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Prediction of size selectivity in trawl codends by simulation

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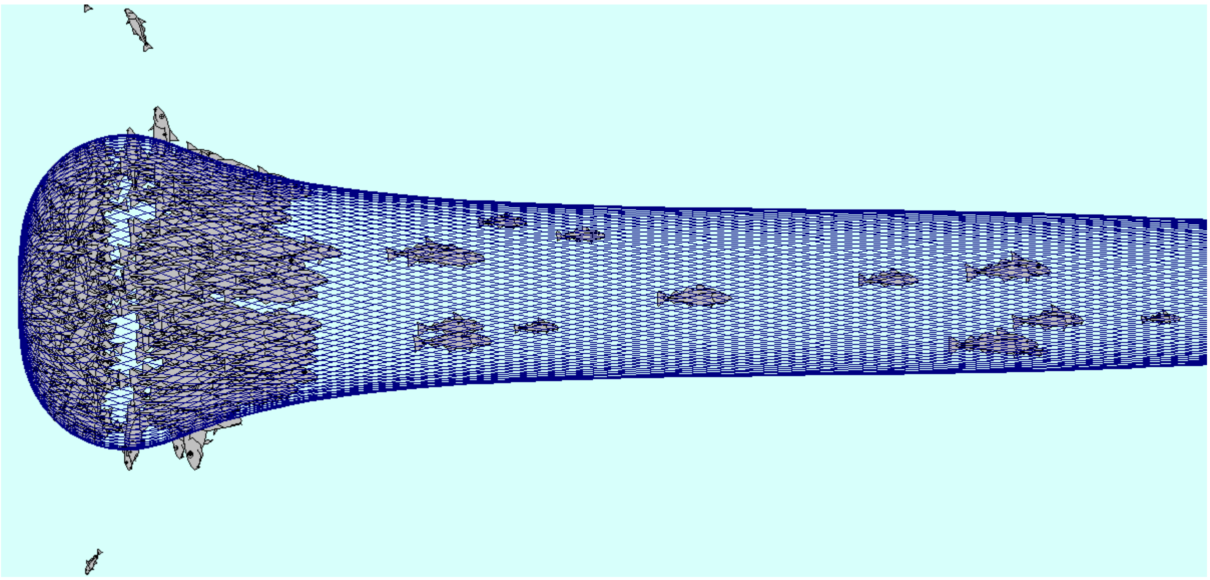

Bent Herrmann 2006
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Introduction

1.1 Structure of the document

The main purpose of the this document is to describe and test the new structural model for cod-end size selectivity and the simulation tool PRESEMO build on this model. A large part of the model development and the application of PRESEMO to simulate size selectivity has been carried in EU projects PREMECS I and PREMECS II. The contribution to the described work by the partners in these projects is acknowledged. Especially have the contributions of Daniel Priour, Finbarr O'Neill and Antonello Sala been important for the work and results reported here.

Before we describe the model and PRESEMO it is convenient first to describe the methods used today to assess selectivity and describe factors known to affect cod-end selectivity to be able to build on the experience gained from there. The testing of the models ability to simulate selectivity is on one hand tested by comparing model predictions with similar published data and on the other hand with experimental results collected as part of this project. Therefore this chapter also contain a section describing experimental trials carried in this project. The last part of the chapter describes some studies where the models as been applied to make new predictions of cod-end selectivity where no experimental results are available for comparison.

1.2 Assessing selectivity today

According to Wileman et al. (1996) size selection of fish by a fishing gear is a process that causes the catch of the gear to have a size composition different to that of the fish populations of the geographical area in which the gear is used. The size selectivity of a fishing gear describes the relative likelihood that different sizes of fish have of being caught by the gear, given that there are equal numbers of each size in the population.

The selectivity of a cod-end can be affected in two ways. Firstly, there is the variation due to controlled changes in the net. These may be changes in mesh size or number of meshes around in circumference. Secondly, there is the variation that occurs from haul to haul even though the net remains unaltered. This variation is generally attributable to several uncontrolled variables such as the randomness of fish arrival in the cod-end (Herrmann & O'Neill, 2005).

The main method used to assess the selectivity of trawl cod-ends has been to run sea trials followed by statistical analysis of the experimental catch data. Well-established procedures are documented by Wileman et al. (1996). But the between-haul variability necessitates numerous sea trials to obtain reliable results, making selectivity assessment a difficult, resource consuming task.Size selectivity experiments investigate the performance of a cod-end by comparing the size distribution of fish retained in the cod-end to the distribution of fish entering it. One method of obtaining this information is to attach a small-mesh cover over the test cod-end, so that fish which escape from the test cod-end will be retained in the cover net.

Usually several tows, also called hauls, are carried out with this net construction. For each haul, the lengths of the fish retained in the test and cover cod-ends are measured. For each species of interest, the fish in both cover and cod-end are sorted into groups by length, called length classes. Each length class (L) covers a length interval of 1.0 cm (Wileman et al., 1996). For each length class the number of fish in the cover (N2(L)) and the cod-end (N1(L)) are counted. This information can be used to estimate the retention rates r(L) for the length classes for the cod-end investigated:

$$r(L) = \frac{N1(L)}{N1(L) + N2(L)} \quad (1)$$

LENGTH CLASS L (CM)	NUMBER OF FISH IN COD-END N1(L)	NUMBER OF FISH IN COD-END + COVER N1(L)+N2(L)
15.5	0	106
16.5	0	118
17.5	0	94
18.5	2	83
19.5	5	46
20.5	0	13
21.5	0	9
22.5	1	6
23.5	1	7
24.5	3	10
25.5	2	16
26.5	15	32
27.5	25	44
28.5	32	46
29.5	68	84
30.5	44	61
31.5	26	36
32.5	42	42
33.5	25	25
35.5	18	18

Table 1: Typical set of selection data.

For one species of interest this collection of information to estimate the retention rates is called selection data. Table 1 shows a typical set of selection data.

A. size selectivity curve describes the probability that a fish will be retained by the net as a function of the length of the fish. For a cod-end in a trawl the size and shape of the mesh openings are important parameters governing the selectivity. Hence, larger fish are more likely to be retained than smaller fish. Towed gear selection curves are therefore often assumed to be monotone functions, increasing with fish length. The most commonly used mathematical description of towed gear size selection uses the logistic function:

$$p(L) = \frac{\exp(\alpha + \beta \bullet L)}{1 + \exp(\alpha + \beta \bullet L)} \quad (2)$$

where *p(L)* is the probability that a fish with length L is retained in the cod-end. The curve is described by the two parameters α and β, which are determined by fitting the function to retention rates estimated from selection data. Other types of selection curves exist, but if a satisfactory fit can be obtained with (2) then this function is preferred (Wileman et al., 1996). Two parameters are widely used to characterise the size selection of fish in a cod-end. The first is the 50% retention length L50, which is the length of fish that has a 50% probability of being retained after entering the cod-end. The second is the selection range SR, which is the difference in length between the fish that has a 75% probability of retention and that with a 25% probability of retention. Thus, SR is a measure of the sharpness of selection. If the selection is described by (2) then L50 and SR can be calculated as:

$$L50 = -\frac{\alpha}{\beta} \quad (3)$$

$$SR = \frac{2 \bullet \ln(3)}{\beta}$$

The process of performing a single haul estimation of selection parameters L50 and SR is shown in Figure 6.

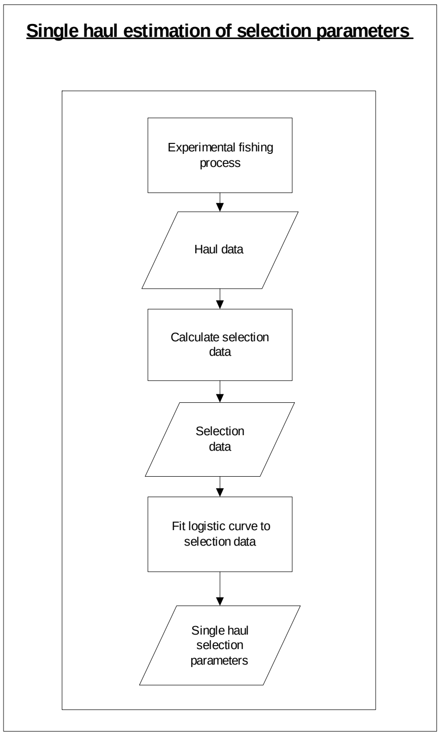

Figure 6: Flowchart for single haul estimation

1.3 Factors affecting cod-end selectivity

It has become obvious that mesh size is not the sole factor determining cod-end selection. Reeves et al. (1992) and Galbraith et al. (1994) both report that the number of meshes around the cod-end circumference affects the selectivity of round fish. Lowry and Robertson (1996) report on results indicating that the cod-end netting twine thickness affects the size selection of haddock. O’Neill and Kynoch (1996) and Lowry et al. (1998) both found that total catch weight at the end of hauling may affect size selection. Theoretical work by Jones (1963) and Reeves and Stewart (1988) both indicate that the openness of the cod-end meshes ought to be important for the size selection process. Essential to a study of this subject is knowledge of cod-end geometry, which is determined by interactions between water flow, catch size and the design and physical characteristics of the netting (O’Neill, 1997). Tschernij and Holst (1999) report that the type of vessel used in the fishing process may influence the selectivity. Furthermore, research has also investigated the role of environmental parameters, such as light intensity, water temperature and water flow, in modifying the behavioural responses of fish to their environmental and physical surroundings (Wardle, 1993).
A better understanding of the mechanisms that affect cod-end selectivity involves knowledge of how the shape of the cod-end changes during the fishing process. An understanding of the interactions between fish and cod-end is also needed.

Model of selectivity process

Demands of the model of size selectivity of cod-ends

The introduction of this chapter described well-established procedures for estimation of selection parameters L50 and SR based on haul data from an experimental fishing process (Figure 6). The new model-based method to assess selectivity described in this chapter should be able to apply these procedures but without the need for experimental fishing. Therefore the *experimental fishing process* in Figure 6, should be replaced by an artificial fishing process. This process should be based on a structural model including the interaction of the factors affecting selectivity described in the introction of this chapter. The model should thus be able to generate artificial selectivity data comparable to that produced by sea trials in assessing cod-end selectivity using the covered cod-end technique. This information can then be used to predict retention rates for the lengths classes.
A structural model would make the best use of present knowledge in the field, since it would be based on modelling the structural interactions of its components. This would open up to possibilities of investigating the internal processes of the model.

A system model consisting of fishing vessel, fishing gear and sea can be constructed. In that case, one haul of experimental trawl fishing can be viewed as a process of this system. The cod-end is a subsystem of the fishing gear. As this project is limited to the study of cod-end selectivity, it is convenient to separate out the gear and sea subsystems, as shown in Figure 14.

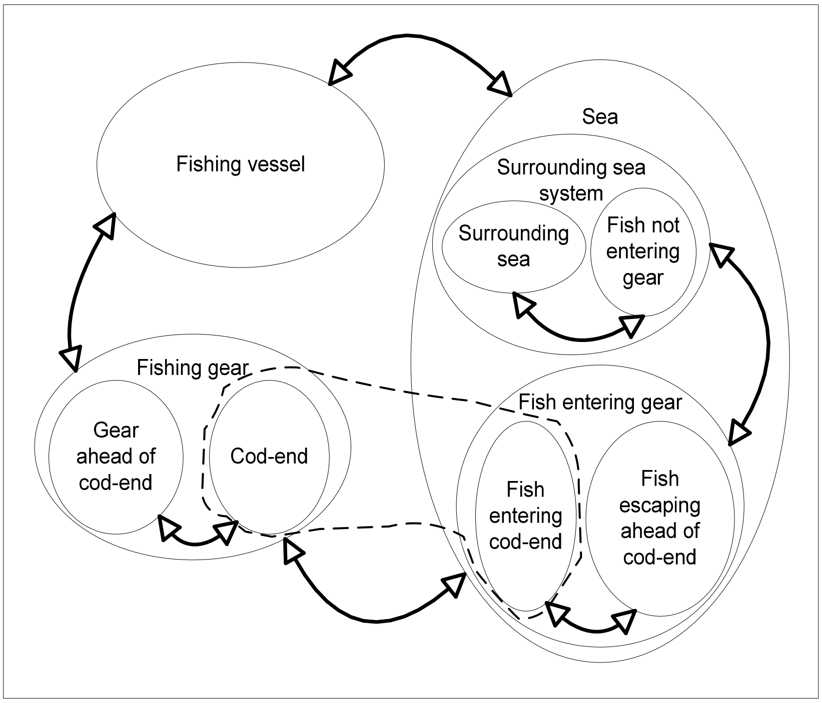

Figure 14: Overall system model for the experimental fishing process. Arrows illustrate the structural interaction between components. System within the dashed line represents the limited system that is relevant when studying cod-end processes.

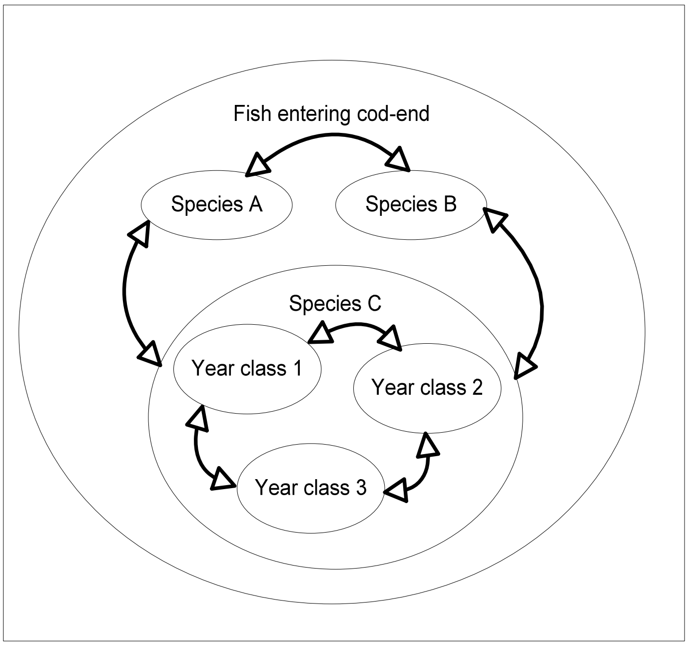

Figure 15: Separation of subsystem for fish entering cod-end in to species subsystems and further in to year classes.

According to Figure 14 a limited system model consisting of the cod-end and the fish entering the cod-end can be constructed (the system within the dashed line). The cod-end is affected by its environment, including the surrounding sea, the gear ahead of cod-end and thereby also the vessel. The fish population entering the cod-end are a subsystem of the fish population entering the gear. This subset is the subject of cod-end selectivity studies.

The fish population entering the cod-end can also be divided into species subsystems, which can again be divided into year classes (Figure 15). This separation is convenient when modelling a multi-species fishery of multiple year classes having complicated length distributions within the species groups.

Mathematical description of the cod-end size selectivity process

Based on the system outlined in the previous section, the modelling of cod-end selectivity involves the ability to predict the relationship between the population of fish entering the cod-end and the population of fish being retained in it. Fish entering the cod-end that do not escape become part of the catch. The amount of catch influences the shape of the cod-end, which in turn influences the escapement possibilities of the fish. Thus, modelling the cod-end size selection process involves solving a coupled problem of the interaction between the cod-end shape and the fish being caught. The likelihood that a fish escapes or is caught after entering a diamond mesh cod-end depends on its cross-section size and shape relative to the size and the shape of the mesh at the time when the fish tries to pass through. A structural model should therefore take into account the morphological parameters of the fish. The shape of a diamond mesh cod-end is known to change as the catch builds up in it. Consequently the shape of the meshes also changes, which in turn affects the possibilities for the fish to escape. Fish entering the cod-end at different points in time will therefore have different chances of success when trying to escape. Also, the shape of the meshes along the length of the cod-end is known to vary. It is therefore significant at which position in the cod-end the fish tries to escape. A structural model should also be able to take into account the cod-end shape, and how it depends on the catch in it. Finally, the time pattern of the fish entry time, when and where they try to escape, and for how long they can continue to attempt, need also be modelled.

In any given small time interval dt around the point of time t in the trawling process, the cod-end selection will be governed by: the cod-end shape, which depends on the total catch cw(t) at that point in time; the number of fish escaping in the time interval dt; and the number of fish becoming exhausted in that interval. The events fish escapement and fish becoming exhausted in the time interval dt around the point of time t are both dependent on the time integration of fish entry from the start of towing (t = 0) to t - ½ dt and the behaviour of these fish in this interval. The cod-end selection can then be approximated by a discrete process viewing the changes in the process as taking place in small time steps Δt. What happens at time t is then influenced by integration of the process from time 0 to time t.

Model development and implementation

Using the time step integration technique the described in the previous section a cod-end simulator tool PRESEMO (PREdictive SElective MOdel) has been build.

PRESEMO is based on an individual-based structural model of the selection process in the cod-end of a trawl fishing gear. It models different populations of fish entering the cod-end during a tow. Each fish is assigned a weight and a maximum width and height dependent on its length, and is assumed to be of elliptical cross-section. Each is also allocated a travel time down the cod-end, a time it can swim in the cod-end without being exhausted, a time between escape attempts and a packing density for swimming in front of the catch. An escape attempt is deemed successful, if the fish can pass through the mesh opening at the point of the cod-end, where the attempt takes place. The openness of a mesh is a function of the cod-end geometry, calculated external to PRESEMO and imported into PRESEMO. Fish that do not escape fall back and become part of the catch when their exhaustion time is reached. The cod-end shape is continually updated, as the catch builds up during the tow. At the end of a simulation, a logistic function is automatically fitted to the simulated selection data to obtain estimates of the 50% retention length ($L50$) and selection range (*SR)*. The model is thus based on information about the fundamental mechanical, hydrodynamic and biological processes that govern cod-end selection.

PRESEMO requires information on cod-end design, the fish behaviour, the escape process, the fish population structure, and the fish morphology. It contains a number of facilities to set up and test different ways of modelling and simulating these aspects. Figure 1 to Figure 3 illustrates the main sequence to simulate a fishing process using PRESEMO.

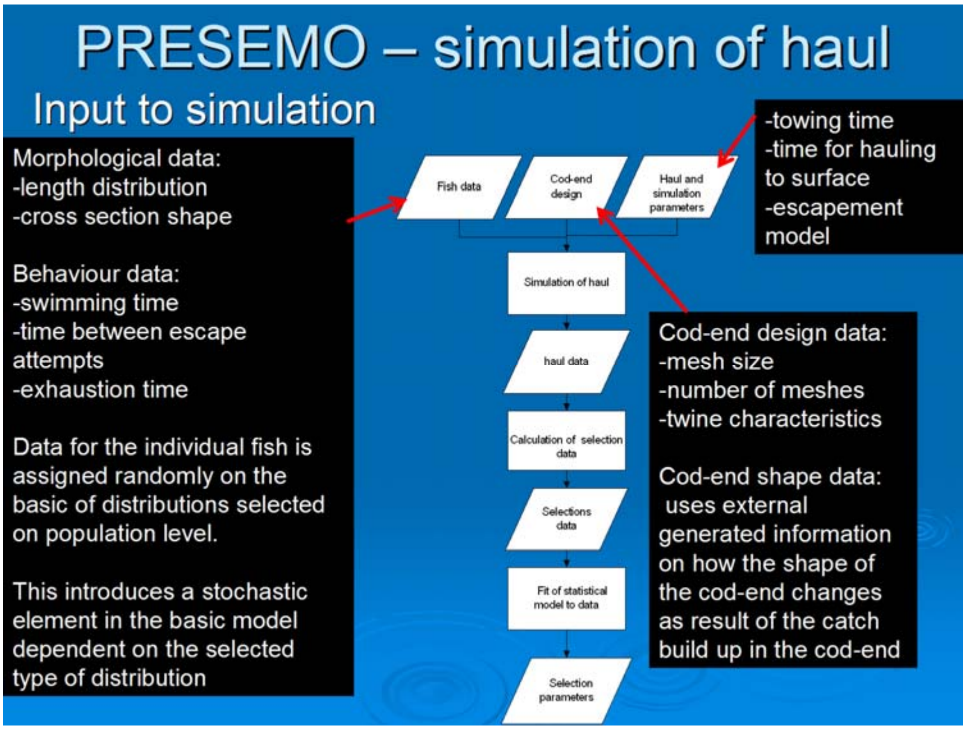

Figure 1: PRESEMO input to simulation.

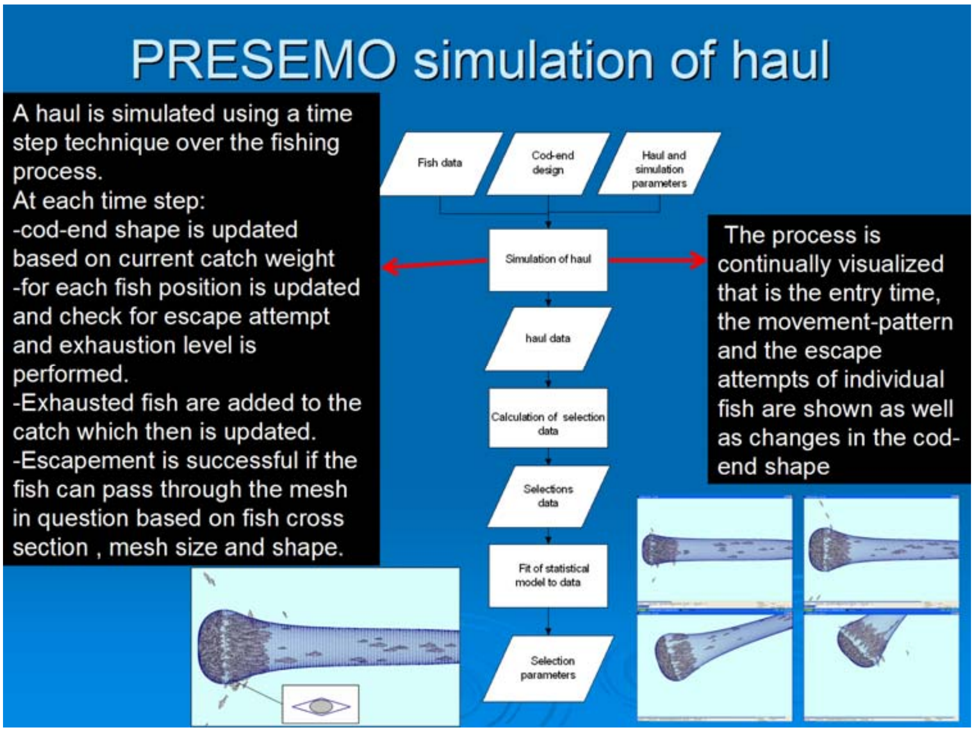

Figure 2: PRESEMO simulation of haul.

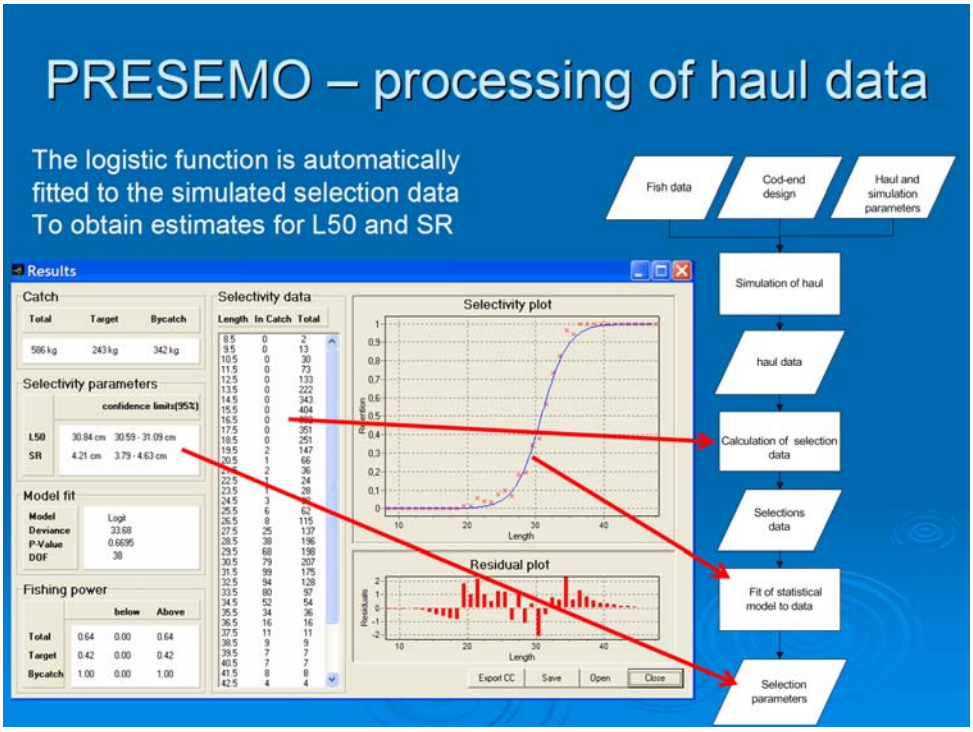

Figure 3: PRESEMO processing of haul data.

PRESEMO contains facilities to model between haul variation, testing different cod-end designs against each other under the same varying fishing conditions and to look into details on individual fish to examine why it got the fate it did in a specific simulated fishing process.
PRESEMO also has a number of facilities to export haul data to be analysed external to PRESEMO.
The model behind PRESEMO is described in detail in Herrmann (2005a; 2005b).
PRESEMO has been build to run on a personal computer having a Microsoft Windows operating system. An overview of the facilities in PRESEMO and how to navigate between the different windows is given in appendix X.

Figure 17 shows a sequence of screen dumps from a simulation process using PRESEMO.

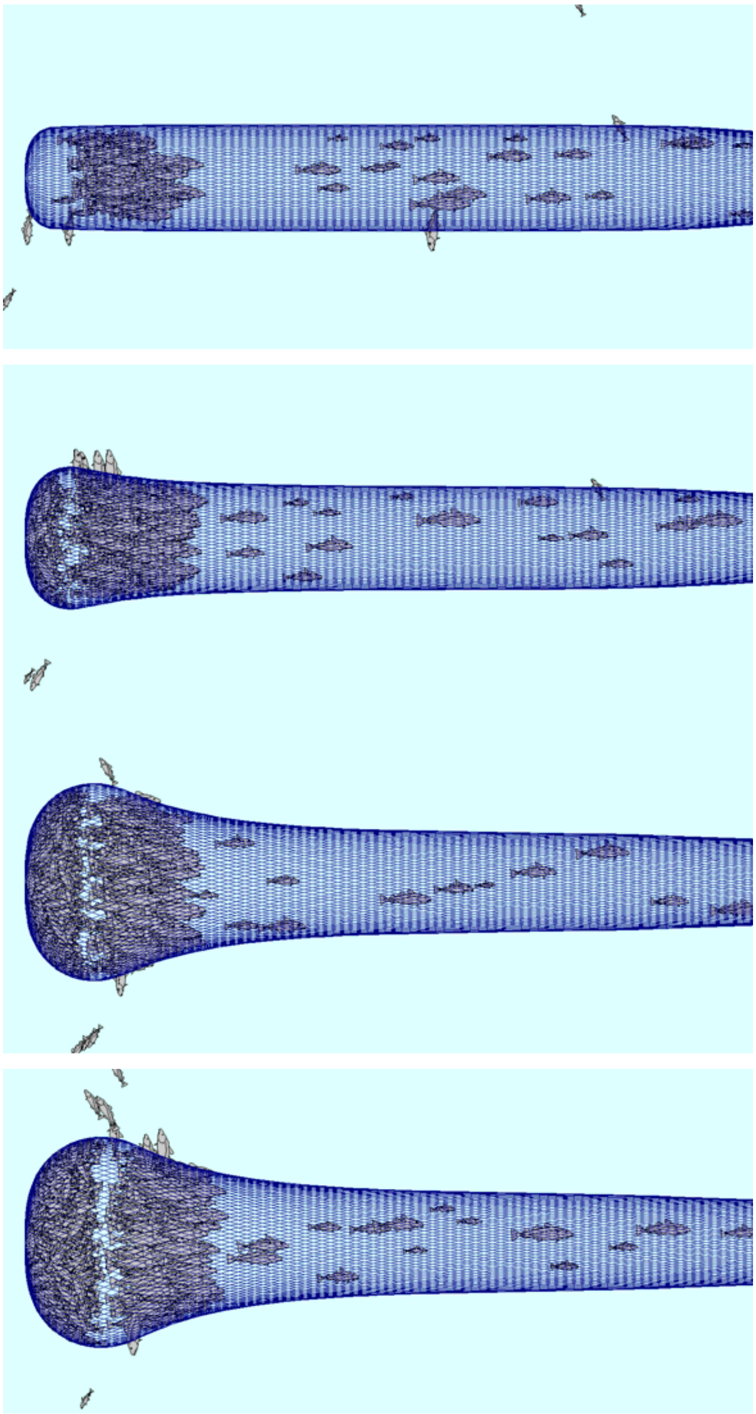

Figure 17: Screen dumps from PRESEMO when simulating a haul.

To make PRESEMO user-friendly the process of fitting the logistic function to the selection data is implemented in the program. Figure 18 shows the result screen, displayed at the end of each simulation. The screen shows the selection parameters L50 and SR and their confidence intervals; selection data, the selection curve and model fit information.

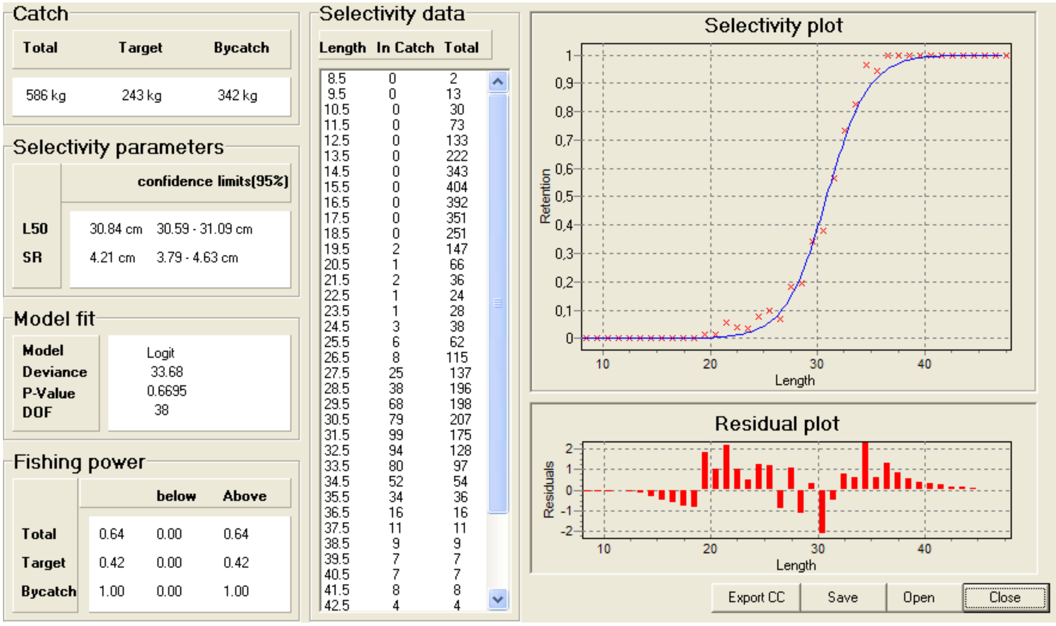

Figure 18: Result screen from PRESEMO appearing after a simulated haul.

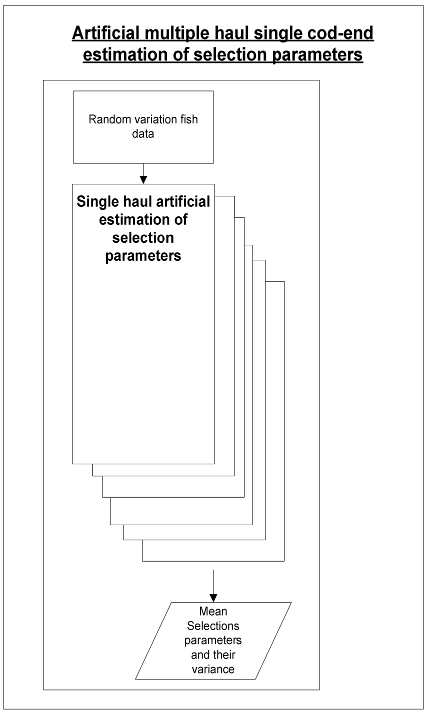

Figure 21: Flowchart for artificial multiple haul estimation of selection parameters using a single cod-end.

A stochastic simulation technique was used to simulate between haul variation, where values of parameters assumed to affect selectivity were made to vary randomly between hauls. The approach is illustrated in Figure 21. Figure 22 shows the result screen for a multiple haul simulation in PRESEMO.

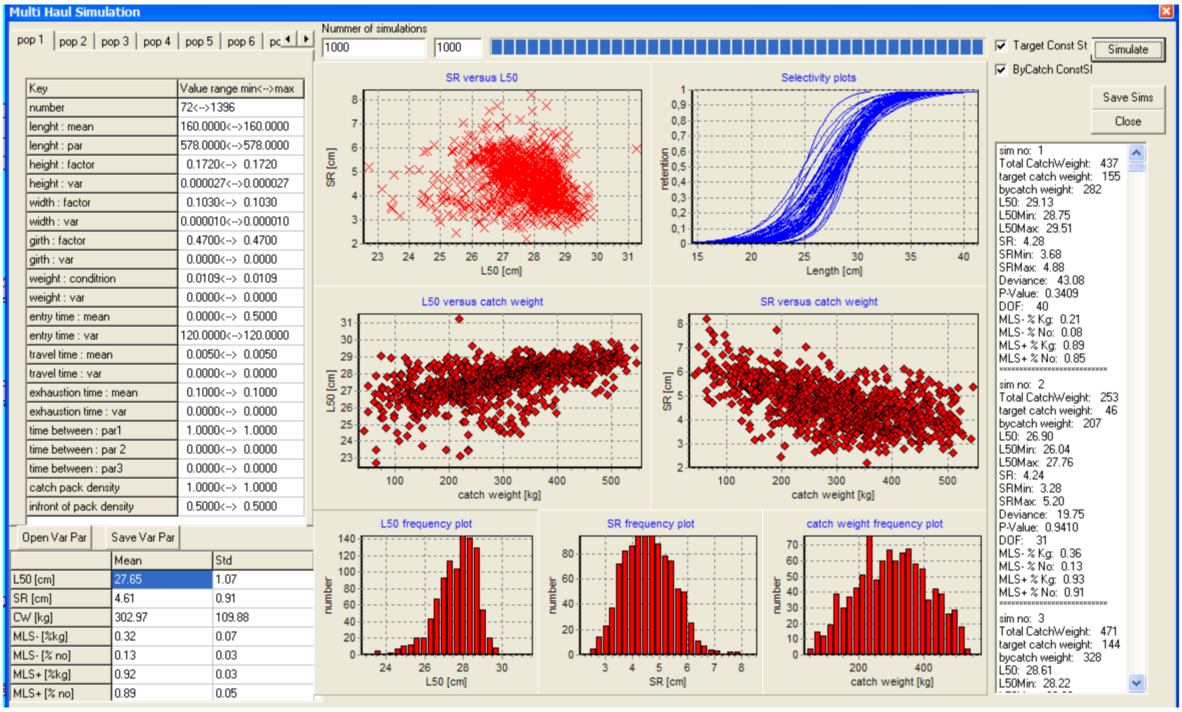

Figure 22: Result screen for multiple hauls in PRESEMO.

Discussion.

A major limiting element in the PRESEMO model description of the fish behaviour is that it does not take into account any stimulation the fish may experience while travelling down the cod-end. For a simple diamond mesh cod-end without any escape panels or grids this may be a reasonable simplification, but for more advanced gear designs it would be preferable to incorporate such stimulations in the model. Thus the behaviour part of the model is descriptive. This part could in the future be replaced by a more fundamental description of these elements.

Another restriction in the current version of the model is that it is only able to deal with axis-symmetrical diamond mesh cod-ends of uniform mesh size and type. Future development could be on non axis-symmetrical cod-ends and other mesh types.

The PRESEMO model introduces several parameters that describe fish morphological data and behaviour. Today there is limited information about these parameters realistic values. Therefore several sets of simulations must be carried out using the model and comparing these results to empirical results in order to validate the model and establish standard values for the parameters.

The PRESEMO gives several options for modelling the fish escapement process through the diamond mesh cod-ends of towed fishing gears. The models make assumptions about the way the meshes are distorted when a fish tries to escape through them and generalise that all fish have the same possibilities of distorting the meshes independently of species and size. The assumptions on how the allowed mesh distortion may decrease with catch weight have been made arbitrarily – they are simplifications which may affect the results. The concept that fish can distort the meshes at the beginning of the fishing process lacks experimental proof. As far as we know no underwater observations have looked at fish escapement processes at the very beginning

of towing when there are no or very few fish in the catch.
The model presented here has demonstrated that it has become realistic to build simulation models that predict selectivity in the cod-ends of towed fishing gear.

Comparison and predictions

introduction

Several studies were carried out applying the selectivity simulator PRESEMO to predict the selective properties of different gear designs including comparing prediction with experimental available results for similar gear designs. These studies are described in the following sections.

Simulation of between haul variations of haddock selection

A theoretical study of between-haul variation of haddock selection in a diamond mesh cod-end was carried out. Results theoretical obtained results were compared to published experimental ones to find good agreement. The study is described in detail in (Herrmann & O'Neill, 2005). The main findings in the study was that we could demonstrate how haul-to-haul variation of the population density, the population structure and the spatial distribution of both the target and by-catch species may lead to between-haul variation of cod-end selection. We also showed that for reasonable levels of variation of these parameters PRESEMO can simulate selection estimates that are consistent with and have comparable levels of between-haul variation as those obtained experimentally. Figure 7-8 and table 1 compares the simulated results with the experimental ones published in O'Neill and Kynoch, 1996. Cod-end shape estimations were carried out using the method described in O'Neill (1997; 1999).

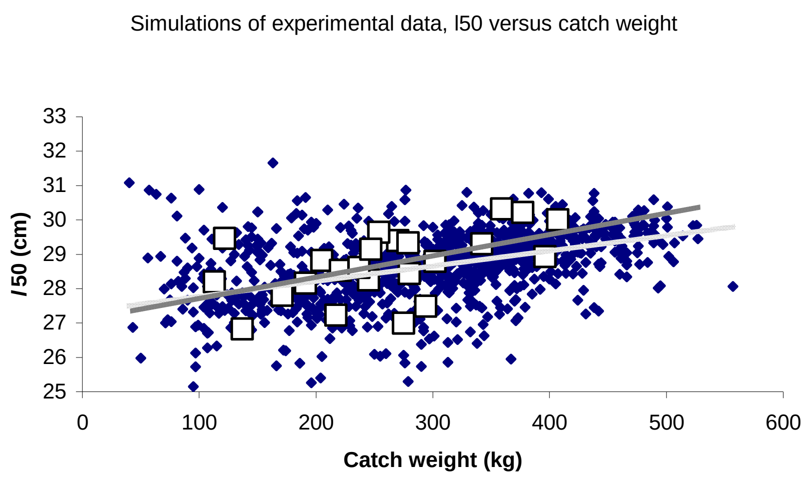

Figure 7: Estimates of *l*50 versus catch weight from simulations to reproduce the experimental data of O'Neill and Kynoch (1996). The □ are their experimentally obtained estimates, the black line is a linear regression fit to their data and the grey line is one to the simulated data.

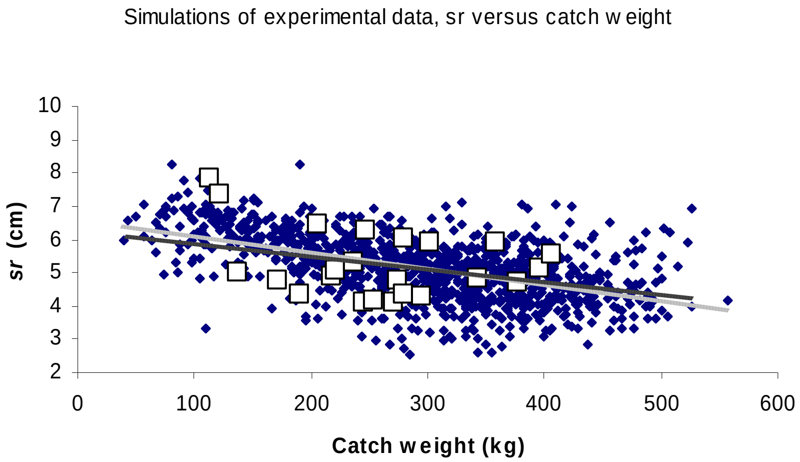

Figure 8: Estimates of *sr* versus catch weight from simulations to reproduce the experimental data of O'Neill and Kynoch (1996). The □ are their experimentally obtained estimates, the black line is a linear regression fit to their data and the grey line is one to the simulated data.

	O'Neill and Kynoch (1996)	PRESEMO simulations of experimental results
$l50$ (cm)	28.69	28.63
sd_{l50} (cm)	0.98	1.07
sr (cm)	5.26	5.14
sd_{sr} (cm)	1.02	0.96
catch weight (kg)	258	294
$sd_{\text{catch weight}}$ (kg)	83	105

Table 1: The haddock selectivity results of O'Neill and Kynoch (1996) and of the PRESEMO simulations where we have simultaneous variation of the size and spatial distribution of the target and by-catch species and of the standard deviation of the morphological parameters and the mesh size.

Simulation of the effect of mesh size for haddock selection and number of meshes around

A theoretical study of how selectivity of haddock depends on cod-end mesh size and number of meshes around was carried out. Theoretical obtained results were compared to predictions based on empirical models published by Galbraith et al., 1994. Reasonable agreements between results were found. Figure 9-12 shows the comparison between PRESEMO estimates and estimates bases on empirical models by Galbraith et al., 1994. Cod-end shape estimations were carried out using the method described in O'Neill (1997; 1999).

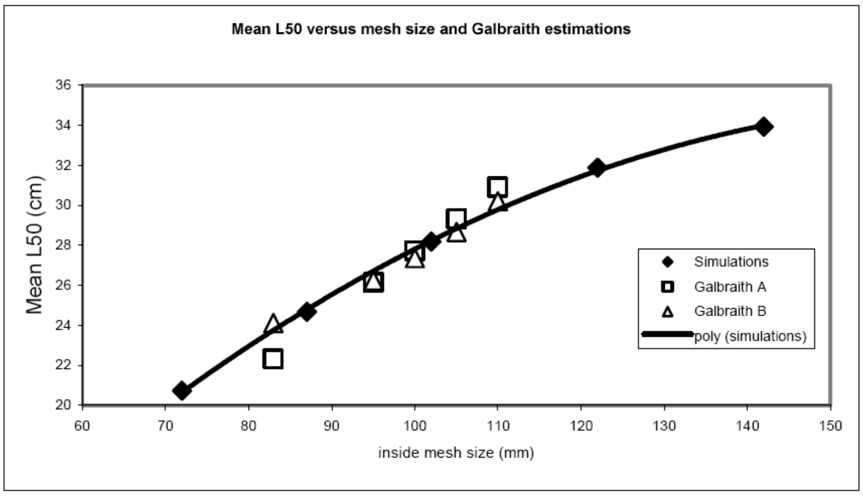

Figure 9: Mean L50 versus cod-end mesh size. Simulation single effect model for the influence of mesh size and estimations using Galbraith models A and B.

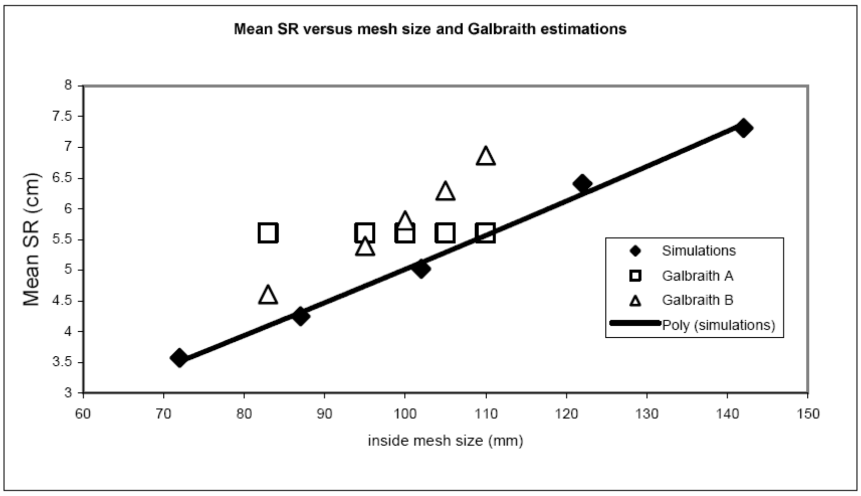

Figure 10: Mean SR versus cod-end mesh size. Simulation single effect model for the influence of mesh size and estimations using Galbraith models.

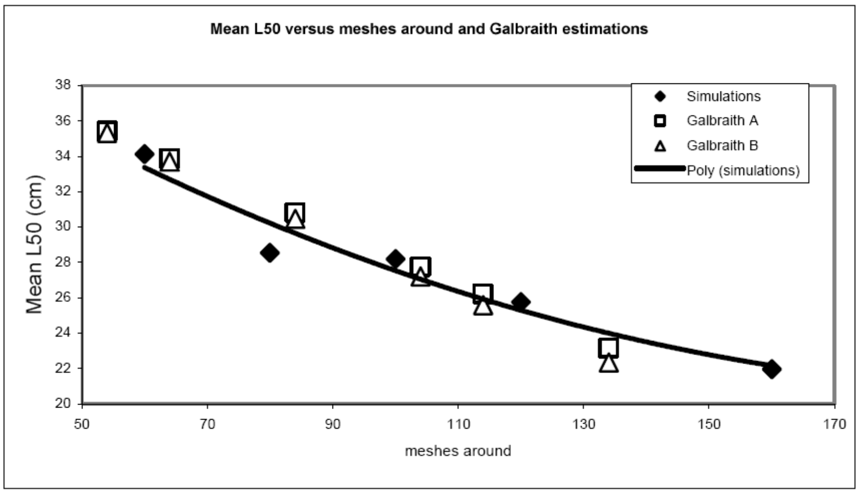

Figure 11: Mean L50 versus number of meshes around. Simulation single effect model for the influence of number of meshes around and estimations using Galbraith models.

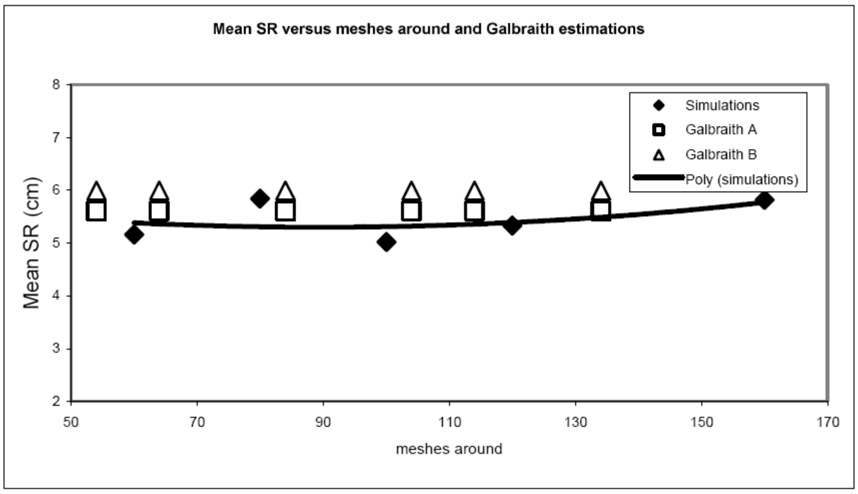

Figure 12: Mean SR versus number of meshes around. Simulation single effect model for the influence of number of meshes around and estimations using Galbraith models.

Based on the results above a model taking into account both mesh size and number of meshes around can be constructed. Figure 13 and 14 shows how such a model can be used to plot iso-lines (lines of same value) for L50 and SR dependent on both mesh size and number open meshes around. This highlights how this method can be used as a tool for fisheries management.

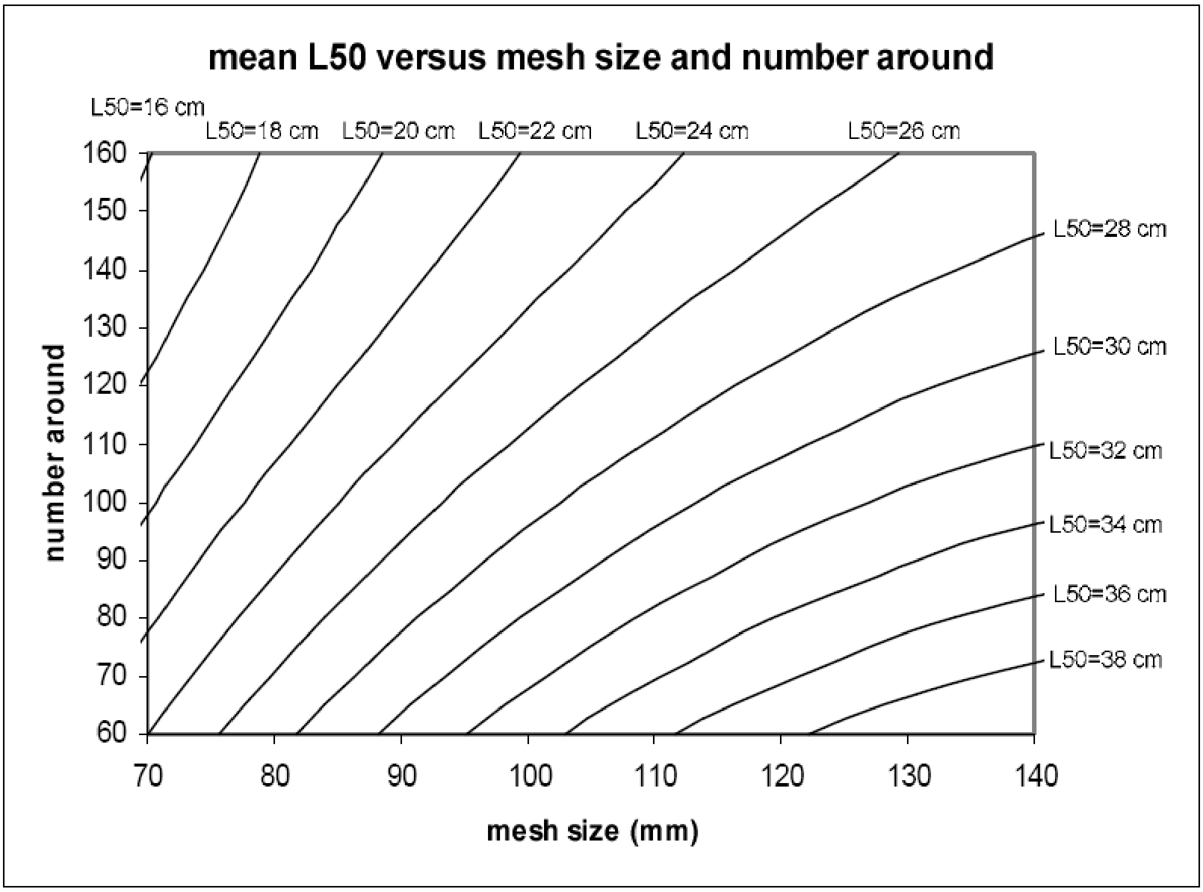

Figure 13: Contour plot for mean L50 versus mesh size and number of meshes around.

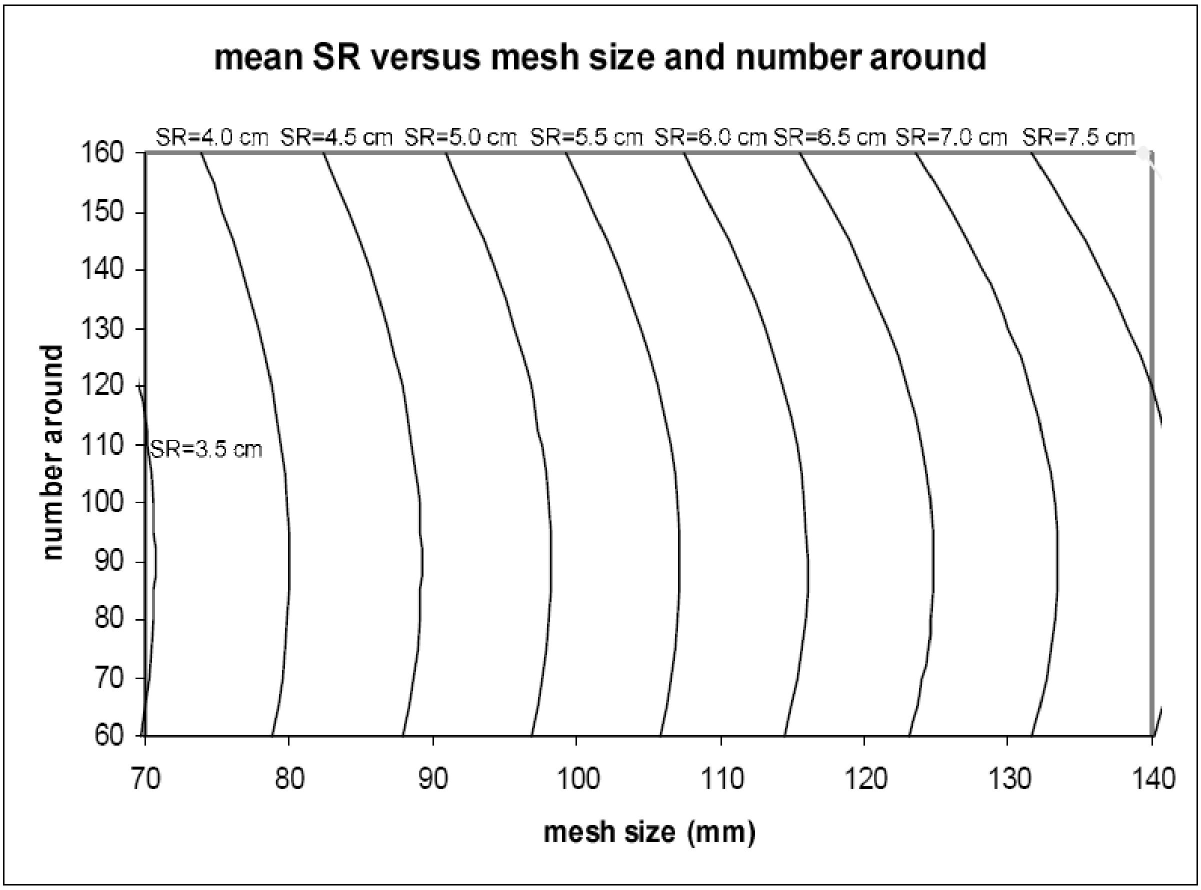

Figure 14: Contour plot for mean SR versus mesh size and number of meshes around.

Simulation of the effect of cod-end twine thickness on the selection of haddock

A theoretical study of the influence of cod-end twine thickness on selection of haddock in a diamond mesh cod-end was carried out. Results theoretical obtained results were compared to published experimental ones. The main findings in the study was that the reduction of lateral mesh opening that arises as a result of both twine bending stiffness and the physical presence of the twine cannot fully explain the relationship found in the available experimental data (Lowry and Robertson (1996); Kynoch et al. (1999)). The effect twine thickness may have on the ability of a fish to deform a mesh during the early part of a haul and how netting made of thicker twine may discourage a fish from making escape attempts were also studied. The influence that these factors may have was then included in the simulations and these results were a much better representation of the experimental results. Results for selection factor SF which is L50 divided with mesh size and for selection ratio SRA which is SR divided with mesh size were used to be able to compare with experimental results were the mesh sizes were not identical. Figure 15-16 compares simulated and experimental results. Cod-end shape estimations were carried out by partner 2 based on the method described in O'Neill (1997; 1999).

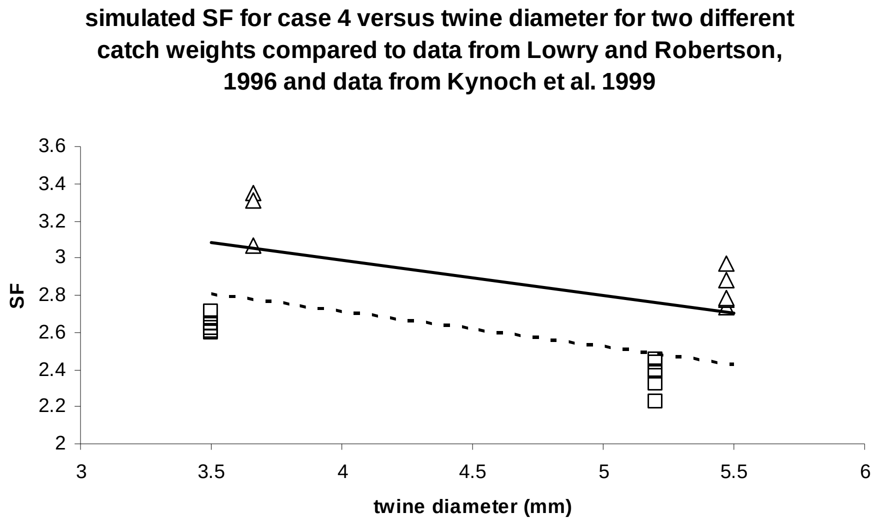

Figure 15: Regression lines for the simulated *SF* values versus twine diameter for two different catch weights compared to the data from Lowry and Robertson (1996) and to the data from Kynoch et al. (1999). The broken line is for a catch of 182 kg and the black for a catch of 554 kg. □ refers to the data of Lowry and Robertson (1996). Δ refers to the data of Kynoch et al. (1999).

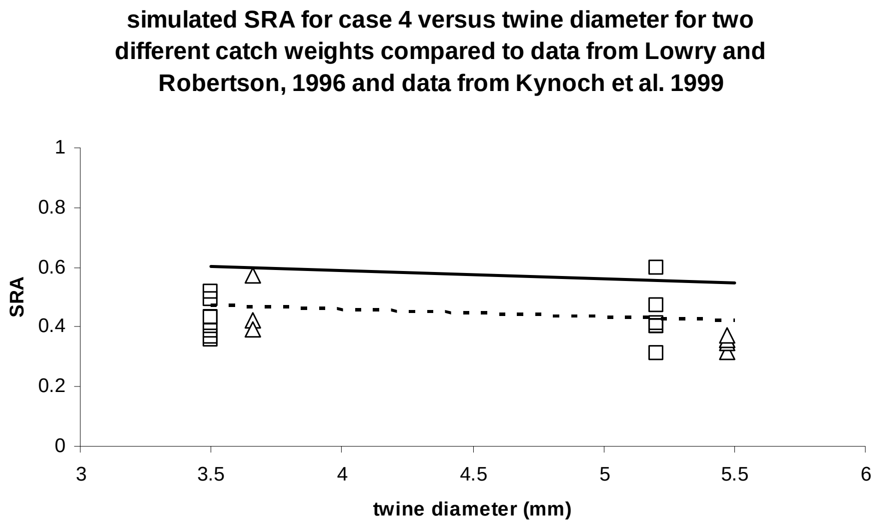

Figure 16: Regression lines for simulated *SRA* values versus twine diameter for two different catch weights compared to the data from Lowry and Robertson (1996) and to the data from Kynoch et al. (1999). The broken line is for a catch of 182 kg and the black for a catch of 554 kg. □ refers to the data of Lowry and Robertson (1996). Δ refers to the data of Kynoch et al. (1999).

Simulation of the selection of Red Mullet in diamond mesh cod-ends.

A study of red mullet selection was carried out. FEMNET of partner 1 was used to estimate shapes for cod-end designs of commercial interest. Morphological data for red mullet and population structure data for red mullet were both collected by partner 3. This information was then loaded into PRESEMO and the behaviour description of red mullet in cod-ends was adjusted to reflect experimental selection results collected by partner 3. The study was carried out for the 3644 twine cod-end of partner 3 as this cod-end were the one being of most commercial interest. The main findings were that it was possible to adjust the behaviour parameters in PRESEMO in a simple way so that simulated results were in agreement with the experimental ones. Figure 17-18 plots L50 and SR versus total catch weight for the individual hauls. ♦ are experimental results, while □ are simulated results using FEMNET and PRESEMO.

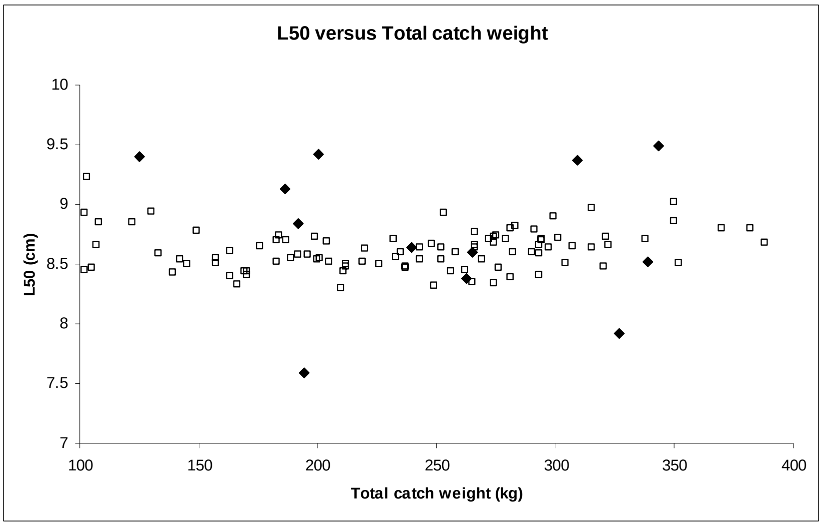

Figure 17: L50 versus total catch weight for the individual hauls. ♦ are experimental results, while □ are simulated results using FEMNET and PRESEMO.

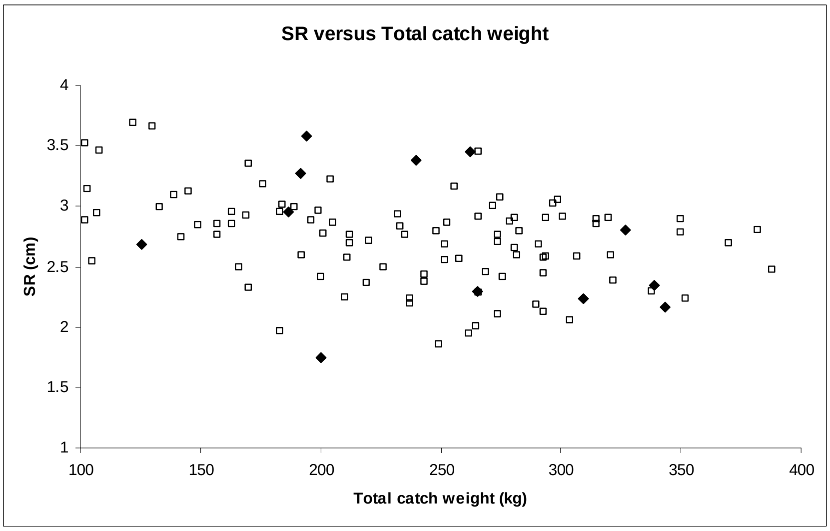

Figure 18: SR versus total catch weight for the individual hauls. ♦ are experimental results, while □ are simulated results using FEMNET and PRESEMO.

Then assuming that the "calibration" of the behavioural parameters for red mullet simulated in PRESEMO gives a reasonable representation this can be used to predict what the changes in the selectivity of red mullet would be if the cod-end design was changes. We did this using FEMNET to estimate cod-end shapes for other designs and then simulated the selection process in PRESEMO using the calibrated behavioural parameters. Table 2 summarizes results.

	Experimental Results 44x280	Simulated Results 44x280	Simulated Results 44x210	Simulated Results 44x140	Simulated Results 50x280	Simulated Results 50x210	Simulated Results 55x280
Mean Catch Weight (kg)	249	230	204	179	218	176	163
Sd Catch Weight (kg)	71	75	68	64	75	65	60
Mean L50 (cm)	8.78	8.63	9.65	10.75	9.13	10.31	10.95
Sd L50 (cm)	0.62	0.21	0.32	0.79	0.33	0.51	0.66
Mean SR (cm)	2.74	2.76	3.25	5.50	3.46	4.11	5.69
Sd SR (cm)	0.59	0.40	0.28	0.95	0.67	0.64	1.33

Table 2: Result for red mullet selection in different cod-ends. Column 1: experimental results for a cod-end having mesh size 44 mm and 280 open meshes around the circumference. Column 2: simulated results using FEMNET and PRESEMO for the same cod-end design as in column 1. Column 3: simulated results using FEMNET and PRESEMO for a cod-end having mesh size 44 mm and 210 open meshes around the circumference. Column 4: simulated results using FEMNET and PRESEMO for a cod-end having mesh size 44 mm and 140 open meshes around the circumference. Column 5: simulated results using FEMNET and PRESEMO for a cod-end having mesh size 50 mm and 280 open meshes around the circumference. Column 6: simulated results using FEMNET and PRESEMO for a cod-end having mesh size 50 mm and 210 open meshes around the circumference. Column 7: simulated results using FEMNET and PRESEMO for a cod-end having mesh size 55 mm and 280 open meshes around the circumference.

Often discard of undersize fish result from conflict between the selective properties of a given gear design being regal compared to the minimum allowed landing size (MLS). How a big problem this discard is also depends on size structure of the fish that the gear is applied at. Using the population structure found by partner 3 during experimental fishing we were by using a facility in PRESEMO also able to compare the predicted catching efficiency of the different gear designs listed in table 2 for fish below and above MLS. Result of this is listed in table 3.

Efficiency In fraction of the Amount entering	Simulated Results 44x280	Simulated Results 44x210	Simulated Results 44x140	Simulated Results 50x280	Simulated Results 50x210	Simulated Results 55x280
Below mls (kg)	70%	50%	42%	61%	44%	38%
Below mls (no)	64%	47%	40%	56%	41%	37%
Above mls (kg)	97%	90%	74%	92%	82%	72%
Above mls (no)	96%	87%	70%	90%	79%	68%

Table 3: predicted catching efficiencies below and above MLS given in % of kg fish entering and in % of number of fish entering below and above MLS.

Ideal the efficiency below MLS should be close to 0% meaning that nearly no one of the fish below MLS is retained. The ones being retained represents discards. On the other hand the efficiency above MLS should be close to 100% because fish above MLS

that are not retained represents a loss of fish that could be landed by the fishermen thus must be compensated by an increased effort.
This study highlights how this method can be used as a management tool to fisheries management.

Simulation of the effect of round straps on the selection of haddock

A theoretical study of how round straps can effect the selective properties of a diamond mesh cod-end was carried. The numerical tool, FEMNET based on the finite element method, was applied to estimate the shapes a number of different diamond mesh cod-ends would obtain during fishing. The only difference between the cod-end designs is the attachment of round straps of different lengths, positions and numbers used. These cod-end shape estimates were then used in the selectivity simulation tool PRESEMO to simulate the selectivity processes of the various cod-ends under the same varying fishing conditions. In this way we theoretically investigated the influence on cod-end selectivity by applying round straps. We demonstrate how one or two round straps along the cod-end axis may affect the selectivity of the cod-end. Comparing simulated results to those from a simulated reference cod-end, without round straps, we predict how cod-end designs according to the EU-legislation can affect on the 50% percentage retention length L50 by up to 1.8 cm (6%) for haddock. We investigate how the effects of round straps are coupled to the catch build up process in the cod-end during fishing. Figure 19 shows an underwater recording of a cod-end having a round strap (top) while the bottom plot shows a similar but simulated using FEMNET and PRESEMO.

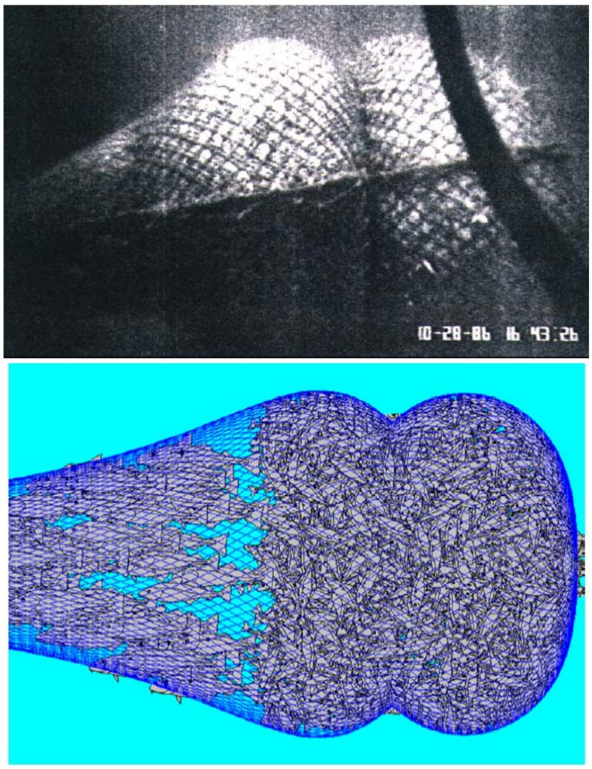

Figure 19: Cod-end with round strap. Top: Underwater photo. Bottom: Simulation using FEMNET and PRESEMO.

Figure 20 shows screen dumps from PRESEMO from simulations with the different designs investigated (top to bottom) at different catch weights (left to right).

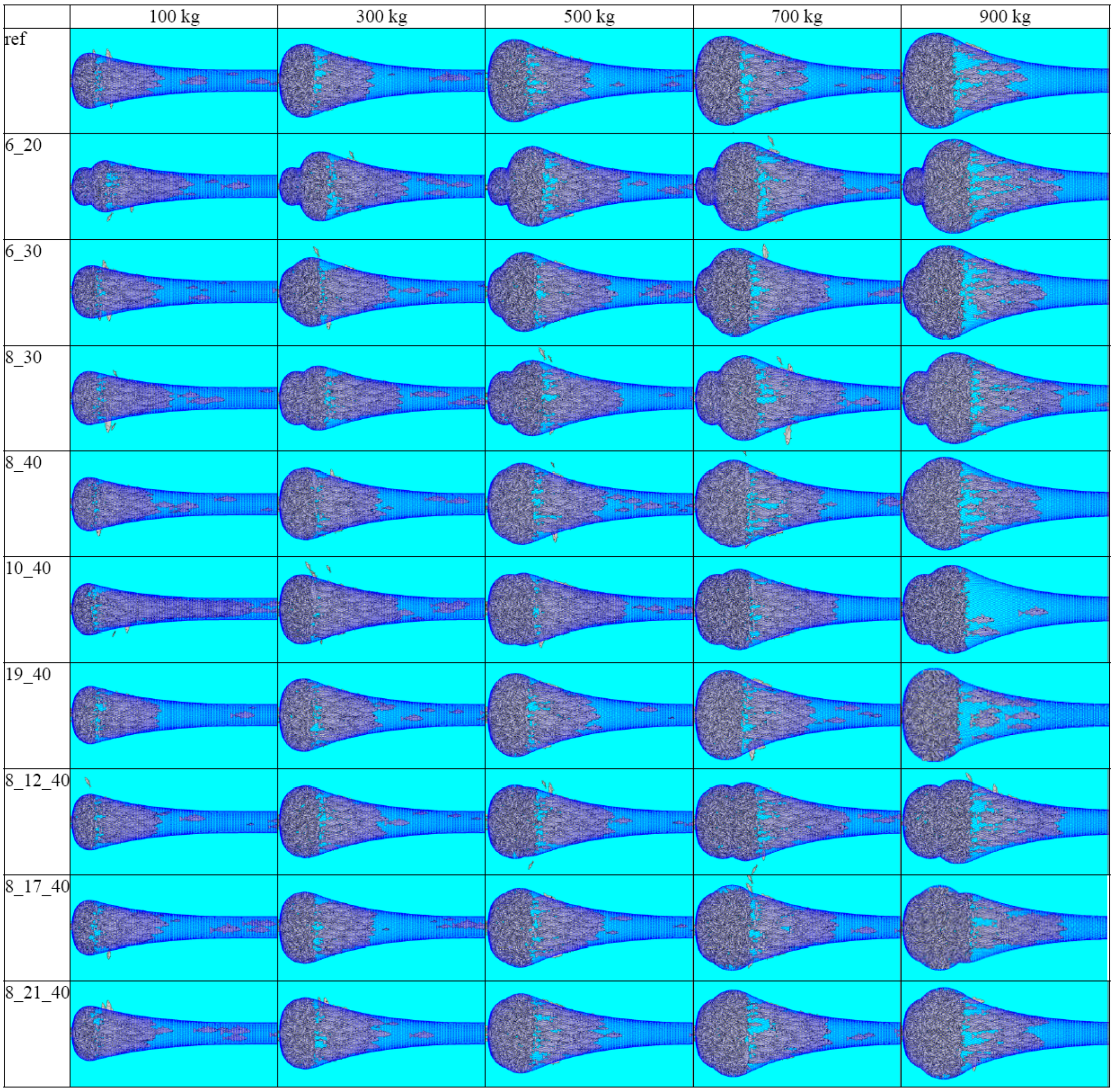

Figure 20: screen dumps from PRESEMO from simulations with the different designs investigated (top to bottom) at different catch weights (left to right). The label in the left column for example 10_40 tells that this design have a round strap positioned 10 mesh rows from the codline and that the length of this round strap is 40% of the stretched circumferential length of the cod-end. 8-12-40 means that there are two round straps one positioned 8 mesh rows from the codline and the other 12 mesh rows from the codline. Both straps have a length of 40% of the stretched circumferential length of the cod-end.

Figure 21 shows a plot of the prediction of how L50 dependents on total catch weight in the cod-end at end of the fishing process for the designs shown in figure 20.

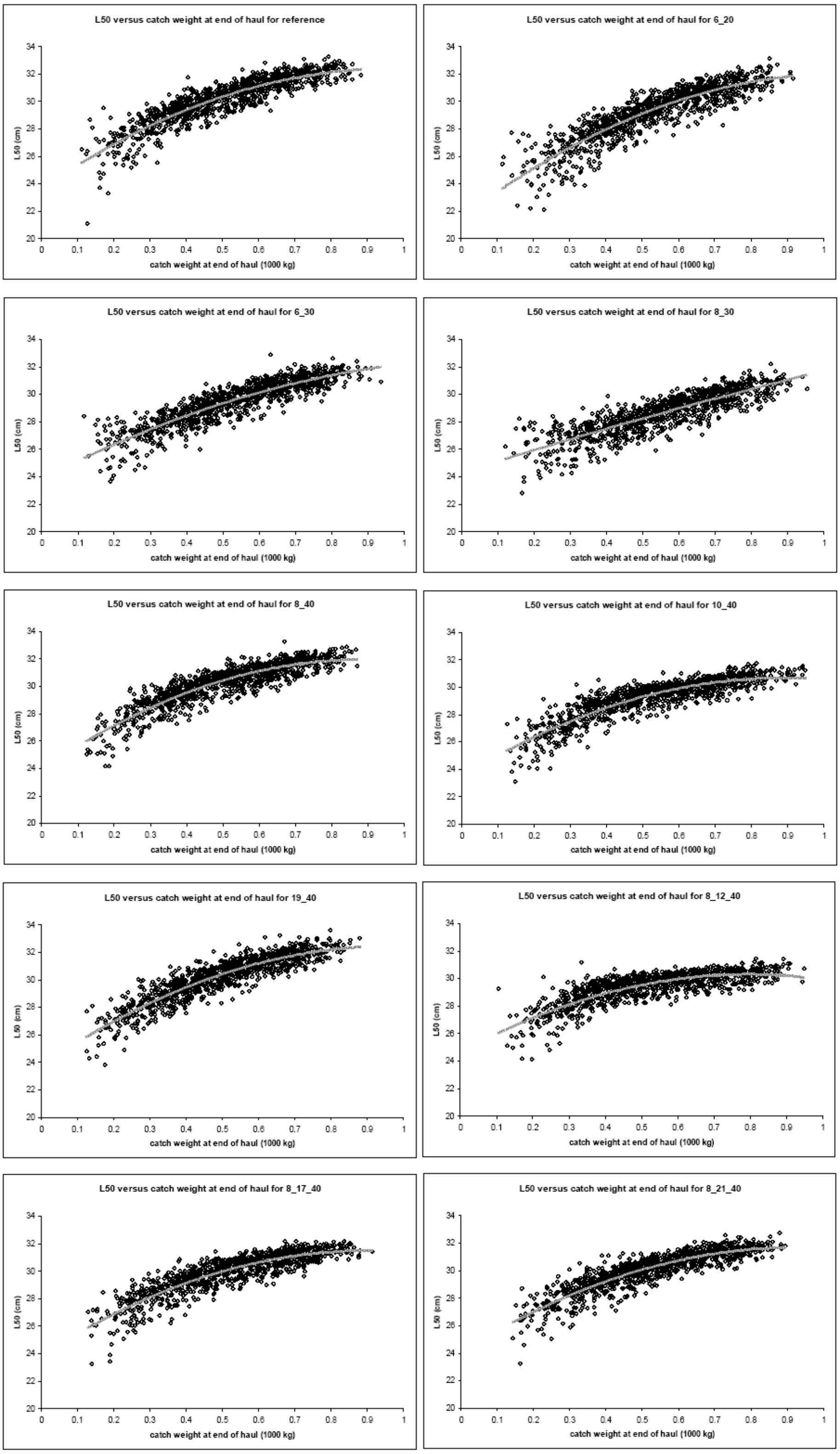

Figure 21: L50 dependents on total catch weight in the cod-end at end of the fishing process in 1000 kg for the designs shown in figure 19. The curve is a polynomial regression to the data.

Based on FEMNET shape calculations of cod-ends having different mesh size the predicted effect on selection of haddock were studied including the interaction between mesh size and total catch weight in the cod-end on selection parameters. The study was made for cod-end designs having 100 open meshes around the circumference for designs having mesh size from 80 mm to 160 mm. The catch weights were simulated in the range 0 to 2500 kg total catch at end of the hauls. Figure 22 shows the simulated results from one of the designs (100 mm mesh size) and plots L50 versus total catch weight. The curve is a regression curve to the simulated data.

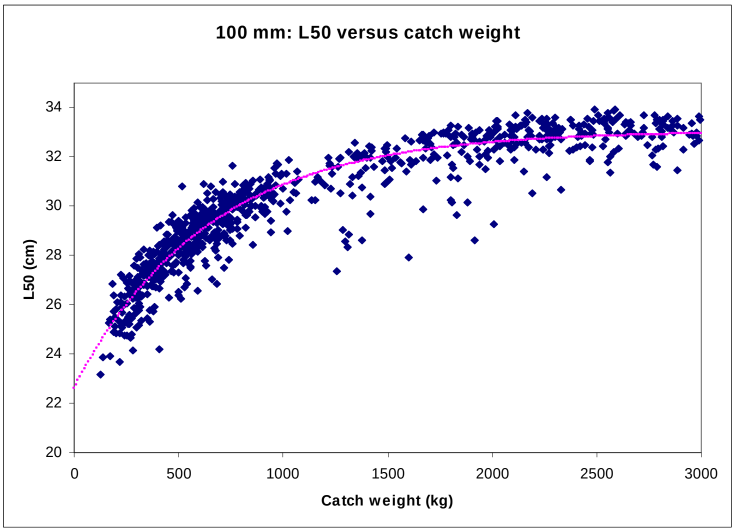

Figure 22: shows the simulated results from one of the designs (100 mm mesh size) and plots L50 versus total catch weight. The curve is a regression curve to the simulated data.

Figure 23 summarizes the regression results for L50 versus total catch weight at end of haul for the different designs having different mesh sizes 80 mm to 160 mm.

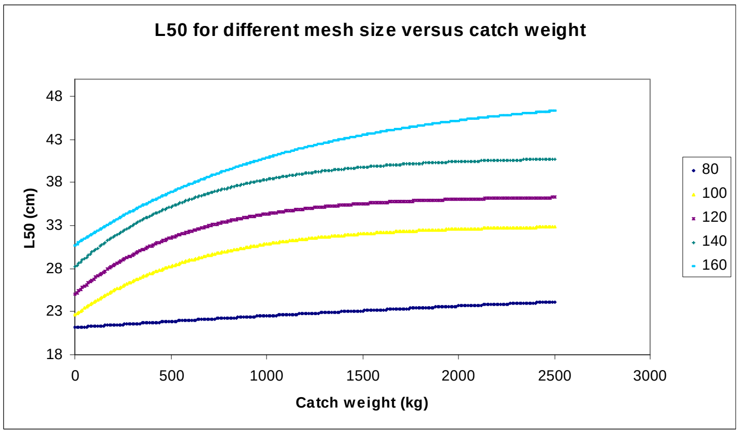

Figure 23: regression results for L50 versus total catch weight at end of haul for the different designs having different mesh sizes 80 mm to 160 mm.

Theoretical study of two different methods to improve the selective properties of a 100 mm mesh size diamond mesh cod-end.

A theoretical study was conducted on two different ways to improve the selective properties of a 100 mm mesh size diamond mesh cod-end. One problem with diamond mesh cod-end is that the mesh openings at the catch edge where most escapes are known to take place is very dependent on the amount of catch in the cod-end. We used FEMNET to estimate cod-end shapes for various designs. Then the maximum escapement length lmax at catch edge were predicted using PRESEMO. Last PRESEMO was used to simulate the selective properties. The reference (basis) cod-end was a 100 mm mesh size having 100 open meshes around. We used haddock in the case study but will expect similar results for other round fish. As we focused on the mesh openness at catch edge affecting selectivity we investigated two mechanisms that potentially could affect this:

- insert a canvas in the aft end of the cod-end to emulate a certain amount of catch to spread out the cod-end more when the amount of catch is small in the cod-end.
- use a design having fewer meshes around the circumference to make the individual meshes at catch edge open more for the same amount of catch.

Figure 24 shows predicted lmax at catch edge (or canvas edge) versus catch weight for the basis cod-end (100x100x00) and for cod-ends having inserted a canvas blocking different percentages of cod-end meshes in the length from the codline towards the entry part. 100x100x5 means that 5% of the mesh rows counted from the codline is blocked by canvas while 100x100x25 means that 25% of the mesh rows are blocked.

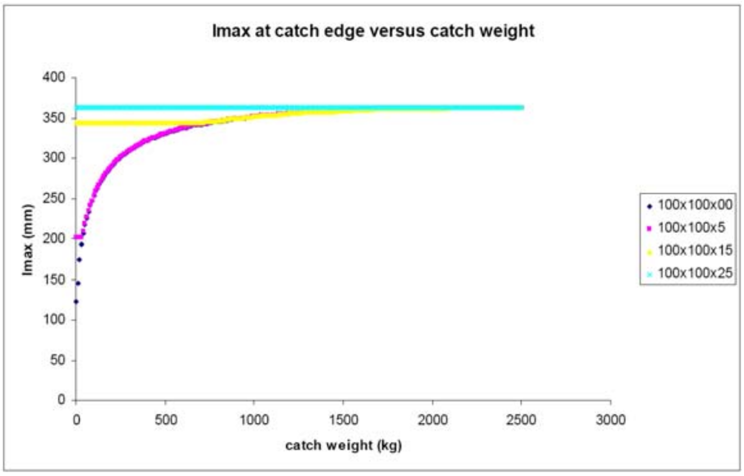

Figure 24: lmax at catch edge versus catch weight for basis design (100x100x00) and for designs having different amounts of the total mesh row from the codline towards the entry row of the cod-end blocked by a canvas inserted in the cod-end. 100x100x15 mean that 15% of the mesh rows counted from the codline is blocked.

The results in figure 24 show that lmax for the basis cod-end and fore the one having 5% of the mesh rows blocked are very dependent on the catch weight. The conditions are must more constant for the designs having 15% and 25% of the mesh rows blocked. The main assumption for this also to be the case in a real fishing process is that fish do escape in front of the canvas in the cod-end. This needs experimental confirmation. Figure 25 shows predicted lmax at catch edge versus catch weight for the basis cod-end (100x100x00) and for cod-ends having reduced number of open meshes around the circumference. 100x60x00 means 60 open meshes around.

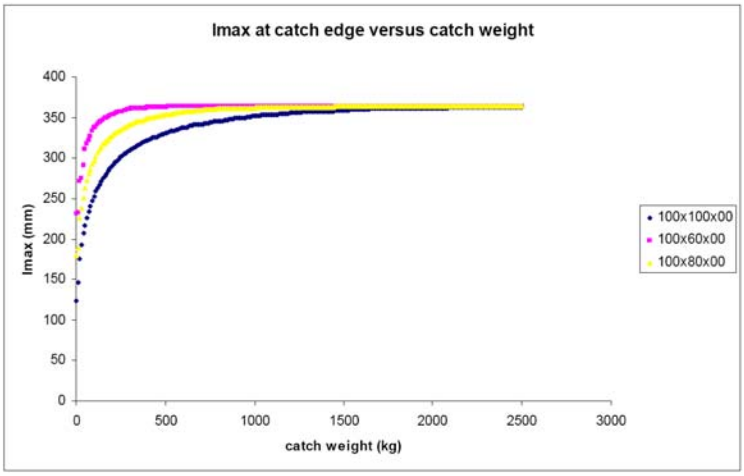

Figure 25: lmax at catch edge versus catch weight for basis design (100x100x00) and for designs having reduced number of open meshes around the circumference. 100x80x00 means that the cod-end has 80 open meshes around the circumference.

Comparing the results plotted in figures 24 and 25 it can be seen that the same type of effect on lmax can be achieved by reducing the number of open meshes around except for a small amount of catch but without being the dependent on the assumption that fish will make their escape attempts ahead of a canvas blocking mesh rows in the cod-end. Thus reducing the number of open meshes is properly a simpler and safer way to achieve a similar effect also because inserting canvas in the aft-end of the cod-end may cause some practical problems during the fishing operations. To verify that the predicted effect on selectivity is similar for the two methods (canvas and reduced number of meshes around) we have simulated selectivity for the different designs using PRESEMO. Figure 26-27 plots and compares predicted selectivity versus total catch weight for the basis design, for the design having 15% blocked meshes and for the design having the number of meshes around reduced to 60.

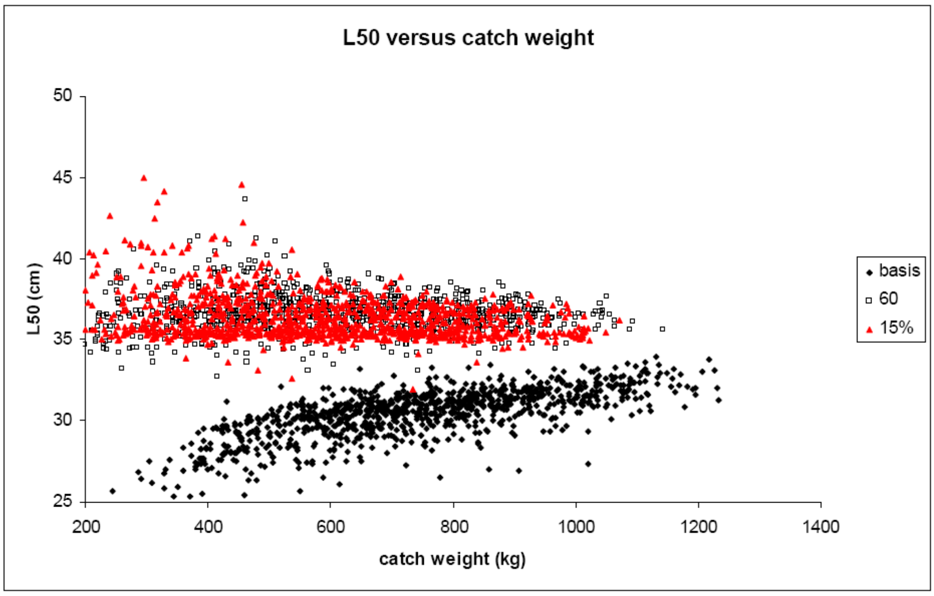

Figure 26: plots and compares predicted L50 versus total catch weight for the basis design (♦), for the design having 15% blocked meshes (▲) and for the design having the number of meshes around reduced to 60 (□).

Figure 26 confirms that the effect on L50 by on one hand reducing the number of open meshes around and on the other by causing the cod-end meshes at the aft-end to spread more by inserting a canvas in the cod-end are very similar. Figure 27 shows similar comparison for SR. But here the results show that for the canvas cod-end there is a tendency of many hauls having small SR.

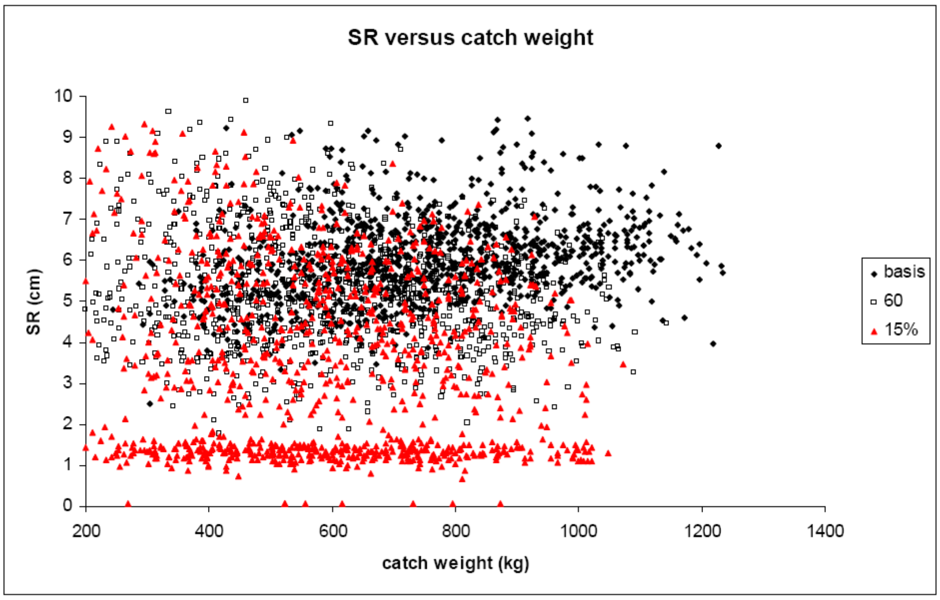

Figure 27: plots and compares predicted SR versus total catch weight for the basis design (♦), for the design having 15% blocked meshes (▲) and for the design having the number of meshes around reduced to 60 (□).

This study highlights how this method can be used to explore the potential effect of applying different design strategies for cod-end design in an attempt to improve the selective properties.

Theoretical comparison between the twin trawl method and the covered cod-end method to assess cod-end selectivity.

This study was induced by concern about an unforeseen distribution of selective parameters, obtained when analyzing experimental data according to the twin trawl method. We carried out a theoretical study of this methodology and compared results obtained by the covered cod-end method. Irregularities in parameter values of single hauls are often encountered when analysing twin/trouser gear data and have previously been explained merely by shortcomings in the experimental setup (e.g., Madsen & Holst 2002 and Valdemarsen et al. 1996). Through simulated catch data, we demonstrated that extreme parameter values as well as discrepancies in results between the twin trawl and covered cod-end experiments, do not necessarily reflect physical or biological mechanisms but may be a consequence of the methods used when analysing data. We used PRESEMO to simulate a range of different scenarios. The results indicate that application of the twin or trouser trawl method for estimating cod-end selectivity, may, in some cases, seriously bias the estimated selection parameters. Figure 28 plots results from different scenarios of the split were on one hand data are analyzed using the twin/trouser method (□) and on the other using the covered method (▲).

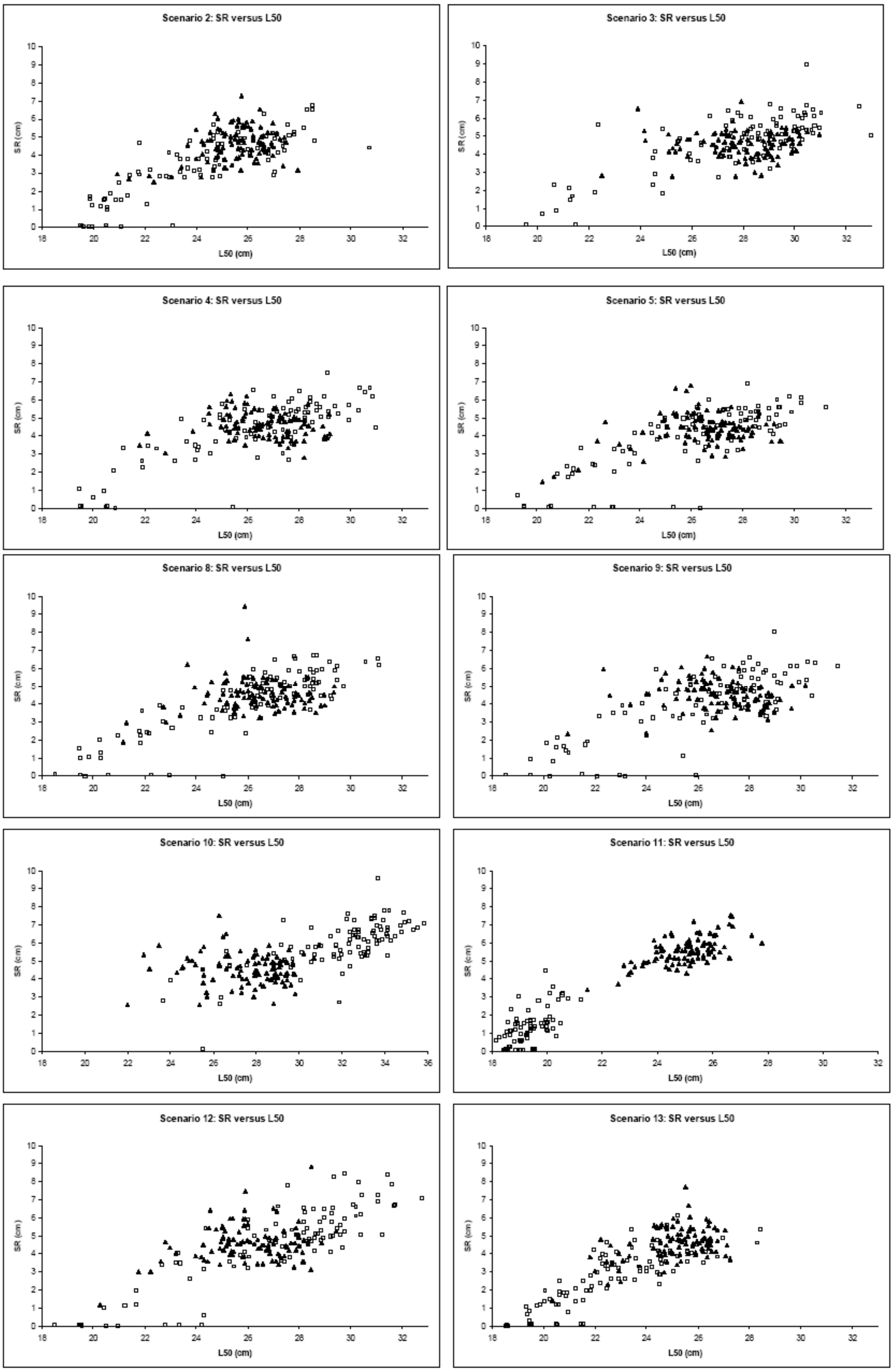

Figure 28: selectivity results (SR versus L50) from different scenarios of the split were on one hand results are analyzed using the twin/trouser method (□) and on the other using the covered method (▲).

Creating different scenarios for the split process going on in a twin/trouser fishing gear we have using PRESEMO in an 'experimental' design that besides the control cod-end has a cover around the test cod-end generated artificial haul data that can be analysed by both the twin/trouser method and by the covered method. We were by doing so able to on a haul to haul basis to get comparable results from applying the two different methodologies. One potential benefit of the simulation-based methodology outlined in this study is that it in the future can be used to investigate if other methodologies to analysis data from twin/trouser experiments would be more robust to the split process scenarios we have modelled. Our approach can easily be applied in a controlled way both on a haul to basis and on a mean basis for multiple hauls to test the robustness and efficiency (variance estimates) for the estimation of the selective parameters for a gear obtained by the twin/trouser methods compared with the covered cod-end method for a large range of different scenarios when using different procedures to analyse the data. Thus this study has highlighted a new area in the fisheries research where the simulation method can be used.

Discussion

This chapter of the report has described a new model and method for assessing the size selectivity of a diamond mesh cod-end. These results build on an individual based structural model and computer simulations. The use of a stochastic technique to simulate the between-haul variability of size selection was also described. Haddock was used as a case study to validate the model and the method, namely regarding the obtained range of values for L50, SR and their dependency on catch weight (except for one study on red mullet). The model could also explain the between-haul variability in size selection observed in experiments with haddock. Using the model to investigate the influence of mesh size and number of meshes around the cod-end showed a reasonable agreement with predictions based on empirical models of haddock selection.

This project has demonstrated that the new method for assessment of size selectivity is at a stage where it can be applied to selectivity studies for different cod-end designs.

Using the model and method

The method opens new possibilities to investigate the effect of different cod-end designs on selectivity without the need to conduct a large number of expensive and time-consuming sea trials. Therefore, the method should lead to gear designs with improved size selectivity, if combined with sea trials where the predictions from the method are used to optimize the gear designs before conducting the sea trials,.

The development of a simulation tool like PRESEMO, which can visualize the behaviour of individual fish in the cod-end during towing, enables tuning of model parameters until the selection processes in the cod-end resemble those seen in underwater recordings. In future, the combined use of underwater recordings with the simulated visualization of fish behaviour could be beneficial to research on fish behaviour in towed fishing gear. The structural model approach also enables gain of knowledge on the internal processes of fish size selection by comparing model predictions to corresponding experimental data.

The PRESEMO model introduces several parameters that describe fish behaviour and morphological data. The availability of information on realistic values for these parameters is today limited. Therefore, several sets of model simulations should be carried out and these results should be compared to empirical data to calibrate the model and establish default sets of parameters for different species.

Madsen et al. [1998 and 1999] report on fishing-experiments that use cod-ends with various sorts of integrated square mesh panel sections, inserted to improve the size selection of round fish. The method and model described in this thesis should be developed further to be able to predict size selection in those kinds of cod-ends. Research could also be directed at investigating what effect the type of mesh the cod-end netting is made from has on size selection. For instance, Roberson and Stewart [1988] report on the use of pure square mesh cod-ends while Suuronen et al. [1991] report on the use of hexagonal mesh cod-ends.

So far, the model ought to predict size selection for round fish. However, further research is needed to investigate model performance at predicting size selection for species other than haddock. Future research could also be directed towards applying the model and method to the prediction of size selection for different species of flatfish.