Institut Für Ostseefischerei

Alter Hafen Süd 2, 18069 Rostock Telefon 0381 8116122 Telefax 0381 8116-199 juan.santos@ti.bund.de

Bericht

über die 709. Reise des FFS Solea
vom 09.09 **bis** 25.09.2015

Fahrtleitung: Juan Santos

Das Wichtigste in Kürze

Ziel der Reise SO709 war die Entwicklung und der Test einer neuen Selektionseinrichtung für die Nephropsfisherei. Damit soll der unerwünschte Beifang von Rundfischen - vor allem Kabeljau - reduziert werden. Dafür wurde ein $11m$ langes Trennblatt mit einem Anstiegswinkel von $2,6°$ im Schleppnetztunnel installiert. Das Trennblatt besteht aus schenkelgerecht eingestellten Maschen. Durch diese Maschen sollen Kaisergranat in die untere Tunnelsektion hineinfallen, während die Fische durch das Netzblatt bis zum Ende der oberen Tunnelsektion weitergeleitet werden sollen. Am Ende dieses Schleppnetz-Tunnels ist ein horizontal geteilter Steert angebracht. Die Fische und Kaisergranat oberhalb des Trennblattes gelangen in die obere Steertsektion, während der Rest in der unteren Steertsektion aufgefangen wird. In den Fangversuchen konnte gezeigt werden, dass sowohl Nephrops, als auch Kabeljau sich wie gewünscht verhalten: Kabeljau vermeiden den Kontakt mit dem Trennblatt und werden in den oberen Steert geleitet. Nephrops kontaktiert das Trennblatt und gelangt dort entsprechend seiner Größe in den unteren Steert. Hierbei zeigte sich aber, dass trotz teilweise sehr großer Maschen im Trennblatt nicht alle Nephrops durch das Trennblatt "gesiebt" wurden.

Verteiler:
BLE, Hamburg
Schiffsfuhrung FFS SOLEA
BMEL, Ref. 614
Deutsche Fischfang-Union
Sassnitzer Seefischerei e. G.
Landesverband der Kutter- u. Kustenfischer
DFFU Cuxhaven
Thünen Institut – Pressestelle, Dr. Welling
Thünen Institut – Präsidialburo
Thünen Institut – FIZ
Thünen Institut fur Fischereiokologie
Thünen Institut fur Seefischerei
Thünen Institut fur Ostseefischerei

BFEL HH, FB Fischqualitat
Reiseplanung Forschungsschiffe, Herr Dr. Rohlf
Fahrtteilnehmer
Bundesamt fur Seeschifffahrt und Hydrographie, Hamburg
Mecklenburger Hochseefischerei Sassnitz
Doggerbank Seefischerei GmbH, Bremerhaven
Deutscher Fischerei-Verband e. V., Hamburg
Leibniz-Institut für Meereswissenschaften IFM-GEOMAR
BSH, Hamburg
Leibniz-Institut fur Ostseeforschung Warnemunde
Institut fur Fischerei der Landesforschungsanstalt
LA fur Landwirtschaft, Lebensmittels. Und Fischerei
Euro-Baltic Mukran

Contents

1 Introduction

Nephrops (*Nephrops norvegicus*) is a valuable decapod species, patchily distributed in the Northeast Atlantic, North Sea and Mediterranean sea [7], and exploited as target species by demersal trawl fleets [10]. The life history of nephrops consist of a pelagic juvenile phase and an adult phase, the later inhabiting muddy grounds where they construct burrows for sheltering. Besides nephrops, a mix of species cohabit the same grounds becoming available for the trawl gears, and when they enter into the trawl, the possibilities to avoid the catch will mostly rely on the selectivity properties of the codend used [9]. Due to the reduced small mesh codends needed to retain/catch nephrops, many fish species are not able to use the meshes to escape. They will finally be retained unintentional, causing the high bycatch rates associated to the nephrops fisheries.

How to supplement the codend selectivity to provide unwanted fish with extra opportunities of escapement has been a main topic of research in fishing technology for decades. In particular, the problem of bycatch in nephrops fisheries has been widely addressed, resulting in different solutions tested by experimental sea trials, and some of them finally adopted in regional management plans. This is the case for example with Square Mesh Panels (SMPs) [1, 2, 3] guiding panels+SMPs [4, 13] or grid systems [5, 6]. However, the low effectiveness found for SMP in western fisheries [15], or the handling difficulties and potential blocking produced by grids [5], indicate that further efforts should be invested to further develop the current selection devices, or to find new perspectives for alternative solutions.

While the main aim of the previous `SO693` cruise was to optimize the functioning of a well known selection device (SMPs), the current `SO709` cruise was used to develop and test a new selectivity concept for nephrops fisheries. The original idea of the device presented in this report was firstly proposed by Bent Herrmann, (SINTEF Denmark), while the design, construction, development and experimental testing were carried out by the Thünen Institute of Baltic Sea Fisheries. The so-called HESPAN (HErrmann's Sieve PANel) concept relies on the assumption that nephrops and fish species travel towards the codend in different ways. In particular, it is assumed that nephrops is mainly drifted by the water flow, rolling and hitting the lower panel of the net/trawl [12], while fish prefer to stay clear of the net panels [9]. With HESPAN it is intended to utilize such differences to split the catch by species into two separated codends, enabling a better definition of codend selectivity in commercial conditions.

The research cruise `SO709` was designed to materialize and experimentally test the conceptual idea of HESPAN. The cruise was conducted in a Danish nephrops fishery in Skagerrak sea. Only two HESPAN setups were defined at the beginning of the cruise, while two additional experimental setups were defined during the cruise by analyzing the information from under water video recordings, and the real-time assessment of the experimental fishing.

2 Material and Methods

2.1 Test gear

The HESPAN consist of a long net panel inserted obliquely in the extension of the trawl (or net tunnel), between the gear belly and the codend. The oblique panel is mounted with a bottom-up angle of ~ 2.5 degrees, producing a smooth slope backwards, and splitting at the same time the aft of the trawl in two longitudinal spaces - lower and upper -, ending in two separated codends.

As mentioned above, by inserting the oblique panel it is intended to split fish species from nephrops. On the one hand, the oblique panel should passively guide fish species upwards towards the upper codend, while on the other hand, nephrops should roll over its surface, and being sieved to the lower codend. In summary, for this concept to work properly, the oblique panel should act as a guiding panel for fish species, and as a sieve panel for nephrops (Figure 1).

The oblique panel was mounted in a 4-panel net tunnel $11.5m$ long, made of PE single netting, with $1.8mm$ twine thickness and $47.9mm$ measured mesh size. The codends were $6m$ long and made of 2 panels PA 210/96 netting, and the observed mesh sizes where $48.45mm$ and $49.55mm$ for the upper and lower codend respectively.

HESPAN was connected to a demersal trawl model Spaeghugger 45m/41m, spread by Thyborön doors Type 11 ($2.25m^2$).

2.1.1 Experimental setups

Three different oblique panels were tested during the sea trials. The first panel was made of knotless square mesh netting with $50mm$ nominal bar length and $2.5mm$ twine thickness. This panel defined the HESPAN setup-0. The second sieve panel tested was made of ULTRACROSS^{TM}square mesh netting with $60mm$ nominal bar length, defining the setup-1. Only setup-0 and setup-1 were predefined before the experimental tests, while setup-2 and setup-3 were defined *in situ* during the sea trials, by a dynamic development protocol, which included real-time quantitative data analysis combined with underwater video recordings observations.

The setup-2 only differed from setup-1 by mounting 6 floating lines attached to the oblique panel. The floating lines were grouped (3×2) and attached in two different zones of the oblique panel (middle section and end section), aiming to increase the bottom-up inclination.

The setup-3 was defined by using a sieve panel made of extra large diamond mesh ($196.2mm$ measured mesh size). The diamond mesh panel was turned 45 degrees in relation to the towing direction to achieve a square shape of the mesh. The big mesh chosen for setup-3 aimed to avoid size selection of nephrops and hence to facilitate nephrops sieving.

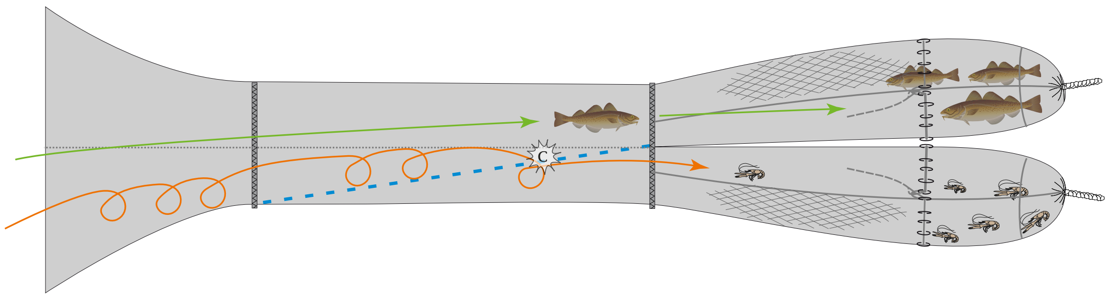

Figure 1: Side view of HESPAN with the oblique panel mounted ahead of the double codend. It is expected the bottom-up inclination of the oblique panel to guide fish upwards towards the upper codend (green path). Assuming that nephrops pass through the extension by rolling and hitting the panel, it is expected they will be sieved to the lower codend after achieving an efficient contact with the open meshes (C) .

2.2 Data collection

Experimental hauls were divided into two different phases: development phase and fishing phase.

2.2.1 Development phase

Hauls in shallow water and with short duration were performed during the first two days of the cruise to assess the physical properties of HESPAN during towing. In particular, we were interested on the assessment of the shape of the oblique panel (panel inclination, curvatures due to the drag of the flow, smoothness of the forward insertion, etc...), besides the general appearance of the tunnel. Different variations from the starting setup-0 were introduced and tested in order to avoid structural problems which could reduce the effectiveness of HESPAN during the fishing phase.

The assessment was done by collecting and analyzing underwater video recordings, taken from each haul by using wide angle, self recording cameras sheltered within polycarbonate housing (GoPro^{TM}Hero3/Hero4 ^{TM}). Four different positions were considered, all mainly focused on the oblique panel.

2.2.2 Fishing phase

The fishing phase started after defining the best version of setup-0 during the pilot hauls. The fishing tracks were chosen based on previous experiences in the fishery (see `SO693` cruise report), and real-time information on the fleet behavior provided by colleagues from DTU-Aqua (Denmark). Haul duration was determined for each haul separately based on catch profile and abundance obtained in previous hauls.

Catches obtained at haul level were sampled for each compartment (codend) separately. The sampling scheme started by sorting the catch into species or group of species. Total weight and length distribution were collected for each species by using digital scales and electronic length measurement boards. Efforts were allocated to avoid sub-sampling. When sub-sampling was needed, the raising factor was obtained by collecting the sub-sampling weight.

By using small mesh codends in the experimental gear (section 2.1) it was assumed that all relevant length classes of nephrops/fish entering in the extension piece would be collected in any of the defined compartments. Being $n_{uc,i}$ the number of fish caught in the upper codend during haul i, $n_{lc,i}$ the number of individuals caught in the lower codend, and $n_{+,i} = n_{uc,i} + n_{lc,i}$ the catch proportion in the lower codend observed for haul i, then

$$s_i = \frac{n_{lc,i}}{n_{uc,i}} \tag{1}$$

can be used to empirically assess the sieving properties of the oblique panel. s_i only can take values between 0 and 1. Values of $s_i \sim 1$ indicate that most individuals of a given species which entered in the HESPAN zone were sieved to the lower codend, while the opposite ($s_i \sim 0$) indicates the species were mostly guided to the upper panel.

It is of main interest for this study to assess if length size influences the sieving properties of the oblique panel, therefore we extend equation 1 by assuming that the number of nephrops/fish of length l in the lower codend is a random observation from the following binomial mass distribution function:

$$n_{lc,l} \sim Binom(n_{+,l}, s(l)) \tag{2}$$

where $s(l)$ is an unknown function describing the probability of a given nephrops/fish length size to be observed in the lower codend.

Besides the quantitative data, underwater video recordings were collected during selected hauls from the fishing phase. The aim was to collect qualitative information on how nephrops and fish species interact with the oblique panel in their way to the codends. The information from the video recordings were crossed with the quantitative fishing data to better understand the performance of the tested setups, the outputs of data analysis, and to develop new strategies for future developments. Depth waters housing and artificial light (Figure 1) were used in this phase to adapt the camera system to the specific conditions in the deep fishing grounds.

2.3 Data analysis

2.3.1 The sieve model

The method presented below is used to find the most likely sieve function behind the experimental fishing data collected during the fishing phase. For a nephrops/fish to be found in the lower codend, two events have to occur in the zone where HESPAN is mounted:

1. That nephrops/fish effectively contact the oblique panel
2. That it passes through the square meshes once it contacts the panel

Combining the two events, the probability for a nephrops/fish of length l to be sieved to the lower codend will be:

$$s(l) = C \times (1 - r(l)) \tag{3}$$

In model 3, C is the parameter denoting the probability for a nephrops/fish to contact the oblique panel, and hence becoming available for sieving. C only can take values between 0 (null contact probability) and 1 (full contact probability), for example, $C = 0.5$ can be interpreted as 50% contact probability. $r(l)$ is a monotonic function describing the probability for a given length l not to pass through the open meshes of the oblique panel. Contrary, $(1 - r(l))$ denotes the probability of length l to be sieved through the

Figure 2: Depth waters housing and artificial beam light used during the fishing phase

panel towards the lower compartment. To model $r(l)$, we use the well-known *logit* function, specifically transformed into a form allowing the direct estimation of the selectivity parameters of the different sieve panels used during the cruise:

$$r(l) = \frac{exp(log(9) \times \frac{l-L50}{SR})}{1 + exp(log(9) \times \frac{l-L50}{SR})} \quad (4)$$

where L50 is the length with 50% probability of being sieved to the lower codend, and SR is the range between the lengths with 75% and 25% probability.

Equation 3 accounts therefore for the conditional probability that nephrops/fish can pass through the square meshes once it contacted the oblique panel.The contact probability C and the selectivity parameters associated to $r(l)$ were estimated by minimizing the *-Log* of the likelihood mass function (2) associated to the experimental data:

$$-\sum_{l} \left\{ \sum_{h=1}^{H} n_{lc,l} \times ln(s(l)) + \sum_{h=1}^{H} n_{uc,l} \times ln(1 - s(l)) \right\} \quad (5)$$

Where the outer summation is over length classes l in the experimental data and the inner summation over experimental fishing hauls h, $1 \ldots H$. To better undertand the practical usability of the model developed above, It can be said that for HESPAN to work optimally, the minimization of 5 should yield the following results:

1. High contact probability and no size selection for nephrops (very large L50 and/or SR values).
2. Low contact probability for fish species.

The confidence intervals (CIs) associated to the estimated $s(l)$ curve and associated parameters were defined by using the non-parametric technique known as block bootstrap. This technique differs from the standard approach used in selectivity studies [14], on the Data Generating Process (DGP). In particular, the artificial data is generated compartment-wise, that is, accounted for the observations in the lower and upper codend separately. The technique is used separately for each species and gear setup as described below:

1. A random sample of hauls $h_1^*, \ldots, h_N^*$ is artificially obtained by resampling with replacement on the observed N hauls $(h_1, \ldots, h_N,\ i = 1, \ldots, N)$. In other words, after the extraction of a haul, this is replaced in the original sample such that it can be chosen again

2. The same resampling technique is applied independently on catches in the lower and upper codend for each of the resampled hauls h_i^* from the previous step. A new set of pseudo-hauls $(h_1^{**}, \ldots, h_N^{**})$ are therefore computed in this step, with $h_i^{**} = \{n_{lc,il}^*, n_{uc,il}^*\}$

3. Catch data from (2) is pooled over the pseudo-hauls $H^* = \sum_{i=1}^{n} h_i^{**}$

4. The target *-Loglik* function (equation 5) is minimized using the data generated in (3)

5. Steps 1 to 4 are repeated a large number of times $(b = 1, \ldots, B = 2000)$ to obtain a set of sieve curves $\hat{s}^{*1}(l), \ldots, \hat{s}^{*B}(l)$, together with the related parameters.

Once this process is completed, the $100 \times (1 - \alpha)$ limits of the confidence interval for the original estimation $\hat{s}(l)$ is given by:

$$(\hat{s}(l) - \hat{s}^{*1-\frac{\alpha}{2}}(l), \hat{s}(l) - \hat{s}^{*\frac{\alpha}{2}(l)}) \tag{6}$$

Same procedure is applied to estimate the CIs for the parameters associated to $s(l)$.

3 Results

3.1 Operational information

A total of 7 short pilots hauls were carried out during the first two operational days of the cruise (11/09 and 12/09), in the way to the fishing grounds, at shallow waters in the North Sea. As mentioned above, the pilot hauls performed during the development phase were used to assess the structural behavior of the new selection device. At the end of each haul, the video recordings were analyzed together with the netmaker onboard, in order to identify structural problems and to find solutions at real time. This phase ended once a reasonable performance was achieved (see Figures 4 and 5).

Four different setups were tested during the fishing phase between 12/09 and 24/09. The scarcity of nephrops catches obtained during the first part of the cruise delayed the replacement of setup 0 by the setup 1 until the 16/09 (13 hauls). The setup 1 was tested between 16/09 and 19/09 excluding 18/09, day of landing in Hirtshals (DK). The day ashore was used to replace part of the scientific crew, and to discuss the definition of setup 3 with colleagues from SINTEF and DTU-Aqua. Setups 2 and 3 were tested between 20/09 and 24/09, performing 7 and 11 valid hauls, respectively. Further information associated to the fishing hauls can be found in Table 1.

Nephrops was caught in sufficient amounts except for setup 0 (Figure 3), therefore no further analysis will be shown in the next section for this setup. The catch profile improved significantly for the remaining setups, that is, mixed catches comprising nephrops besides roundfish and flatfish species.

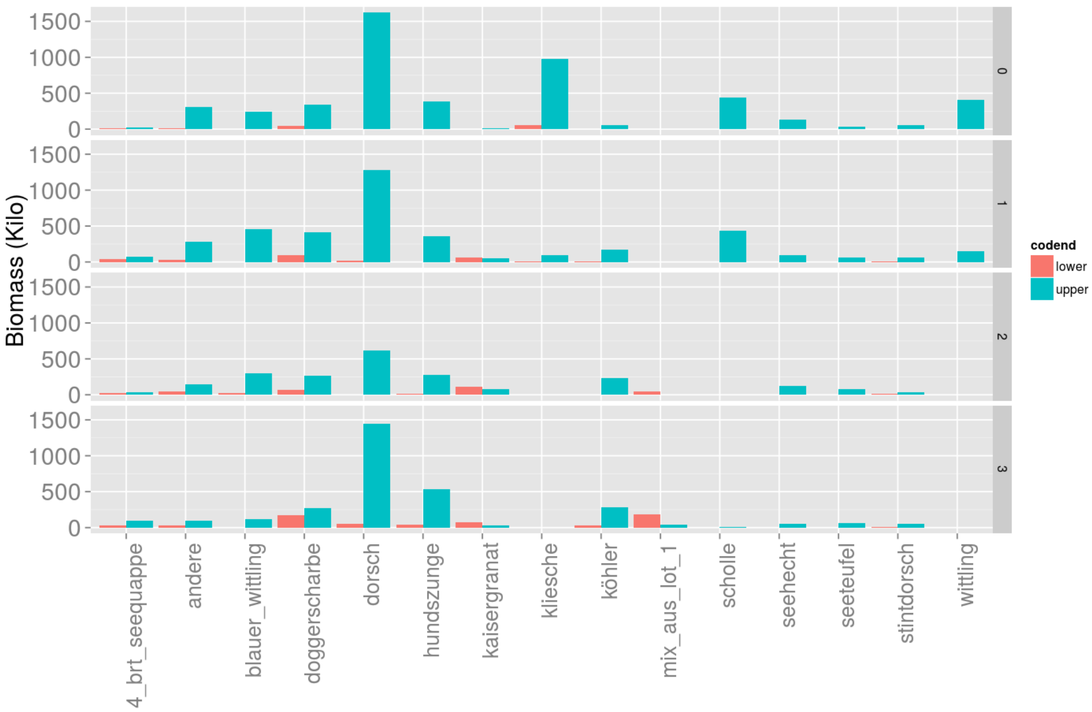

Figure 3: Biomass caught during the fishing phase (12/09 to 24/09). Data shown by setup after pooling the haul data. Only the species representing 95% of the cumulative catches are shown, while species representing the remaining 5% are grouped as "andere".

Cruise	Station	Haul	Trawl	Setup	Date	Time.start	Time.end	Lat.start	Lon.start	Lat.end	Lon.end	Towing.direction	Fishing.depth	Spread.doors	Warp.length
709	698	1	Spaeghugger 45/41	0	12-Sep-2015	10:03:00	11:01:00	57 29.9538N	08 40.7987E	57 29.2565N	08 36.3890E	236±0.7	NA±NA	96±NA	231.3±1
709	699	2	Spaeghugger 45/41	0	12-Sep-2015	12:13:00	14:11:01	57 32.0965N	08 35.1206E	57 34.9879N	08 42.5378E	73±0.2	NA±NA	61.1±1.2	299.2±0.8
709	700	3	Spaeghugger 45/41	0	13-Sep-2015	07:43:02	08:11:02	57 38.7835N	09 39.2405E	57 39.1960N	09 41.3069E	79.6±0.5	NA±NA	57.7±0.8	200.4±0
709	701	4	Spaeghugger 45/41	0	13-Sep-2015	10:15:03	10:43:01	57 47.0235N	09 24.0917E	57 47.5647N	09 26.0916E	82.6±1.3	54.1±0.1	57±3	201.8±0
709	702	5	Spaeghugger 45/41	0	13-Sep-2015	13:39:01	14:23:01	57 49.7084N	09 28.5141E	57 50.6240N	09 31.7747E	80.4±0.5	78.3±0	NA±NA	300.4±0
709	703	6	Spaeghugger 45/41	0	14-Sep-2015	07:53:03	08:51:03	58 07.3651N	10 13.0560E	58 06.5432N	10 08.6148E	232.2±0.6	113.5±4.5	60.1±1.6	557.2±0
709	704	7	Spaeghugger 45/41	0	14-Sep-2015	10:35:03	11:33:03	58 05.2070N	10 04.8566E	58 04.1875N	10 00.4702E	219.5±0.9	136.7±2.3	60.9±1.8	500.3±0
709	705	8	Spaeghugger 45/41	0	14-Sep-2015	12:55:02	13:53:02	58 03.9209N	10 03.9988E	58 04.8671N	10 08.6600E	104.2±0.7	133.1±0.6	56.5±2.2	450.4±0
709	706	9	Spaeghugger 45/41	0	15-Sep-2015	07:49:03	08:17:03	58 05.5434N	10 15.0799E	58 05.4406N	10 12.9083E	245.9±0.6	132±0.2	101.1±2.3	450.4±0
709	707	10	Spaeghugger 45/41	0	15-Sep-2015	09:17:03	09:45:03	58 06.8670N	10 12.1628E	58 06.5365N	10 10.1469E	236.7±1	100.6±2.8	94.6±3.1	500.5±0
709	708	11	Spaeghugger 45/41	0	15-Sep-2015	10:37:04	11:05:04	58 06.0487N	10 05.6780E	58 05.5707N	10 03.8954E	240.4±1	111.7±2.8	79.5±4.3	593.9±0
709	709	12	Spaeghugger 45/41	0	15-Sep-2015	12:25:04	13:23:04	58 05.3990N	10 03.3695E	58 04.4478N	09 59.7170E	229±0.3	128±4.9	105±11.6	550.3±0
709	710	13	Spaeghugger 45/41	0	15-Sep-2015	14:45:02	16:41:03	58 03.6810N	09 57.0235E	58 01.5306N	09 49.3640E	222.7±0.6	124±1.6	71.3±5	550.3±0
709	711	14	Spaeghugger 45/41	1	16-Sep-2015	07:45:03	08:43:03	57 52.1642N	09 37.8544E	57 51.4019N	09 34.5746E	238.7±0.6	77.9±0	100.5±16.3	300.1±0
709	712	15	Spaeghugger 45/41	1	16-Sep-2015	10:23:03	11:21:04	57 53.5999N	09 32.5190E	57 52.6281N	09 29.2978E	234.8±0.3	109.4±0.1	58.9±1.3	380.3±0
709	713	16	Spaeghugger 45/41	1	16-Sep-2015	12:45:04	14:43:04	57 57.1064N	09 30.1411E	57 59.0591N	09 37.5501E	80.9±0.5	111.3±NA	88±1.3	610.6±0
709	714	17	Spaeghugger 45/41	1	16-Sep-2015	15:31:04	17:29:03	57 59.8914N	09 41.1370E	58 02.0095N	09 47.8851E	88.4±1.3	115.2±2.8	91.5±2.4	650.5±0
709	715	18	Spaeghugger 45/41	1	17-Sep-2015	07:17:04	09:15:05	58 04.6600N	09 57.7043E	58 02.7106N	09 50.6678E	221.7±0.6	125.2±1.9	113.2±2.7	600.2±0
709	716	19	Spaeghugger 45/41	1	17-Sep-2015	10:03:05	12:01:05	58 02.3430N	09 49.4761E	58 00.1277N	09 43.1488E	224.4±0.6	120.5±1.6	101.3±4.2	600.4±0
709	717	20	Spaeghugger 45/41	1	17-Sep-2015	12:45:05	14:43:04	58 00.5462N	09 44.3277E	58 02.9722N	09 50.9933E	78.2±0.5	97.5±NA	94.5±12.8	550.5±0
709	718	21	Spaeghugger 45/41	1	19-Sep-2015	08:55:06	09:53:06	57 50.9058N	09 43.4026E	57 50.4125N	09 39.6640E	264.5±0.8	55.9±0	110.3±1.5	220.3±0
709	719	22	Spaeghugger 45/41	1	19-Sep-2015	11:15:06	13:13:05	57 56.6150N	09 28.8585E	57 54.7210N	09 21.6928E	251.8±0.2	120.9±3.7	79.7±2.1	600.2±0
709	720	23	Spaeghugger 45/41	1	19-Sep-2015	13:57:05	15:55:05	57 55.0803N	09 23.4350E	57 56.9632N	09 30.4652E	43.2±0.6	124.1±5.4	55.4±1.4	560.4±0
709	721	24	Spaeghugger 45/41	2	20-Sep-2015	07:07:05	09:05:05	57 56.5147N	09 27.4237E	57 54.5115N	09 20.4142E	242.9±0.5	100.4±2	95.1±2.7	600.2±0
709	722	25	Spaeghugger 45/41	2	20-Sep-2015	09:49:06	11:47:07	57 53.6344N	09 18.2007E	57 51.9923N	09 11.1414E	249.7±0.6	132.8±1.3	74±3.1	600.4±0
709	723	26	Spaeghugger 45/41	2	20-Sep-2015	12:35:07	14:33:07	57 52.6210N	09 13.1740E	57 54.6672N	09 19.9241E	44.9±0.4	116.5±4.1	121.5±2.1	600.2±0
709	724	27	Spaeghugger 45/41	2	21-Sep-2015	07:09:07	08:37:07	57 55.6554N	09 21.9906E	57 54.3053N	09 16.8676E	244.8±0.3	NA±NA	NA±NA	604.3±0
709	725	28	Spaeghugger 45/41	2	21-Sep-2015	09:17:07	10:45:07	57 54.6172N	09 19.5406E	57 55.6455N	09 25.0513E	67.9±2.5	NA±NA	117.6±3.1	625.9±5.6
709	726	29	Spaeghugger 45/41	2	21-Sep-2015	11:25:07	12:53:07	57 56.6354N	09 28.6580E	57 58.0051N	09 33.9987E	38.8±2.1	NA±NA	93.4±3	551±0
709	727	30	Spaeghugger 45/41	2	21-Sep-2015	14:11:08	15:39:08	57 58.9514N	09 37.4483E	58 00.1724N	09 42.7222E	63±0.4	NA±NA	84.1±4.8	550.3±0
709	728	31	Spaeghugger 45/41	3	22-Sep-2015	07:09:07	08:37:08	58 05.8392N	10 05.6211E	58 04.4514N	10 00.5463E	231.3±0.5	NA±NA	72.6±3.6	500.5±0
709	729	32	Spaeghugger 45/41	3	22-Sep-2015	09:19:07	10:47:08	58 04.2916N	09 57.3554E	58 02.9787N	09 52.2895E	238±0.5	NA±NA	86.7±6.7	601.5±0
709	730	33	Spaeghugger 45/41	3	22-Sep-2015	11:33:08	13:01:08	58 02.6736N	09 50.5873E	58 00.9532N	09 45.8691E	227.8±0.2	NA±NA	85±4.2	600.6±0
709	731	34	Spaeghugger 45/41	3	22-Sep-2015	14:01:08	15:29:09	57 58.9485N	09 36.8702E	57 57.6552N	09 31.7380E	241±0.4	NA±NA	94.2±2.4	600.6±0
709	732	35	Spaeghugger 45/41	3	23-Sep-2015	07:08:37	08:36:38	57 52.3756N	09 12.3704E	57 53.9775N	09 17.2550E	67.6±0.8	NA±NA	65.4±1.2	600.2±0
709	733	36	Spaeghugger 45/41	3	23-Sep-2015	09:22:38	11:20:38	57 54.0297N	09 17.6343E	57 51.9870N	09 11.0027E	237±0.5	NA±NA	NA±NA	600.6±0
709	734	37	Spaeghugger 45/41	3	23-Sep-2015	11:58:38	13:56:37	57 52.1609N	09 12.0234E	57 53.6853N	09 18.7594E	68.1±0.4	NA±NA	99.1±2.9	525.4±0
709	735	38	Spaeghugger 45/41	3	23-Sep-2015	14:46:37	16:44:37	57 55.6457N	09 22.6734E	57 57.4322N	09 29.2343E	62.9±0.5	NA±NA	75.4±1.5	600.6±0
709	736	39	Spaeghugger 45/41	3	24-Sep-2015	06:02:37	07:32:38	57 57.0777N	09 27.2440E	57 58.4207N	09 32.5329E	72.9±0.7	NA±NA	NA±NA	603±1.5
709	737	40	Spaeghugger 45/41	3	24-Sep-2015	08:10:38	09:38:38	57 59.1336N	09 35.9096E	58 00.2820N	09 41.1091E	75.4±0.7	NA±NA	NA±NA	625.1±0
709	738	41	Spaeghugger 45/41	3	24-Sep-2015	10:44:38	12:12:38	58 00.6320N	09 42.7959E	58 02.2191N	09 47.6295E	66.9±1.9	NA±NA	NA±NA	622.3±1.3

Table 1: Operational information associated to the experimental hauls (pilot hauls excluded) (NA= Non Available).

3.2 Development phase

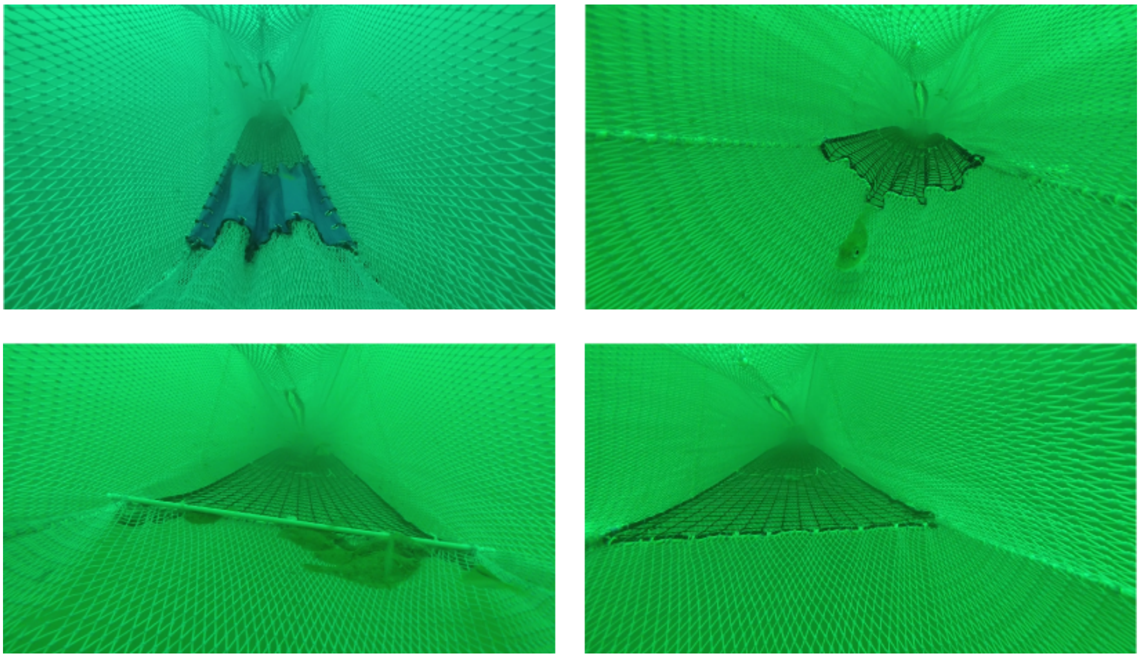

Figure 4: Top-left clockwise: Front view of HESPAN setup-0 variants 1,2,3 and 4. Efforts were invested in smoothing the connection between the oblique panel (black square mesh) and the lower panel of the body net. The desired smooth transition was finally achieved in variant 4.

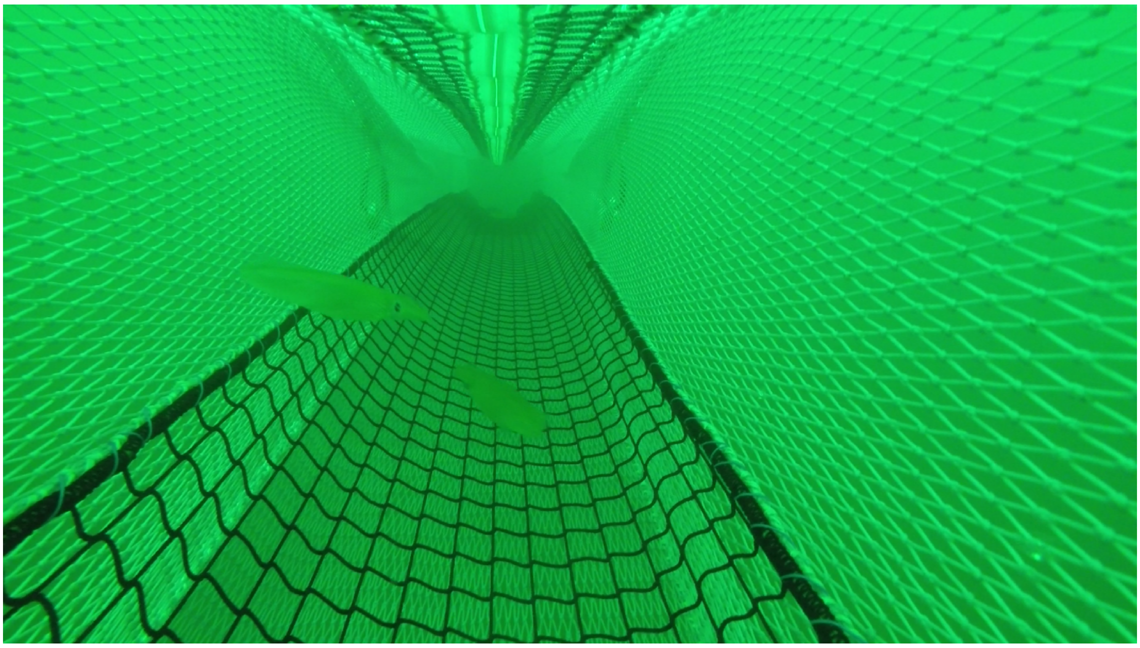

Figure 5: View of HESPAN oblique panel (variant 4) from an upper midpoint view of the oblique panel. Camera orientated towards the codends. The oblique panel showed a funnel shape due to the drag of the water flow. Even thought this undesirable shape, there was sufficient space between the oblique panel and the net body bellow, allowing the passage of fish/nephrops to the lower compartment.

3.3 Fishing phase

Here we show the catch profile and the model results for four different species commonly observed in catches during the cruise. The selection includes the target species (nephrops), bycatch roundfish species (cod and blue whiting), and flatfish species (witch flounder).

Even though a greater fraction of nephrops catches were observed in the lower panel, considerable amounts were also found in the upper codend (see bi-histograms in Figure 6). The modeling results for this species indicates that the probability for nephrops to contact the oblique panel was high (Table 2), but a clear size selection took place in all the three setups (see Figure 6 and Table 2), explaining the nephrops catches in the upper panel.

Contrary to nephrops, most of fish catches occurred in the upper codend (see bi-histograms in Figures 7 to 9), indicating that the oblique panel acted as guidance driving fish species towards the upper codend. No clear differences in catch distribution among the compartments are found between setups except for cod, with a greater fraction of marketable sizes entered into the lower codend in setup 3 (Figure 7). The estimated contact probability for cod was very low in all the three setups. In contrast, unexpected high contact probability was found for the three remaining species (Table 2). The wide confidence intervals associated to the contact parameter in these cases reflects the large uncertainty in the estimation, therefore inference should be taken with caution in these cases.

Species	setup	C	L50	SR
nephrops	1	0.95(0.81-0.95)	50.38(47.8-56.4)	20.38(14.82-28.3)
	2	0.95(0.92-0.95)	52.17(49.47-56.99)	19.3(15.22-25.13)
	3	0.85(0.68-0.95)	72.02(60.16-89.96)	34.43(1-83.11)
cod	1	0.08(0.05-0.95)	1(1-15.06)	19.19(5.55-32.25)
	2	0.12(0.05-0.41)	27.11(1-29.16)	5.28(2.12-84.31)
	3	0.05(0.05-0.95)	28.68(1-294.24)	18.36(1-1000)
blue whiting	1	0.42(0.27-0.95)	19.53(3.47-22.63)	10.07(3.66-23.8)
	2	0.95(0.23-0.95)	1.73(1-1000)	31.33(4.8-1000)
	3	0.95(0.95-0.95)	16.59(14.9-18.12)	12.74(10.81-16.87)
witch flounder	1	0.05(0.05-0.1)	17.93(1-79.81)	31.74(1-1000)
	2	0.95(0.05-0.95)	19.58(3.66-30.5)	7.28(1.04-21.09)
	3	0.95(0.13-0.95)	18.57(10.52-40.24)	16.36(2.99-27.59)

Table 2: Parameters estimated by the sieve model (3) for the different species and HESPAN setups analyzed in this report. Bootstrap CI (95%) in brackets.

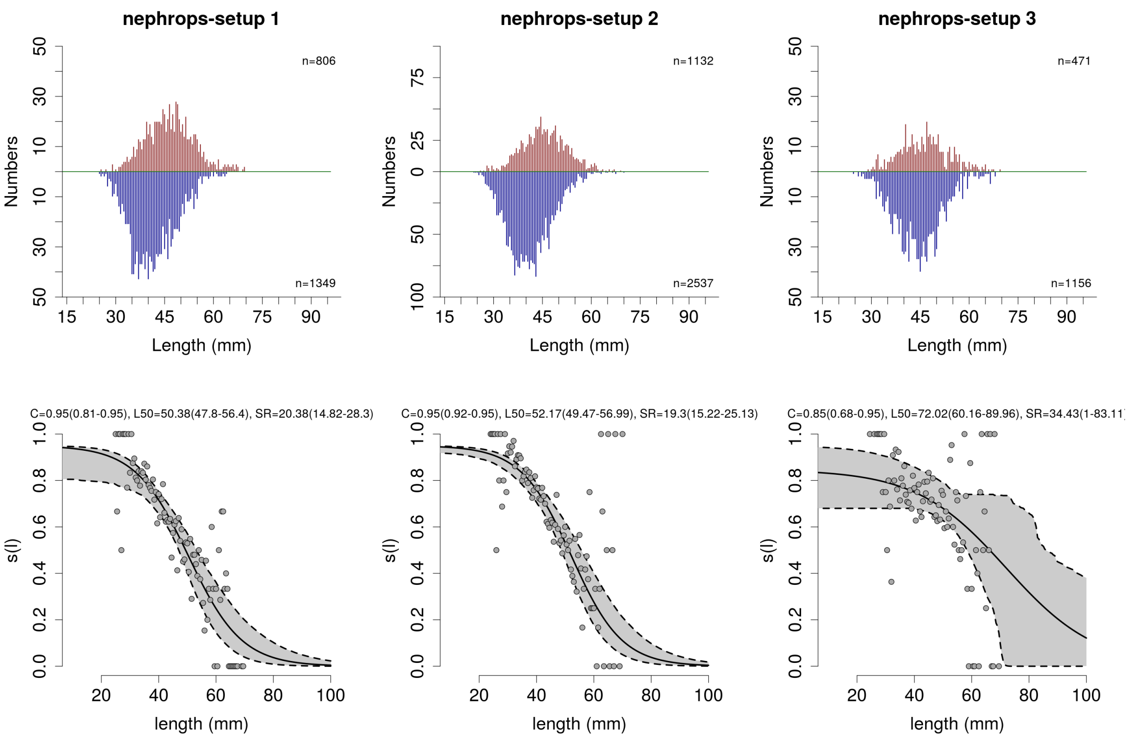

Figure 6: Top row: nephrops catches in the upper codend (red bars) and lower codend (blue bars). Data shown by gear setup (only setups 1, 2 and 3 represented) and pooled over hauls. Bottom row: Estimated sieve curves (s(l)) and associated bootstrap confidence intervals for nephrops and the three selected experimental setups.

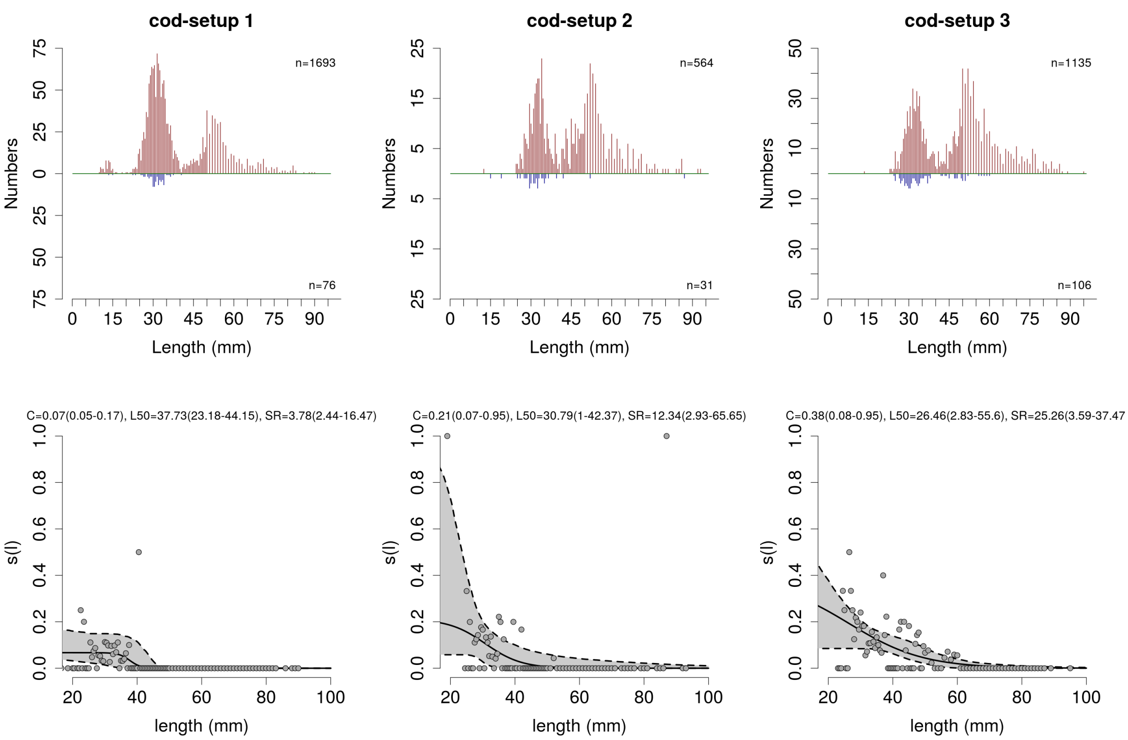

Figure 7: Top row: cod catches in the upper codend (red bars) and lower codend (blue bars). Data shown by gear setup (only setups 1, 2 and 3 represented) and pooled over hauls. Bottom row: Estimated sieve curves (s(l)) and associated bootstrap confidence intervals for cod and the three selected experimental setups.

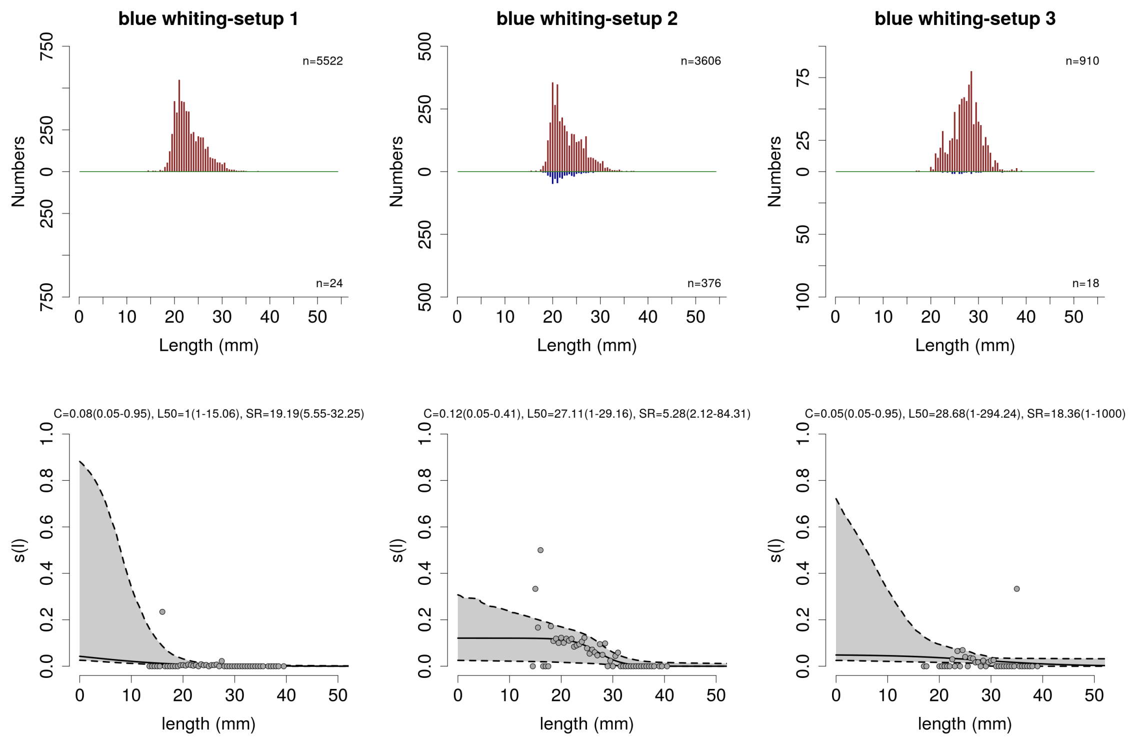

Figure 8: Top row: blue whiting catches in the upper codend (red bars) and lower codend (blue bars). Data shown by gear setup (only setups 1, 2 and 3 represented) and pooled over hauls. Bottom row: Estimated sieve curves (s(l)) and associated bootstrap confidence intervals for blue whiting and the three selected experimental setups

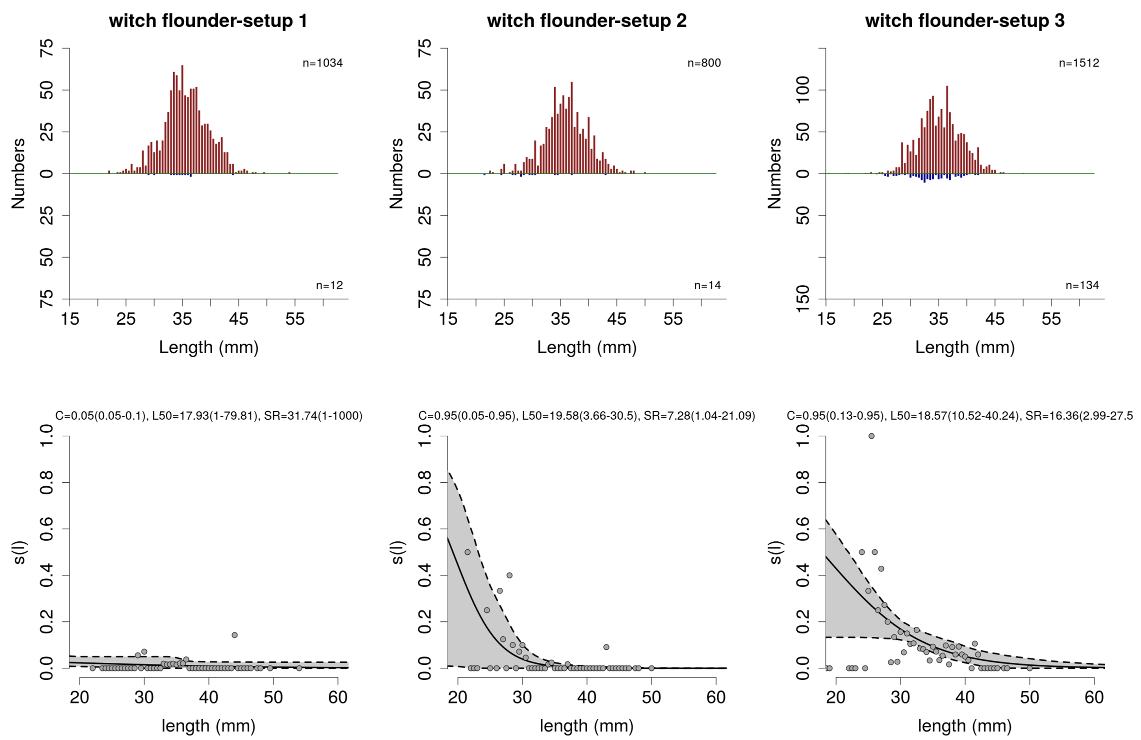

Figure 9: Top row: witch flounder catches in the upper codend (red bars) and lower codend (blue bars). Data shown by gear setup (only setups 1, 2 and 3 represented) and pooled over hauls. Bottom row: Estimated sieve curves (s(l)) and associated bootstrap confidence intervals for witch flounder and the three selected experimental setups.

Underwater video recordings

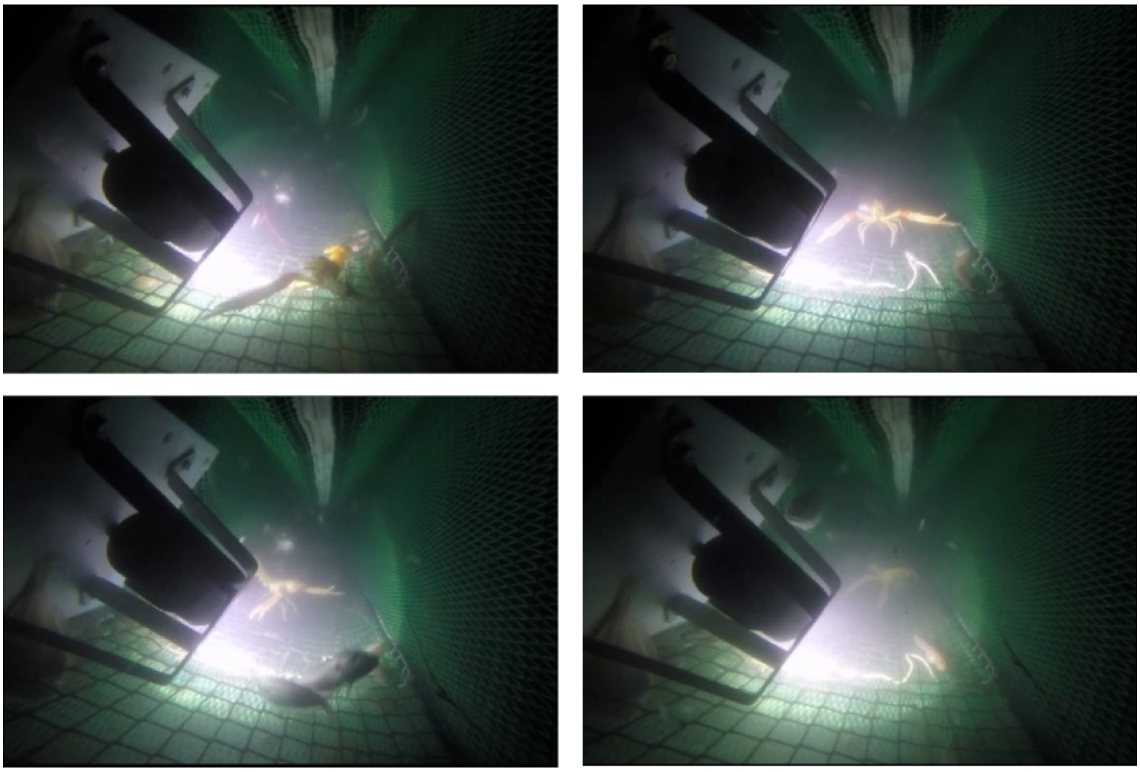

Figure 10: Nephrops walking over the panel until it lost the balance, being drifted by the water flow towards the aft of the gear (snapshots from haul 7).

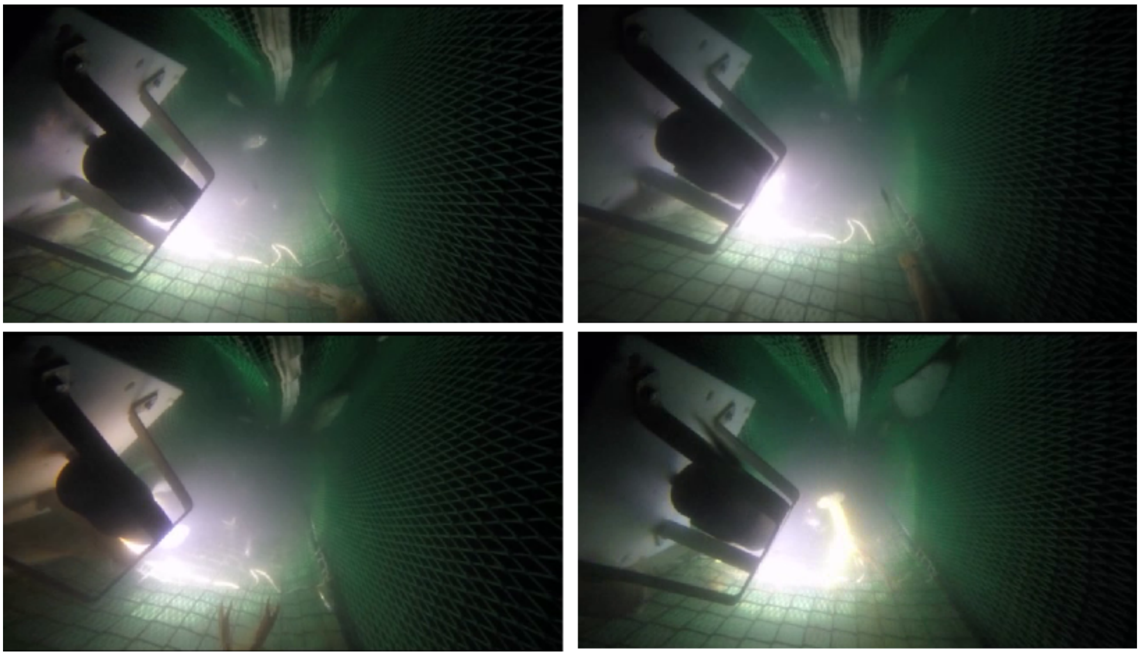

Figure 11: A medium sized individual attempting to get buried using the HESPAN meshes. After some seconds, it get back to the surface, being finally drifted by the water flow (snapshots from haul 7).

4 Discussion

Two pre-requisites were stated in section 2.3.1 for an optimal performance of HESPAN. On one hand, nephrops should contact and pass though the square meshes regardless individual size. Meanwhile, the panel should guide the fish towards the upper codend (low contact probability). The results extracted from model 5 (Table 2 and Figures 6 to 9) demonstrates that all three setups achieved the goals in terms of contact probability, at least for nephrops and cod.

However, the results from model 5 indicate that it was not possible to avoid nephrops size selection in any of the tested setups (Table 2 and Figure 6). This conflicts at least with the *a priori* expectation for the large mesh panel (195mm) used in setup-3. While it is known that the mode nephrops contact mesh panels greatly influences the size selection, the big mesh size used in setup-3, in conjunction to the overall length of the oblique panel, should be sufficient to ensure that all nephrops contacted in a mode that would allow all sizes to pass to the lower codend. Contrary, with the increment in mesh size we only achieved an increment in L50 and SR. Even though such increments are desirable, they were not sufficient to completely avoid size selection over the available range of length classes.

The underwater video recordings provides additional information to help to understand the present results. Although few nephrops were recorded interacting with the oblique panel during towing, some observations indicate that the roll and hit motion cannot be generalized in all cases. Some individuals presented an active behavior, hanging the twines, walking or trying to get buried using the HESPAN meshes (Figures 10 and 11). Such active reactions could prevent efficient contact necessary for sieving. We speculate with the possibility that such active behavior were positively related to individual size, being absorbed by the size selection parameters in model 4 and confounded with the physical size selection.

Attempts to separate species to improve the selectivity of fishing gears has been applied in the past using other strategies, for example by utilizing horizontal panels [9]. The effectiveness of horizontal panels to sort the catches by species depends on the assumption that species distribute at different heights when swimming in the water column towards the codend [9]. However, behavioral studies revealed that the vertical distribution for several target species can be nearly uniform [11], or it can be influenced by environmental conditions [8]. These findings compromise the effectiveness of such approach, being discarded as a potential strategy to be adopted in the present study.

The results presented in this report are promising but not optimal, therefore more efforts should be invested to further develop the concept towards a better separation of catches. Achieving this goal would finally allow the definition of different size selection properties for each of the codends in commercial conditions. As an example, fishermen could use large mesh size in the upper codend to reduce or avoid catches of small *Gadoids*, at the same time they could use small mesh size in the lower codend, adapted to the small size of *Nephrops*. Further, this configuration would allow the fishermen to completely avoid the catches of *Gadoid* species under quota exhaustion, simply by opening the upper codend during towing. We consider this feature useful for the sustainability of the fisheries, in particular considering the landing obligation enforced by the new European Fishing Policy.

5 Research crew members

Juan Santos	Cruise Leader	TI-OF
Kerstin Schöps	Technician	TI-OF
Sven Dressler **	Technician	TI-OF
Peter Schael	Technician	TI-OF
Robin Breski	Volunteer	Universität Rostock
Huajing Yan	Volunteer	Universität Kiel
Jorrit Lucas*	Volunteer	BTU

(*) First half of the cruise, (**) Second half of the cruise

6 Acknowledgments

The research crew thank the FFS Solea crew for the flexibility they showed to adapt their work to our experimental design. Special thanks to Arne Schwegmann (captain) and Leo Röschke (netmaker); their active involvement in the research contributed significantly to end the cruise with success. We also thank the good service provided by the kitchen: long working days at sea get shorter with good meals on the table. Finally, thanks to our colleagues Bernd Mieske, Annemarie Schütz, Ina Hennings, Daniel Stepputtis (TI-OF, Rostock), Ludvig A. Krag (DTU-Aqua, Hirtshals) and Bent Herrmann (SINTEF-DK, Hirtshals) for their availability, support and suggestions provided from land.

References

[1] K Arkley. Fishing trials to evaluate the use of square mesh selector panels fitted to nephrops trawls—mfvheather sprig (bck 181) november/december 1990. *Seafish Report SR383. Sea Fish Industry Authority, Hull, England*, 1990.

[2] M. J. Armstrong, R. P. Briggs, and D. Rihan. A study of optimum positioning of square-mesh escape panels in irish sea nephrops trawls. *Fisheries Research*, 34(2):179–189, 1998.

[3] RP Briggs. An assessment of nets with a square mesh panel as a whiting conservation tool in the irish sea¡ i¿ nephrops¡/i¿ fishery. *Fisheries Research*, 13(2):133–152, 1992.

[4] A. Campos and P. Fonseca. The use of separator panels and square mesh windows for by-catch reduction in the crustacean trawl fishery off the algarve (south portugal). *Fisheries Research*, 69(2):147–156, 2004.

[5] T. L. Catchpole, A. S. Revill, and G. Dunlin. An assessment of the swedish grid and square-mesh codend in the english (farn deeps) nephrops fishery. *Fisheries Research*, 81(2-3):118–125, 2006.

[6] T. L. Catchpole, A. N. Tidd, L. T. Kell, A. S. Revill, and G. Dunlin. The potential for new nephrops trawl designs to positively effect north sea stocks of cod, haddock and whiting. *Fisheries Research*, 86(2-3):262–267, 2007.

[7] A. Farmer. Synopsis of biological data on the norway lobster nephrops norvegicus (linnaeus, 1758). *FAO Fisheries Synopses (FAO). no. 112.*, 1975.

[8] RST Ferro, EG Jones, RJ Kynoch, RJ Fryer, and BE Buckett. Separating species using a horizontal panel in the scottish north sea whitefish trawl fishery. *ICES Journal of Marine Science: Journal du Conseil*, 64(8):1543–1550, 2007.

[9] C.W. Glass. Conservation of fish stocks through bycatch reduction: a review. *Northeastern Naturalist*, 7(4):15, 2000.

[10] I. Herraiz, M.A. Torres, A.C. Farina, J. Freire, and J.R. Cancelo. The nao index and the long-term variability of nephrops norvegicus population and fishery off west of ireland. *Fisheries Research*, 98(1):1–7, 2009.

[11] L.A. Krag, R. Holst, and N. Madsen. The vertical separation of fish in the aft end of a demersal trawl. *ICES Journal of Marine Science*, 66(4):772–777, 2009.

[12] J. Main and G.I. Sangster. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. *Scottish Fishing Resources Reports*, 23:1–23, 1981.

[13] S . Méhault, R.J. Kynoch, R.J. Fryer, and Ferro R.S.T. Effect of introducting a species selective trawl in a scottish nephrops fishery. Technical report, 2007.

[14] R.B. Millar. Incorporation of between-haul variation using bootstrapping and non-parametric estimation of selection curves. *Fisheries Bulletin*, 91:564–572, 1993.

[15] N. Nikolic, J. Dimeet, S. Fifas, M. Salaun, D. Ravard, Fauconnet L., and M.J. Rochet. Efficacy of selective devices in reducing discards in the nephrops trawl fishery in the bay of biscay. *ICES Journal of Marine Science*.