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Bericht

über die 725. Reise des FFS Solea
vom 07.09 **bis** 23.09.2016

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Das Wichtigste in Kürze

Gemeinsame Forschungsfahrt des Thünen-Institut für Ostseefischerei, des Wageningen Marine Research Institute und niederländischer Fischerei.

Das Hauptziel der Fahrt war die Entwicklung und der Test von Konzepten zur Reduktion von unerwünschtem Beifang in der Nephrops-Fischerei.

Das deutsche Hespan-Netz und das niederländische Sepnep-Trawl wurden während der Fahrt auf deutschen und niederländischen Fischereigründen getestet.

Beide Konzepte zeigten eine hohe Wirksamkeit. Durch weitere Untersuchungen könnte eine weitere Verbesserung der Arten-Trennung erreicht werden.

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1 Introduction

How to supplement the codend selectivity in *Nephrops* (*Nephrops norvegius*) trawls to provide extra opportunities of escapement for non targeted fish has been a main topic of research during decades. Such efforts resulted in a relatively wide catalog of Bycatch Reduction Devices (BRD's), some of them adopted in regional management plans [4, 12]. In general, these devices attempt to provide additional escapement possibilities for non targeted fish before they enter the codend. This is the case with two of the most applied BRD's in commercial fisheries; the Swedish grid [12] for mono-specific *Nephrops* fisheries, and Square Mesh Panels (SMP's) for mixed fisheries [2, 3]. Although these devices can significantly reduce bycatch rates, none of them have demonstrated to deliver an efficient multispecies size selection. Depending on the population structure fished, this can drive to considerable amounts of bycatch of small fish [1, 9, 12], or even losses of marketable *Nephrops* [5].

Achieving an efficient species and size selection for both, the target and the bycatch species, is a feature of increasing demand in Europe due to the Common Fisheries Policy (CFP) reform (EU1380/2013), introduced in *Nephrops* fisheries from 2016 onwards. The reform address the bycatch problem by adopting a Landing Obligation (LO), which force fishermen to land all catches of quoted species and count them against their quota. Under such scenario, large bycatch of fish species with limited quota can alter the fishing strategy or even force fishermen to stop fishing at all without exhausting the *Nephrops* quota. Investing further efforts on improving species and size selectivity in these fisheries is more than ever required to secure both the biological, ecological and economical sustainability.

One alternative strategy to improve the global selectivity in these fisheries is based on split up *Nephrops* and fish species into separated codends with selectivity properties adapted to the different catch fractions. By using horizontal separator panels at different heights, Main and Sangster [7] attempted to utilize differences in swimming behavior (vertical zoning) between species to separate them in two different codends. Whiting and haddock were mainly caught in the upper codend, while a mix of *Nephrops*, flatfish and cod were observed in the lower codend. Even though the relative success, the sorting efficiency achieved in [7] would not be sufficient for fisheries where the bycatch of cod and/or flatfish represent the main problems to be addressed.

In 2015 the German Thünen Institute of Baltic Sea Fisheries developed the so-called Hespan, an alternative BRD's device for *Nephrops* mixed fisheries. The general design consisted on a long square mesh panel mounted in the floor of the net with a smooth upwards-backwards inclination, splitting the aft of the gear into a bottom and a top codend. The concept was though to perform similarly as the sievenets used in other crustaceans fisheries like brown shrimp fisheries [10]. For a good functioning, Hespan should sieve *Nephrops* into the lower codend, while guiding most of fish towards the upper codend. Four different setups of Hespan were tested during the RV/ Solea cruise `SO709` [11], conducted in September 2015 on Danish fishing grounds in Skagerrak. The analysis of the experimental catch data showed that most of fish were guided towards the upper codend, while $\sim 70\%$ *Nephrops* was sieved into the lower codend. Although promising, it was reported the need of investing further research efforts on increasing the *Nephrops* sieving efficiency, in order to avoid catching individuals in the upper codend, which could drive in potential marketable losses under commercial use [11].

The 2015 Hespan results were presented during the ICES-FAO Working Group of Fishing Technology and Fish Behavior (FTFB) annual meeting, held in Mérida (Mexico) between April 25-29 (2016). During the meeting, Pieke Molenaar of Wageningen Marine

Research (Netherlands) presented preliminary results of Sepnep, a sorting device designed by former fisherman Kees van Eekelen, under the support of the Dutch national fisheries management plan, which is investing maximal effort to reduce unwanted bycatch stepwise in all fisheries, in order to address the challenges brought by the European LO.

As in the case of Hespan, the Sepnep concept is based on separation of fish and *Nephrops* in a modified trawl that mounts a sievenet. As the relatively high by-catch rates of undersized *Nephrops* counts against the limited quota available for Dutch fishermen, the experimental Sepnep trawl was supplemented with an innovative grid, mounted in the front of the lower codend (the *Nephrops* codend), with the aim of providing an efficient *Nephrops* selectivity. Sepnep was tested in commercial conditions during 2015, and the results showed the experimental trawl to produce $\sim 65\%$ less discards compared to the conventional trawls. The design was in particular effective in reducing the bycatch of the undersized flatfish dab (*Limanda limanda*) ($\sim -69\%$) and plaice (*pleuronectus platessa*) ($\sim -78\%$). However, a loss of $\sim 21\%$ marketable *Nephrops* was found compared to the conventional trawls, and the results for the grid were not satisfying. The commercial conditions of the experimental cruises carried out made it difficult for Dutch researchers and fishermen to establish valid hypothesis on the working mechanisms of both devices, and therefore to establish development guidelines for improving them.

The conceptual analogies of Hespan and Sepnep, and the need of understanding and optimizing both 2015 designs, were arguments for the representatives of the Thünen Institute and Wageningen Marine Research, to work together in designing and conducting a research cruise, which should be used for further developing and testing both gears in the same experimental and fishing conditions. Such a joint research cruise was also seen by stakeholders as a window of opportunity to exchange experiences between the researchers and fisherman involved, and to enhance the collaboration framework.

This report present the results obtained in research cruise `SO725`, used for further developing and testing Hespan and Sepnep gears in the same experimental fishing conditions, under the agreement between Wageningen Marine Research and Thünen fishing technology working groups. The cruise was conducted from 7.09.2016 to 23.09.2016 in German and Dutch fishing grounds onboard the German RV/Solea. The objectives of the cruise were:

1. To test for first time Sepnep gear in research vessel, with full control on the experimental design.
2. To test Hespan concept in different fishing grounds.
3. To optimize Sepnep and Hespan trawls by further developing the 2015 designs.
4. To obtain fundamental knowledge on the sorting mechanism of the Hespan and Sepnep sievenets.
5. To develop, test, and estimate the selectivity properties of the *Nephrops* grid mounted in the Sepnep trawl.

2 Material and Methods

2.1 Target fishery

The sea trials were conducted in the Dutch *Nephrops* fishery, a seasonal fishery usually occurring from April till November. Typical fishing grounds are at least 70 miles from the Dutch mainland in the central North Sea and range from the Dutch/English EEZ (Botney Gut) up to the Danish/German EEZ (White bank). There are $\sim$ 25 Dutch vessels mainly based in the harbour of Den Oever, besides 7 Belgium around 5 German flag vessels performing this seasonal fishery. Vessels are up to $24m$. and have maximal $300Hp$ and usually make trips of $4-5$ days. Specialized $80mm$ *Nephrops* trawls with low head ropes ($\leq$ 1 meter) are used and vessels are usually rigged with 4 trawls (quad-rig). Haul duration may be up to 5 hours, depending on catch quantities. This *Nephrops* fishery is a mixed demersal fishery and catch composition is dependent on trawled area. Catches are usually dominated by flatfish as dab, plaice, and the targeted *Nephrops*. Dependent on weather circumstances and water clarity, *Nephrops* are caught during either day or night. With calm weather and clear water *Nephrops* catches occur during night with a peak during dawn and dusk. The marketable catch in this fishery is variable but may consists of $\sim$ 50% *Nephrops* and $\sim$ 50% fish species as sized plaice, turbot, brill and several other demersal species in small amounts. European Minimum Conservation Reference Size (MCRS)for *Nephrops* is $25mm$ Carapace length (CL) but due to tight Dutch *Nephrops* quota, the Dutch industry adopted their own landing restrictions, with a maximum number of 35 individuals in one kilogram, corresponding to individual sizes $\sim 32mm$ CL (hereafter referred as the Industry Minimum Commercial Reference Size, or Industry MCRS). Discard rates in this fishery are estimated to vary between $\sim 50-80\%$ of the total catch, of which two third usually consists of the undersized dab and plaice on those fishing grounds.

2.2 Test gears

2.2.1 Hespan 2016

The original design of Hespan was updated considering the 2015 results and experiences. With the aim of improving the sieving efficiency on *Nephrops*, three main aspects from the original design were updated:

- Material: Use of rope panel instead of net panel. Thick ropes were used, attempting to avoid *Nephrops* hanging on the panel, a behavior assumed to reduce sieving efficiency.
- Shape of sievenet openings: Rectangular spaces between ropes instead of square mesh openings. Based on theoretical simulations, rectangular shape might mitigate the unintended length dependency observed for the Hespan 2015 designs.
- Inclination: Steeper mounting slope at the first section of the sievenet. Assuming that *Nephrops* travel on the bottom of the trawl, with this adaptation it was intended to improve the probability for individuals to contact optimally with Hespan.

Two different designs, hereafter referred as Hespan 5 and Hespan 6, were tested. The only difference in design was the vertical space between ropes, increasing from $226mm$ and $250mm$ in hespan 5 to $476mm$ and $500mm$ in Hespan 6. Hespan 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 ($2.25m^2$).

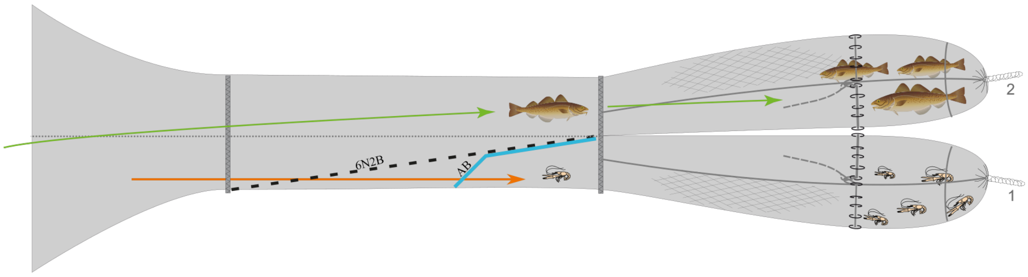

Figure 1: Side view of the experimental gear mounting the 2015 Hespan general design, represented by the black dotted oblique line, and the 2016 design (blue line). Codend numbering (1=lower codend, 2=upper codend) will be used throughout the document to label the experimental catch compartments.

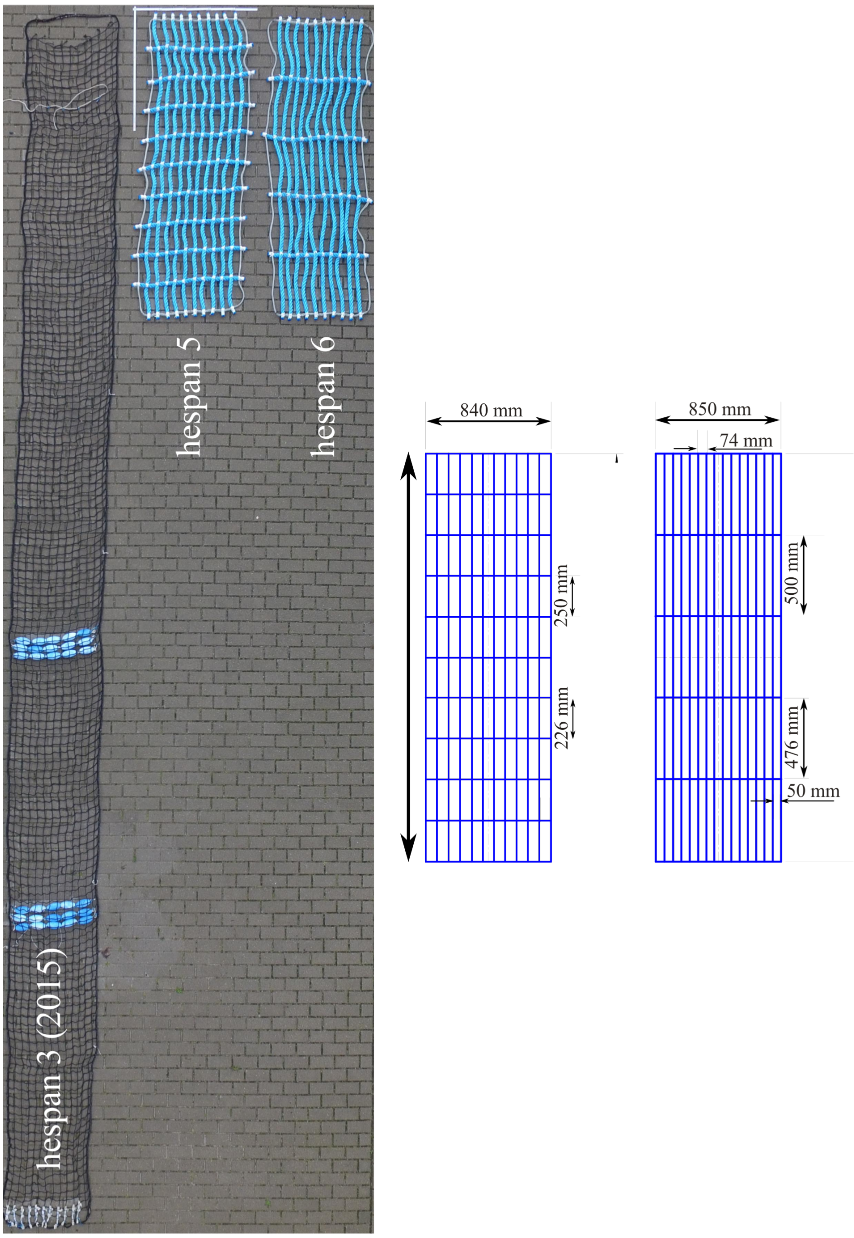

Figure 2: Left: Aerial view of one of the 2015 designs besides the 2016 designs. Right: Dimensions of Hespan 5 and 6.

2.2.2 Sepnep

The first Sepnep designs in 2015 were mounted in four sided trawls and were tested under commercial conditions on the vessel with code WR189, rigged with 6 trawls. In those trawls the sievenet was constructed of diamond and square meshes. To make the design suitable for wider application in the (Dutch) *Nephrops* fishery the design needed to be improved, simplified and tested in a two sided quad-rig trawl. Compared to the original design the following changes were applied:

- A new two sided quad-rig trawl with a smooth tapering was designed and constructed to ensure easy guidance of the catch toward the codends.
- The tapered 11 meter sievenet was simplified and made of 102mm double knotted single Dyneema netting, the complete sievenet consisted of diamond mesh.
- A new design plastic selection grid for *Nephrops* was mounted ahead of the lower codend(s) aiming for removal of non-marketable *Nephrops* ($< 32mm$ CL). A bar spacing of $\sim 19.2mm$ was chosen to achieve the preferred selection. Exact dimensions can be found in Figure 3.
- To increase contact probability and maximal utilization of available bar spacing of the grid, the top panel of the lower cod-end was equipped with a curtain of weighed ropes.
- Five floats were connected inside the second tunnel to ensure an undisturbed entrance towards the upper cod-end.

To experimentally measure the fish and *Nephrops* passing through the spaces between bars, a third codend was attached to the rear of the grid. With the additional codend the trawl was equipped with 3 blinded Dyneema single twine netting codends to retain the separated fractions of the catch. Measured mesh sizes were $53.25mm$ for codend 1 (lower), $51.75mm$ for codend2 (middle) and $45.10mm$ for codend 3 (upper), respectively (Figure 4). The Sepnep trawl was spread with the same doors used with Hespan, and to ensure optimal performance, trawl door spreading was restricted to $28m$ by a Dyneema line connected to both swivels that connect the doors and fishing lines.

Four different Sepnep designs were developed onboard (Figure 5), but only Sepnep 1 and Sepnep 2 were considered and successfully tested for multiple hauls. For the preferred position and stabilization of the codends, several modifications were applied in the Sepnep 1 setup: $5.5kg$ additional weight was tied to the bottom corners of the grid, the top panel of codend 2 was, two meshes ahead of the grids top corners connected to both selvedges of codend 3, which were equipped with 5 floats ($5.2L$) just above the grid.

The difference between Sepnep 1 and 2 was that the later mounted two lines of 4 floats connected to the netting at the underside of the sievenet. The first float was applied $1m$ from the connection with the bottom panel, while subsequent floats were placed on a distance of $1m$ from the previous one. This modification was aiming to improve the sieving efficiency by creating more lift and space in the first section of the sievenet.

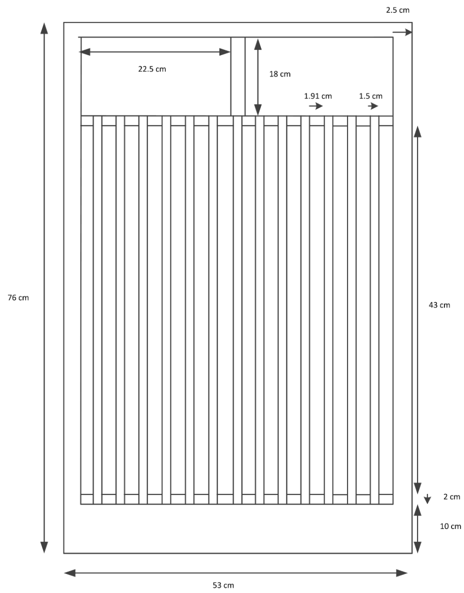

Figure 3: Scheme of the innovative *Nephrops* grid mounted in the lower compartment of Sepnep trawl.

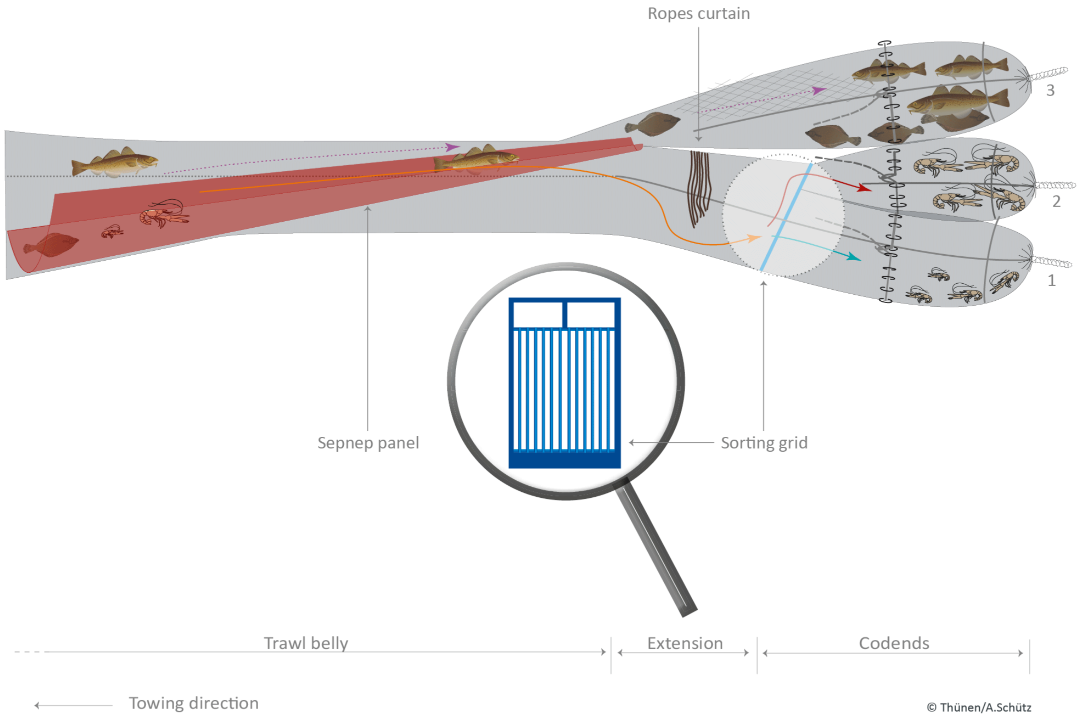

Figure 4: Side view of Sepnep gear illustrating the expected functioning of the Sepnep sievenet (red) and the *Nephrops* grid (blue).Codend numbering (1=lower codend, 2=mid codend and 3=upper codend) will be used throughout the document to label the three experimental catch compartments in Sepnep.

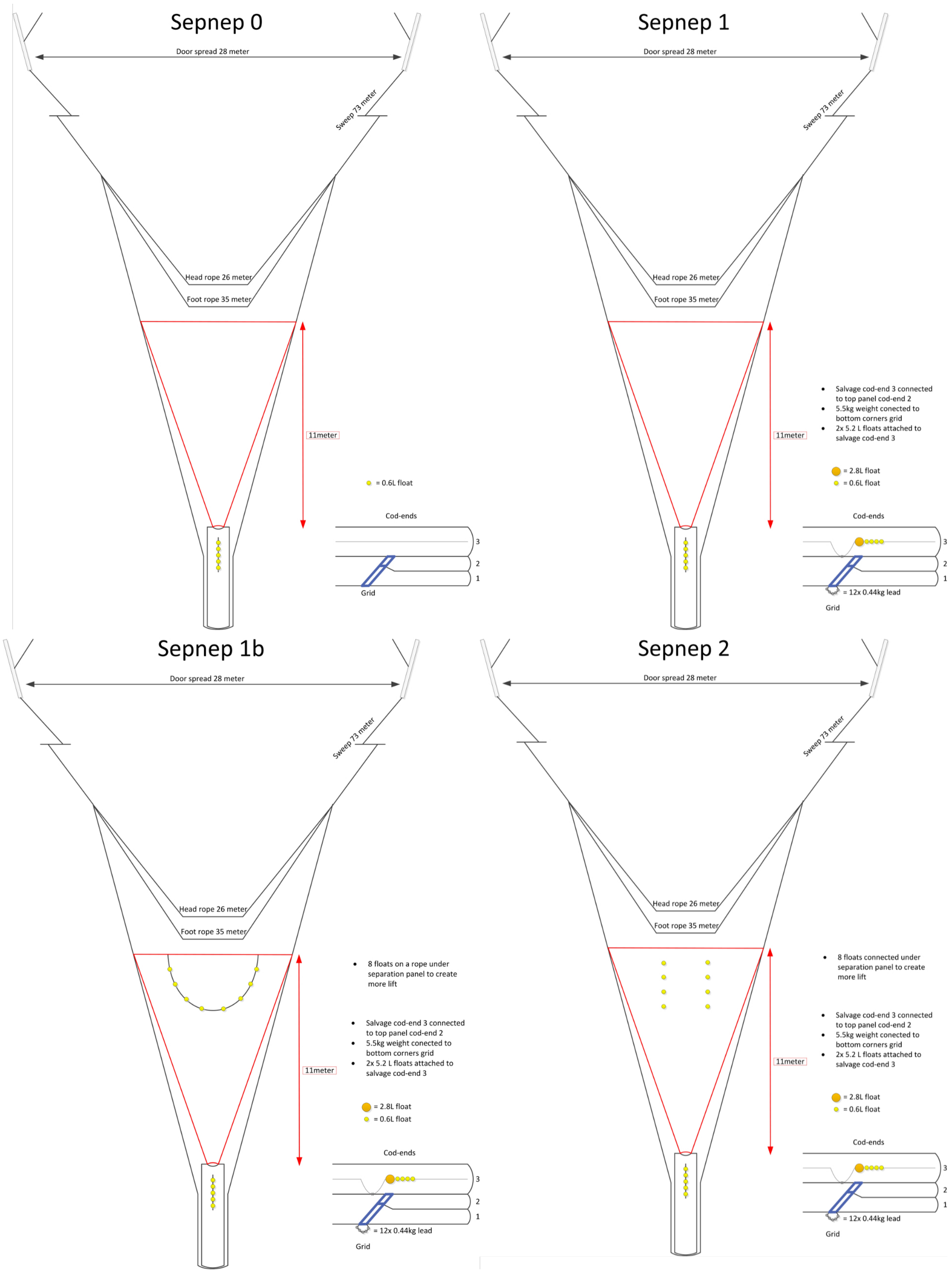

Figure 5: Schemes of the four different Sepnep designs developed onbard during the cruise. Only Sepnep 1 and Sepnep 2 were considered in the experimental design.

2.3 Experimental design and data collection

Short pilot hauls in shallow grounds were conducted to assess the physical behavior of the gears, before starting the experimental fishing trials. In particular, in this pilot phase we were interested on the assessment of the shape of sievenets (panel inclination, curvatures due to the drag of the flow, smoothness of the forward insertion, etc...), and the *Nephrops* grid stability. The assessments was done by using underwater video recordings (UWR) focusing on the selective devices. Any technical issue observed was addressed onboard by the netmakers, before the next pilot haul took place. This phase ended after achieving a first testable configuration.

The design of experimental fishing trials started by defining an adequate fishing strategy, which should ensure collecting experimental catches representative of the commercial catches. In particular, catch profile should be composed by a wide range of length classes from the target species, besides a mix of by-catch lengths and/or species, specially dab and plaice usually taken as bycatch by the fishermen. Information provided by the crew from the research vessel and the Dutch partners led to the definition of two main fishing grounds to be used during the trials. The first zone was the German EZZ fishing grounds located on the white bank and north of white bank, while the second main fishing grounds were located in the Puzzle hole (Dutch EZZ). Fishing hauls were conducted at night in order to maximize the catches of the *Nephrops*. Haul duration was determined for each haul separately based on the 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 groups 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. For large catches, a minimum of 1000 measurements were conducted, in accordance with [6].

We were mostly interested in estimating the sieving efficiency of the sievenets, and the grid selectivity. Both analysis were conducted by direct assessments on the proportion of catches observed in each of the experimental codends. By using small mesh codends (see sections 2.2) it was assumed that all relevant length classes entering in the experimental gears would be collected in any of the defined compartments. In the case of Hespan, being $n_{1,i}$ the number of fish caught in the lower codend (Figure 1) during haul i, $n_{2,i}$ the number of individuals caught in the upper codend, and $n_{+,i} = n_{1,i} + n_{2,i}$ the total catch, then the proportion caught in the lower codend in haul i is

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

which can be used to empirically assess the sieving properties of the Hespan sievenets. On the other hand, for Sepnep this assessment was done by simple adaptation of Equation 1:

$$s_i = \frac{(n_{1,i} + n_{2,i})}{n_{+,i}} \tag{2}$$

where $n_{+,i}$ is the sum of catches from lower, middle and upper codends (Figure 4).

s_i only can take values between 0 and 1. Values of $s_i \sim 1$ indicate that most individuals from a given species were mostly sieved towards the lower codends, while the opposite ($s_i \sim 0$) indicate they were mostly guided to the upper codend.

In particular for the case of Sepnep, the rate of catches for a given species not able to pass through the spaces between bars of the *Nephrops* grid was calculated as:

$$g_i = \frac{n_{2,i}}{(n_{1,i} + n_{2,i})} \tag{3}$$

2.4 Modelling the sieving efficiency and Sepnep grid selectivity

The results obtained in 2015 [11] indicate that the sieving process in Hespan is a complex process which cannot be exclusively explained by classic mechanical size selection, discouraging the application of the same structural modelling approach applied in [11]. Instead, we use a empirical model based on maximizing a highly flexible function $S(l)$ with the following structure:

$$S(\boldsymbol{\beta}, l) = H(\beta_0 + \beta_1 \cdot l + \beta_2 \cdot l^2 + \beta_3 \cdot l^3) \tag{4}$$

where $S(\boldsymbol{\beta}, l)$ is the averaged, length dependent sieving efficiency, described by applying a 3^{rd} order polynomial in the model matrix, providing high flexibility to account for non-linear patterns in the experimental data. In Hespan, the estimation of the values of the parameters $\boldsymbol{\beta} = \beta_0, \ldots, \beta_3$, which make the observed experimental data averaged over hauls most likely was carried out by minimizing the following maximum likelihood function for binomial data, with respect to $\boldsymbol{\beta}$:

$$LL = -\sum_l \sum_i \{n_{1,il} \times \log(S(\boldsymbol{\beta}, l)) + n_{2,il} \times (1 - \log(S(\boldsymbol{\beta}, l)))\} \tag{5}$$

where the sums are for hauls i and length classes l. As mentioned, in Equation 4 and Equation 5 we considered a polynomial up to the order 3. Leaving out one or more of the parameters led to 15 additional simpler models that were also considered potential candidates for the sieve efficiency curves $S(\boldsymbol{\beta}, l)$, and therefore they were also estimated using Equation 5 . Selection of the best model for $S(\boldsymbol{\beta}, l)$ among the 16 competing models was based on a comparison of their respective AICc values (AIC with a correction for finite sample sizes). The model with the lowest AICc value was used to describe the sieving efficiency data in Hespan.

Additionally, the Sepnep trawl incorporated a grid system in the lower compartment of the gear, with the aim of selecting the target species by size. To be able to simultaneously model the efficiency of the sievenet and the size selection of the grid, Equation 5 was upgraded to the following form:

$$LL = -\sum_l \sum_i \{n_{3,il} \times (1 - \log(S(\boldsymbol{\beta}, l))) + (n_{1,il} + n_{2,il}) \times \log(S(\boldsymbol{\beta}, l)) + n_{1,il} \times \log P(C, L50, SR) + n_{2,il} \times (1 - \log(P(C, L50, SR)))\} \tag{6}$$

In Equation 6, $P(C, L50, SR)$ is the length dependent probability for a *Nephrops* or fish individual to pass through the grid towards codend 1:

$$P(C, l, L50, SR) = C \times (1 - r(l, L50, SR)) \tag{7}$$

In Equation 7, parameter C denotes the length-independent probability for a individual to efficiently contact the grid becoming available for size selection. $r(l)$ is a *logit* function [13], describing the size selection properties of the grid, which is summarized by two parameters: *L50*, the length with 50% probability of being retained by the grid, and *SR*, the range between the lengths with 75% and 25% probabilities.

By this simple modification:

$$R(C, l, L50, SR) = (1 - P(C, l, L50, SR)) \tag{8}$$

we estimate the contact retention probability of the grid, which is showed in the results section together with the sieving efficiency of the sievenet,

As in the case of Hespan analysis, model selection was performed automatically by using AICc. The rank of candidate models varied in the polynomial structure describing the Sepnep panel efficiency, while the part used to describe the grid selectivity was fixed to the structure showed in Equation 7 and Equation 8

The confidence intervals (CIs) associated to averaged $S(\boldsymbol{\beta}, l)$ curve and the $\boldsymbol{\beta}$ parameters were defined by using the non-parametric technique known as block bootstrapping. This technique differs from the standard approach used in selectivity studies [8], on the Data Generating Process (DGP). In particular, the artificial data is generated compartment-wise, that is, accounted for the observations in the codend 1 and codend 2 separately. Below it is described the technique applied on Hespan data, which is the same for the Sepnep, but in this case considering the three-codends setup:

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 $h_i^{**} = \{n_{1,il}^*, n_{2,il}^*\}$

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

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

5. Steps 1 to 4 are repeated a large number of times $(b = 1, \ldots, B)$ to obtain a set of sieve curves $\hat{S}^{*1}(\boldsymbol{\beta}^*, l^*), \ldots, \hat{S}^{*B}(\boldsymbol{\beta}^*, l^*)$.

Once this process is completed, the 95% limits of the CI for the average curve $S(\boldsymbol{\beta}, l)$ is given by:

$$(\hat{S}^{*(\frac{\alpha}{2})}(\boldsymbol{\beta}^*, l^*), \hat{S}^{*(1-\frac{\alpha}{2})}(\boldsymbol{\beta}^*, l^*)) \tag{9}$$

With $\alpha = 0.05$.

2.4.1 Underwater video recordings

Besides the quantitative catch data, UWR were collected using at least one fishing haul per day. Normally the selected fishing haul was the first or second haul of the day, in order to ensure maximum catches of the target species. Different camera positions were defined, with the aim of collecting valuable information about the target / by-catch species behavior in relation to the selection devices tested. Wide angle, self recording cameras (GoPro™Hero3/Hero4 ™) were used, and mounted in depth water housing model Go-Benthic™. The camera system was supplemented with flood beam artificial light 1400 lumens.

3 Results

The cruise was organized in two parts. The first part started on 7.09. from Cuxhaven (Germany) and it was used to test the new Hespan designs. Two pilot hauls in clear waters were conducted in the way to the fishing grounds, to set up the Hespan 5 before starting the experimental fishing on the 08.09. A total of 7 valid hauls were completed on the German fishing grounds, with depths ranging between $\sim 45m$ and $\sim 50m$, and towing speed $\sim$ 2.5 knots. Haul duration was $120'$ for all hauls except for haul 4 ($60'$). The remaining 4 hauls with this design were conducted on the Dutch fishing grounds, with higher abundance of the target species, but with population structure shifted towards smaller length classes. Hespan 6 followed the same fishing plan, therefore the same number of hauls were conducted on the same fishing grounds as with Hespan 5. Two hauls with an additional setup for Hespan 6 (so-called Hespan 6b) were conducted before ending the Hespan trials. These hauls were used to collect information which might be used in future developments, therefore catch information is not presented in this report.The vessel docked in the harbor of Den Helder (Netherlands) on 15.09. to load the Sepnep trawl. A pilot haul was conducted short after leaving the harbor on 16.09., and before start fishing on the same day in the Puzzle hole. Sepnep testable designs were developed directly onboard. the starting design was referred as Sepnep 0 (3 hauls), which was discarded due to problems in the grid system. Grid behavior improved with Sepnep 1, being therefore tested in multiple hauls (7 hauls), following the same experimental design and fishing strategy as for the case of Hespan. Sepnep 1b (1 haul) was defined by mounting a line of floats connected to the netting at the underside of the sievenet, but entanglement forced a re-organization of the floats, which defined the final Sepnep 2 design (11 hauls).
The analysis on the catch data is presented in the next sections for each of the gears separately.

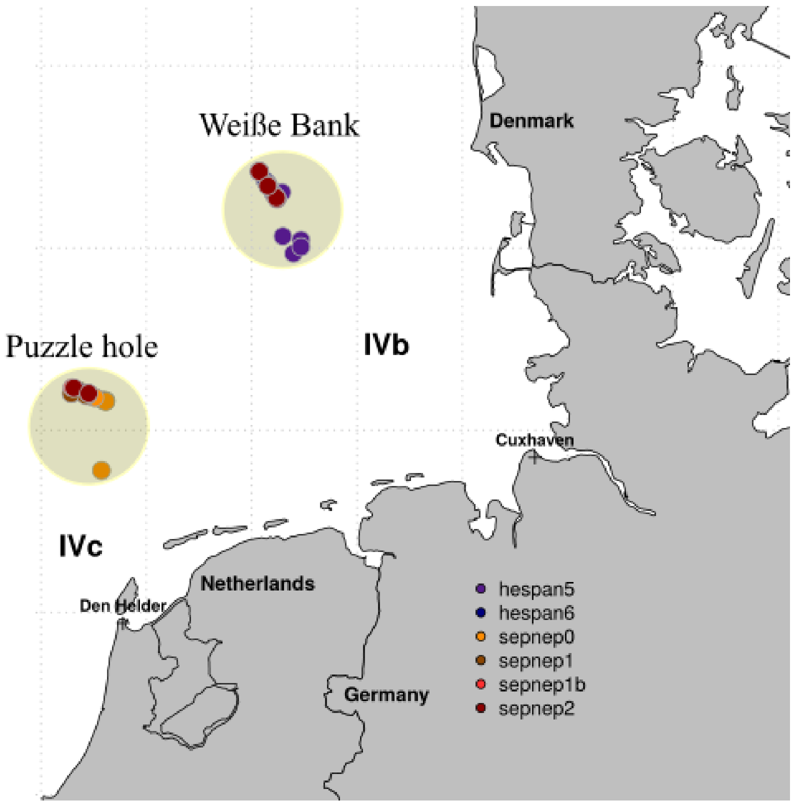

Figure 6: Distribution of the experimental fishing hauls at shooting positions. Locations might overlapped due to the geographical proximity between hauls.

3.1 Sieving efficiency and Sepnep grid selectivity

3.1.1 Hespan 5

- 11 valid hauls performed with Hespan 5 between 8 and 11 September 2016. The first 7 hauls were conducted on the White bank, and the last 4 in the Puzzle hole Table 1.

- The largest catch volumes with Hespan 5 occurred within the first 7 hauls, due to the large amounts of whiting and dab available on the German grounds. Most of these volumes were caught in codend 2 (upper codend Figure 7).

- The largest proportion of *Nephrops* catches was observed in codend 1 (lower codend), Although the presence of individuals in codend 2 indicate that the sieving efficiency achieved was below the target (Figure 8).

- considering the Industry MCRS, $\sim 75\%$ and $\sim 90\%$ of the marketable and undersized *Nephrops* were caught in codend 1, respectively. Further information related to the experimental catch fractions of *Nephrops* can be found in Table 2.

- As in the 2015 Hespan designs, the efficiency of Hespan 5 to sieve *Nephrops* into codend 1 was dependent on individual CL. The sieve curve describes a sinusoidal decreasing trend with minimum efficiency estimated in $\sim 56\%$ for CL $\sim 55mm$ (Figure 9).

- Plaice was mostly caught in codend 2 (Figure 10). As intended, the sieving efficiency on this species was very low and with a slight dependency on fish length (Figure 11).

- Except for the first haul of the series, dab was mostly caught in codend 2 (Figure 12). The sieving efficiency for this species described a bell shape with a maximum of $\sim 28\%$ located at $\sim 20cm$ (Figure 13).

- Whiting catch sorting followed a similar pattern as for the flatfish species, and most of catches were found in the upper codend (Figure 14). The average sieve efficiency presented values below $\sim 15\%$ for lengths larger than $\sim 10cm$ (Figure 15).

Operational and catch information

Gear	Haul	Station	Shooting	Lat.	Long.	Heaving	Lat.	Long.	Depth	Speed
hespan5	1	742	2016-09-08 18:11:26	54.97	6.40	2016-09-08 20:11:16	55.04	6.32	45.07	2.5
	2	743	2016-09-08 21:08:56	55.06	6.30	2016-09-08 23:08:47	54.99	6.37	44.24	2.5
	3	744	2016-09-09 00:39:47	55.04	6.47	2016-09-09 02:09:37	54.99	6.54	45.57	2.5
	4	745	2016-09-09 03:25:17	55.01	6.47	2016-09-09 04:25:17	54.97	6.43	44.65	2.4
	5	746	2016-09-09 18:06:55	55.36	6.14	2016-09-09 20:06:45	55.29	6.22	48.85	2.4
	6	747	2016-09-09 20:57:35	55.31	6.29	2016-09-09 22:57:25	55.34	6.17	49.34	2.4
	7	748	2016-09-09 23:25:25	55.35	6.15	2016-09-10 01:25:15	55.28	6.23	48.68	2.4
	8	749	2016-09-10 18:05:34	54.21	4.36	2016-09-10 20:05:24	54.18	4.49	48.81	2.4
	9	750	2016-09-10 20:34:44	54.18	4.51	2016-09-10 22:34:44	54.21	4.39	49.61	2.5
	10	751	2016-09-10 23:07:44	54.21	4.37	2016-09-11 01:07:35	54.18	4.50	49.17	2.5
	11	752	2016-09-11 01:31:44	54.18	4.50	2016-09-11 03:31:34	54.21	4.37	49.91	2.5

Table 1: Physical description of the experimental hauls conducted with Hespan 5.

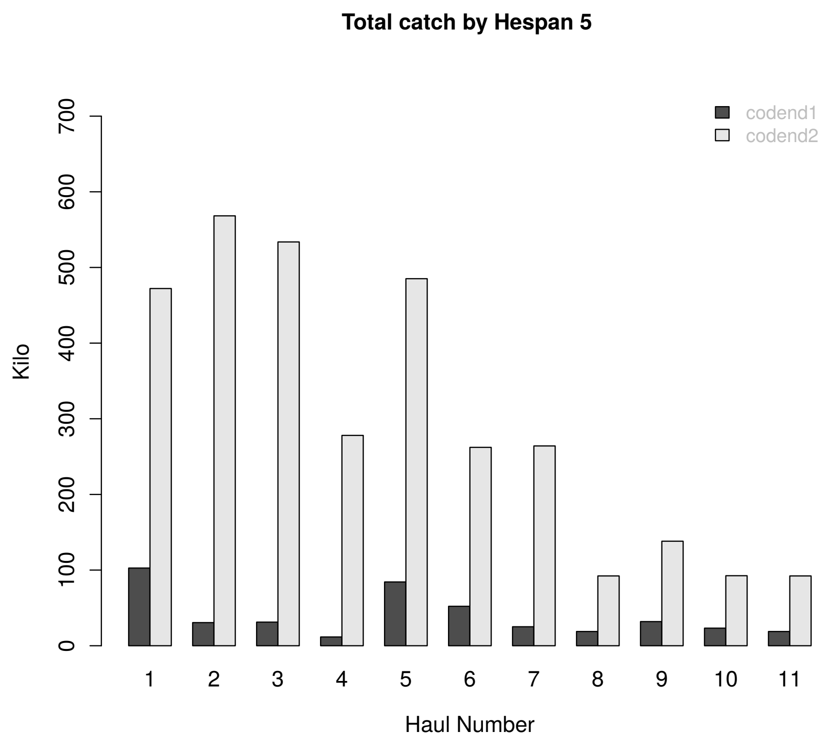

Figure 7: Total biomass caught by Hespan 5 per haul and codend (all species catches pooled).

Nephrops

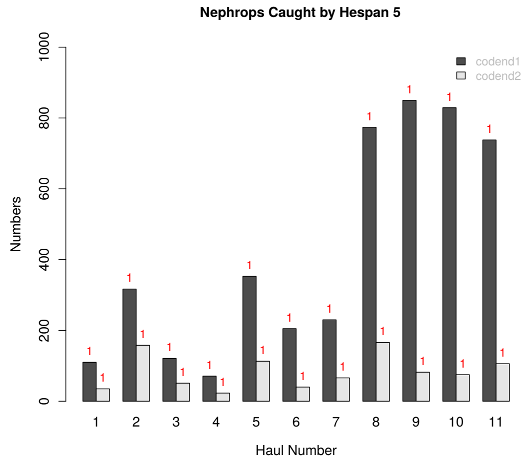

Figure 8: *Nephrops* catches with hespan 5 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

MCRS	type	fraction	codend1	codend2	rate.codend1	rate.codend2
Industry	numbers	above	2227.00	654.00	77.30	22.70
		below	2371.00	261.00	90.08	9.92
	weight	above	77.86	26.44	74.65	25.35
		below	35.45	3.98	89.91	10.09
EU	numbers	above	4302.00	890.00	82.86	17.14
		below	296.00	25.00	92.21	7.79
	weight	above	110.67	30.19	78.57	21.43
		below	2.63	0.22	92.14	7.86

Table 2: *Nephrops* catch rates observed in each codend relative to the total catch. Estimates were done using the experimental data collected, split up using Industry and EU MCRS (CL= $32mm$ and CL= $25mm$, respectively).

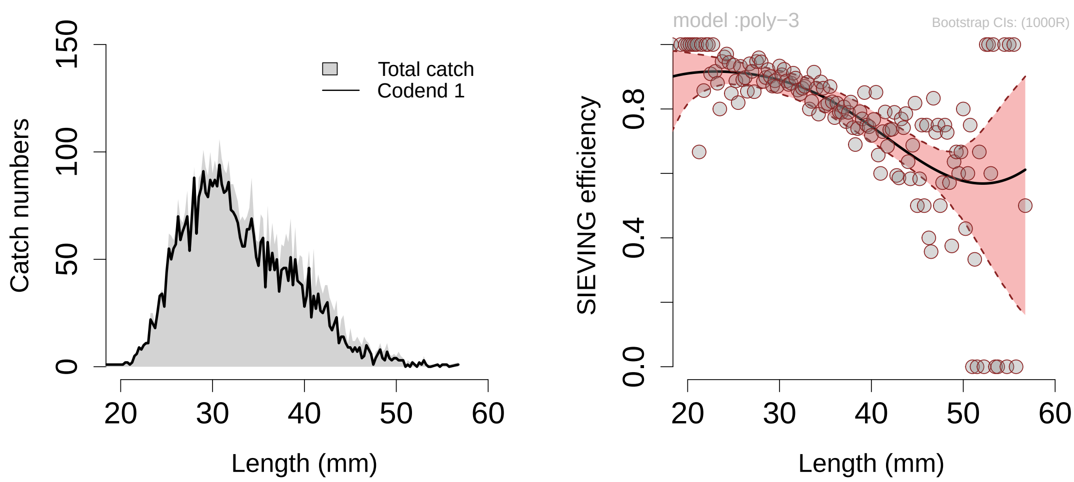

Figure 9: Left: *Nephrops* catch profile observed in Hespan 5 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

Plaice

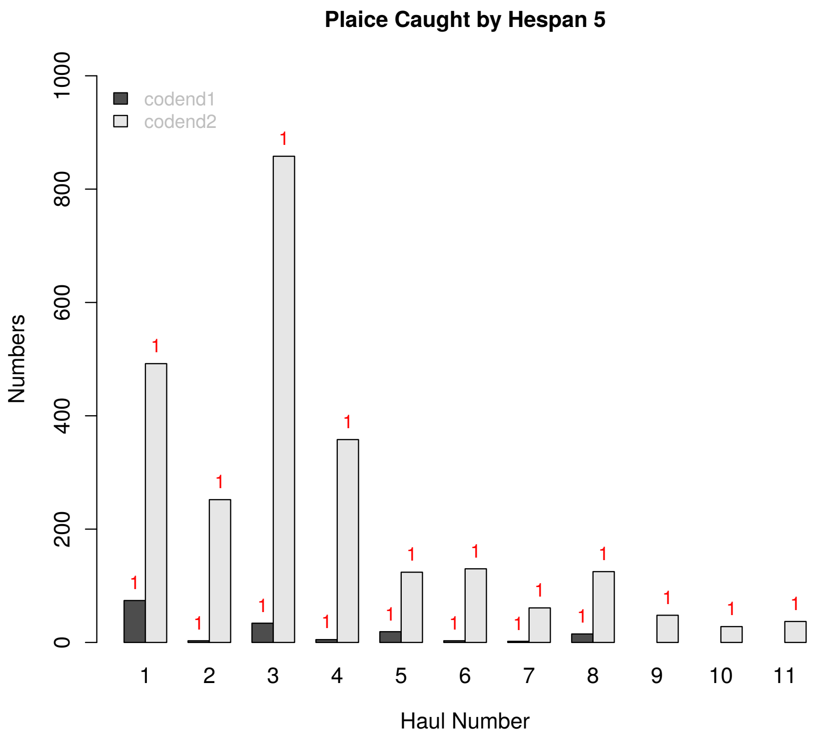

Figure 10: Plaice catches with Hespan 5 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

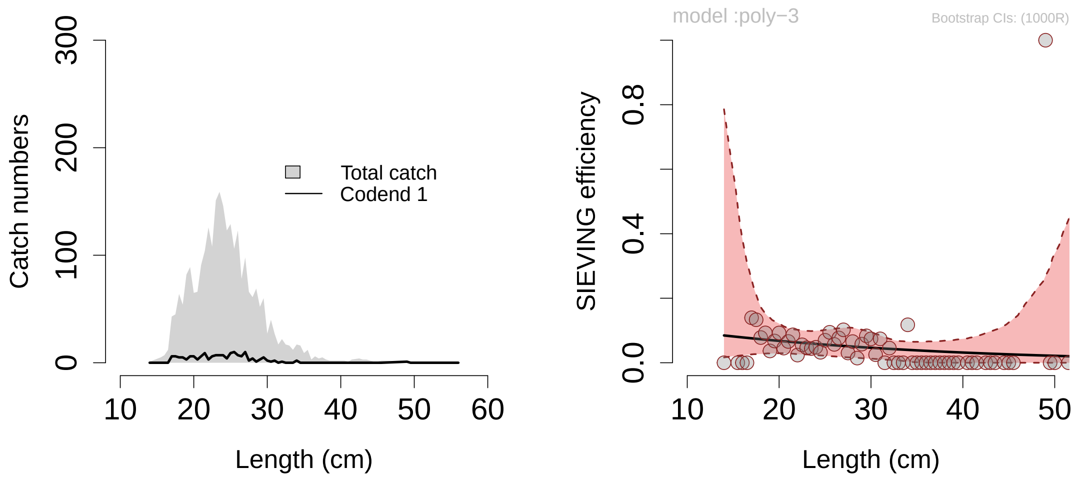

Figure 11: Left: Plaice catch profile observed in Hespan 5 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

Dab

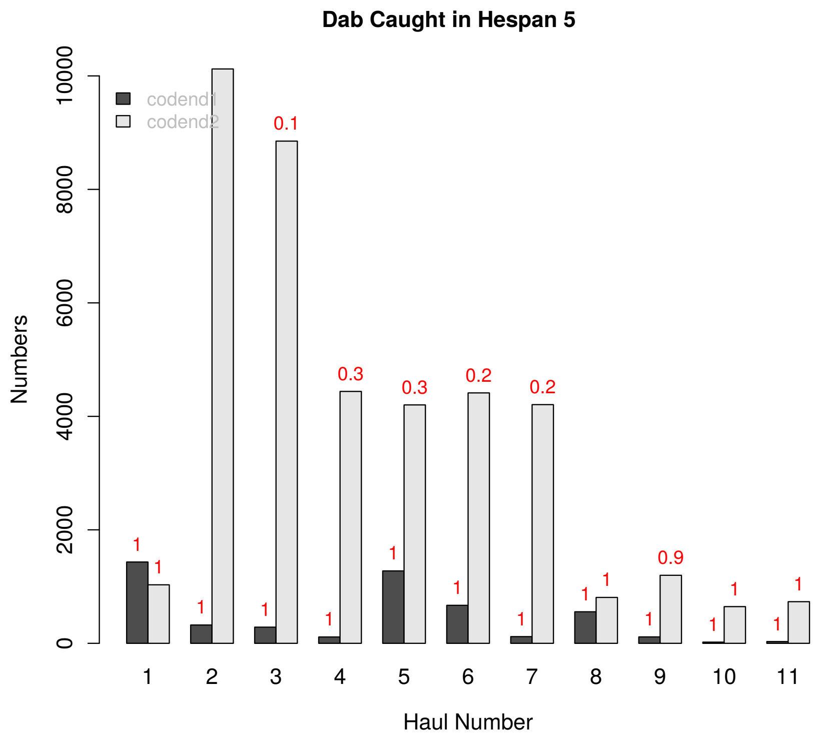

Figure 12: Dab catches with Hespan 5 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

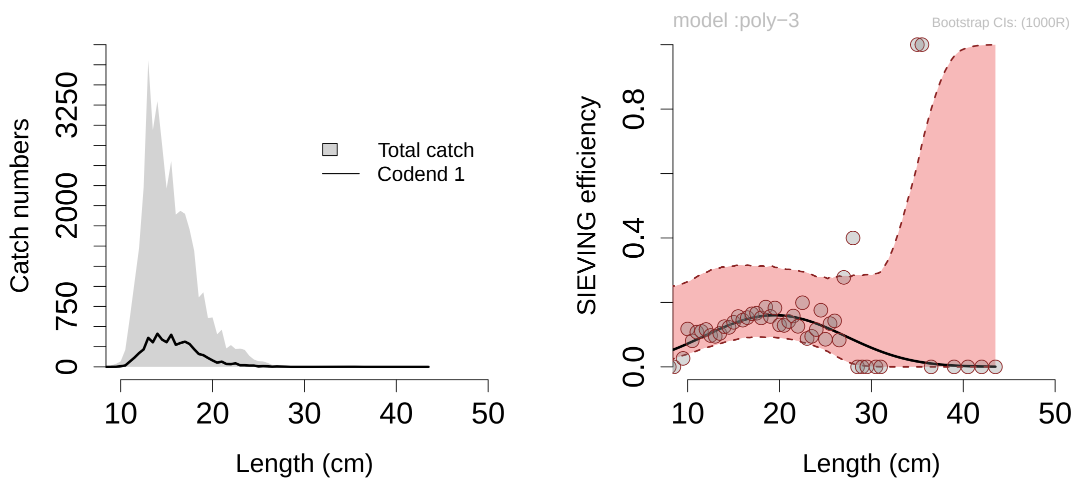

Figure 13: Left: Dab catch profile observed in Hespan 5 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

Whiting

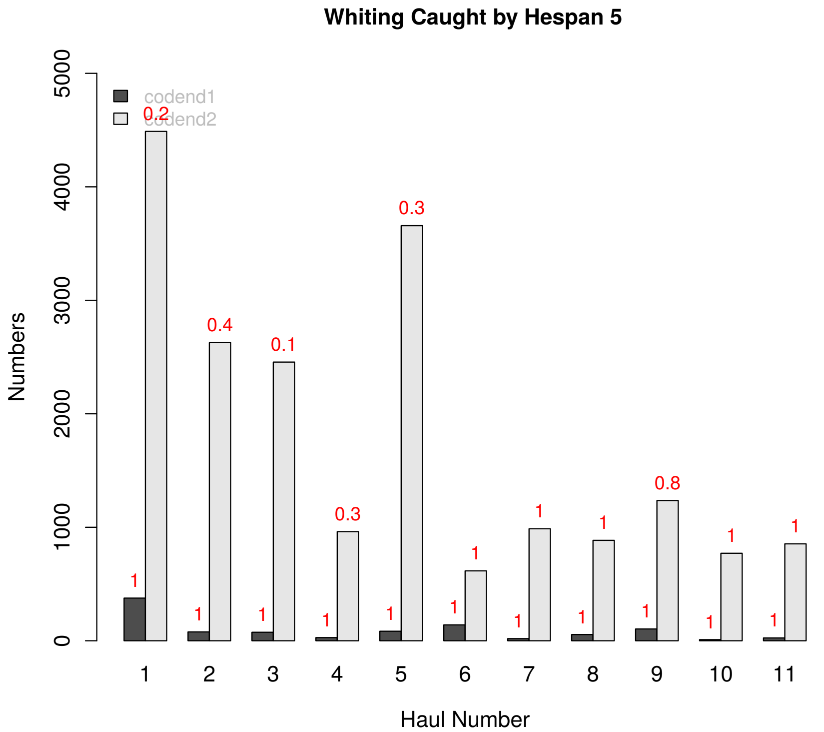

Figure 14: Whiting catches with Hespan 5 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

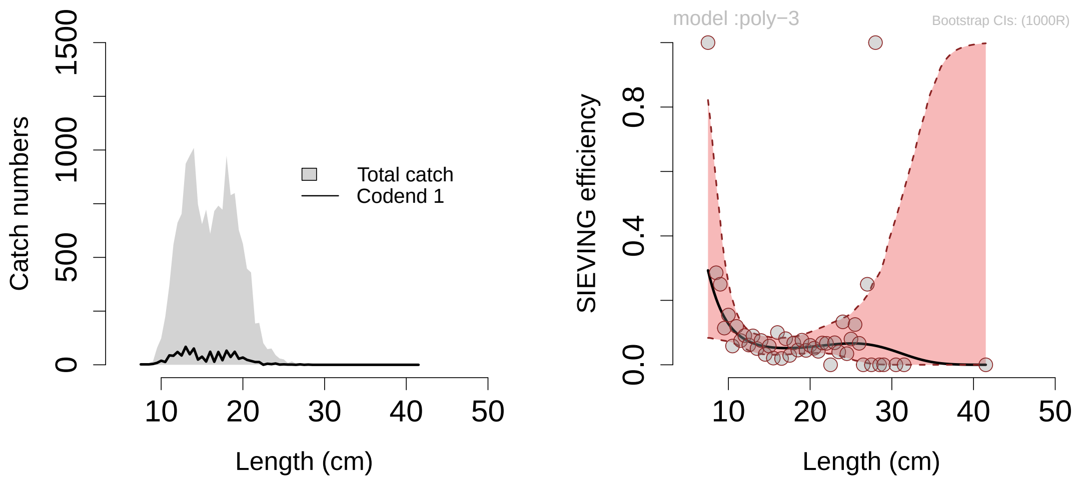

Figure 15: Left: Whiting catch profile observed in Hespan 5 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

3.1.2 Hespan 6

- 11 valid hauls were conducted using Hespan 6 between 11.09 and 14.09. The first 4 hauls were conducted in the Puzzle hole, and the last 7 on the White bank(Table 3).
- As with Hespan 5, largest catches occurred in the White bank. Most of these volumes were caught in codend 2. (Figure 16).
- Similarly as in the case of Hespan 5, few but large *Nephrops* individuals were often observed in codend 2 (Figure 17).
- $\sim$ 77% and $\sim$ 90% of the marketable (above Industrial MCRS) and undersized (below Industrial MCRS) *Nephrops* catch volume (biomass) were caught in codend 1. Further information related to the catch fractions by weight and numbers can be found in Table 4.
- The sieving efficiency curve achieved in hespan 6 is very similar in shape as the hespan 5 curve. (Figure 18).
- Plaice was mostly caught in codend 2 (Figure 19). But (Figure 20) indicates that increasing the space between the transverse ropes, increased the probability for individuals below species MCRS to be sieved into the lower codend.
- The sieving efficiency curve for dab present a slightly different form compared to Hespan 5, the maximum average sieve efficiency is located at length $\sim 13cm$, being estimated as in the previous design below $\sim$ 20% (Figure 22).
- Whiting catch sorting followed a similar pattern as for the flatfish species, and the average sieve efficiency curve was below $\sim$ 15% for lengths larger than $\sim 10cm$.

Operational and catch information

Gear	Haul	Station	Shooting	Lat.	Long.	Heaving	Lat.	Long.	Depth	Speed
hespan6	12	753	2016-09-11 18:07:55	54.16	4.62	2016-09-11 20:07:45	54.19	4.48	48.53	2.7
hespan6	13	754	2016-09-11 20:37:25	54.19	4.45	2016-09-11 22:37:15	54.16	4.58	46.39	2.4
hespan6	14	755	2016-09-11 23:05:05	54.16	4.59	2016-09-12 01:04:45	54.19	4.47	48.91	2.3
hespan6	15	756	2016-09-12 01:32:56	54.19	4.45	2016-09-12 03:32:45	54.17	4.58	48.11	2.5
hespan6	16	757	2016-09-12 18:04:16	55.27	6.24	2016-09-12 20:04:06	55.34	6.16	49.13	2.5
hespan6	17	758	2016-09-12 21:10:47	55.35	6.15	2016-09-12 23:10:37	55.28	6.23	48.55	2.4
hespan6	18	759	2016-09-13 00:07:07	55.34	6.16	2016-09-13 02:06:57	55.41	6.09	49.53	2.7
hespan6	19	760	2016-09-13 18:10:58	55.42	6.08	2016-09-13 20:10:48	55.35	6.15	49.28	2.4
hespan6	20	761	2016-09-13 21:23:38	55.35	6.15	2016-09-13 22:53:28	55.30	6.21	48.8	2.4
hespan6	21	762	2016-09-13 23:19:58	55.30	6.21	2016-09-14 01:19:49	55.37	6.14	49.32	2.2
hespan6	22	763	2016-09-14 01:44:38	55.37	6.13	2016-09-14 03:14:29	55.31	6.19	48.74	2.4

Table 3: Physical description of the experimental hauls conducted with hespan 6.

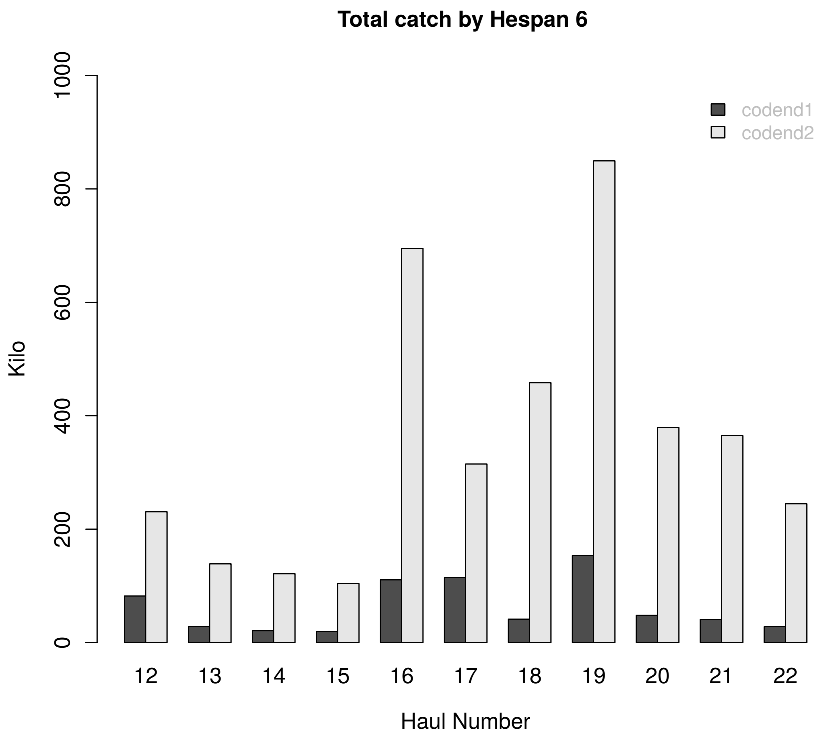

Figure 16: Total biomass caught by Hespan 6 per haul and codend (all species catches pooled).

Nephrops

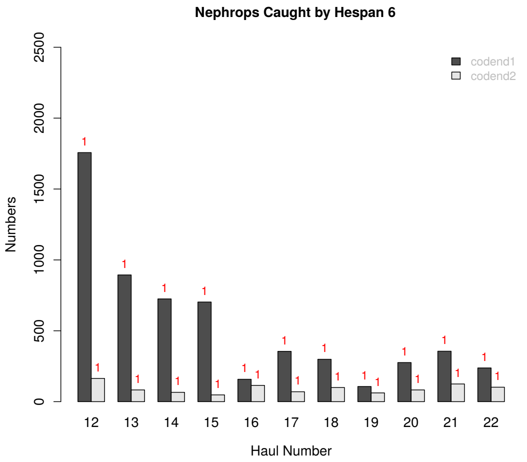

Figure 17: Total Nephrops catches (pooled hauls) with hespan 6 gear. Subsampling ratios showed in red on top of the bars (1=full sampled).

mrcs	type	fraction	codend1	codend2	rate.codend1	rate.codend2
Industry	numbers	above	2912.00	724.00	80.09	19.91
		below	2956.00	294.00	90.95	9.05
	weight	above	95.83	28.54	77.05	22.95
		below	44.04	4.49	90.74	9.26
EU	numbers	above	5446.00	983.00	84.71	15.29
		below	422.00	35.00	92.34	7.66
	weight	above	136.16	32.72	80.63	19.37
		below	3.71	0.32	92.16	7.84

Table 4: Nephrops catch rates observed in each codend relative to the total catch from Hespan 6. Estimates were done using the experimental data collected, split up using Industry and EU MCRS (CL= $32mm$ and CL= $25mm$, respectively).

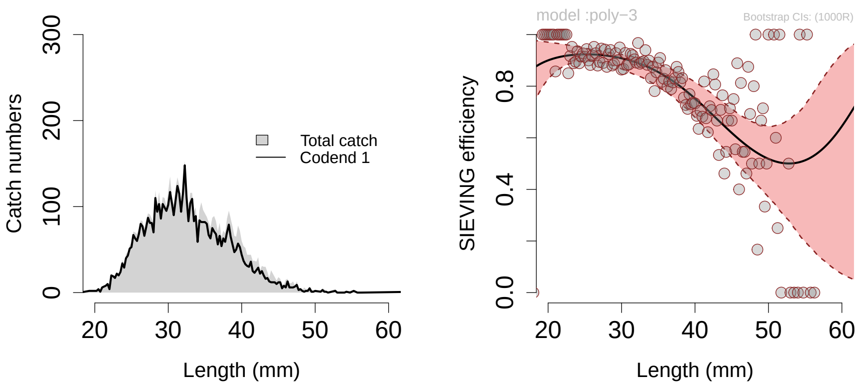

Figure 18: Left: Nephrops catch profile observed in Hespan 6 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

Plaice

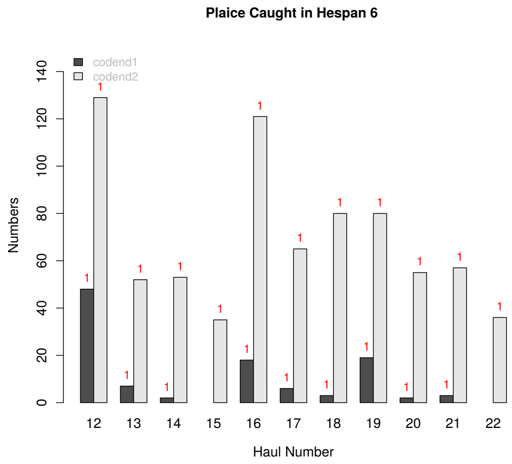

Figure 19: Plaice catches with hespan 6 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

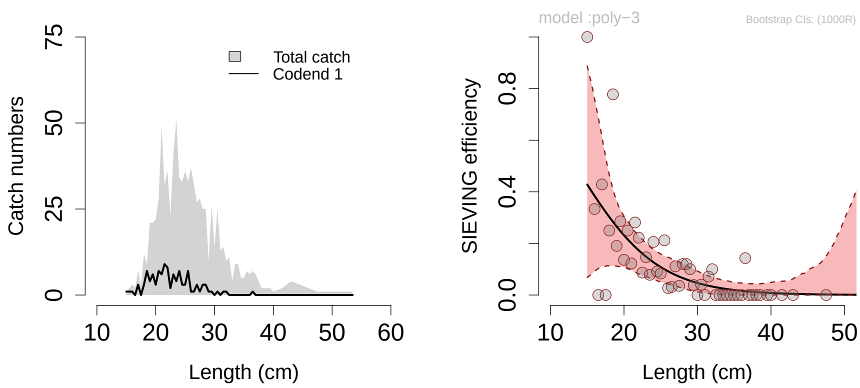

Figure 20: Left: Plaice catch profile observed in Hespan 6 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

Dab

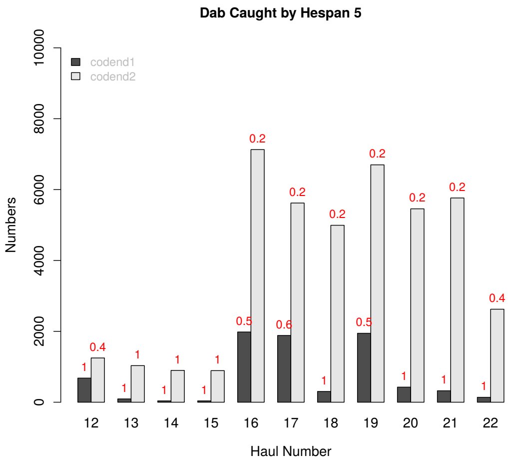

Figure 21: Dab catches with hespan 6 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

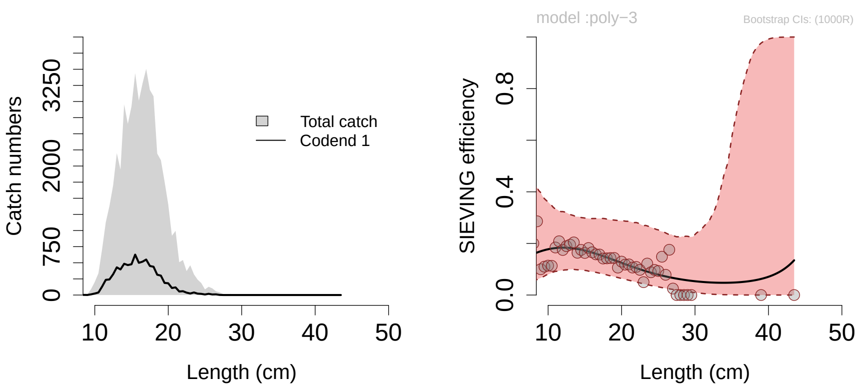

Figure 22: Left: Dab catch profile observed in Hespan 6 per codend (pooled hauls). Right: Sieving effiency curve and bootstrap CI.

Whiting

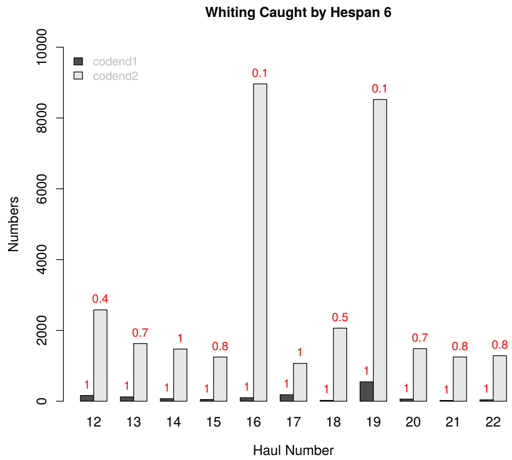

Figure 23: Whiting catches with hespan 6 per haul and codend. Subsampling ratios showed in red on top of the bars (1=full sampled).

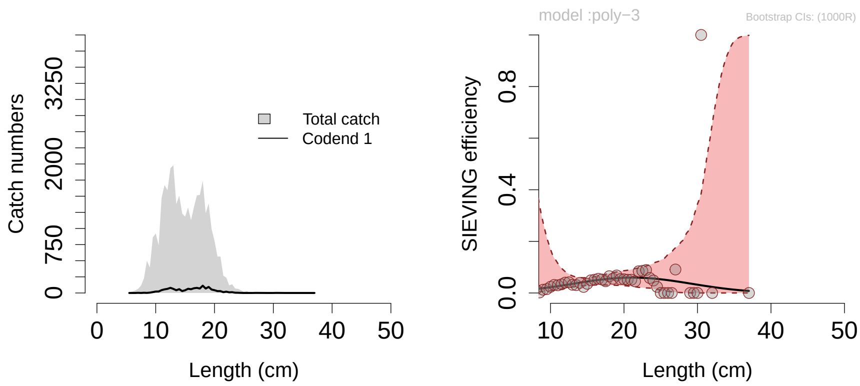

Figure 24: Left: Whiting catch profile observed in Hespan 6 per codend (pooled hauls). Right: Sieving efficiency curve and bootstrap CI.

3.1.3 Sepnep 1

- A total of 7 valid hauls performed with Sepnep 1 between 17.09 and 20.09. Four hauls were performed in Dutch waters while the remaining three in the white bank (German EEZ). Fishing depth ranged between 48 and 50 meters. Towing speed ranging between 2.3 and 2.9 knot.

- Most of *Nephrops* catches were found in codends 1 and 2, while the fraction observed in codend 3 where mostly composed by larger individuals (Figure 26).

- Considering the Industry MCRS $\sim$ 72% of the *Nephrops* weight was observed in codend 2, while the remaining catches where distributed between the codend 1 ($\sim$ 8%) and 3 ($\sim$ 20%). Non-marketable *Nephrops* where mostly observed in codend 1 $\sim$ 53% followed by codend 2 $\sim$ 38% , while less than 10% non-marketable *Nephrops* where found in codend 3. Further information related to the catch fractions by weight, numbers and the EU MCRS sorting criteria can be found in Table 6.

- As with Hespan, sieving efficiency of Sepnep 1 sievenet was negatively influenced by *Nephrops* CL, causing relative large catches ($\sim$ 20%) of marketable *Nephrops* in codend 3. On the other hand, the grid yield a steeped and precise size selection curve for *Nephrops*, with an estimated contact probability of $C = 0.69$, $L50 = 32.7mm$ and $SR = 4.0mm$ (Figure 27).

- Plaice catches were mostly observed in codends 2 and 3, and only few individuals caught in haul 28 were observed in codend 1. The plaice model shows that the effectiveness of Sepnep 1 to guide plaice towards the upper codend was strongly dependent to fish length. The models predicted that the probability for small individuals of $15cm$ to be sieved towards the lower compartment (codends 1 and 2) was $\sim$ 60%, this probability drastically reduced to 0% from lengths greater than $29cm$. The model predicted very low grid selectivity, being this results consistent with the negligible catches in codend 1 (Figure 28,Figure 29).

- Similar to plaice, dab catches were mostly observed in codends 2 and 3, although some individuals were consistently observed in codend 1 in all hauls. The effectiveness of Sepnep 1 to guide dab towards the upper codend was also strongly dependent to fish length. But in contrast to the case of plaice, the probability for small individuals to be sieved towards the lower compartment (codends 1 and 2) reached a peak $\sim$ 50% in length $16cm$, being this probability reduced towards smaller and larger sizes, resulting in a bell-shaped curve. The grid size selection curve was positioned far in the left side ($L50 = 5.9cm$, $SR = 7.0cm$), the available population length range, is explaining the low catches in codend 1 (Figure 30,Figure 31).

- Whiting was mostly observed in codends 2 and 3, although some smaller individuals were consistently observed in codend 1 in all hauls. Contrary to the other species, the sorting efficiency of Sepnep 1 was not length-dependent, and the probability for a individual to be sieved was $\sim$ 40% regardless body length. The estimated grid size selection curve was located in the left side of the plot ($L50 = 12.3cm$, $SR = 6.6cm$), resulting in a clear size selection for small sizes below 20 cm (Figure 32,Figure 33).

Operational and catch information

Gear	Haul	Station	Shooting	Lat.	Long.	Heaving	Lat.	Long.	Depth	Speed	
sepnep1	28	770	2016-09-17 18:10:04	54.20	4.29	2016-09-17 20:09:53	54.19	4.45	49.44	49.44	2.90
sepnep1	29	771	2016-09-17 20:37:43	54.19	4.44	2016-09-17 22:37:33	54.20	4.28	49.93	49.93	2.30
sepnep1	30	772	2016-09-17 23:03:03	54.20	4.29	2016-09-18 01:02:53	54.19	4.44	48.90	48.90	2.50
sepnep1	31	773	2016-09-18 01:30:03	54.19	4.43	2016-09-18 03:30:03	54.20	4.28	48.96	48.96	2.70
sepnep1	37	779	2016-09-19 20:48:58	55.34	6.16	2016-09-19 22:48:48	55.42	6.08	49.54	49.54	2.60
sepnep1	38	780	2016-09-19 23:12:08	55.42	6.07	2016-09-20 01:11:58	55.35	6.15	49.26	49.26	2.70
sepnep1	39	781	2016-09-20 01:37:38	55.35	6.15	2016-09-20 03:37:38	55.27	6.23	48.60	48.60	2.70

Table 5: Physical description of the experimental hauls conducted with Sepnep 1.

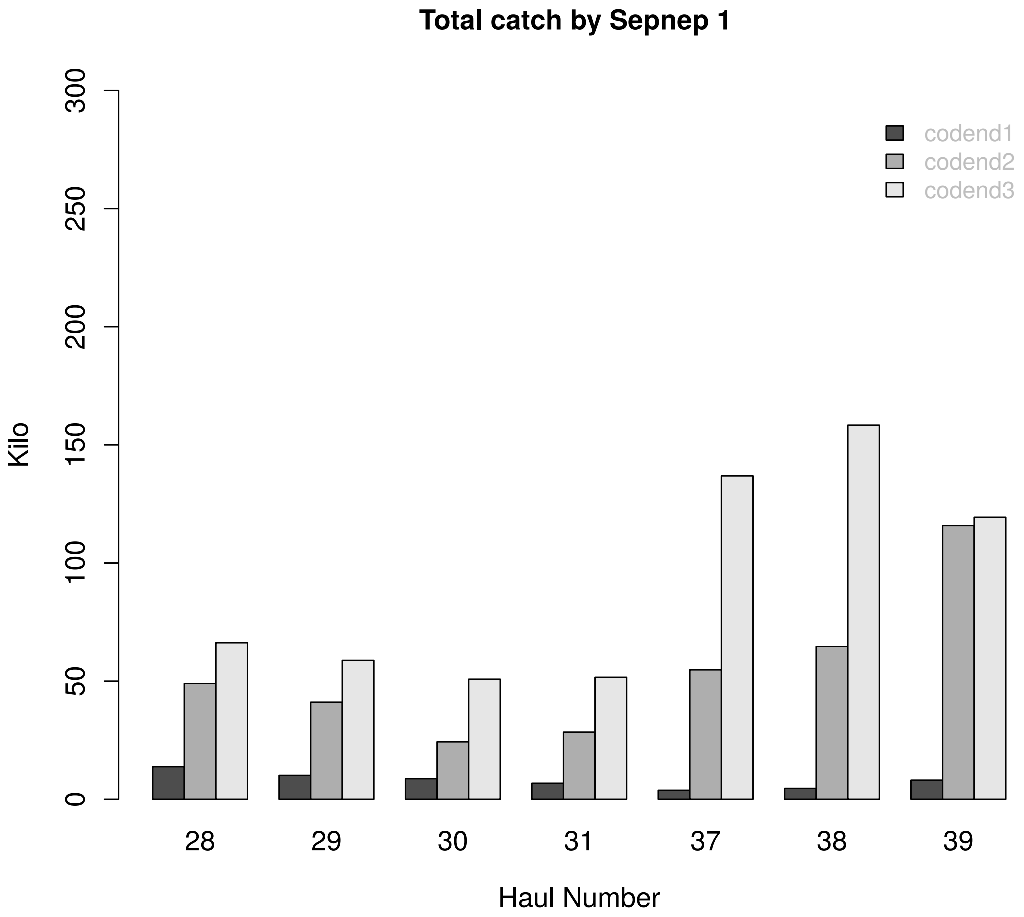

Figure 25: Total biomass caught by Sepnep 1 per haul and codend (all species catches pooled).

Nephrops

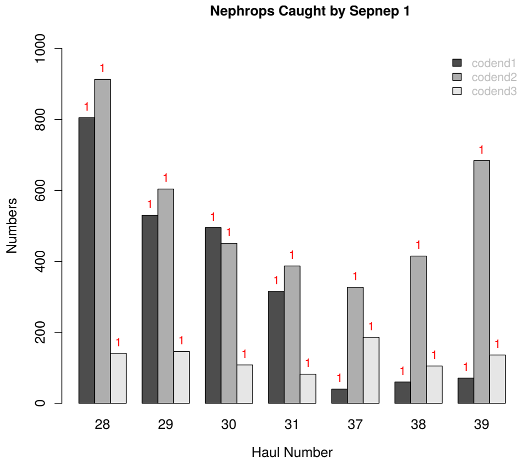

Figure 26: Total Nephrops catches (pooled hauls) with Sepnep 1 gear. Subsampling ratios showed in red on top of the bars (1=full sampled).

MRCS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
Industry	numbers	above	363.00	2486.00	636.00	10.42	71.33	18.25
		below	1954.00	1295.00	268.00	55.56	36.82	7.62
	weight	above	9.06	86.21	23.84	7.60	72.38	20.01
		below	27.31	19.97	4.05	53.20	38.91	7.89
EU	numbers	above	1893.00	3628.00	861.00	29.66	56.85	13.49
		below	424.00	153.00	43.00	68.39	24.68	6.94
	weight	above	32.74	104.84	27.51	19.83	63.51	16.66
		below	3.63	1.34	0.38	67.89	25.04	7.07

Table 6: *Nephrops* catch rates observed in each codend relative to the total catch from Sepnep 1. Estimates were done using the experimental data collected, split up using Industry and EU MCRS (CL= $32mm$ and CL= $25mm$, respectively).

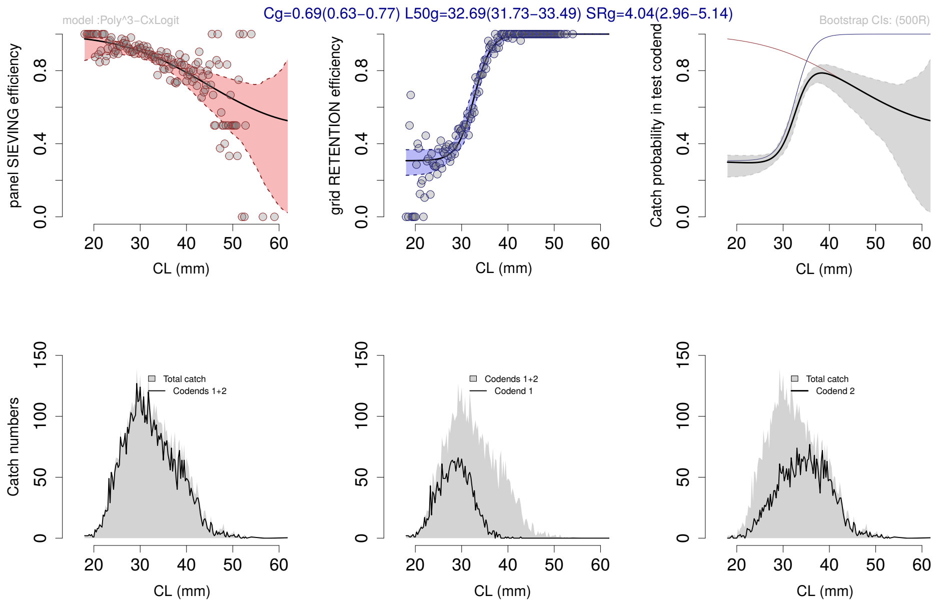

Figure 27: Predicted sieving efficiency by Sepnep 1 sievenet (top left), size selection curve of t he grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

Plaice

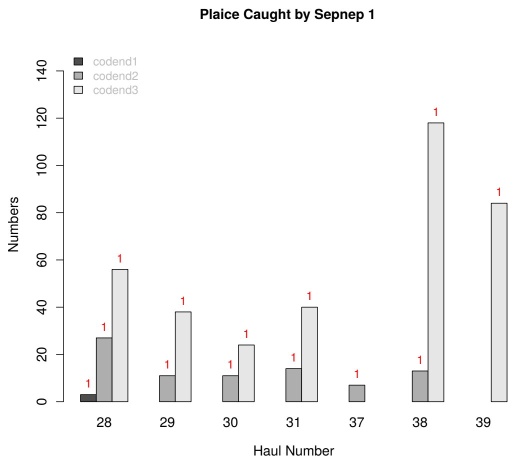

Figure 28: Total plaice catches (pooled hauls) with Sepnep 1. Subsampling ratios showed in red on top of the bars (1=full sampled) Data from hauls 37 and 39 not used in model analysis due to technical problems in the collection of length data from codend 2 or 3.

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
27cm	numbers	above	0.00	0.00	129.00	0.00	0.00	100.00
27cm		below	3.00	83.00	231.00	0.95	26.18	72.87
27cm	weight	above	0.00	0.00	40.69	0.00	0.00	100.00
27cm		below	0.23	7.69	29.22	0.61	20.71	78.68

Table 7: Catch rates of plaice observed in each codend relative to the total catch from Sepnep 1. Rates estimated for fractions above and below species MCRS (27cm) in terms of abundance and biomass (estimated using available length-weight relationship.)

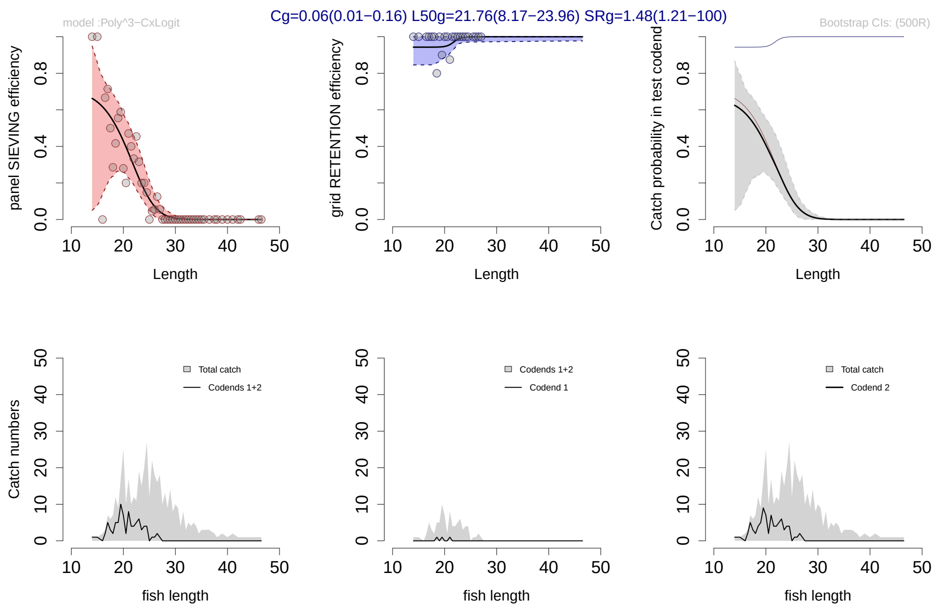

Figure 29: Predicted sieving efficiency by Sepnep 1 sievenet on plaice (top left), size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

Dab

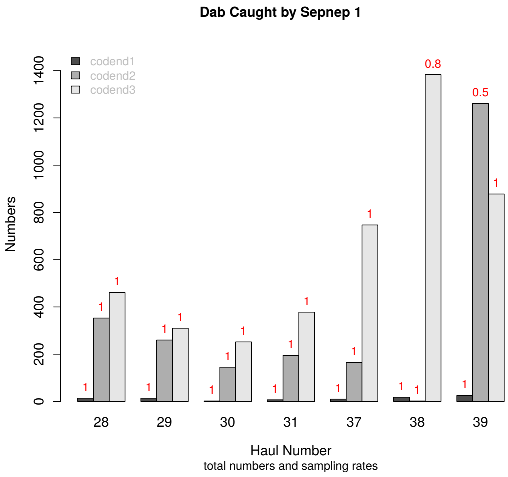

Figure 30: Total dab catches (pooled hauls) with Sepnep 1 gear. Subsampling ratios showed in red on top of the bars (1=full sampled). Data from hauls 37 and 38 not used in model analysis due to technical problems in the collection of length data from codend 2.

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
25cm	numbers	above	0.00	4.82	64.25	0.00	6.98	93.02
25cm		below	90.00	2376.30	4345.08	1.32	34.89	63.79
25cm	weight	above	0.00	1.08	12.86	0.00	7.71	92.29
25cm		below	3.46	123.29	262.84	0.89	31.65	67.47

Table 8: Catch rates of dab observed in each codend relative to the total catch. Rates estimated for fractions above and below an arbitrary MCRS of 25cm.

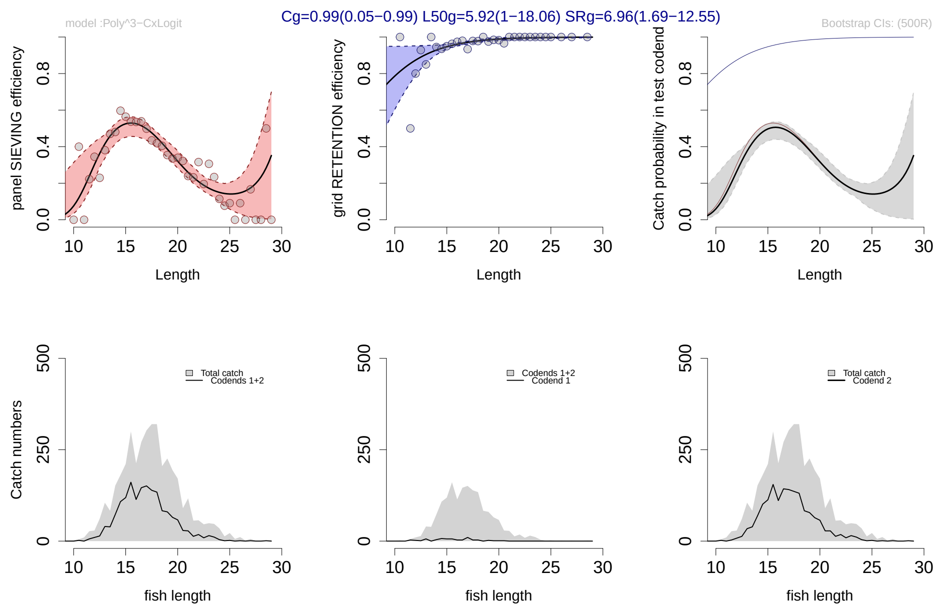

Figure 31: Predicted sieving efficiency by Sepnep 1 sievenet (top left) on plaice, size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

Whiting

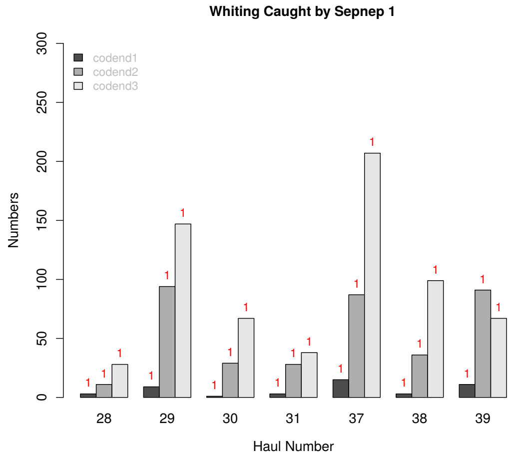

Figure 32: Total whiting catches (pooled hauls) with Sepnep 1 gear. Subsampling ratios showed in red on top of the bars (1=full sampled).

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
27cm	numbers	above	1.00	2.00	6.00	11.11	22.22	66.67
27cm		below	44.00	374.00	647.00	4.13	35.12	60.75
27cm	weight	above	0.21	0.45	1.75	8.85	18.73	72.42
27cm		below	1.45	23.90	38.16	2.28	37.63	60.09

Table 9: Whiting catch rates observed in each codend relative to the total catch. Rates estimated for fractions above and below species MCRS(27cm) in terms of abundance and biomass (estimated using available length-weight relationship.)

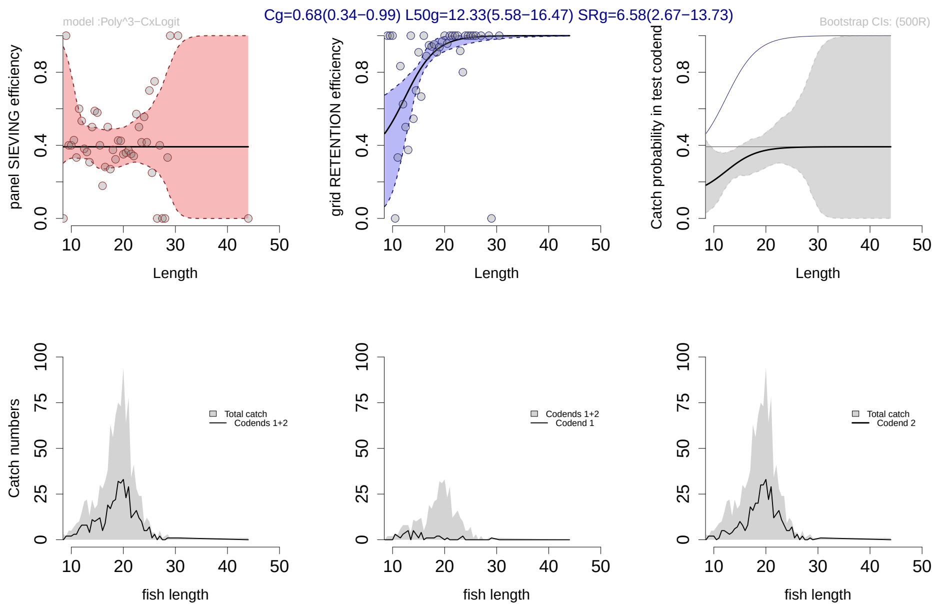

Figure 33: Predicted sieving efficiency by Sepnep 1 sievenet (top left) on whiting, size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top

3.1.4 Sepnep 2

- A total of 11 valid hauls performed with Sepnep 2 18.09 and 22.09. Three hauls were performed in Dutch waters while the remaining 9 were on the white bank (German EEZ). Fishing depth ranged between 49 and 50 meters. Towing speed ranged between 2.5 and 2.8 knots.

- Most of the *Nephrops* were observed in codends 1 and 2, specially in the first 3 hauls (Dutch fishing grounds). On the fishing grounds around the white bank (German EEZ) most *Nephrops* were found in codend 2. (Figure 35). Fractions observed in codend 3 where mostly composed by larger individuals.

- Considering the Industry MCRS $\sim$ 81% of the *Nephrops* biomass was observed in codend 2, while the remaining catches where distributed between the codend 1 ($\sim$ 6%) and 3 ($\sim$ 13%). Non-marketable *Nephrops* where mostly observed in codend 1 $\sim$ 56% followed by codend 2 $\sim$ 39% , while less than 6% non-marketable *Nephrops* where found in codend 3. Further information related to the catch fractions by weight, numbers and the EU MCRS sorting criteria can be found in Table 11.

- Catches of larger *Nephrops* observed in codend 3 occurred due to a size-dependency of Sepnep 2 sieving efficiency. On the other hand, the grid yields a steep and precise size selection curve for *Nephrops*, with an estimated contact probability of $C = 0.68$, $L50 = 33.0mm$ and $SR = 3.6mm$ (Figure 36).

- Plaice catches were mostly observed in codends 2 and 3, and only few individuals caught in haul 40 were observed in codend 1. The plaice model shows that the effectiveness of Sepnep 2 to guide plaice towards the upper codend was strongly dependent to fish length. The models predicted a probability of $\sim$ 65% for small individuals of 15 to be sieved towards the lower compartment (codends 1 and 2), being this probability drastically reduced to 0% from lengths greater than $29cm$. The model predicted very low grid selectivity, being this results consistent with the negligible catches in codend 1 (Figure 37,Figure 38).

- Similar to plaice, dab catches were mostly observed in codends 2 and 3, although few individuals were consistently observed in codend 1 in all hauls. The effectiveness of Sepnep 2 to guide dab towards the upper codend was also strongly dependent to fish length. But in contrast to the case of plaice, the probability for small individuals to be sieved towards the lower compartment (codends 1 and 2) reached a peak $\sim$ 55% at a length of $16cm$, this probability decreased towards smaller and larger sizes, resulting in a bell-shaped curve. The grid size selection curve was positioned far in the left side ($L50 = 1.2cm$, $SR = 11.7cm$) considering the available population length range, this could explain the low catches in codend 1 (Figure 39,Figure 40).

- Whiting was mostly observed in codends 2 and 3, although some individuals were consistently observed in codend 1 in all hauls. The sorting efficiency of the sepnep 2 was length-dependent, and the probability for a individual to be sieved was increasing with body length from $\sim$ 20% at $10cm$ towards $\sim$ 40% at $30cm$. The estimated grid size selection curve was located in the left side of the plot ($L50 = 14.5cm$, $SR = 4.5cm$), resulting in a clear size selection for small sizes below 20 cm (Figure 41,Figure 42).

Operational and catch information

Gear	Haul	Station	Shooting	Lat.	Long.	Heaving	Lat.	Long.	Depth	Speed	
sepnep 2	33	775	2016-09-18 20:51:45	54.20	4.45	2016-09-18 22:51:35	54.23	4.31	49.70	49.70	2.50
sepnep 2	34	776	2016-09-18 23:14:15	54.23	4.31	2016-09-19 01:13:49	54.20	4.45	48.79	48.79	2.60
sepnep 2	35	777	2016-09-19 01:36:09	54.20	4.45	2016-09-19 03:35:57	54.23	4.31	48.81	48.81	2.70
sepnep 2	36	778	2016-09-19 18:10:28	55.28	6.22	2016-09-19 20:10:18	55.36	6.14	49.10	49.10	2.60
sepnep 2	40	782	2016-09-20 18:09:17	55.27	6.24	2016-09-20 20:09:07	55.34	6.16	49.17	49.17	2.70
sepnep 2	41	783	2016-09-20 20:35:47	55.34	6.15	2016-09-20 22:35:37	55.42	6.08	49.45	49.45	2.60
sepnep 2	42	784	2016-09-20 22:57:47	55.42	6.08	2016-09-21 00:57:37	55.34	6.15	49.18	49.18	2.80
sepnep 2	44	786	2016-09-21 18:09:56	55.28	6.24	2016-09-21 20:09:46	55.35	6.15	49.27	49.27	2.60
sepnep 2	45	787	2016-09-21 20:35:17	55.34	6.15	2016-09-21 22:35:06	55.42	6.08	49.43	49.43	2.60
sepnep 2	46	788	2016-09-21 22:59:06	55.42	6.07	2016-09-22 00:58:56	55.34	6.15	49.03	49.03	2.60
sepnep 2	47	789	2016-09-22 01:20:26	55.34	6.15	2016-09-22 03:20:16	55.26	6.24	48.46	48.46	2.6

Table 10: Physical description of the experimental hauls conducted with Sepnep 2.

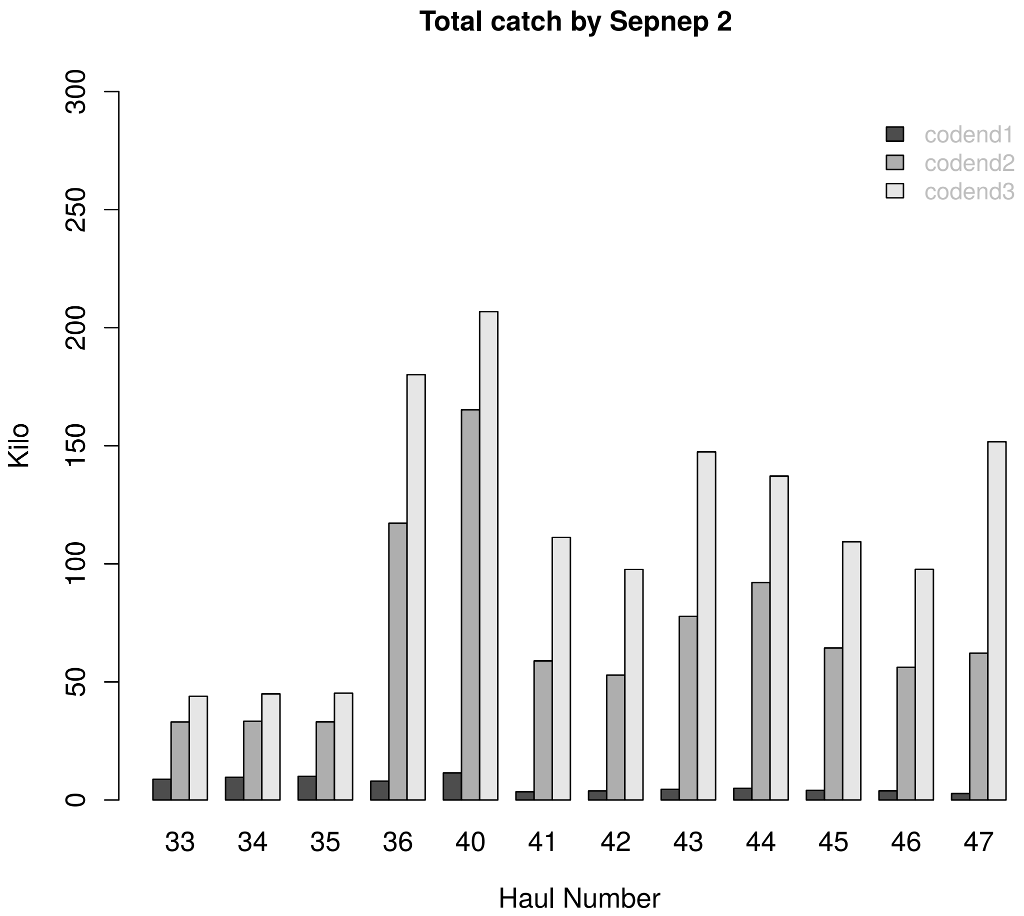

Figure 34: Total biomass caught (pooled hauls) with sepnep 2 gear.

Nephrops

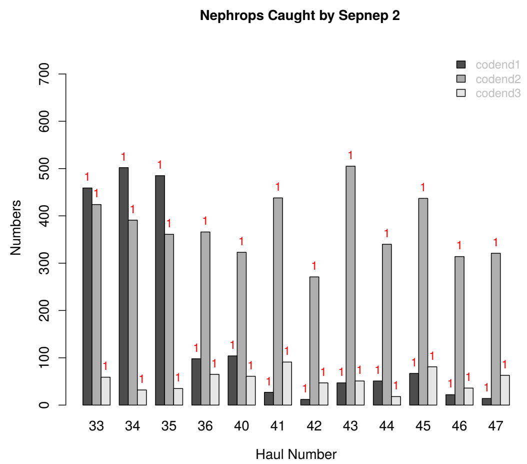

Figure 35: Total *Nephrops* catches (pooled hauls) with sepnep 2. Subsampling ratios showed in red on top of the bars (1=full sampled).

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
Industry	numbers	above	404.00	3533.00	504.00	9.10	79.55	11.35
		below	1484.00	958.00	135.00	57.59	37.18	5.24
	weight	above	10.26	129.53	20.73	6.39	80.69	12.91
		below	21.17	14.78	2.06	55.69	38.88	5.43
EU	numbers	above	1613.00	4375.00	622.00	24.40	66.19	9.41
		below	275.00	116.00	17.00	67.40	28.43	4.17
	weight	above	28.97	143.27	22.64	14.87	73.52	11.62
		below	2.46	1.05	0.16	67.13	28.57	4.29

Table 11: *Nephrops* catch rates observed in each codend relative to the total catch from Sepnep 2. Estimates were done using the experimental data collected, split up using Industry and EU MCRS (CL= $32mm$ and CL= $25mm$, respectively).

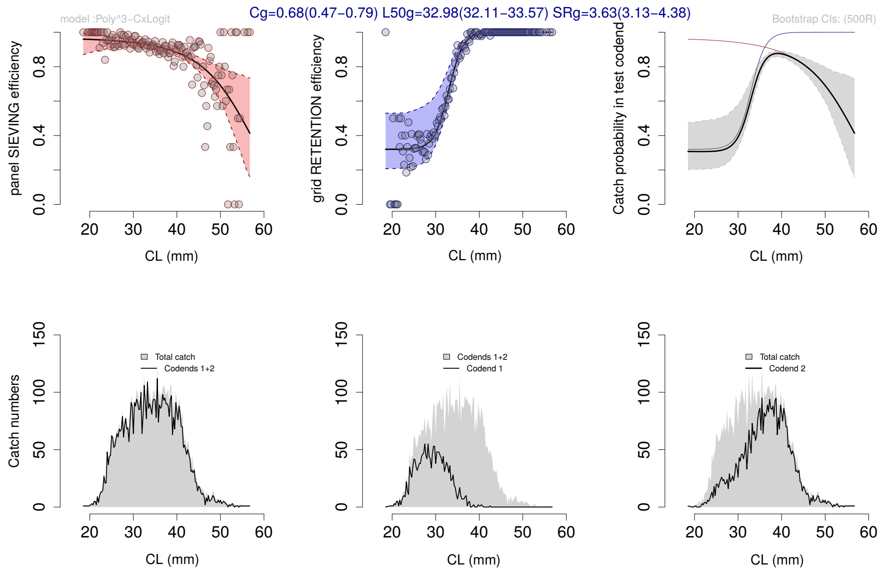

Figure 36: Predicted sieving efficiency by Sepnep 2 sievenet on *Nephrops* (top left), size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

Plaice

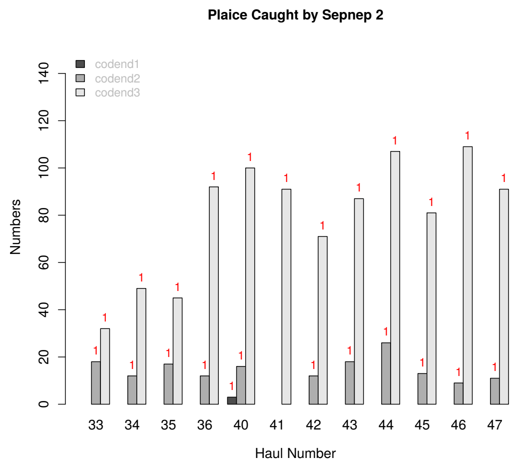

Figure 37: Total plaice catches (pooled hauls) with Sepnep 2. Subsampling ratios showed in red on top of the bars (1=full sampled).

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
27cm	numbers	above	0.00	2.00	354.00	0.00	0.56	99.44
27cm		below	3.00	133.00	423.00	0.54	23.79	75.67
27cm	weight	above	0.00	1.37	109.75	0.00	1.23	98.77
27cm		below	0.32	13.91	58.34	0.44	19.17	80.39

Table 12: Plaice catch rates observed in each codend relative to the total catch. Rates estimated for fractions above and below species MCRS (27cm) in terms of abundance and biomass (estimated using available length-weight relationship).

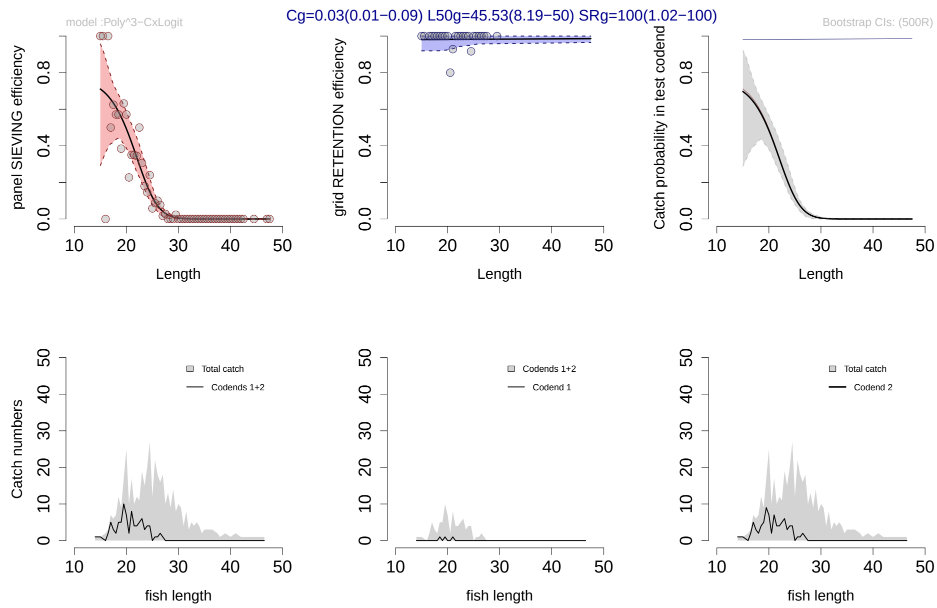

Figure 38: Predicted sieving efficiency by Sepnep 2 sievenet on plaice, size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top

Dab

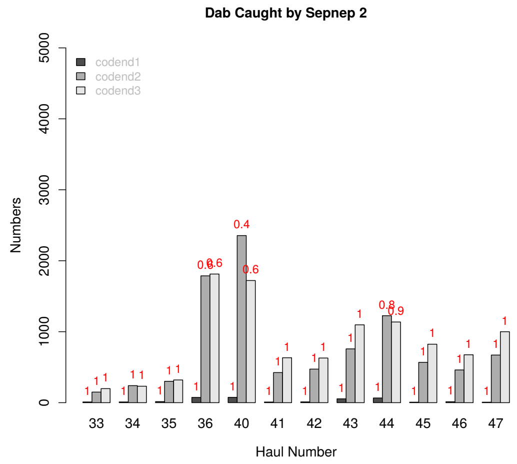

Figure 39: Total dab catches (pooled hauls) with Sepnep 2. Subsampling ratios showed in red on top of the bars (1=full sampled). Data from hauls 46 and 47 not used in model analysis due to problems in the collection of length data from codend 3.

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
25cm	numbers	above	0.00	5.51	117.78	0.00	4.47	95.53
25cm		below	290.00	7978.40	8063.88	1.78	48.85	49.37
25cm	weight	above	0.00	1.00	25.65	0.00	3.75	96.25
25cm		below	12.36	406.37	496.44	1.35	44.40	54.25

Table 13: Dab catch rates observed in each codend relative to the total catch. Rates estimated for fractions above and below an arbitrary MCRS of 25cm.

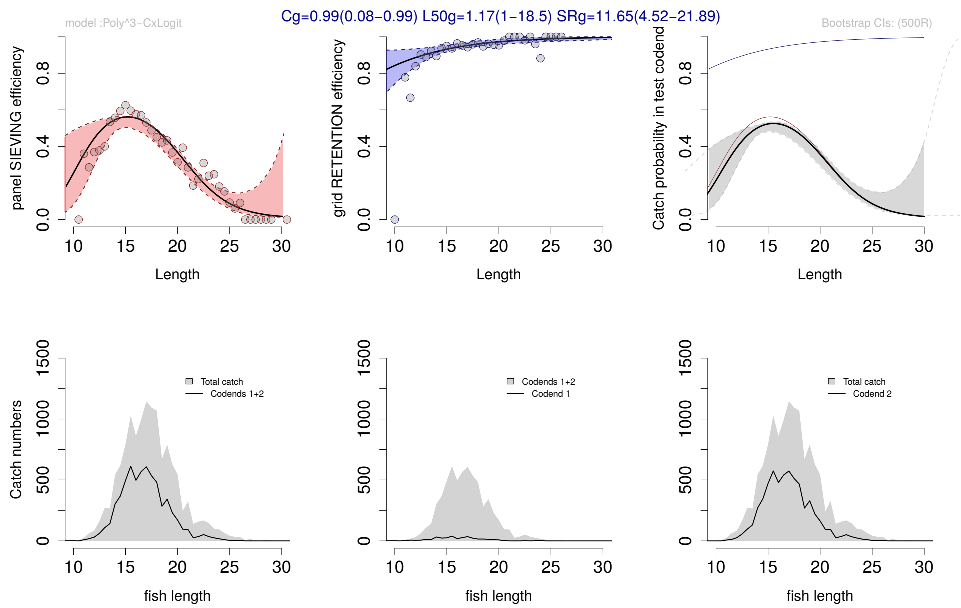

Figure 40: Predicted sieving efficiency by Sepnep 2 sievenet on dab (top left), size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

Whiting

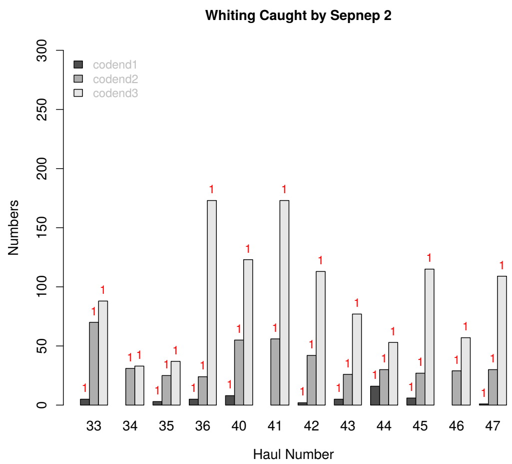

Figure 41: Total whiting catches (pooled hauls) with Sepnep 2. Subsampling ratios showed in red on top of the bars (1=full sampled).

MCRS	type	fraction	codend1	codend2	codend3	rate.codend1	rate.codend2	rate.codend3
27cm	numbers	above	0.00	8.00	8.00	0.00	50.00	50.00
27cm		below	45.00	381.00	957.00	3.25	27.55	69.20
27cm	weight	above	0.00	1.90	2.02	0.00	48.56	51.44
27cm		below	1.82	27.87	61.16	2.00	30.68	67.32

Table 14: Whiting catch rates observed in each codend relative to the total catch. Rates estimated for fractions above and below an MCRS of 27cm

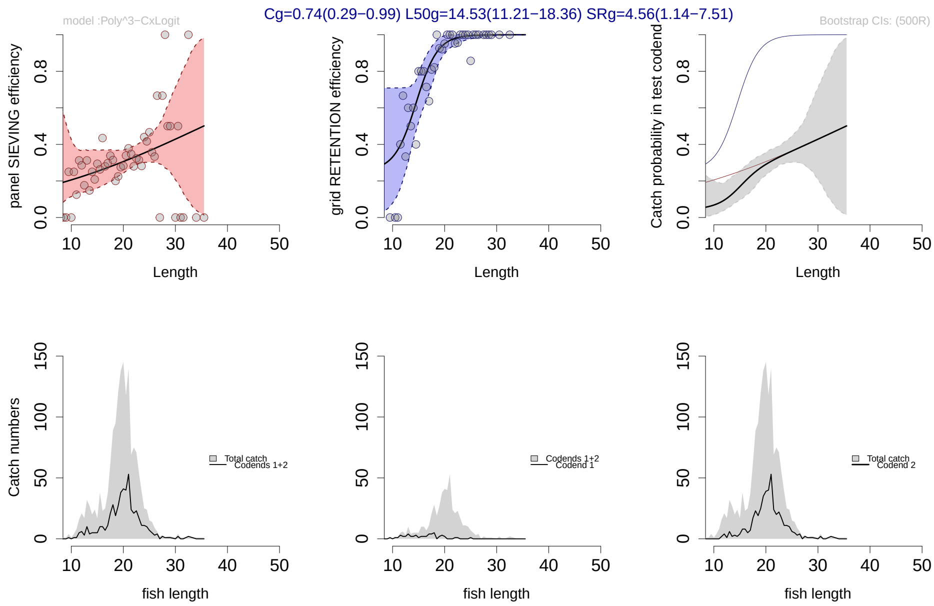

Figure 42: Predicted sieving efficiency by Sepnep 2 sievenet 'On Whiting (top left), size selection curve of the grid installed ahead of codends 2 and 3 (top center), and combined size selection (top right). Bottom: Catch comparisons related to the model figures on top.

3.2 Pairwise comparisons

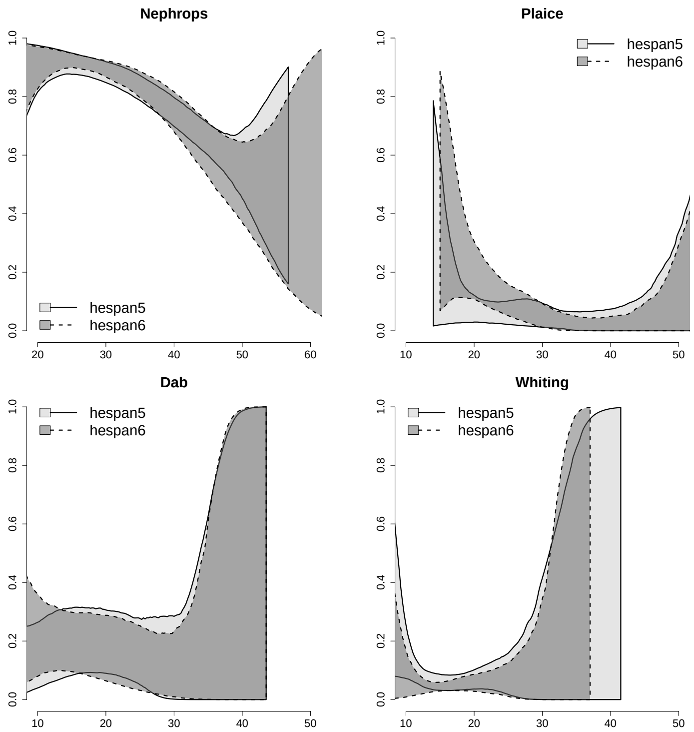

Figure 43: Comparison between hespan 5 and 6 sieving efficiency on the different species analyzed. The comparison is taken pairwise, by plotting together the bootstrap CI's from each of the estimates sieving curves estimated in the previous section. The overlap of the CI's in all cases indicate no significant differences between both designs performance.

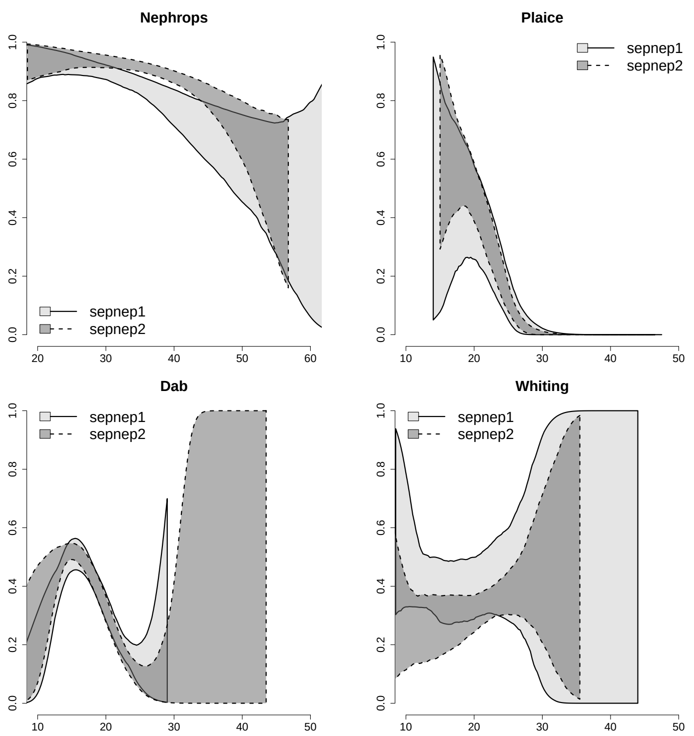

Figure 44: Comparison between sepnep 1 and sepnep 2 sieving efficiency. Sepnep 2 improved significantly the sieving efficiency obtained by Sepnep 1 on *Nephrops* in the range of sizes between $\sim 35mm$ and $\sim 45mm$ CL.

4 Underwater video recordings

Hespan

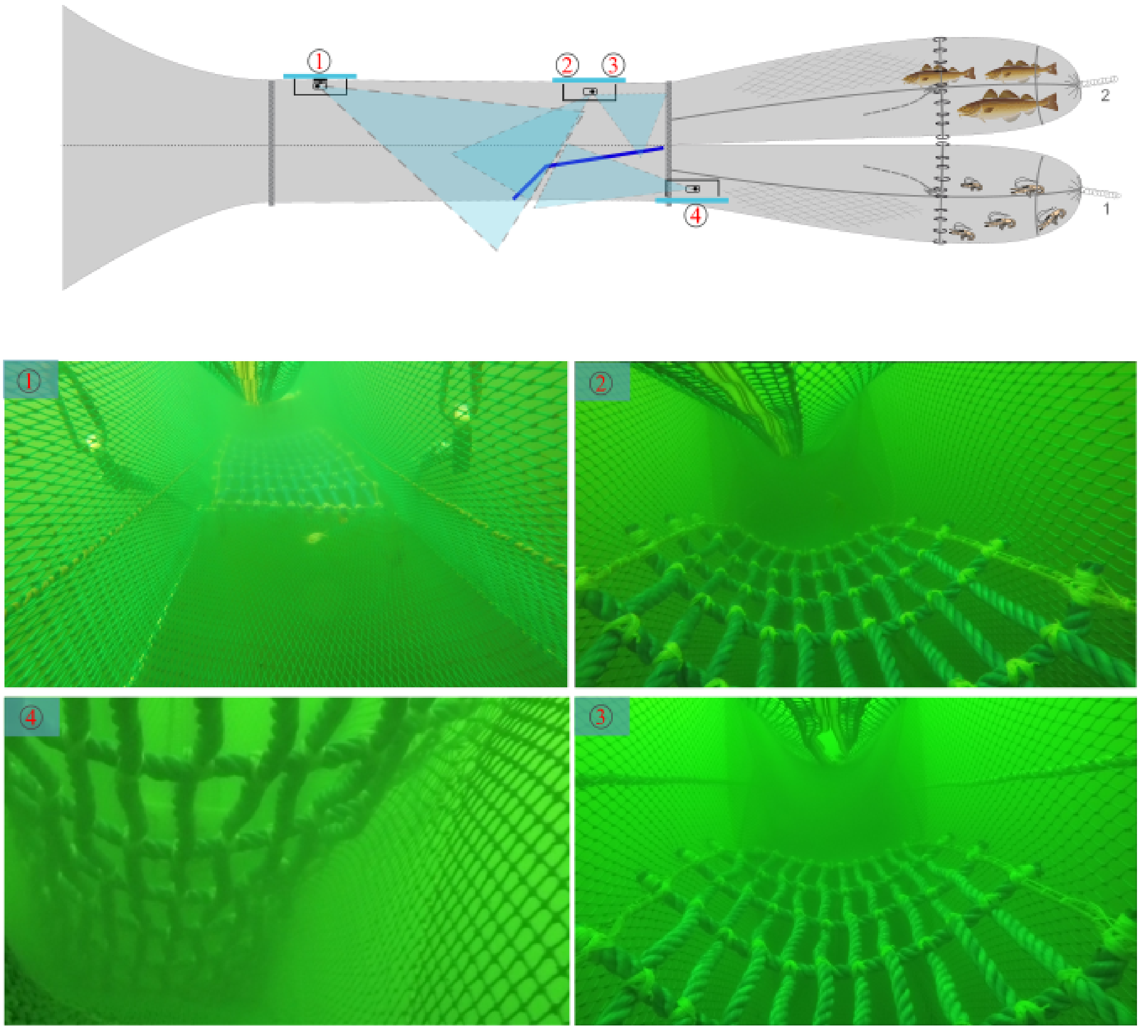

Figure 45: Different perspectives of the hespan 5. As intendend, the spaces between ropes achieved a rectangular shape. Based on the experiences from 2015 sea trials, it was assumed this shape to improve the sieving effciency on Nephrops. The panel achieved the intendend shape and inclination, consequently the lower and upper compartments were well defined. Images taken in a test haul previous to the experimental fishing.

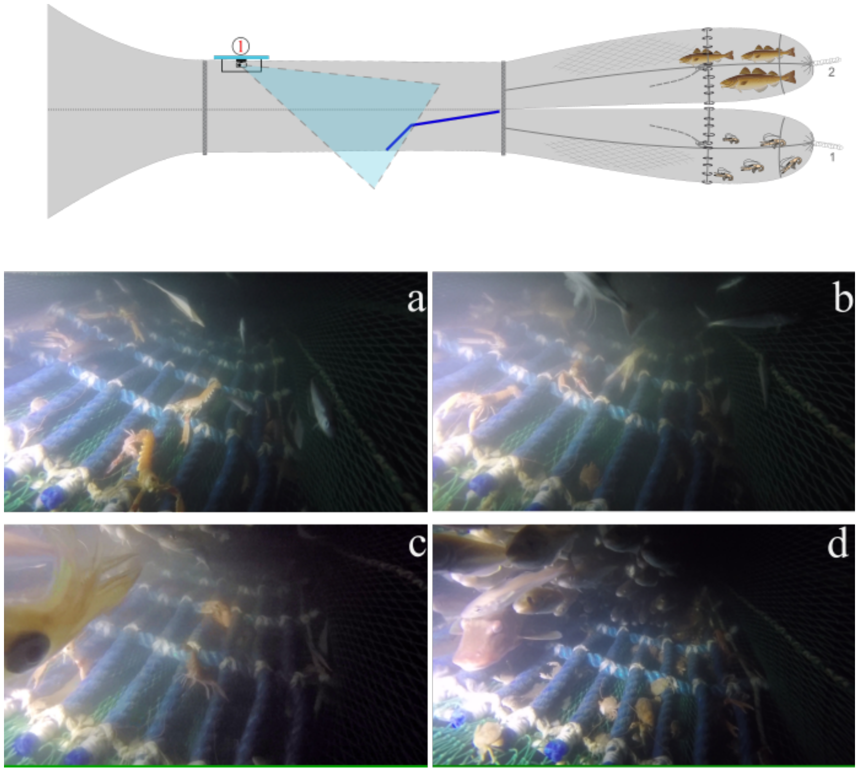

Figure 46: The thick ropes and the rectangular shape of the meshes did not prevented Nephrops behaviour that might counteract the sieving process. The video recordings showed individuals lying on the bar meshes, holding the mesh twines with the chelipeds, both in the natural or reverse body orientation , or simply walking trough the panel using the 2nd to 5th pair of pereipods (a,b). The video recordings also showed a considerable number of individuals passively passing through the first three rows of rope spaces (c). Fish were mostly guided upwards (d)

Figure 47: Most of nephrops catches were separated from the fish catch fraction, although usually a number of large individuals were found in the upper codend (green arrows).

Sepnep

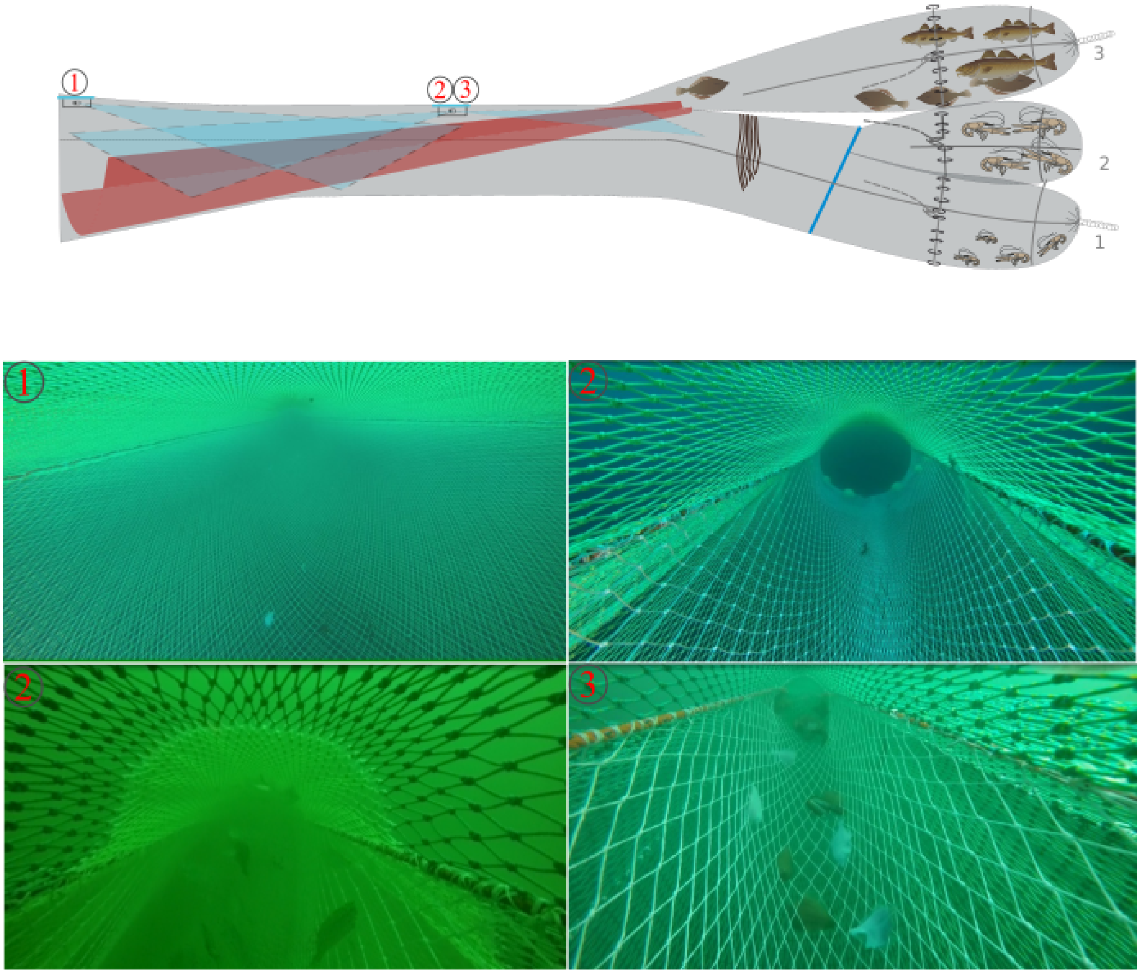

Figure 48: Several perspectives of the Sepnep sieving panel. The panel hanging lose between the red ropes, allowing sufficient space between the mesh openings to sieve Nephrops to the lower cod-end. Nephrops tend to entangle in the mesh of the panel, by struggling free they fall trough the panel. By lifting the first section of the panel from the bottom of the trawl sieving efficiency was improved. The majority of the fish is guided towards the upper cod-end, although some dab actively pass the meshes of the panel. Most images were taken while hauling or shooting the trawl, as most footage is unclear due to the proximity of the trawl to the seafloor.

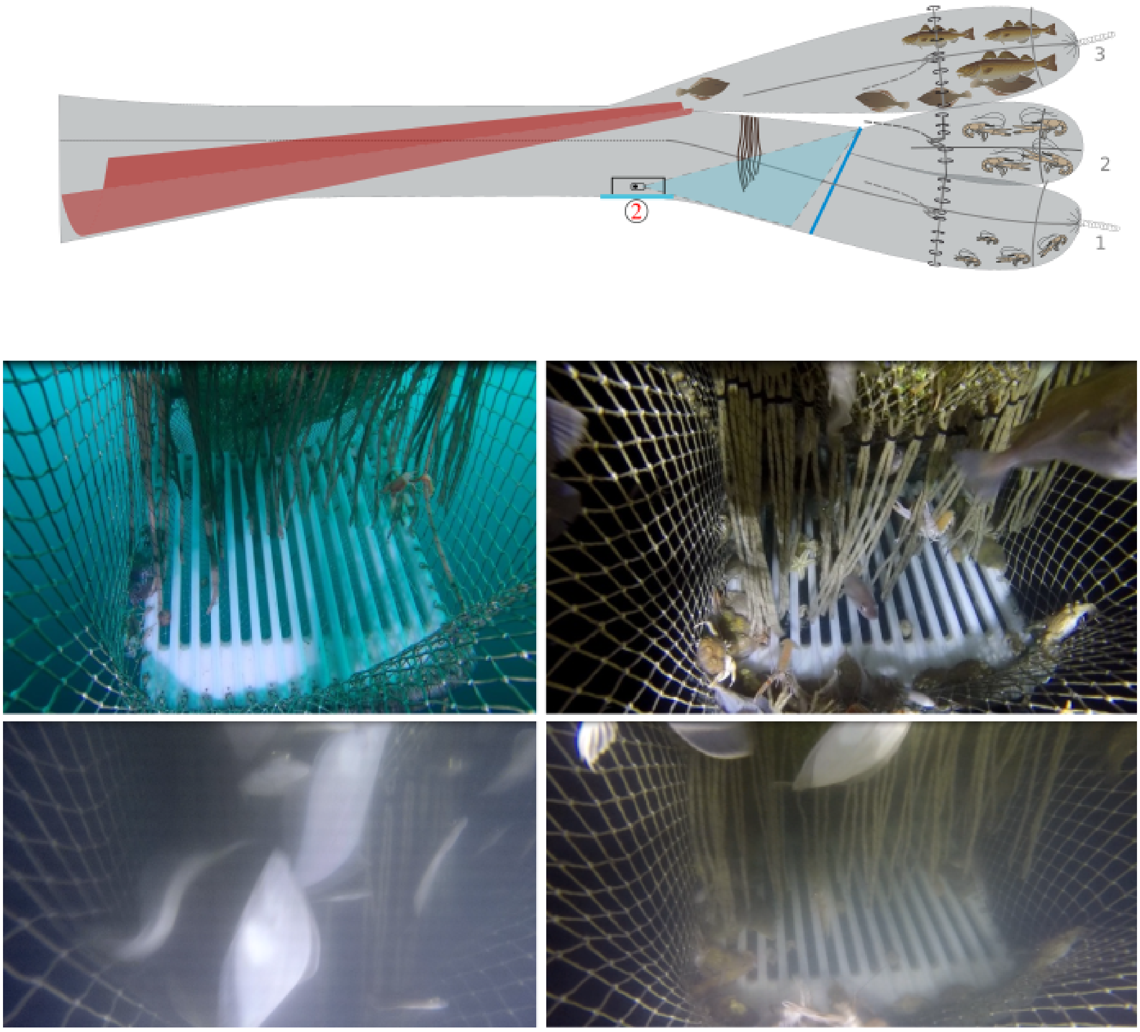

Figure 49: Nephrops sorting grid with rope curtain for size selection of Nephrops.The curtain made of weighted ropes pulled the uper panel down, preventing free entrance to cod-end2, all catch need to have contact with the bars. Observations showed an unexpected additional advantage of the ropes, the moving tip cleaned the bar openings mechanically. Besides, Nephrops were actively holding on the ropes, guiding them in position for size selection of bar openings. Dab seems to swim ahead of the rope curtain and is actively searching for an escape as can be seen on the left bottom picture.

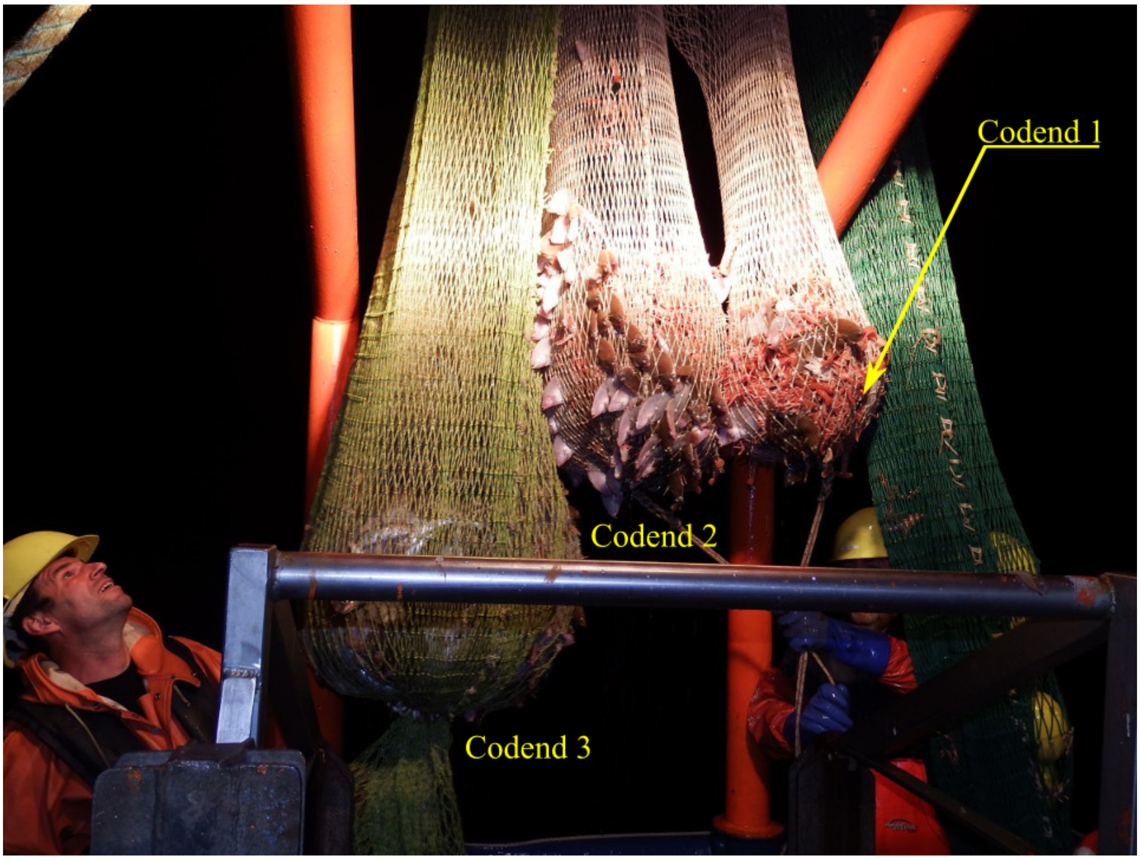

Figure 50: Crew handling the Sepnep gear with the three codends configuration. It can be observed most of catches in codend 1 is composed by (non-marketable) *Nephrops*, where cod-end 2 is a mix of marketable *Nephrops* and some dab.

5 Discussion

Achieving an efficient, multispecies size selectivity based on split up catch into separated codends with species-adapted selectivity requires a stepwise development process. First, efforts have to be invested in developing a sorting mechanism enabling an efficient catch separation. Once this is consistently achieved, the next step involves defining the size selection for each of the codends considering the market preferences and the quotas restrictions imposed by the EU LO.

Here we mainly focused on the first phase of the development process. Different designs of two species separation devices were tested experimentally. Although Hespan and Sepnep have been originally designed for different *Nephrops* fisheries, they share the same principle of implementing a sieving process in the trawl. The natural step of establishing a collaborative work between the German and Dutch partners to further develop this principle was materialized during the present `SO725` cruise.

Hespan 5 and 6 were designed shorter, and more handling and resistant than the 2015 designs, getting closer to the technical preferences of professional fishermen. The new Hespan's improved sorting efficiency, resulting in cleaner *Nephrops* catches in the lower codend (Figure 47). This good separation was possible due to the improved efficiency to guide flatfish towards the upper codend (codend 2).

However, a number of large *Nephrops* individuals were often observed in the upper codend. As in the case of 2015 designs, the probability to sieve *Nephrops* towards the lower codend was negatively related to individual CL (Figure 9 and Figure 18). The underwater video observations showed that the thick ropes used in the current designs did not deter *Nephrops* from holding the panel with the chelipeds, behavior that might counteract the sieving process. While results are promising, the sieving efficiency for the largest and most valuable *Nephrops* is still of concern. Further improvements of current designs should be developed and tested to turn the concept acceptable for uptaking in the commercial fishing fleet.

Lifting the first section of the Sepnep 2 sorting panel significantly improved the sieving efficiency on *Nephrops*, this may indicate the importance of sufficient spacing between the sorting panel and bottom of the trawl to maximize contact probability over the full length of the panel. However, this is also present for undersized dab, an increased fraction of the catch has been found in codend 2. Video analysis showed that those dab are actively attempting to escape in the lower codend just before the rope curtain. This might be a potential location to reduce unwanted bycatch of dab in codend 2 by designing an horizontal escape opening.

The steep selection curve of the improved *Nephrops* grid offers various possibilities for commercial applications. Besides reducing catches of small non-marketable *Nephrops*, various bar spacing could be used in occurrences of limited quota to particularly catch the valuable sizes. Utilization across the fleet could have positive effects on the stocks as unwanted *Nephrops* escape from the trawl in their natural habitat and are not exposed to the catch and discarding process.

Achieving optimal separation between *Nephrops* and fish species has the potential of reducing dramatically the bycatch and improve the exploitation patterns in commercial conditions. For example, under a scenario with a relative balance between plaice and *Nephrops* quota, fishermen could mount a flatfish-selective upper codend to avoid catches of small individuals. Under quota exhaustion for plaice, fishermen might completely avoid the flatfish catches by opening the upper codend during towing. In other occasions when there are no *Nephrops* in the catch during daylight hours, the lower codend could be opened to avoid unwanted by-catch.

Although the European Technical Measures do not allow fisherman to use trawls with multiple cod-ends with different mesh sizes, the results demonstrate the potential for this concept and it may be a step forward in implementing and acceptance of the EU LO by the industry.

6 Research crew members

Beate Büttner*	Technician	TI-OF)
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Stefanie Haase*	Volunteer	University of Hamburg
Steffen Hagemann	Technician	TI-OF)
Pieke Molenaar	Researcher	Wageningen Marine Resear
Juan Santos	Cruise Leader	TI-OF
Peter Schael **	Technician	TI-OF
Kerstin Schöps	Technician	TI-OF

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

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