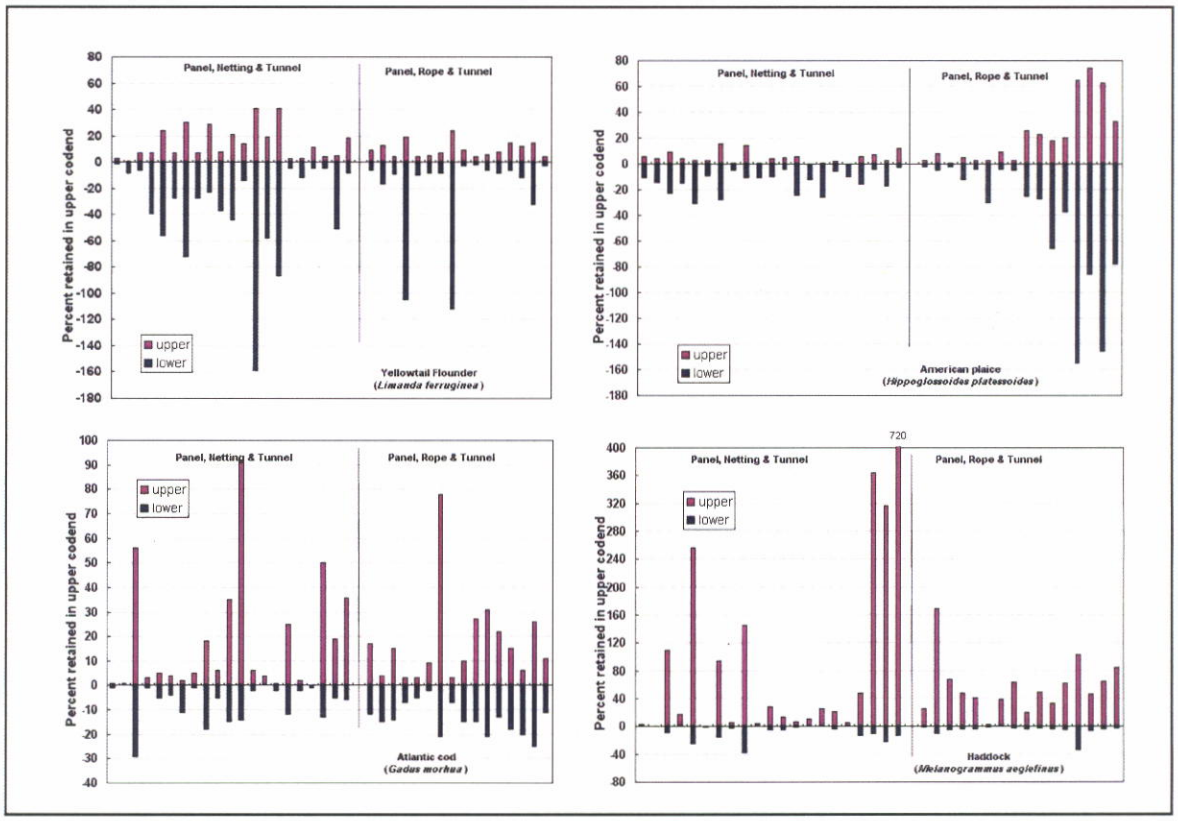


Figure 23. Yellowtail flounder, dab, cod and haddock caught in the upper and lower codends. The vertical line in each graph divides the tows with different separator designs. Design A - Panel, Netting & Tunnel; Design B - Panel, Rope & Tunnel.

swim though the rope from the upper level to the lower level, while more haddock swim up through the gaps between the ropes. These findings can be compared with findings from behavioral analysis from video recordings in the previous section.

There was a trend of an increased proportion of flounder retained in the upper codend when Design B was used in comparison with Design A, even though the majority of flounders were still in the lower codend. The differences are however not statistically different between the designs for flounders either by individual species basis or as a species group (P>0.05). This trend may indicate that some flounders may have swum up through the ropes to the upper level. Means and statistical values are shown in Table 11, and graphically presented in Fig. 24.

Table 12. Statistical results between two designs tested in April - May, 2005. Design A: Black panel, netting and tunnel (PNT). Design B: Black panel, rope and tunnel (PRT).

Design / Species	Design A			Design B			Differences (Design A vs Design B)
	Mean	N	SE	Mean	N	SE	
Yellowtail	33.5%	17	4.6%	44.4%	15	5.1%	t=1.632, p=0.056, NS
Dab	26.6%	18	5.1%	38.2%	12	5.4%	t=1.417, p=0.083, NS
Cod	64.0%	11	6.3%	49.9%	15	5.4%	t=1.913, p=0.034, *
Haddock	89.9%	14	2.4%	92.4%	15	6.0%	t=0.243, p=0.405, NS
Flatfish	31.5%	14	3.6%	37.0%	16	4.0%	t=0.998, p=0.163, NS
Roundfish	82.5%	21	2.8%	78.9%	16	5.0%	t=1.427, p=0.081, NS

NS - not significant, * - significant at 95% level.

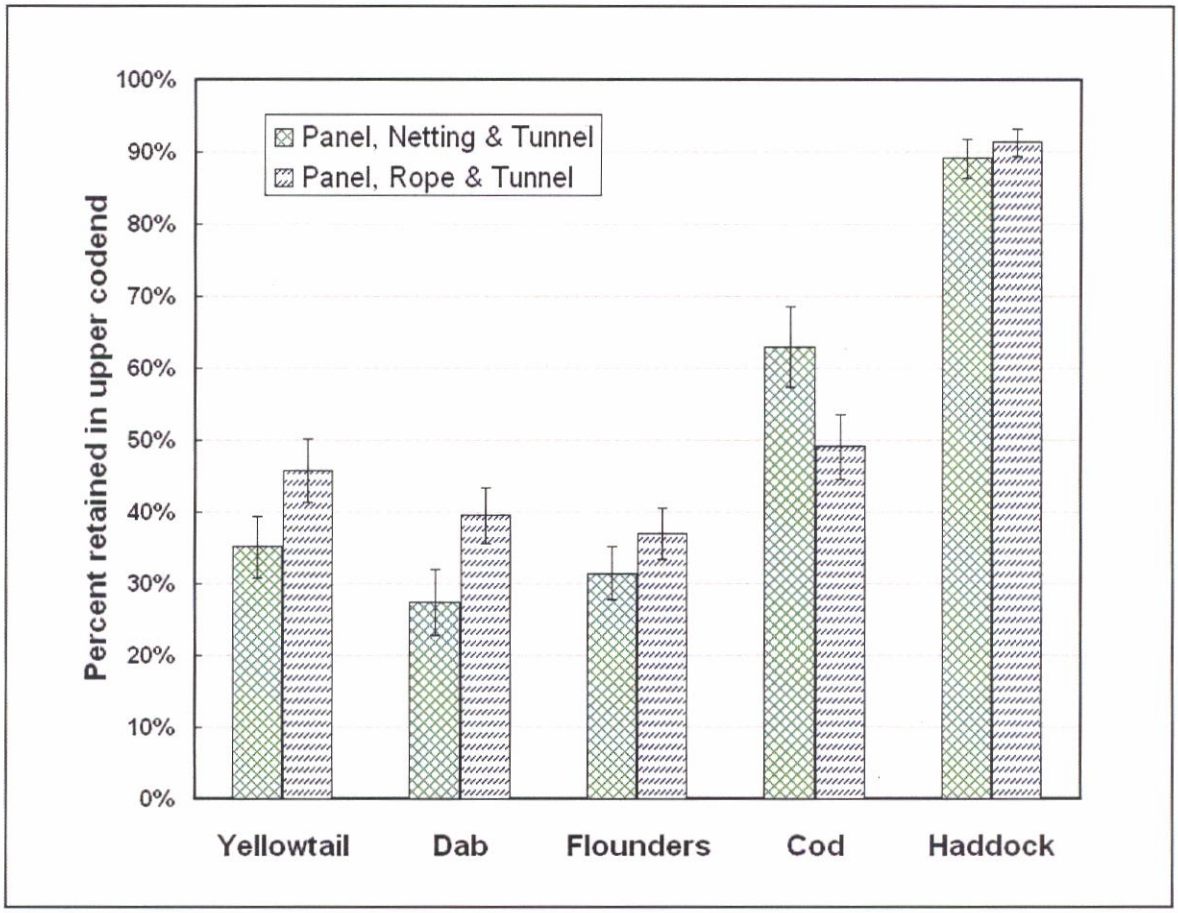


Figure 24. Average proportion of fish in the upper codend for the two separator designs for yellowtail flounder, dab, cod and haddock, and for the two flounder species (yellowtail and dab) combined.

Separation Indexes (I_{sep}) for cod, haddock, yellowtail and dab are shown in Fig.25. Positive I_{sep} indicates that most of the individuals for the species are retained in the upper codend. Negative I_{sep} indicates that most of fish of that species are retained in the lower codend. I_{sep} equal to zero indicates that fish are split half and half between the upper and the lower codends. Haddock consistently ended up in the upper codend while cod split between the upper and lower codends. Flatfishes were mostly retained in the lower codend. Results also indicate an important finding that haddock can be reliably separated from the rest of species, warranting for the design and testing of a haddock trawl. Fig. 26 combined yellowtail flounder and dab as flounder group and cod and haddock as roundfish group. It can be seen that there is clear separation of these two species groups with roundfish in the upper codend and flatfish group in the lower codend.

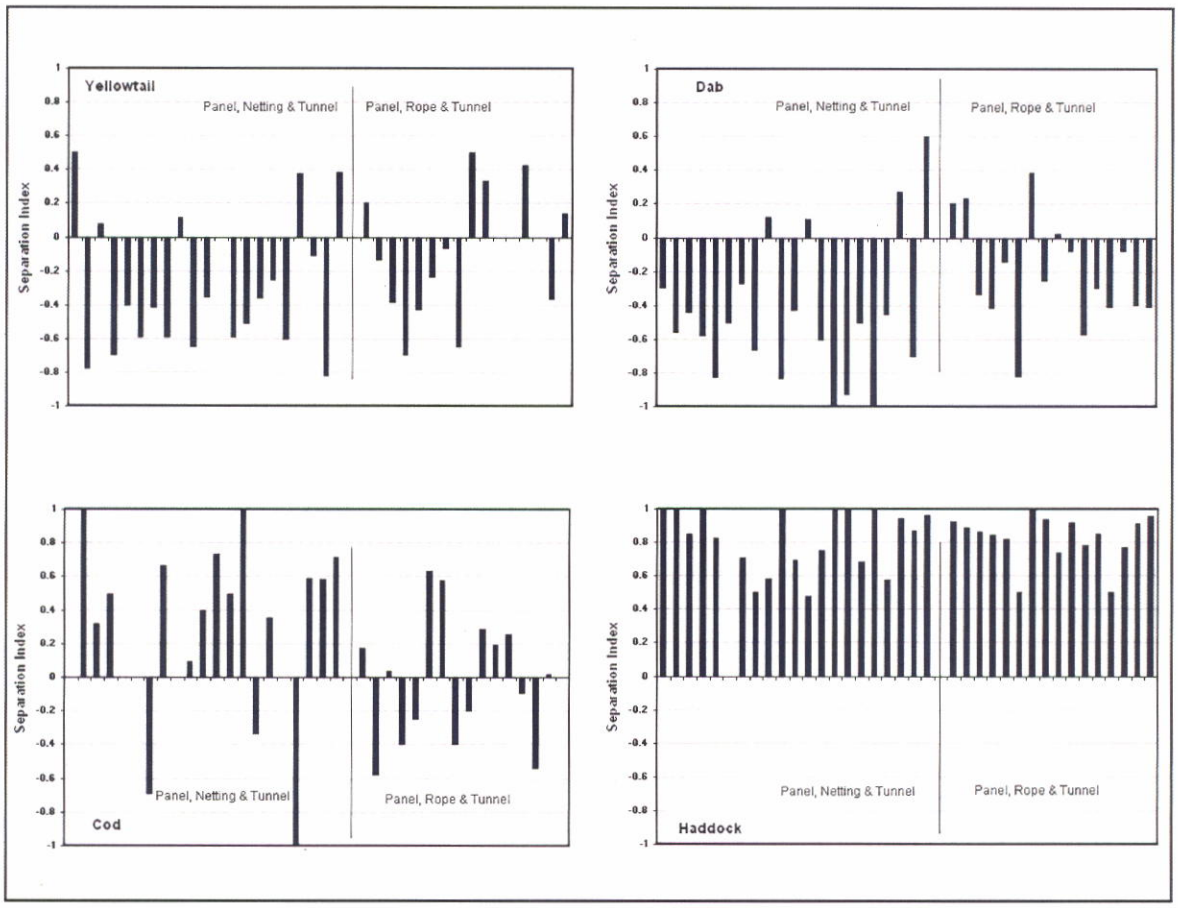


Figure 25. Species Separation Index for yellowtail flounder, dab, cod and haddock.

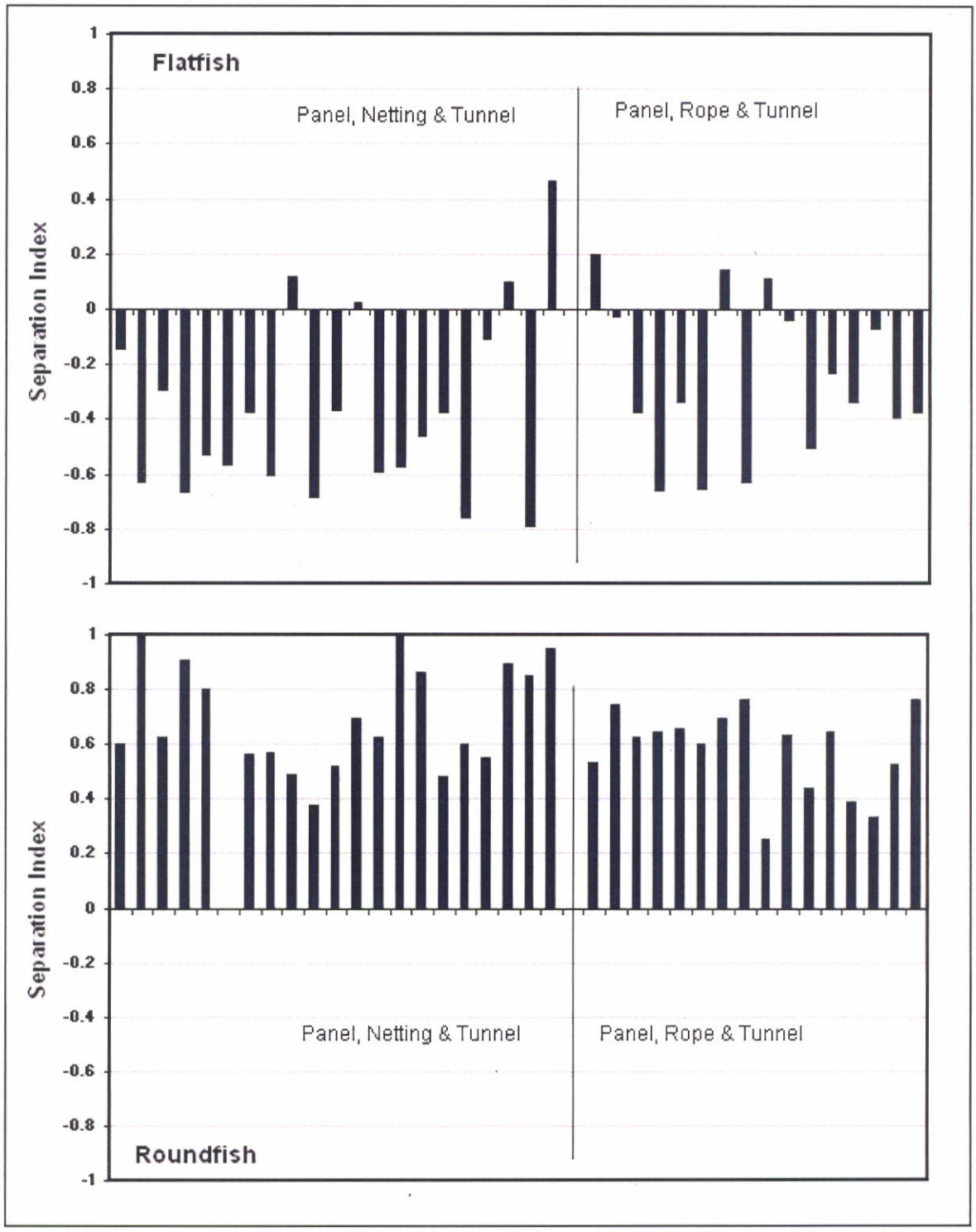


Figure 26. Species Separation Index for the flatfish group and roundfish group.

4. DISCUSSION

This project systematically tested rear-end separator panel designs for separating roundfish and flounders. Progression from the simple netting panel, to visually enhanced black panels and tunnels, to rope panels allowed critical identifications of the elements important to species separation during fishing operations. All the additional devices are made of soft materials for easy handling using existing deck machinery in Gulf of Maine inshore vessels. The rear-end separator devices are in sharp contrast to the full length horizontal separator trawl which involves a horizontal separator starting at the mouth area.

Understanding fish behavior in and around fishing gears is the key to species separation during fishing processes (Wardle, 1986). Video cameras have been used in other studies, such as to observe fish reaction to longline bait and have provided quantitative information on fish capture process and bait properties (Lokkeberg et al., 1989; He, 1996). Description of fish behavior near otter trawls has, however, been largely qualitative (Main & Sangster, 1982; Wardle, 1986; 1989; Watson, 1989; Glass et al., 1999), though very useful, partly due to limited field of view and low resolution of video images in mostly deepwater conditions. Tracking acoustically tagged fish near the trawl provided some detailed movements of the tagged fish relative to the gear components (SOAFD, 1998). Recent application of sonar cameras has proven their values in understanding fish behavior inside trawls and other gears regardless of water depth and light level (Rose et al., 2005; Rose 2005). However, if the area of interest is relatively small, such as in the extension of a trawl, video recordings can be quantitatively analyzed to describe fish behavior in that area (He, 2003). In this study, some of the video recordings made at water depths around 30 fm on Jefferys Ledge provided good quality material for quantitative behavioral analysis.

Comparison of results from video analysis and from codend catch revealed that a very similar proportion of fish destined for each codend and were actually retained in each codend. More fish were observed in the video than retained in the codend due to escape through codend meshes. The 6.5" diamond mesh codend used during the study would allow a large proportion of fish, especially undersized fish, to escape from the codend as revealed in a codend mesh selectivity study by the authors (He, et al., 2005).

Use of the black tunnels has shown to increase the escapement of juvenile fish (Glass and Wardle, 1995; Glass et al., 1995). The use of the black tunnel in this study resulted in more roundfish in the upper codend than the design without a black tunnel. However, the black tunnel has much less effect on flounders. This indicates that visual stimuli such as a black tunnel can be used to enhance separation of flounders and roundfish.

The black panel and tunnel design was tested in three fishing seasons, and the results were very similar (Fig. 27). For haddock, separation rate was more than 90%, but less and more variable rates between 52 and 74% for cod. There were about 30% of flounders retained in the upper codend (70% in the lower codend). If the gear is targeting haddock only, the lower codend may be left open. In this case, we will see less than 10% haddock loss and about 70% reduction in flounder catch.

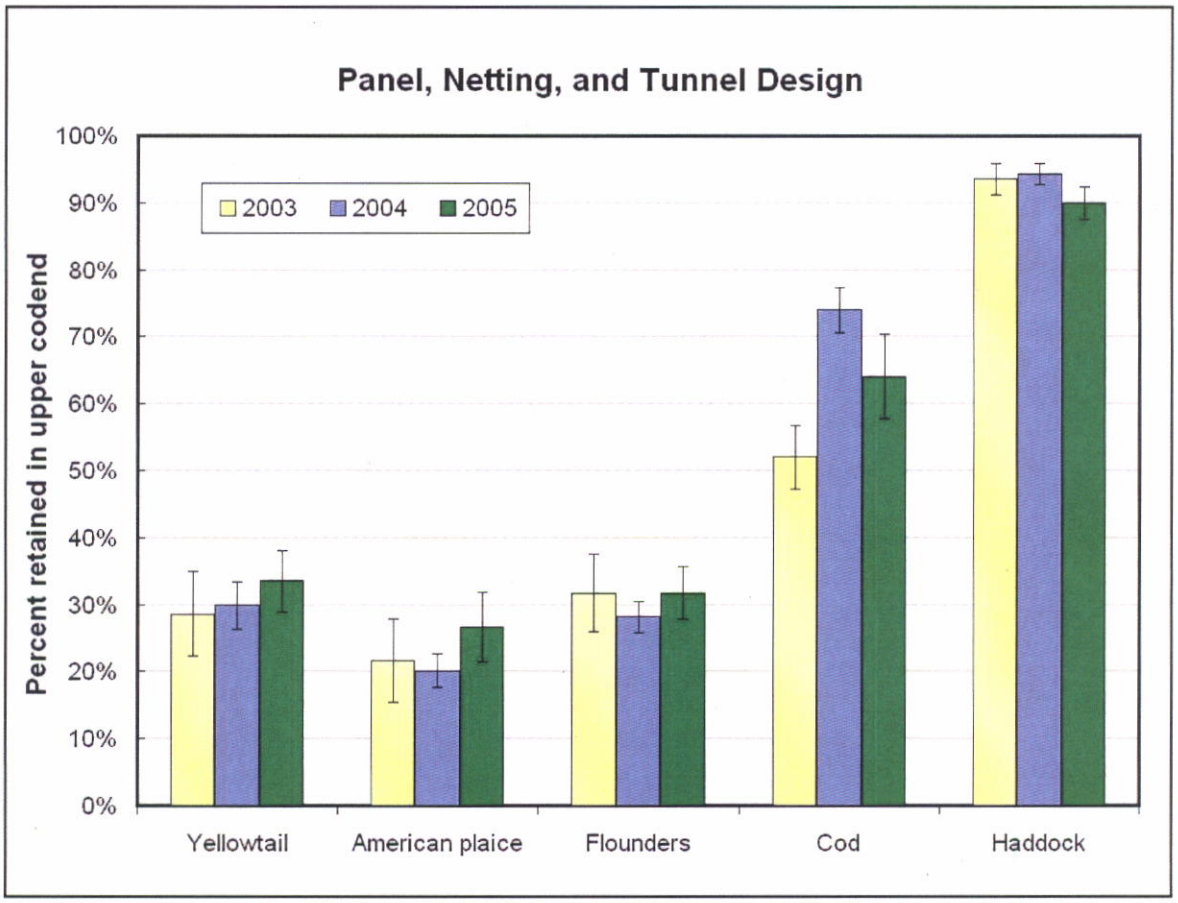


Figure 27. Comparison of the catch separation results of the panel, netting and tunnel design from the 2003, 2004 and 2005 sea trials.

During the April/May 2005 trials, we also tested a panel, rope and tunnel design (PRT). The purpose was to test if the netting between the black panel and tunnel can be replaced by parallel ropes. Ropes are easier to rig and less likely to cause meshing of fish in the area. Meshing of fish in the horizontal panel can distort the panel and reduce separation efficiency of the device. It was found that the rope design actually improved separation of haddock, but reduced cod and flounder separation (Fig. 24). Haddock were observed to be more likely to swim up through the ropes than swim down the ropes as observed by video camera, and rope design actually increased the proportion of fish in the upper level. This finding has been applied to the design of a rope separator haddock trawl to reduce cod and flounder catch by the authors. Preliminary results of the rope separator haddock trawl showed good promise in separating haddock and other species (He & Bouchard, 2005b).

Haddock showed interesting "side to side" swimming behavior when headed or drifted down the extension section of the trawl toward the codend. Almost half of haddock observed showed this type of behavior compared with only 2% of flounders showing similar behavior. This side to side behavior can be considered as "active" escape seeking behavior. Exit openings or open meshes on the side of trawl such as the Exit windows (Fig. 28) would provide suitable opportunity for haddock to escape. Indeed a preliminary project by Morse et al (2005) on a four panel trawl using 6" square mesh side panels resulted in much reduced juvenile haddock, but also too much loss of market size haddock, indicating that haddock do employ side to side behavior when pass down to the codend in other trawling situations.

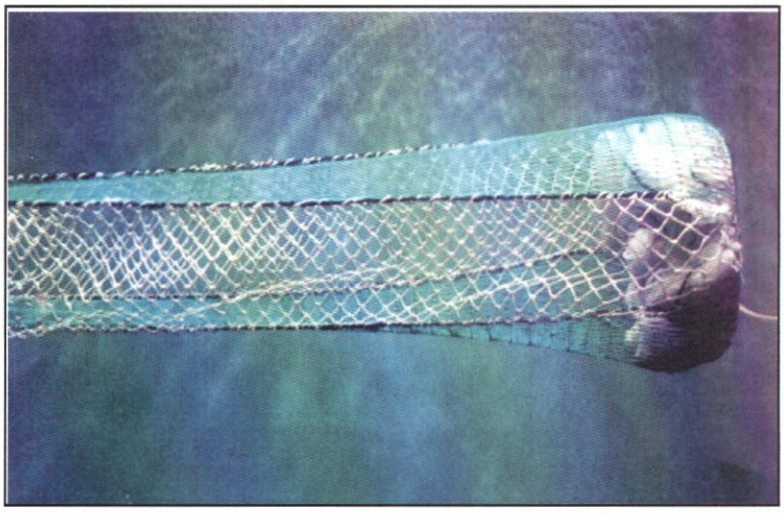


Figure 28. Exit window design for releasing juvenile fish.

5. CONCLUSIONS AND FURTHER WORKS

The two designs, black panel, netting and tunnel (PNT) and black panel, rope and tunnel (PRT), tested in the spring of 2005 showed good promise of separating roundfish and flounders at the rear part of the trawl. The rope design (PRT) showed less separation compared with the netting design (PNT), but there were much less meshed fish in the separator panel. Changes in the proportion of fish of different species between the two designs indicated differences in behavior toward the ropes. Haddock and cod are more likely to swim through parallel ropes than flounders. More haddock swim up than swim down in the rope section, resulting in increased proportion in the upper codend. The findings may be used for separating cod and haddock using ropes as a separator as suggested by this research team in another project (He & Bouchard, 2005b).

Different behavior between species at the separator section as observed by video camera provided knowledge base for designing species-specific fishing gears. Pronounced side to side behavior in haddock can be utilized to catch or to release the species by modifying the side panel of the extension piece.

Future works include presenting the findings from this project at the ICES/FAO Symposium on Fishing Technology in 21st Century to be hold in Boston in October 2006. Information contained in this report will be disseminated to the fishing industry and other interested parties through workshops and other gatherings.

6. ACKNOWLEDGMENT

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