# Cod-end selectivity for sole (Solea solea) and plaice (Pleuronectes platessa) in North Sea pulse-trawl fisheries

## Best Practices II – WP4 selectivity

Authors: Pieke Molenaar and Chun Chen

Wageningen University &
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# Summary

Electrified pulse trawls have replaced traditional tickler chain beam trawls in the North Sea fisheries for sole. This study investigates the mesh selection in pulse trawling of conventional cod-ends (80 mm cod-end mesh) used in the current pulse trawl fishery, and the effects of increasing the cod-end mesh size to 90 mm on catches of sole (*Solea solea*) and undersized plaice (*Pleuronectes platessa*). Cod-end selectivity was estimated for 79-80 mm and 87-88 mm cod-ends during two experiments on a commercial pulse trawler using a cover cod-end. The results show that with a mesh size of 79-80 mm the length where 50% of the individuals are retained (L50) for sole is 19 cm with a selection range (SR) of 4.9 cm. Given the observed length distribution of sole on the fishing ground this results in a 10% loss of marketable sole catches in the 24-27 cm length range. Increasing the mesh size in experiment one to 87 mm resulted in a L50 for sole of 22 cm with SR = 4.9 cm and in experiment 2 to a L50 of 26 cm and SR = 4.9 cm was found for 88 mm cod-end, resulting in a loss of marketable sole of 24% and 38% in experiment 1 and 2, respectively. These losses were detected in the 24-33 cm length range. Compared to sole, plaice showed steeper selection curve with a L50 of 14.4 cm (SR 2.5) and 14.1 cm (SR 2.1) for the 79-80 mm cod-ends in experiment 1 and 2, respectively. In the 87 mm cod-ends, this L50 shifted to 15.6 cm (SR 2.5) for experiment 1 and 18.7 cm (SR 2.1) for the second experiment. The ratio of plaice discards per kg marketable sole caught was 0.4 in experiment one for 80 mm cod-ends, and increased to 0.5 in a 87 mm cod-end. In the second experiment this was 2.3 for 79 mm and 2.5 for 87 mm. Increasing the minimum cod-end mesh to 90 mm thus increases the discard quantities of undersized plaice when the sole total allowable catch (TAC) is fully exploited.

# 1 Introduction

In many countries, capture fisheries only land the marketable part of the catch and discard undersized or unwanted species. Discarding is particularly pronounced in bottom trawl fisheries. Discarding reduces the sustainable yield and may cause unwanted ecological consequences. FAO estimated global discards at 27 million tonnes in 1994 and 7.3 million tonnes in 2005 ((Alverson et al., 1994);(Kelleher, 2005)). In order to reduce discarding the EU has imposed an obligation to land all fish caught in the 2012 reform of the Common Fisheries Policy ((Borges, 2015)). It is expected that a ban on discarding will create an incentive for fishers to avoid fishing grounds with large number of discards or develop discard saving technologies ((Condie et al., 2013a; Condie et al., 2013b)). Discarding may be reduced by improving the selectivity of the gear. Gear modifications may comprise of release and separation panels, net configurations such as large meshed top panels, square mesh and other trawl modifications.

The North Sea flatfish fishery is one of the bottom trawl fisheries characterised by a large catch of undersized fish, due to the use of a 80 mm cod-end mesh required to catch the slender sole ((van Beek, 1998)). The fishery also deploys a number of tickler chains to chase sole out of the seabed which leads to unwanted impacts on the benthic ecosystem ((Jennings and Kaiser, 1998); (Kaiser and Spencer, 1996; Bergman and van Santbrink, 2000)).

In order to reduce the ecosystem impacts of the beam trawl fishery, electrified bottom trawls, pulse trawls, have been introduced in 2009. Since then, the number of Dutch beam trawl vessels that switched to using the pulse trawl has increased to 78 in 2018 (ICES, 2018). It is expected that the pulse stimulus may improve the gear selectivity as the response to the electrical stimulation will be size dependent (Stewart, 1975, 1977; (Soetaert et al., 2015)). Van Marlen et al (2014) reported the results of a comparative trawling trial with two pulse trawlers and one traditional beam trawler carried out shortly after the introduction of the innovative gear. The results showed that the catch efficiency of the pulse trawl was not statistically different from the traditional gear for sole. For the other species such as plaice and dab, however, the pulse trawl caught significantly less per area swept. In addition, the pulse trawl caught fewer undersized plaice and sole. A comparative trawling trial in 2015 suggested that the pulse trawl caught significantly more sole (kg/ha), both market-sized (43%) and undersized (61%), than the traditional tickler chain beam trawl. Plaice catches were equal. Compared with the experiment in 2011, when pulse fishing was just introduced, sole catch efficiency increased (van der Reijden et al., in prep). Both comparative studies showed a reduction in the catch of benthic invertebrates of around 50%, in particular of infaunal species ((van Marlen et al., 2014); van der Reijden et al., submitted).

The differences in catch efficiencies estimated in the comparative trawling trials are the combined result of proportion of the fish in the trawl path that enter the net (available-selection sensu Millar and Fryer, 1999) and the proportion that is retained in the cod-end (contact-selection sensu Millar and Fryer, 1999). In the traditional gear, the tickler chains running at fixed distances in front of the ground-rope, prevent flatfish to escape underneath the ground-rope by digging into the sediment ((Creutzberg et al., 1987)). In the pulse trawl, the electrical stimulus invoke a cramp response, which disables the fish to respond to the gear. Once the fish is in the net and outside the electrical field, it recovers and return to its normal behaviour ((van Stralen, 2005); (de Haan et al., 2016)).

This study investigates the cod-end mesh selection of the trawl nets (80 mm cod-end mesh) used in the current pulse trawl fishery for flatfish in the North Sea, and study the effect of increasing the minimum cod-end mesh size to 90 mm on the catch of undersized sole (*Solea Solea*) and plaice (*Pleuronectes platessa*), and on the loss of marketable sized sole.

# 2 Research question

This study addresses the effects of increasing the minimum cod-end mesh size in the Pulse trawl fishery for sole from the current 80 mm to 90 mm cod-ends. The main interests are the effects on the catch of marketable sole and unwanted catches of undersized plaice. For those species a minimum landing size (MLS) of 24 cm for sole and 27 cm for plaice is implemented. The selective performance is compared in terms of weights, length frequency for marketable and undersized catches, and selection curves for both species. The numbers and weight of fish caught are dependent on abundance on the trawled area and its size composition. This is less the case for the selective performance of the gear, in particular the cod-end selectivity is dependent on mesh opening and its specifics and the morphology of the target species.

## 2.1 Experimental design

During two 4.5-day experimental trips, parallel hauls with covered cod-ends were conducted on board of a commercial pulse trawler on the commercial fishing grounds in the southern North Sea. The trawler deployed two pulswing trouser trawls with two cod-ends for each trawl. Except for the cod-end covers this rigging is similar to the commercial practice. In the experiment, new experimental cod-ends were used: two 80 mm cod-ends on starboard side and two 90 mm cod-ends on the portside trawl. To collect all individuals escaping through the meshes of each of the 80 and 90 mm experimental cod-ends (test), the covered cod-end method was used as described by Wileman et al., 1996. With this method a large small mesh cod-end is covering the cod-end to collect all fish that escape through the meshes of the cod-end. To account for potential catch efficiency differences between both trawls, halfway each experiment the portside cod-ends and accompanying cod-end covers were detached from the trawl and switched starboard, this was done the other way around for the starboard cod-ends and covers. For each sampled haul, weights of marketable commercial fishes as well as weights of undersized sole and plaice were recorded. Due to workload, length distribution of undersized plaice and undersized and marketable sole were measured only every second haul.

# 3 Materials and Methods

## 3.1 Experimental timing and locations

The cod-end selectivity experiments were conducted from June 12-16 (week 24) and August 14-18 (week 33) 2017 on board a Dutch commercial pulse trawler in the Southern North Sea (ICES area IV) on regular fishing grounds of pulse trawlers characterized by sandy substrate and muddy banks (Figure 1). Fishing depth ranges between 17-42m during the first experiment and ranges between 20m to 32m during the second experiment. The vessels specifics can be found in Table 1.

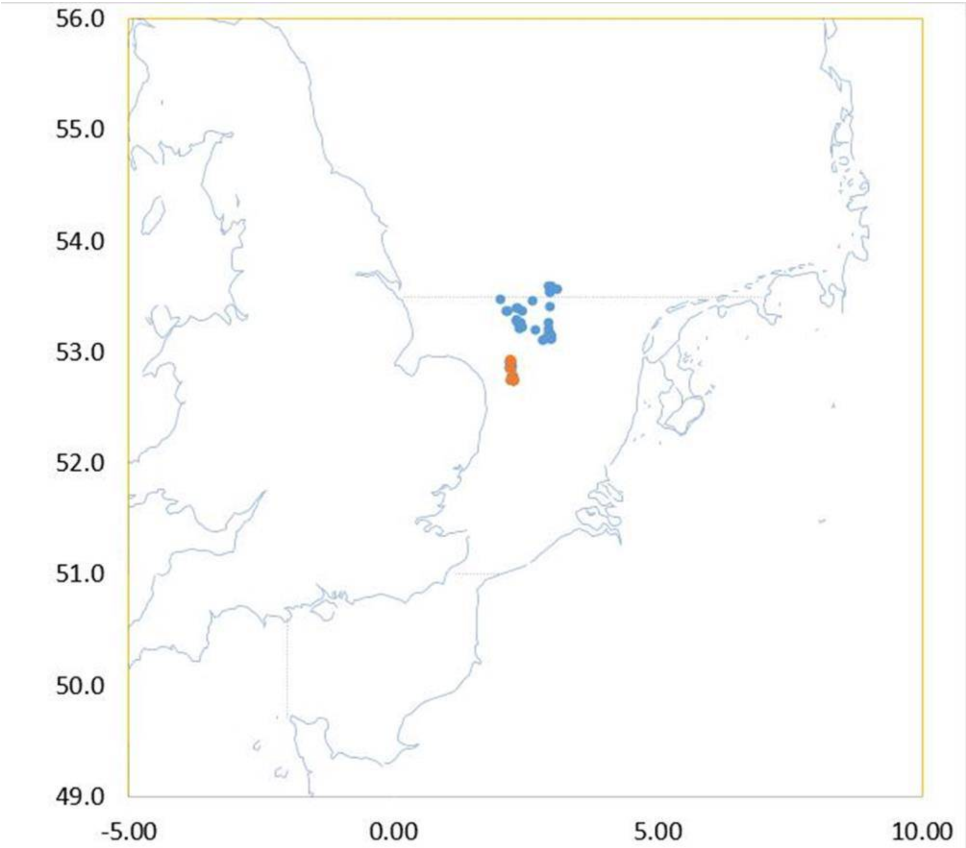


Figure 1. Sampled locations in the Southern North Sea for experiment 1 (orange) and experiment 2 (blue).

## 3.2 Gear

The commercial pulse trawls (pulswing) were used. Each pulse beam trawl consists of a 12m wide wing type beam (HFK) with 28 electrodes and a trouser trawl with two cod-ends. This type of trawl is representative for six vessels of the Dutch pulse trawlers. Commercial towing speed (4.5 knots) and haul duration (120 minutes) was applied for all hauls. Trawl specifications including electrode design, electrics pulse characteristics, ground rope and net material can be found in Table 1.

For the experiments four new 6.8 meter long cod-ends were constructed with a stretched cod-end mesh size of 80 mm and 90 mm. Cod-end material, number of meshes and twine thickness is presented in Table 1. For the second experiment, the same cod-ends and covers were used except for the two 90 mm cod-ends. Two new 90 mm cod-ends were constructed according the same dimensions (Table 1).

The cod-end cover length was limited to 1.5 times the cod-end length, due to the vessels limited operational lifting height capacity. Longer cover designs have handing difficulties on board of this type of beam trawler. All four experimental cod-ends were individually equipped by a single twine cod-end cover with 40 mm diamond (T0) mesh size (Table 1). In the covers upper panel an 2m opening was constructed to enable catch handling of the cod-ends. Before starting a new haul this opening was sewed with an rope. To protect the covers bottom panel from damage related to bottom contact it was protected over its full length by piece of net equipped with dolly ropes.

Each cover was equipped with three rubber 'fishermen's' kites (Figure 4) and three egg shaped floats (buoyancy: 2.5 kg) to ensure sufficient opening between cod-end and cover and minimize the risk of cod-end masking. Kites were constructed from 10 mm thick rubber mats (50 x 45 cm) and were connected to the trawl with two 20 cm ropes in the rear aft and 40 cm ropes in the front aft. To ensure an upright position in the water an additional float tied on top of the front aft. Prior to the trails the effectivity of the kites and floats were visually inspected during two short hauls with GoPro camera's

Table 1. Specifics of vessel, gear and cod-ends used in the selectivity trails

| Specifics | | |
|---|---|---|
| Vessel | Engine power (Kw) | 1119 |
| | Tonnage (GT) | 424 |
| | Length (m) | 40 |
| | Gear | Sumwing pulse |
| | Number of gears | 2 |
| | Fishing speed (kn) | 4.5 |
| Wing | Width (m) | 12 |
| | Length (m) | 1.1 |
| False ground rope | Type | Rubber discs |
| | Length (m) | 12 |
| | Diameter (mm) | 250 |
| Electrodes | Number | 28 |
| | Type | HFK |
| | Total length including isolated first section (m) | 7.6 |
| | Distance between electrodes ( cm) | 41.5 |
| | Length electrodes on seabed (pulse field) (m) | 4.8 |
| Conductor elements | Number | 10 |
| | Diameter (mm) | 30 |
| | Length (mm) | 125 |
| | Distance between elements (mm) | 22 |
| Pulse | Power per trawl (kW) | 7.2 |
| | Width (µs) | 260 |
| | Frequency (Hz) | 80 |
| | Peak voltage over electrode (V) | 60V |
| | Maximum exposure time to pulse field (s) | 2.08 |
| Trawl | Type | Trouser pulse trawl |
| | Number of cod-ends per trawl | 2 |
| | Total length (m) | 40 |
| | Twine cod-end | PE double knotted twine |
| | Twine thickness (mm) | 4 |

| Specifics | | |
|---|---|---|
| Cod-end (80 mm) | Length (# mesh) | 70 |
| | Round (# mesh) | 88 |
| Cod-end (90 mm) | Length (# mesh) | 64 |
| | Round (# mesh) | 80 |
| Cover cod-end (40 mm) | Length (# mesh) | 200 |
| | Round (# mesh) | 253 |
| | Twine cover cod-end | PE single twine |
| | Twine thickness (mm) | 3 |
| | Number of kites | 3 |
| | Number of floats | 3 |

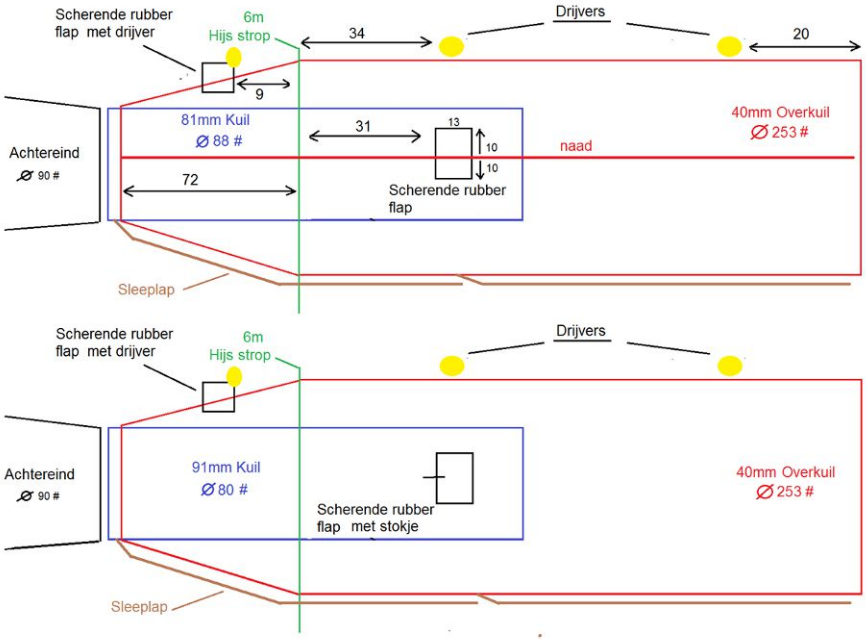


Figure 2. Schematic drawing of the cod-ends and covers including modifications (kites, floats) to prevent the cover masking the cod-ends meshes. Cod-end (blue) and cod-end cover (red) designs with floats (yellow) and kites (black squares), protection netting with dolly ropes (brown) and lifting rope (green).

Figure 3. Left image shows the double cod-end of the port side trouser trawl with cod-end covers (green) and kites (black/yellow). Right image shows the Pulswing beam with electrodes.

Figure 4. Ground rope the trawl (left) and a kite attached to the cover cod-end (right)

## 3.3 Sampling procedure

The first experiment 21 hauls were sampled for weight and of those 12 were sampled for length. The second experiment 25 hauls were sampled for weight and 14 for length (Table 2).
For each haul trawling position, duration, speed, depth were the trawl was deployed and sea state were recorded by the skipper on a trawl list. After hauling the trawls, the starboard and portside covered cod-ends were emptied in separate hoppers, the two 80 mm cover cod-ends were emptied in one hopper, where the both 90 mm cod-ends were emptied in the second hopper. After processing the catch from the covers the catch from the test cod-ends (80 and 90 mm) were processed separately. The catch was processed on a conveyor belt, all marketable fish and every individual sole and plaice were collected from the catch and stored in baskets. Catches of cod-end and cover were marked with a colour code to avoid confusion. Sole was sorted in marketable and undersized individuals prior to weighing the fractions. For all species, catch weights of marketable fish were collected from both test (80 mm, 90 mm) and cover (40 mm) cod-ends. Catch weight per fraction and species was measured on a sea state compensated Marelec scale. For every second sampled haul length distribution (cm-below) was determined for all sole (undersized and marketable sized) and undersized plaice. For each fraction, at least 300 fish were measured if available, in case of larger catch fractions a subsample was measured. During the second experiment (week 33) no subsampling was applied and all sole were measured for the length sampled hauls. The number of fish measured for each experiment are given in Table 2.

Table 2. Sampled hauls and hauls were sole and undersized plaice were measured.

| Experiment | Hauls sampled (Weight) | Hauls sampled (length) | # Sole length measured | # Plaice length measured (<27 cm) |
|---|---|---|---|---|
| 1 | 21 | 12 | 13.842 | 5687 |
| 2 | 25 | 14 | 6013 | 10.407 |

Cod end mesh size was measured with an OMEGA Gauge (Fonteyne et al. 2007) at 125 N (cod-end mesh) and 50 N (cover) for 20 meshes in the longitudinal direction of the net of all cod-ends and covers. For both trails, the mesh size was measured after haul 4 and after the last haul, the average mesh size is each cod-end and cover is given in Table 3.

Table 3. Average mesh size in mm (SD) for each cod-end and cover for experiment 1 and 2. For each cod-end, 20 consecutive meshes were measured with an OMEGA gouge in after the 4th haul and at the end of the trail.

| | Cod-end 1 | Cover 1 | Cod-end 2 | Cover 2 | Cod-end 3 | Cover 3 | Cod-end 4 | Cover 4 |
|---|---|---|---|---|---|---|---|---|
| Experiment1 | 79.7(2.4) | 40.7(1.2) | 79.6(1.6) | 41.1(1.7) | 87.3(1.7) | 40.5(0.9) | 87.2(2.0) | 40.5(1.1) |
| Experiment2 | 78.8(1.8) | 39.6(1.4) | 78.7(2.0) | 39.5(1.0) | 87.4(2.1) | 39.2(1.7) | 88.1(2.1) | 39.3(1.6) |

## 3.4 Data analysis

### 3.4.1 selectivity ogive

Collected data was digitized in Billie turf 8.0, checked for inconsistencies with SAS and analysed in R (R Development Core Team, 2004) and the R packages "lme4" (Douglas Bates etc., 2015). A glmm with binomial distribution of the response variable and a logit link function was applied. The response variables were expressed as the presence/absence in the cod-end. Fish length, mesh size and experiment ID (with their interactions) were included as fixed effects, while the haul ID was included as a random intercept. Model coefficients were estimated through maximum likelihood. The best fitted model was selected using minimum AIC.

# 4 Results

As presented in Table 3 measured mesh opening slightly deviated from 80 mm and 90 mm during both experiments. As mesh opening is important for the results, the average measured mesh opening for each experiment is used for describing and interpreting the results.

## 4.1 Catch composition

Catch weights of marketable turbot, brill, dab and red gurnard are presented in annex 8. forty-six hauls were included in the analysis for plaice and sole for marketable catches and discards. For experiment 1, 21 hauls were weight sampled including 12 hauls with length measurements. Experiment 2 included 25 hauls of which 14 with length measurements. Sole and plaice catch composition will be presented in average weights per haul for both landings and discards.

### 4.1.1 Sole catches per experiment in weight

Overall marketable sole catches (cod-end + cover) per trawl (cod-end plus cover) did not significantly differ between starboard and port-side nets for experiment 1 and 2. In experiment 1, on average 63 kg of marketable sole was caught per haul per trawl. Of the total marketable sole catch entering the trawl in the experiment, 89% was retained in the 80 mm cod-end while 76% was retained in the 87 mm cod-end. In experiment 2 the overall sole catches were lower, with a total of 29 kg for the 79 mm cod-end and cover and 32 kg for the 88 mm trawl. Of those catches 87% was retained in 79 mm and 62% in the 88 mm cod-end. Undersized sole catches were for both trawls on average 24 kg per haul for experiment 1, 55% was retained in the 80 mm where 41% was retained in the 87 mm. For experiment 2 this was 8.4 kg for the 79 mm cod-end and 9.8 for the 88 mm, for those undersized fish 51% and 29% was retained (Table 4 & Figure 6).

Table 4. Mean (SE) catch weight (kg) of sole landings (>24 cm) and undersized discards per haul for tip 1 and 2. Weights are given for cod-end and cover together, for the cod-end and cover separately and the weight percentage of the total weight that retained in the cod-end.

| Experiment | Mesh size (mm) | Size Class | Total (Cod-end + cover) | | Cod-end | | Cover | | Retained in cod-end (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| 1 | 80 | landings | 62.8 | 5.9 | 56.4 | 5.5 | 6.4 | 0.8 | 89.6 | 1.3 |
| | 80 | discards | 24.5 | 1.6 | 13.4 | 0.9 | 11.1 | 1.0 | 55.0 | 2.6 |
| | 87 | landings | 63.2 | 4.5 | 48.9 | 4.1 | 14.3 | 1.1 | 76.4 | 1.7 |
| | 87 | discards | 24.0 | 1.7 | 9.6 | 0.6 | 14.4 | 1.4 | 41.4 | 2.4 |
| | | | | | | | | | | |
| 2 | 79 | landings | 29.2 | 1.9 | 25.6 | 1.8 | 3.6 | 0.4 | 87.1 | 1.3 |
| | 79 | discards | 8.4 | 1.1 | 4.4 | 0.7 | 4.0 | 0.5 | 51.3 | 2.3 |
| | 88 | landings | 31.6 | 1.8 | 19.7 | 1.3 | 11.9 | 0.8 | 61.9 | 1.6 |
| | 88 | discards | 9.8 | 1.0 | 2.9 | 0.4 | 6.9 | 0.7 | 29.1 | 1.9 |

| tripID | SSE_CATEGORY | out_group | p_value | est_diff |
|---|---|---|---|---|
| trip1 | d | cover | 0.0 | 3.3 |
| trip1 | l | cover | 0.0 | 7.8 |
| trip1 | d | test | 0.0 | -3.9 |
| trip1 | l | test | 0.0 | -7.5 |
| trip2 | d | cover | 0.0 | 2.9 |
| trip2 | l | cover | 0.0 | 8.4 |
| trip2 | d | test | 0.0 | -1.6 |
| trip2 | l | test | 0.0 | -5.9 |

Figure 5. Paired t-test result comparing average weight per haul in 87-88 mm vs. 79-80 mm mesh sizes, for landing and discards respectively. The results shown that the average landing as well as discards weight of sole significantly ($p<0.05$) differs between 87-88 mm and 79-80 mm mesh openings in both experiments.

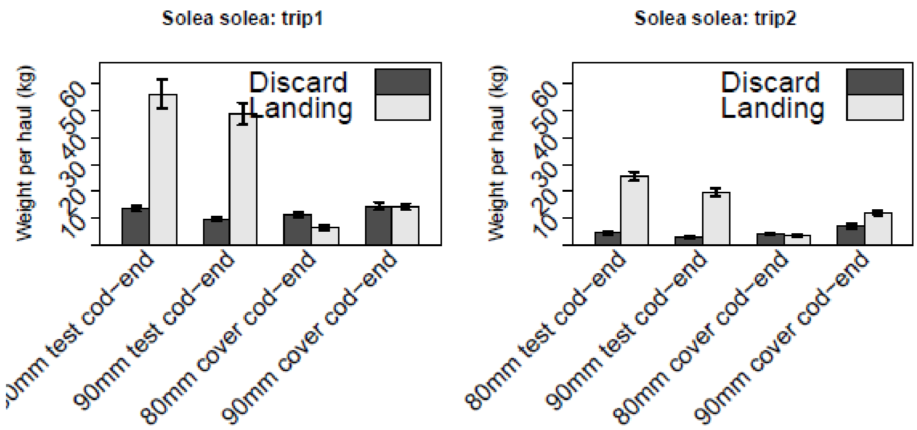


Figure 6. Average catch weights (kg) per haul for sole landings (>24 cm) and discards (<24 cm) in the 80 mm and 87 mm cod-ends and cover cod-ends for experiment 1 (left) and 79 mm and 88 mm cod-ends and cover cod-ends for experiment 2 (right).

### 4.1.2 Plaice catches per experiment in weight

For both experiments all marketable plaice (>27 cm) was found in the 79-80 and 87-88 mm cod-ends (Table 5). Overall undersized plaice catches (cod-end + cover) per trawl were different for experiment 1 and 2, on average 24 and 28 kg of undersized plaice was caught in trawls during experiment 1, of those fish 91% was retained in the 80 mm cod-end and 87% in the 87 mm cod-end. In experiment 2 the overall plaice catches were higher. For the undersized plaice a total of 58kg for the 79 mm cod-end and cover and 70 kg for the 88 mm cod-end. Of those catches 87% was retained in 79 mm and 62% in the 88 mm cod-end (Table 5 & Figure 8)

Table 5. Mean (SE) of the catch weight (kg) of marketable plaice (>27 cm) and undersized discards per haul for tip 1 and 2. Weights are given for cod-end and cover together, for the cod-end and cover separately and the weight percentage of the total weight retained in the cod-end.

| Experiment | Mesh size (mm) | Class | Total (Cod-end + cover) | | Cod-end | | Cover | | Retained in cod-end (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| 1 | 80 | landings | 24.2 | 2.9 | 24.2 | 2.9 | 0 | 0 | 100 | 0 |
| | 80 | discards | 24.4 | 3.2 | 22.0 | 3.0 | 2.4 | 0.6 | 90.6 | 2.2 |
| | 87 | landings | 24.0 | 3.2 | 24.0 | 3.2 | 0 | 0 | 100 | 0 |
| | 87 | discards | 28.0 | 4.5 | 22.8 | 3.2 | 5.2 | 2.1 | 86.6 | 2.5 |
| | | | | | | | | | | |
| 2 | 79 | landings | 56.5 | 8.9 | 56.5 | 8.9 | 0 | 0 | 100 | 0 |
| | 79 | discards | 58.0 | 8.5 | 51.9 | 8.2 | 6.1 | 1.0 | 86.6 | 2.3 |
| | 88 | landings | 59.4 | 8.5 | 59.4 | 8.5 | 0 | 0 | 100 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 88 | discards | 70.0 | 8.8 | 46.5 | 7.2 | 23.5 | 3.2 | 61.5 | 3.3 |

| tripID | SSE_CATEGORY | out_group | p_value | est_diff |
|---|---|---|---|---|
| trip1 | d | cover | 0.2 | 2.8 |
| trip1 | d | test | 0.6 | 0.8 |
| trip2 | d | cover | 0.0 | 17.4 |
| trip2 | d | test | 0.0 | -5.5 |
| trip1 | l | test | 0.9 | -0.2 |
| trip1 | l | cover | | 0.0 |
| trip2 | l | test | 0.6 | 2.9 |
| trip2 | l | cover | | 0.0 |

Figure 7. Paired t-test result comparing average weight per haul in 87-88 mm vs. 79-80 mm mesh sizes, for landing and discards respectively. The results shown that the average discards weight of plaice significant ($p<0.05$) differs between 87-88 mm and 79-80 mm mesh size opening only in experiment 2.

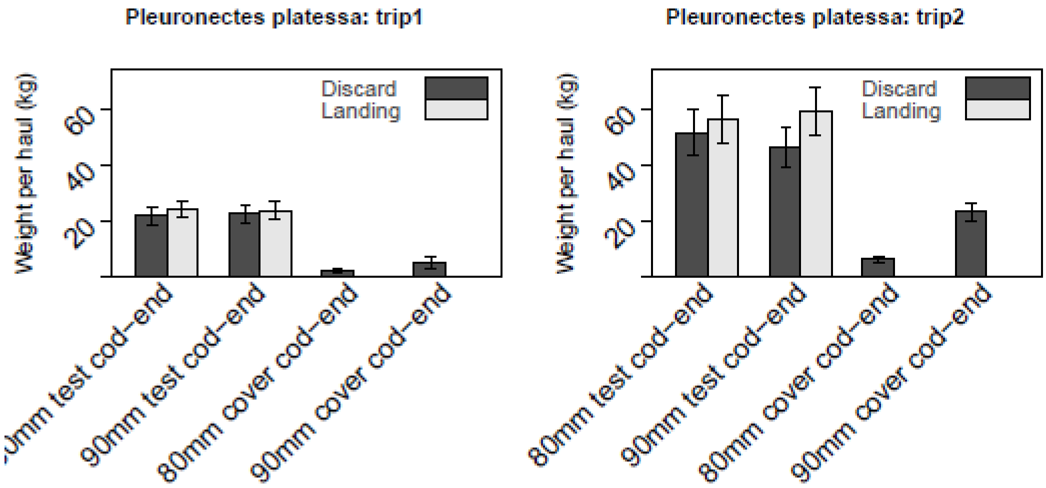


Figure 8 Average catch weights (kg) per haul for marketable- and plaice discards (<27 cm) in the 87-88 mm and 79-80 mm cod-ends and cover cod-ends for experiment 1 (left) and experiment 2 (right).

## 4.2 Length frequency distribution

Length of each individual fish in both cod-end and cover was measured for every second sampled haul, this enables to express the population length frequency (LF) distribution for each haul (annex 6 & 7). Sampled hauls show a large variation in the LF distribution of the population for both species, therefore the population LF is given for all individuals of a certain species per experiment.

### 4.2.1 Sole population distribution

The LF distribution for all catch fractions (test cod-ends and covers) and the total available population for each trawl is given in Figure 9. The total available populations (black line) were not different for both trawls (dashed 87-88 mm and solid 79-80 mm) during experiment 1, this is also visible for experiment 2 for sole larger than 23 cm and smaller than 19 cm, in between the numbers in the 88 mm trawl were higher. In experiment 1 only sole smaller than 27 cm escapes from the 80 mm cod-end, this increases towards 29 cm for the 87 mm cod-end. Similar pattern is visible for the 79 mm cod-end in experiment 2, although this is not present for the 88 mm cod-end. In this experiment sole up to 33 cm managed to escape through the 88 mm mesh openings.

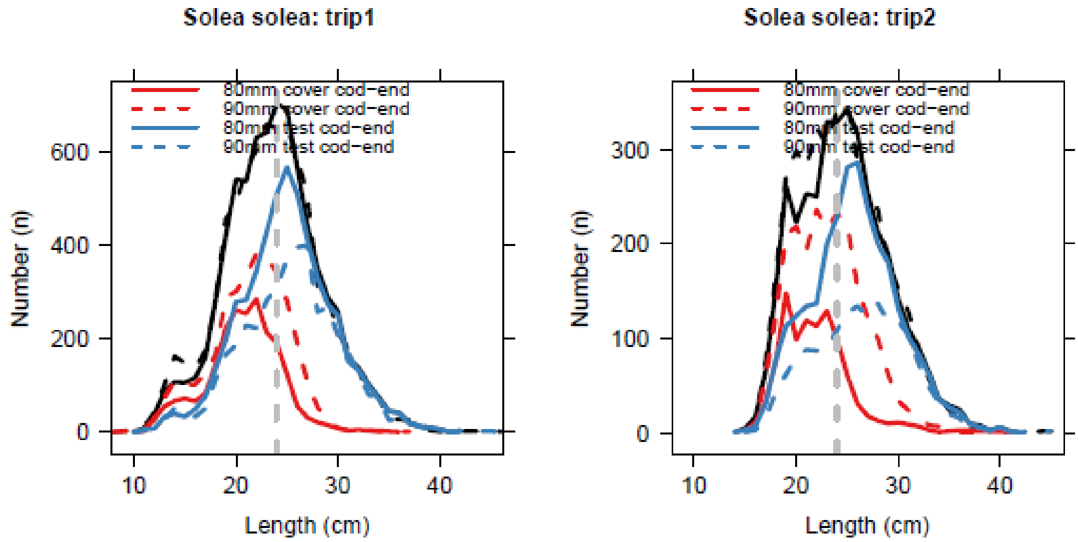


Figure 9. Sole length frequency per cod-end and covers caught for experiment 1 (left) and experiment 2 (right). The black lines indicates the population distribution of the cod-end (blue) and cover (red) together for 79-80 mm (solid line) and 87-88 mm (dashed line). The grey dashed line in the graph presents the minimum landing size (24 cm).

### 4.2.2 Plaice discards population distribution

The LF distribution for all undersized catch fractions (test cod-ends and covers) and the total available undersized population for each trawl is given in Figure 10. The total available populations (black line) were different for both trawls during experiment 1, Differences were mainly found in the 10-17 cm range with higher numbers in the 80 mm cod-end. For experiment 2 the available populations is comparable, with slightly higher numbers for 88 mm cod-end in the in the 19-23 cm range. In experiment 1 plaice smaller than 17 cm escapes from the 80mm cod-end, this increases towards 20 cm for the 87 mm cod-end. For the 79 mm cod-end in experiment 2 a similar pattern is visible, where plaice smaller than 18 cm could escape. For the 88 mm cod-end in experiment 2, plaice smaller than 24 cm managed to escape through mesh openings.

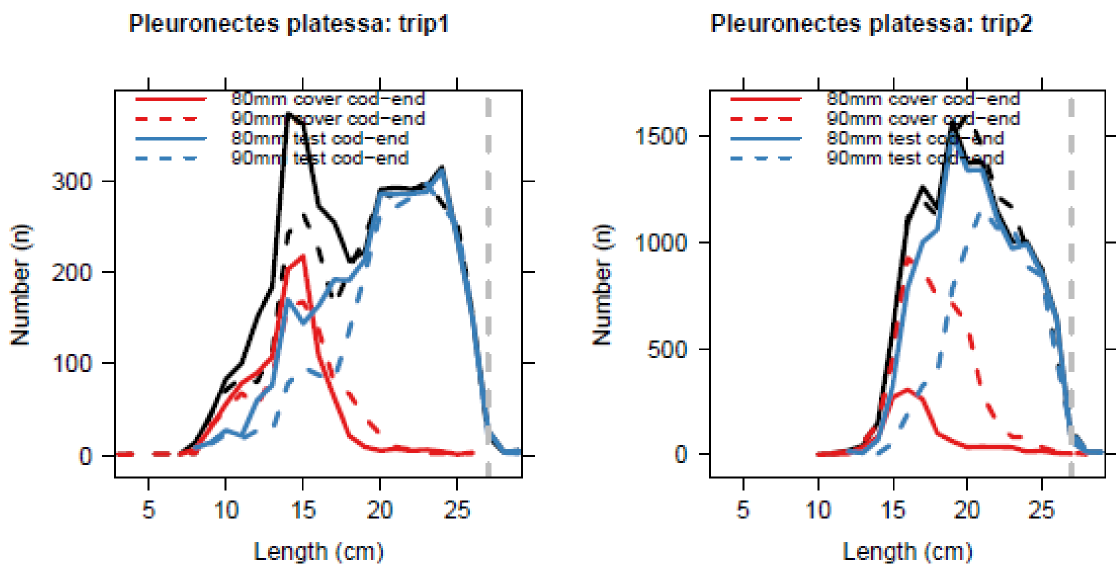


Figure 10. Plaice length frequency per cod-end and covers caught for experiment 1 (left) and experiment 2 (right). The black lines indicates the population distribution of the cod-end and cover together for 79-80 mm (solid line) and 87-88 mm (dashed line). The grey dashed line in the graph presents the minimum landing size (27 cm).

## 4.3 Selection curves

Cod-end selectivity curves and parameters were estimated for sole and plaice, the probability of retaining an individual of a certain length in the cod-end is expressed by the selectivity curve and range. The selected model with the minimum AIC includes the interaction between experiment and treatment (79-80 mm vs. 87-88 mm), implying that the mesh size effect differs between the two experiments. Different to sole, plaice has a different optimal model. The optimal model with the minimum AIC includes the interaction between experiment and treatment (79-80 mm vs. 87-88 mm), as well as the interaction between experiment and length. This implies that not only the mesh size effect, but the length effect also differs between the two experiments. In experiment 2, the length effect is also getting stronger. Therefore, the estimated selectivity is presented for each experiment separately.

Sole yields a flatter selectivity curve as compared to plaice, with a length at 50% retention (L50) of 18.9 and 19.3 cm for experiment 1 and 2 for the 79-80 mm cod-ends (Table 6 & Figure 11). No significant difference was detected for the 79-80 mm selectivity for both experiments (i.e. the optimal was without experiment interaction). In the 87 mm cod-end a L50 of 22.2 cm was estimated for experiment 1 and 26.1 cm for the 88 mm cod-end in experiment 2. The cod-end selectivity of the 79-80 mm and 87-88 mm was significantly different for both experiments.

Plaice showed steep selection curve with a L50 of 14.4 for the 80 mm and 14.1 cm for the 79 mm cod-ends (Table 6 & Figure 11) with no significant difference between experiments. In the 87 mm cod-ends this L50 shifted to 15.6 for experiment 1 and 18.7 cm for the 88 mm cod-ends in experiment 2. Although the larger undersized plaice (<27 cm) has a significantly higher chance of being retained in the 87-88 mm cod-end, for both mesh sizes a full cod-end retention for plaice is reached before the minimum landing size. Observed probabilities and estimated curves are per experiment and species are presented in annex 6 & 7.

Table 6. Estimated lengths at 50% cod-end retention (L50) and selection range with 95% confidence intervals for sole and plaice for experiment 1 and 2. CI UL & CI LL are Confidence Interval Upper limit and Lower Limit

| Species | Experiment | Mesh size (mm) | L50 (95% CI) | | | Selection range | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | CI UL | CI LL | Mean | CI UL | CI LL |
| Sole | 1 | 80 | 18.9 | 19.8 | 17.9 | 4.9 | 5.1 | 4.7 |
| | | 87 | 22.2 | 23.1 | 21.3 | 4.9 | 5.1 | 4.7 |
| | 2 | 79 | 19.3 | 20.2 | 18.4 | 4.9 | 5.1 | 4.7 |
| | | 88 | 26.1 | 27.0 | 25.2 | 4.9 | 5.1 | 4.7 |
| | | | | | | | | |
| Plaice | 1 | 80 | 14.4 | 15.1 | 13.7 | 2.4 | 2.5 | 2.2 |
| | | 87 | 15.6 | 16.3 | 14.9 | 2.4 | 2.5 | 2.2 |
| | 2 | 79 | 14.1 | 14.6 | 13.5 | 2.0 | 2.1 | 1.9 |
| | | 88 | 18.7 | 19.2 | 18.2 | 2.0 | 2.1 | 1.9 |

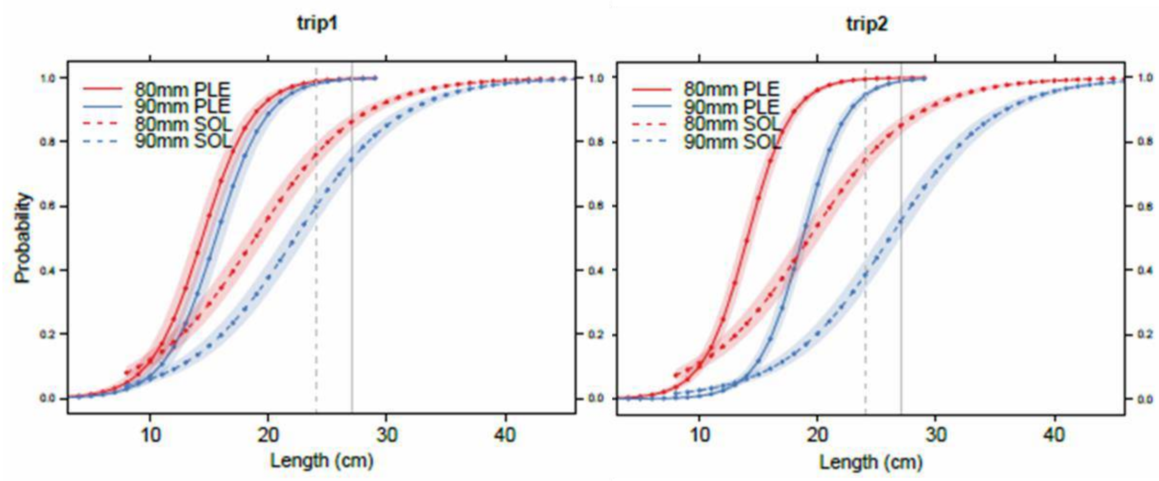


Figure 11. Estimated selectivity of 79-80 and 87-88 mm cod-ends with 95% confidence interval for Sole (SOL) and plaice (PLE) for experiment 1 and 2. The dashed grey line presents the minimum landing sized for sole (24 cm), the solid grey line the minimum landing size for plaice (27 cm).

## 4.4 Catches of plaice discards per kilo marketable sole

With recording the weight of the sole and plaice caches during both experiments the ratio of weight of undersized plaice per kilogram of marketable sole was calculated to assess the effectivity of reducing plaice bycatch by means of increasing the cod-end mesh size. The results are given in Table 7. During experiment 1 sole catches were good and there were limited catches of undersized plaice, this resulted in 0.4 kg undersized place per kilogram of marketable sole in the catches of the 80 mm cod-end. This ratio increased to 0.5 for the 87 mm cod-end. Sole catches were lower for experiment 2 while substantial amounts of undersized plaice were present. Subsequently the ratio went up to 2.3 kg undersized plaice per kilogram of marketable sole. For 88 mm cod-end this ratio was 2.5 during this experiment.

Table 7. Average weight ratio (SE) for catches of undersized plaice per kg marketable sole (kg/kg) for the 79-80 and 87-88 mm cod-ends for experiment 1 and 2.

| Experiment | Mesh size cod-end | Ratio kg plaice discard per kg marketable sole | SE |
|---|---|---|---|
| 1 | 80 | 0.4 | 0.1 |
| | 87 | 0.5 | 0.1 |
| 2 | 79 | 2.3 | 0.4 |
| | 88 | 2.5 | 0.4 |

## 4.5 Discussion

This study assesses the effect of increasing the minimum cod-end mesh size in the sole fishery from 80mm towards 90mm, the effects were primarily focussed on marketable sole and undersized plaice. The revenues of vessels in this 80mm pulse trawl fishery primarily rely on valuable sole catches, and a reduction in the catch of this target species will reduce the revenue and the economic profitability and income for the skipper and crew. The weight of the marketable plaice may be equal or higher than the sole, but due to their lower market value their contribution to the revenue is lower. The strong, slim and flexible morphological body characterises of sole result in a relative flat selection curve where even a proportion of the larger marketable fish may escape from the 80 mm cod-ends. Even with a 79 mm cod-ends, as used in the experiments, this flat selection curve with an L50 of 19 cm resulted in a 10-13% loss of the available marketable (>24 cm) sole escaping through the cod-end mesh. Those escapes were mainly found in the 24-27 cm length range. If this length range is abundant on certain fishing grounds the losses will exceed the weight percentages found in this study. For the 90 mm cod-ends, a smaller 87-88 mm mesh size was measured during the experiments. In the first experiment these cod-ends resulted in a L50 of 22 cm with 24% of the marketable sole weight escaping, those escapees were in the 24-29 cm. In the second experiment the cod-end selectivity curve shifted with the L50 of 26 cm well above the minimum landing size, resulting in a weight loss of 38% of the marketable sole weight, with escapees in the 24-33 cm range. The mechanism behind the difference in 90 mm cod-ends selectivity between both experiments is unknown but is likely due to the different cod-end used in the second experiment. This shift was not visible in 80 mm cod-ends for which the same cod-ends have been used.

The morphological characterises of plaice results in both trails in a steep selection curve, with a L50 of 14 cm in the 80 mm cod-ends. In both trials majority of the available undersized plaice population was above 14 cm therefore 87-91% of the undersized plaice weight was retained by the 80 mm cod-ends. Using 87-88 mm cod-ends resulted in a L50 of 16 cm and 87% cod-end retention, from 20 cm length a full cod-end retention was found. For the second trial this was and 17 cm and 62% cod-end retention for undersized plaice, with a full retention from 24 cm. Although a larger cod-end mesh size mitigate undersize plaice bycatch, the accompanied losses of marketable sole are larger. This visible in the relative shift in selection curve with increasing mesh sizes, the sole curve tends to shift faster towards larger lengths than the plaice curve. This effect of this shift difference is also visible in the ratio of undersized plaice weights per kilo marketable sole, this ratio increases where a shift from 79 mm to 87 mm mesh results in larger undersized plaice catches per kilo marketable sole. Assuming the available sole is fully exploited, fishers using 90 mm cod-ends need to deliver a higher fishing effort to catch their quota. Although less undersized plaice are caught per haul, the increased effort to fully exploit the sole total allowable catch (TAC) will result in higher discard quantities for undersized plaice and an increased bottom impact and CO2 emissions as more area needs to be covered.

In the pulse trawl fishery a 79 mm cod-end is not a legal practice, new cod-ends for this 80 mm fishery are generally 86 mm and after several hauls the mesh shrinks to 81-82. When an average mesh size of 80 mm is approaching, the cod-end is replaced by a new 86 mm cod-end. Considering commercial sole losses 88 mm cod-ends in this trial, 86 mm will have substantial losses of the smaller marketable sole. Due to shrinking mesh twine, with a 90 mm minimum mesh size fishers may have to start with 95 mm cod-ends, this leads to larger reductions in marketable sole catches. Those substantial losses of legal marketable sole may enhance illegal measures to limit the mesh opening in commercial fisheries. Clearly increasing the minimum mesh sized in this fishery does not solve the bycatch problems, trawl innovations separating sole and the other catch may be the way forward to mitigate bycatch in this fishery.

Observed catch differences in this study for marketable turbot and brill are likely the results of natural variation in the abundancy on the fishing grounds. Both species are morphologically not able to escape from the assessed mesh sizes from the cod-end and are frequently caught in low numbers per haul. Therefore, several large individuals in one trawl could result in differences in catch weights per hour (Annex 8).

In commercial fisheries the cod-ends are circumvented with lifting bags with at least twice the mesh size of the cod-end. The lower part of this lifting bag is protected from bottom contact with small netting panels and dolly ropes. In this study the lifting bags were replaced by cod-end covers. The protecting bags with dolly ropes may reduce cod-end selectivity in a commercial fishery, however this never studied in this fishery.

The results of this study could be used to model a different exploitation pattern with a 90 mm fishery aiming for larger sole could. Short and long term economic consequences of a changing exploitation pattern could give more insights it weather is profitable to change to a larger mesh size on the long term.

# 5 Conclusions and recommendations

With a mesh size of 79 mm the L50 for sole is 19 cm and the selection range is 4.9 cm. With the available sole on the fishing grounds of this pulse trawler this results in a 10% loss of marketable sole (>24 cm) in the catch. Those losses were detected in the 24-27 cm length range.

Increasing the mesh size to 87 mm resulted in a L50 for sole of 22 cm and a selection range of 4.9 cm in experiment 1. In experiment 2 this was 26 cm with a selection range of 4.9 cm for the 88 mm cod-end. With the available sole on the fishing grounds this resulted in a 24% and 38% loss of marketable sole (>24 cm) in the catch in experiment 1 and 2, respectively. Those losses were detected in the in the 24-33 cm length range.

Plaice showed steep selection curve in both experiments with a L50 of 14.4 cm (SR 2.5) for the 80 mm cod-ends and 14.1 cm (SR 2.1) for the 79 mm cod-ends. In the 87 mm cod-ends this L50 shifted to 15.6 cm (SR 2.5) for experiment 1 and 18.7 cm (SR 2.1) for the 88 mm cod-ends in experiment 2.

The ratio of kg plaice discards per kg marketable sole was 0.4 in experiment one for 80 mm cod-ends and increased to 0.5 in a 87 mm cod-end. For the second experiment this was 2.3 for the 79 mm and 2.5 for the 88 mm cod-ends.

# Acknowledgements

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# Justification

Report C049/18
Project Number: 4311400005

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Dr. A.D. Rijnsdorp
Senior researcher

Signature:

Date: 18 July 2018

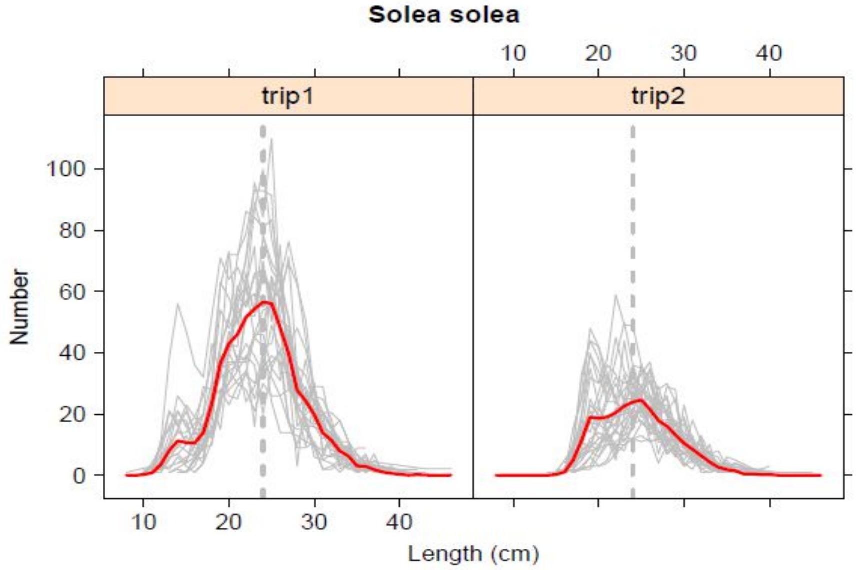
Approved: Dr. ir. T.P. Bult
Director

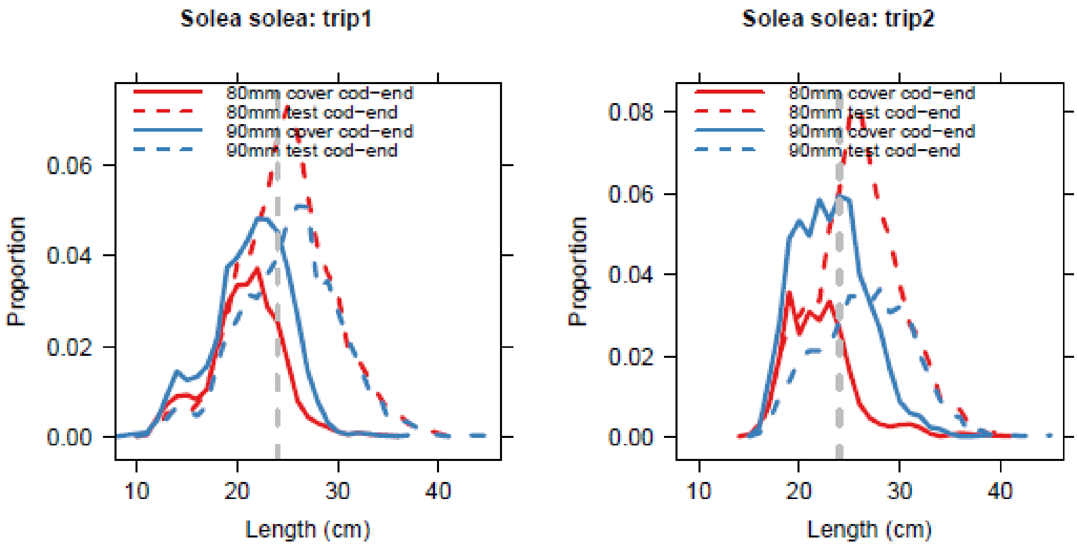
Signature:

Date: 18 July 2018

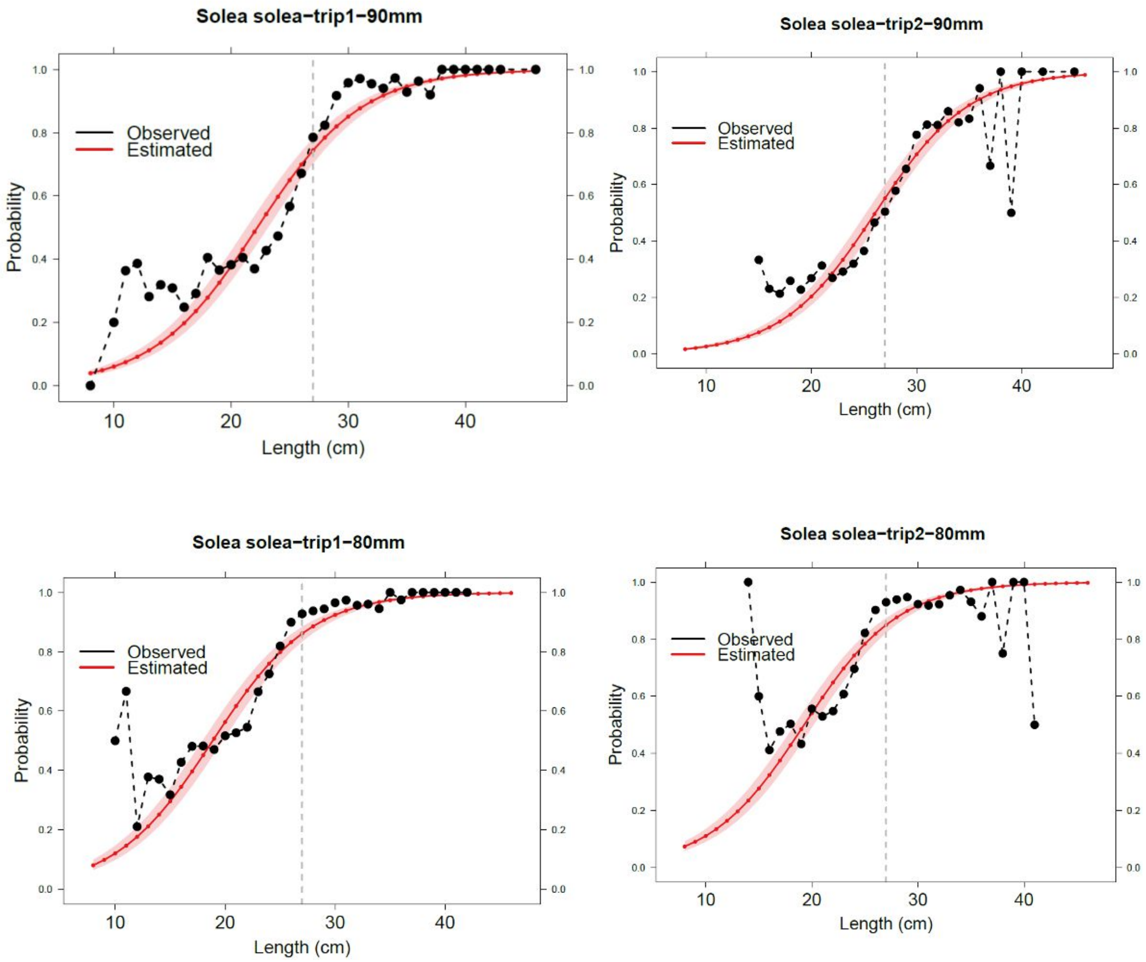
# 6 Annex sole length distribution and selectivity

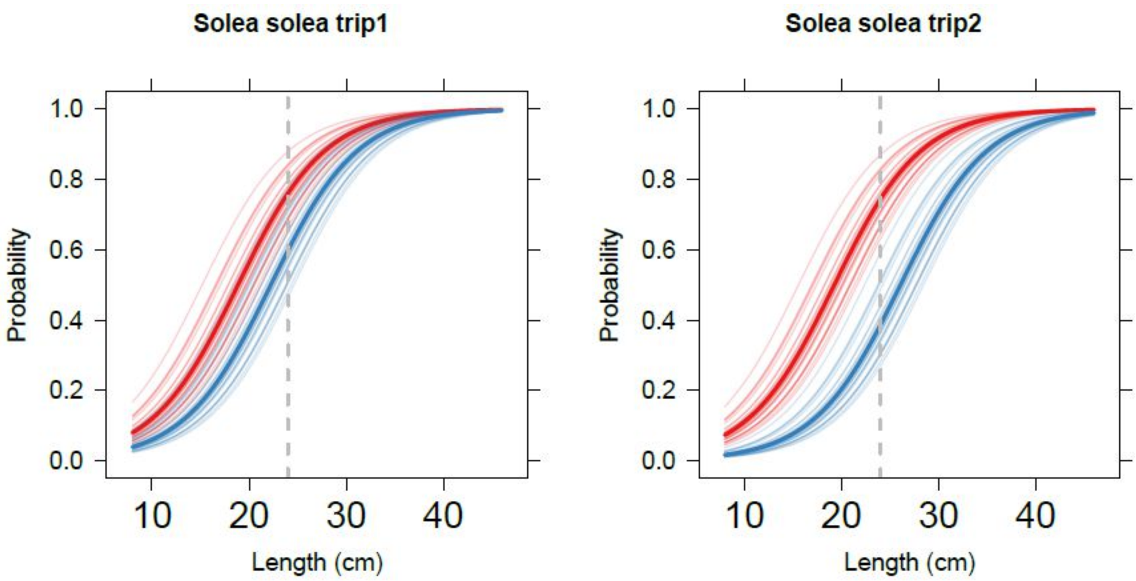
Length frequency per haul, below length frequency als propotion from total observed inividuals of length x.



Seletive probabilities and filleted model trough the data poits. Below moddeled selection corves per haul



# 7 Annex plaice length distribution and selectivity

Selective probabilities and fitted model trough the data poits. Below moddeled selection curves per haul

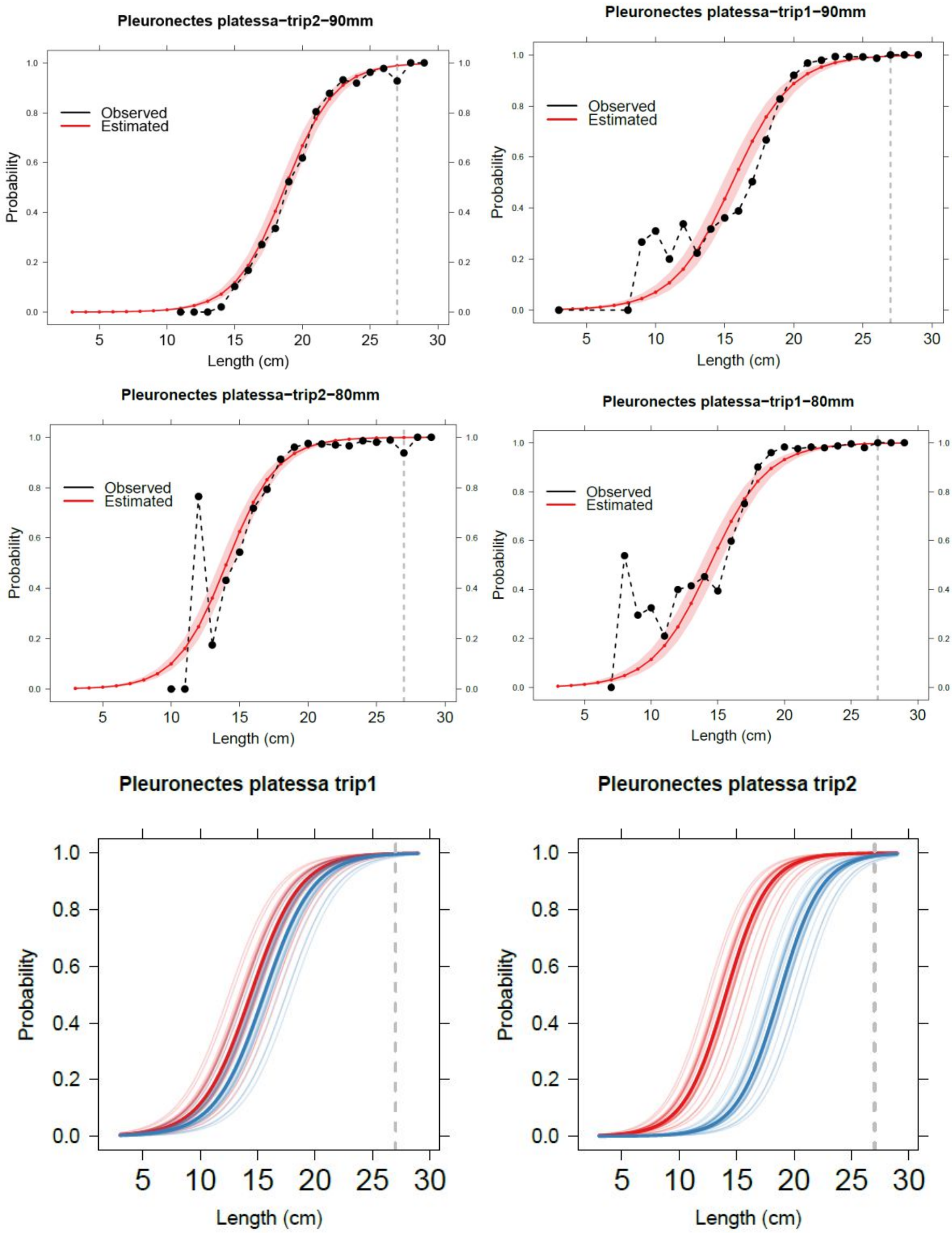
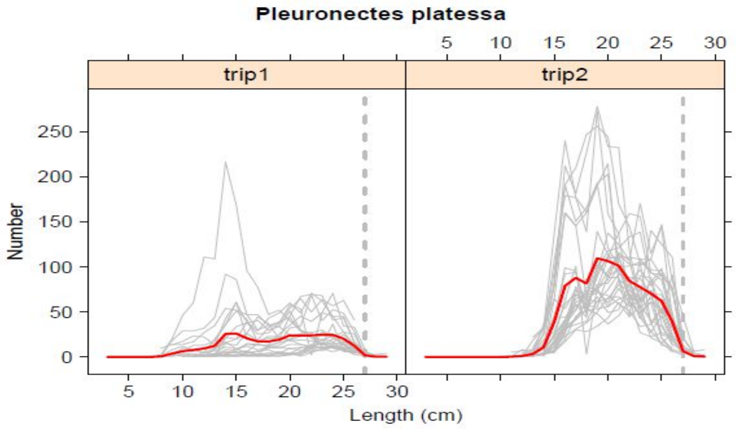
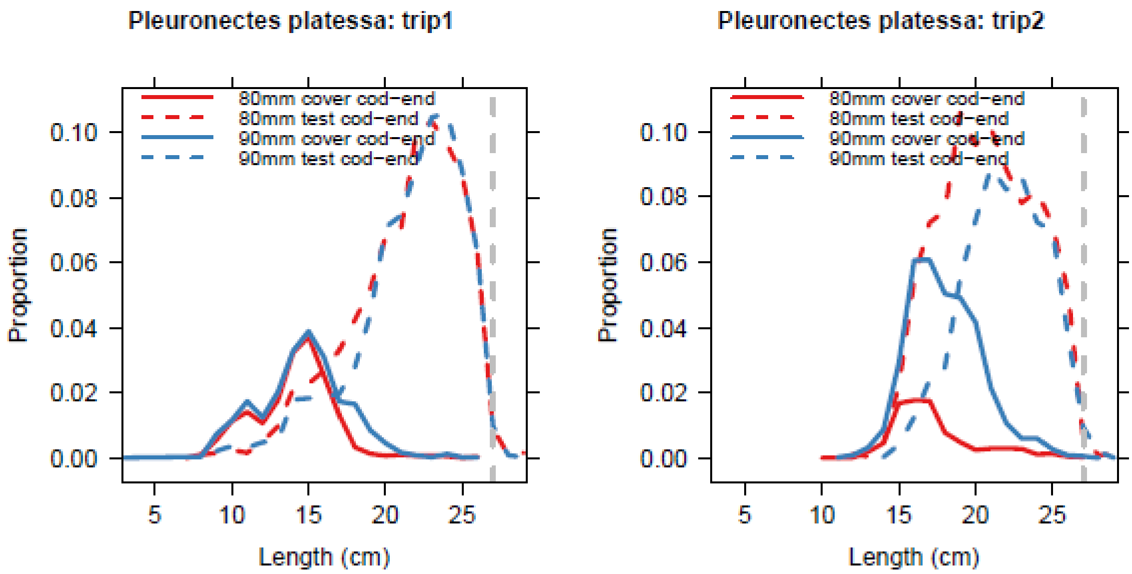
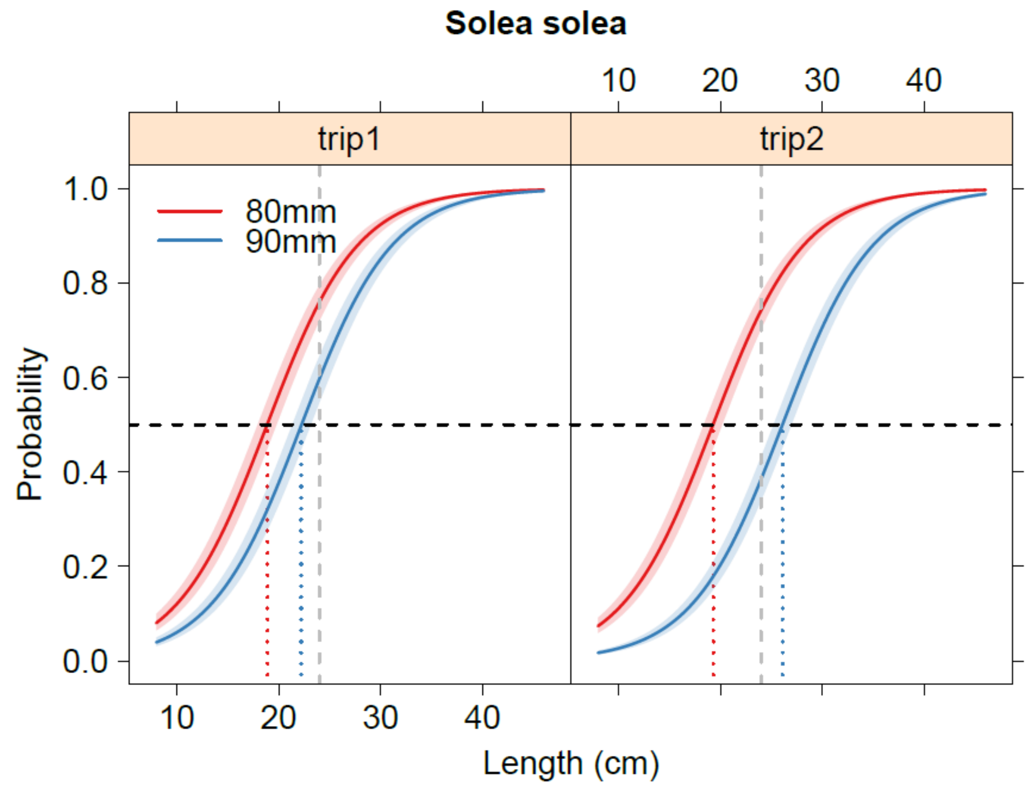


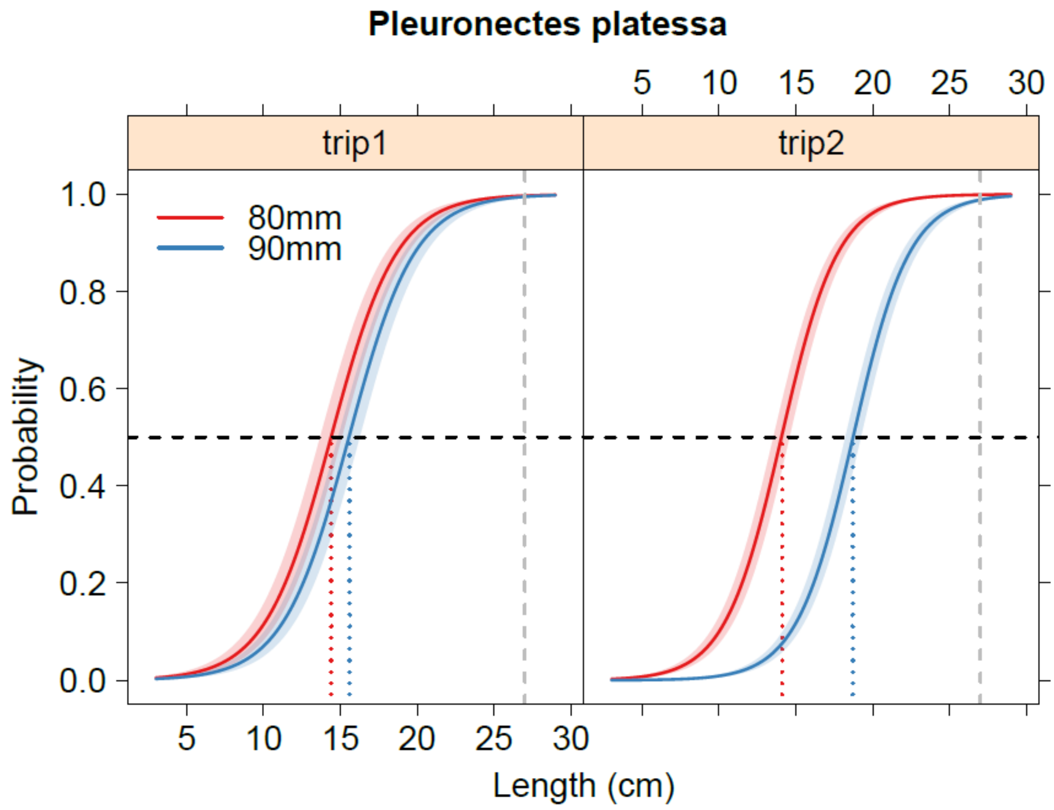

Figure 3: Estimated vs. observed selectivity curve for Solea solea. The observed selectivity is estimated by every 1 cm length bin.

Length frequency per haul, below length frequency als propotion from total observed inividuals of length x

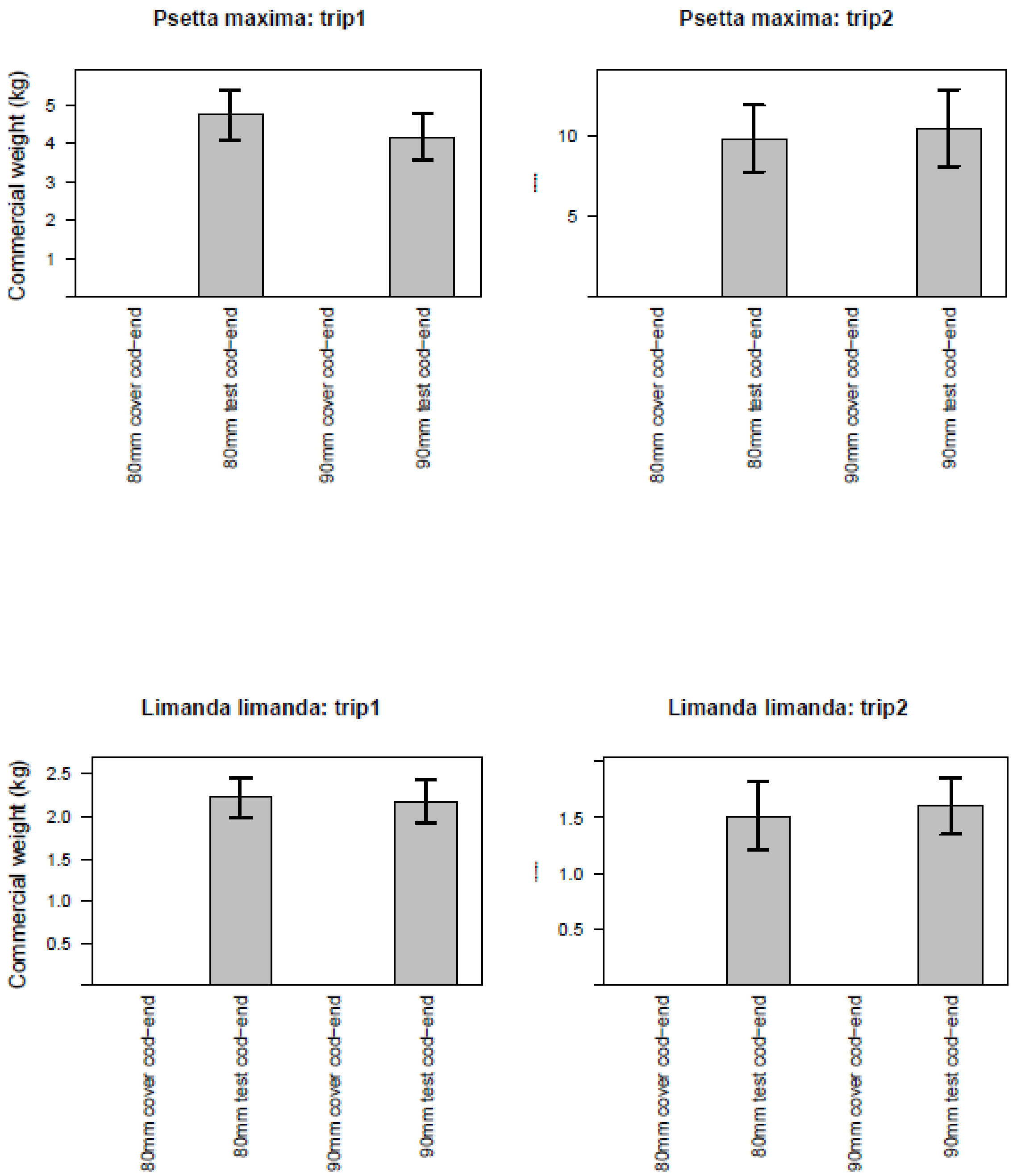


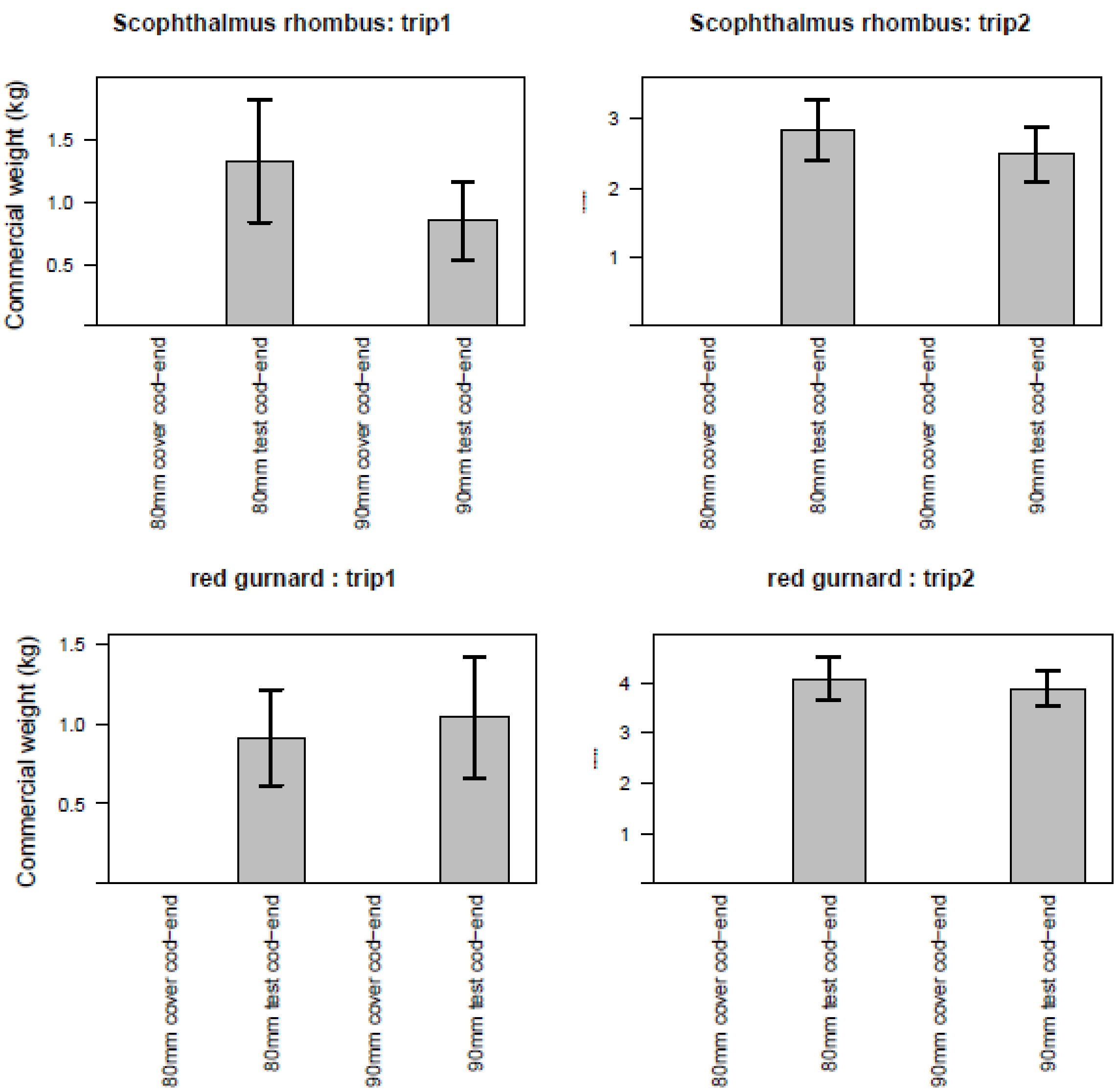




Solea solea
trip1
trip2
80mm
90mm
Probability
1.0
0.8
0.6
0.4
0.2
0.0
10
20
30
40
Length (cm)


Pleuronectes platessa
trip1
trip2
80mm
90mm
Probability
1.0
0.8
0.6
0.4
0.2
0.0
5
10
15
20
25
30
Length (cm)

# 8 Annex average catch weights per haul for other marketable species




Scophthalmus rhombus: trip1
Scophthalmus rhombus: trip2
Commercial weight (kg)
1.5
1.0
0.5
3
2
1
80mm cover cod–end
80mm test cod–end
90mm cover cod–end
90mm test cod–end
red gurnard : trip1
red gurnard : trip2
Commercial weight (kg)
1.5
1.0
0.5
4
3
2
1
80mm cover cod–end
80mm test cod–end
90mm cover cod–end
90mm test cod–end

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