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Questioning the effectiveness of technical measures implemented by the Basque bottom otter trawl fleet: Implications under the EU landing obligation

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ABSTRACT

The selective properties of a bottom trawl fitted with a 70 mm diamond mesh codend and a 100 mm top square mesh panel (SMP) for hake (*Merluccius merluccius*), pouting (*Trisopterus luscus* and *Trisopterus minutus*) and red mullet (*Mullus surmuletus*) were investigated over the period 2011–2013. The experiments were carried out over three separate cruises aboard two commercial Basque bottom otter trawlers in the Bay of Biscay area. "Fall-through" experiments were also undertaken to estimate the potential size selection of 100 mm square mesh for the same species. Results from the "Fall-through" experiments and the at-sea selectivity cruises demonstrated that a 100 mm SMP has the potential to enable undersized and immature individuals to escape through the meshes. However, the selectivity cruises demonstrated that in practice, the SMP was largely ineffective at releasing undersized individuals as only a small fraction of the fish entering the trawl attempted to escape through the SMP during their drift towards the codend. The fraction attempting to escape was quantified by the "SMP contact probability" and was less than 4% for hake and red mullet and less than 15% for pouting. Furthermore, for each species, the release potential for the diamond mesh codend was found to be significantly lower than the length-at-maturity and the legal minimum conservation reference size. On average, the proportions of the total catch of undersized individuals of each species retained by the gear, were 52%, 17% and 45% for hake, pouting and red mullet respectively. Based on our findings, we conclude that the gear currently deployed by the Basque bottom otter trawl fleet operating in the Bay of Biscay is largely ineffective at releasing undersized hake, pouting and red mullet. The introduction of the obligation to land all catches, under the 2013 reform of the EU Common Fisheries policy will create new challenges for the Basque bottom otter trawl fleet and thereby an incentive to improve selectivity to avoid unwanted catches of undersized individuals.

1. Introduction

Over the past 30 years, numerous technical regulations and associated amendments have been introduced in almost all developed fisheries worldwide in an attempt to improve fishing gear selectivity, reduce discards and enhance the status of fish stocks (Madsen, 2007; McClanahan, 2010; Feekings et al., 2012; Santurtún et al., 2014). Despite such measures, discarding in some European fisheries remains high (Uhlmann et al., 2013). The capture and discarding of small immature fish reduces the potential biomass of the exploitable stock and affects subsequent recruitment (Graham et al., 2003). While discarding is a widely recognized problem in many fisheries, it is particularly acute in multi-species trawl fisheries (Daan, 1997). The Basque bottom otter trawl fishery in the Bay of Biscay (ICES Divisions, VIII a, b, d) is one such fishery. Currently, the fleet comprises 7 vessels, ranging from 37 to 42 m overall length. The fleet deploys trawls that have a low headline, typically below 2 m vertical opening, wingspreads between 22 m and 26 m, and

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footropes between 80–100 m in length. Trawling is carried out at a towing speed of 4 knots at depths ranging from 30 m to 200 m. Trip duration varies from 5 to 7 days. The main target species are megrim (*Lepidorhombus whiffiagonis*), anglerfish (*Lophius* spp.), hake (*Merluccius merluccius*) although squids (*Loligo* spp.), red mullet (*Mullus surmulletus*), pouting (*Trisopterus minutus* and *T. luscus*), sole (*Solea solea*), horse mackerel (*Trachurus trachurus*) and mackerel (*Scomber scombrus*) also comprise target species depending on the fishing ground, season and quota availability (Iriondo et al., 2008, 2010). Discarding of both target and bycatch species in the fishery can be substantial. In 2013, on average, estimated discards represented about 52–65% by weight of the total estimated catch (8532 t) of the fleet (Rochet et al., 2014). Discarding occurs for a variety of reasons including capture of individuals below minimum legal landing size, lack of quota, the absence of a market, damaged or degraded individuals in the catch, and high-grading.

In 2002, a recovery plan was introduced for the northern stock of European hake, in an attempt to allow the stock to recover from its then depleted state (EC, 2002). The recovery plan prescribed inter alia, an increase in the minimum codend mesh size for trawls from 70 mm to 100 mm in the Bay of Biscay (EC, 2002). However, since 2006 the provisions of Annex III, Appendix 3 of EC, 2006 were introduced to provide an optional alternative to the mandatory use of bottom otter trawls with a 100 mm codend mesh size. Such provisions permit the deployment of otter trawls with a minimum codend mesh size of 70 mm provided that a 100 mm square mesh panel (SMP) is inserted into the middle of the top panel of the rear tapered section of the trawl just in front of the untapered section constituted by the extension piece and the codend; a configuration intended to improve the selectivity for undersized hake.

Square mesh panels are known to have great potential for improving selectivity in trawls (e.g., Broadhurst, 2000; Fonteyne and Polet, 2002; Madsen et al., 2002; Tschernij and Suuronen, 2002) by increasing the probability to release both undersized individuals and non-target species entering the trawl (Catchpole and Revill, 2008). However, their effectiveness varies for different species and several studies have shown that they are largely ineffective at releasing certain demersal species (Briggs, 1992; Frandsen et al., 2009; Rosen et al., 2012). The efficiency of such selective devices depends not only on the gear characteristics such as the dimensions of the panel itself, the size of the meshes and the position of the panel in the trawl (Herrmann et al., 2015), but also on the reactions of the fish in the trawl during the fishing operation. Such factors determine whether fish are able to come into contact with the panel and escape through the meshes (Glass and Wardle, 1995; Zuur, 2001; Herrmann et al., 2015).

Despite the adoption of the 70 mm + SMP provisions by the majority of the vessels that comprise the Basque trawl fleet, to date, the effectiveness of the 100 mm SMP has not been investigated and quantified. Furthermore, the average discards of hake over the period 2011–2013 are estimated to be approximately 50% of the total catch in weight of hake, 97% or which comprised individuals less than the minimum conservation reference size (MCRS) (Rochet et al., 2014).

Today, most policy frameworks for the marine environment aim to progressively implement an ecosystem approach (Garcia and Cochrane, 2005; Hering et al., 2010; Article 2(3) of EU, 2013). In an ecosystem approach to fisheries management, one of the basic tenets is that harvesting should be conducted with minimal impact on juvenile fish and that discards should be reduced (Graham et al., 2007; Bellido et al., 2011 Article 2(5a) of EU, 2013). Under the provisions of Article 15 of the 2013 reform of the CFP (the landing obligation; EU, 2013), by 2019, discards of most species will no longer be permitted and fishers from EU Member States will be required to land all catches of quota species from the northeast Atlantic and all species subject to a MCRS from the Mediterranean and Black Seas. The rationale for the landing obligation is that it should create economic incentives for the industry to develop measures to improve selectivity to reduce or avoid the capture of juvenile fish, unwanted catches of bycatch species and any potential over-quota catches.

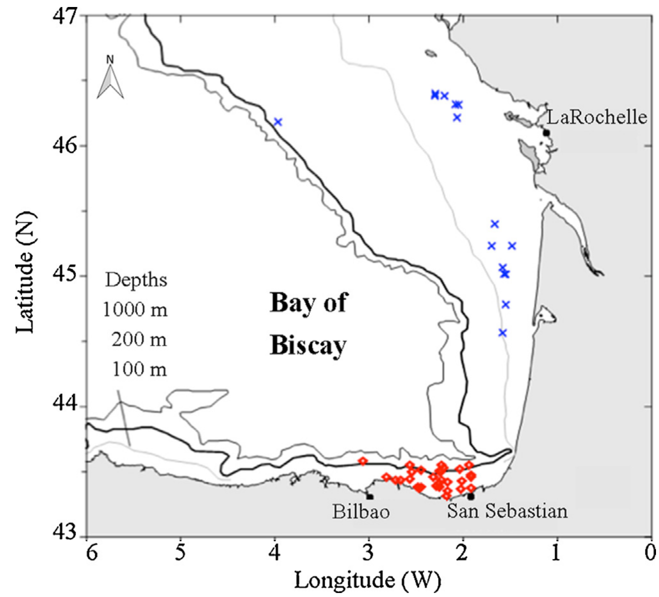

Fig. 1. The Bay of Biscay, showing 100 m, 200 m and 1000 m depth isobaths and fishing position for all hauls during the three cruises between November 2011 and July 2013. Key: X (total selectivity estimation; SMP + C) and ◊ (selection properties of the SMP alone; SMP + CL).

Hence, the question remains whether the provisions of Annex III, Appendix 3 of EC, 2006 are sufficient to meet the objective of releasing undersized hake, whether they allow the Basque fleet to avoid undersized catches of hake and mitigate the potential impacts of the obligation to land all catches. The aim of the present study is therefore to evaluate the selective properties of bottom otter trawl gear deployed by the majority of the Basque fleet and especially the effectiveness of the 100 mm SMP at releasing immature and undersized fish.

2. Material and methods

2.1. Sea trials and data collection

Selectivity cruises were performed at sea on board two Basque commercial trawlers “Gure Gaskuña” (39 m overall length (LOA), 590 hp) and “J. Kalamendi” (40 m LOA, 1190 hp). Three cruises were performed between November 2011 and July 2013 (Table 1). The cruises were conducted in the Bay of Biscay on fishing grounds with depths that varied between 26 m and 267 m (Fig. 1).

All three cruises were conducted using trawls with codends of 70 mm diamond netting attached to an extension of 90 mm diamond mesh constructed using 2.5 mm single polyamide (PA) -twine. The wings and the top panel were PA with a nominal mesh size of 100 mm, 2.5 mm single-twine. In each cruise, the SMP was made from 100 mm (nominal, knot to knot) meshes extended into the middle of the upper section of the extension, positioned 12 meshes in front of the codend. The SMP was one-fourth of the full width of the extension section, where the mean internal vertical opening of the gear was around 1.5 m (240 meshes round). The specifications for the gears used on each cruise varied with respect to length of headline and footrope, codend length and panel position in relation to the codline and are summarised in Table 2.

Table 1
General information about the three cruises. Mean depth, mean towing duration and speed, and ranges (in parentheses).

	Cruise 1	Cruise 2	Cruise 3
Date	November–December 2011	July 2012	June–July 2013
Gear setup	100 mm top SMP 13 m from the codline	100 mm top SMP 7 m from the codline	100 mm top SMP 7 m from the codline
Depth (m)	61.3 (31–144)	103.3 (28–1 82)	125.2 (26–267)
Towing time (min)	170 (40–215)	15	15
Towing speed (knots)	3.9 (3.9–4.0)	3.6 (2.6–4.1)	3.6 (2.9–4.0)
No. of hauls	15	27	26

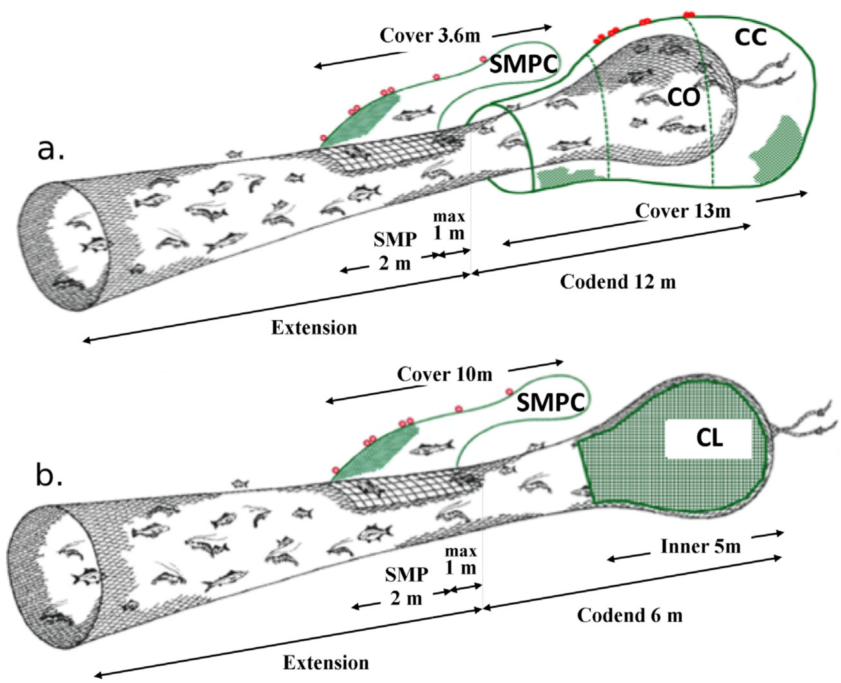

Fig. 2. Gear setup for selectivity cruises. Setup (a) Total selectivity setup (SMP + CO) with the SMPC and the CC used onboard the Gure Gaskuña in 2011. Setup (b) SMP properties setup (SMP + CL) with the SMPC used onboard the F/V J. Kalamendi for the 2012–2013 surveys. Key: SMPC (square mesh panel cover), CO (codend), CC (codend cover) and CL (codend liner).

During the first cruise carried out aboard "Gure Gaskuña" between November and December 2011, a single otter trawl with a stretched circumference of 61.4 m was operated under commercial conditions on its usual fishing grounds. The codend (CO) was 12 m long, in consequence the SMP was positioned 13 m from the codline. Size selectivity data were collected using a three compartment setup, based on the design described by Sistiaga et al. (2010). The codend cover (CC) was installed on the aft of the trawl and mounted with two rigid rings to minimize any potential masking effect (Wileman et al., 1996). The square mesh panel cover (SMPC) installed over the SMP was the same design as that used by Larsen and Isaksen (1993) and then fitted with three rings and floats (Fig. 2a).

For the second and third cruises (July 2012 and June–July 2013, respectively), modified versions of the single otter trawl normally deployed by "J. Kalamendi" were used. These cruises were carried out during research surveys designed to estimate fish abundance and the gears used were those prescribed for the abundance surveys and incorporated small mesh codend liners (see below). In both cruises the codend was 6 m long with the SMP positioned 7 m from the codline. To investigate the selection properties of the SMP, a two-compartment setup was used; a codend incorporating a small mesh liner (CL, lining the full width of the codend and almost the 85% of the length) and a SMPC over the SMP (Fig. 2b).

After each haul, the catch was sorted by species. Only hauls with at least 10 individuals of the same species in the same haul were included in the analysis. Size selection data was collected for hake, pouting and red mullet. These species were available in sufficient numbers in the catch to enable the evaluation of gear performance. Moreover, individuals of these species are potential discard species due to quota restrictions, market demand and minimum size regulations (i.e., hake with MCRS of 27 cm, pouting and red mullet with MCRSs corresponding to minimum landing weights of 50 g and 40 g respectively; EC, 1996). All individuals of each species or a representative sub-sample from each net compartment (CO, CC and SMPC or CL and SMPC, see Fig. 2) were measured to the nearest centimetre below. Sub-sample numbers were raised to total catch number by the ratio sample weight to total weight caught.

Furthermore, a fall-through experiment (Herrmann et al., 2009), using a similar SMP as the one fitted to the gear in all experiments, was carried out on board to assess the potential size selectivity of the 100 mm square mesh. Around 150 fish of each of the selected species were tested. Total length for each fish was measured and its ability to physically pass head-first through the 100 mm square mesh under by the force of gravity only was determined. The individuals were non-randomly selected from the catch in order to cover the widest possible size range.

In addition, underwater observations were recorded to observe fish behaviour in the trawl during the fishing operation and to analyse the escape mechanisms of those individuals that escaped from the gear, either through the SMP or elsewhere. Recordings were made using a Konsberg Simrad OE 1324 camera connected to a self-contained recorder unit with a DVR and two GoPro cameras.

Table 2
Specifications of the gears used during the three cruises.

	Cruise 1	Cruise 2	Cruise 3
Trawl			
Type	Otter trawl	Otter trawl	Otter trawl
Nominal mesh size	90 mm	90 mm	90 mm
Foot rope	100 m	80 m	90 m
Head line	81 m	65 m	74 m
Codend (CO)			
Twine material	Double braided PE	Double braided PE	Double braided PE
Thickness	4 mm	4 mm	4 mm
Mesh size[a]	75.8 mm	74.6 mm	74.1 mm
Length	12.0 m	6.0 m	6.0 m
Circumference	240 meshes	240 meshes	240 meshes
Codend cover (CC)			
Twine material	Single braided PA	Single braided PA	Single braided PA
Thickness	1.3 mm	1.3 mm	1.3 mm
Position	Outer	Inner	Inner
Mesh size[a]	17.3 mm	24.7 mm	28.5 mm
Length	13.0 m	5.0 m	5.0 m
Circumference	400 meshes	250 meshes	250 meshes
SMP			
Twine material	Single braided PA	Single braided PA	Single braided PA
Thickness	3 mm	3 mm	3 mm
Mesh size[a]	106.6 mm	103.4 mm	104.2 mm
Horizontal mesh	36 meshes	36 meshes	36 meshes
Vertical mesh	18 meshes	18 meshes	18 meshes
SMPC			
Twine material	Single braided PA	Single braided PA	Single braided PA
Thickness	1.3 mm	1.3 mm	1.3 mm
Mesh size[a]	27.2 mm	26.4 mm	25.4 mm
Length	3.6 m	10.0 m	10.0 m
Circumference	410 meshes	410 meshes	410 meshes

[a] Measured with an OMEGA gauge (Fonteyne et al., 2007) according to the guidelines described in regulation (EC No. 517/2008).

All cameras were placed inside the net, ahead of the SMP facing the codend.

2.2. Data analyses

We assessed the basic size selective potential for the 100 mm square mesh by fitting a *logit* size selection model with parameters *L50* (length at which a fish has 50% chance of being retained) and *SR* (selection range, *L25–L75*) (Wileman et al., 1996) to the fall through data species by species. The purpose of this exercise was to assist the evaluation of the size selectivity of the square mesh panel in the sea trials. Fall through results can help solving potential confounding problems in data analysis from sea trials regarding contact probability with the panel and contact selectivity in terms of $L50_{SMP}$. Specifically we used the requirement (constraint) that estimated $L50_{SMP}$ should be at least 50% of the assessed fall through *L50*.

To analyse the size selection data from the cruise using the three compartment setup (Fig. 2a), species by species, we used the dual selection model first described by Zuur et al. (2001) and later applied by O'Neill et al. (2006). This model quantifies both the size selection in the SMP and in preceding codend. For the SMP the size selection is described by three parameters: C_{SMP}, $L50_{SMP}$ and SR_{SMP}. C_{SMP} quantifies the assumed length independent probability for a fish to make contact with the SMP during its drift towards the codend. A C_{SMP} value of 1.0 would mean that every fish came into contact with the SMP and attempted to escape through it, while a value of 0.3 for example would mean that only 30% of the fish did contact the SMP and attempted to escape through it. $L50_{SMP}$ and SR_{SMP} are the *L50* and *SR* values for the fraction of fish that make contact with the SMP based on a *logit* size selection model. The size selection in the codend was described by a traditional *logit* model with the parameters $L50_{CO}$ and SR_{CO}. Thus it was assumed that every fish entering the codend would make contact with its meshes and have a size dependent probability of being released. By using the definition of *L50* and *SR*, we could estimate the overall selectivity parameters of the combined system consisting of the SMP and the codend ($L50_{dual}$ and SR_{dual}). This combined selectivity is then defined as the dual selection and it can be estimated based on the values of the five parameters (C_{SMP}, $L50_{SMP}$, SR_{SMP}, $L50_{CO}$ and SR_{CO}). This estimation procedure is thoroughly described in Sistiaga et al. (2010) for a dual selection system with an escapement grid followed by a size selective codend. The model has an identical model structure as for the SMP + codend system applied here. The hauls belonging to the cruise with the three compartment setup were used to define a group of hauls. For each species separately, we fitted the dual selection model to the pooled data for the group of hauls using the maximum likelihood method based on the procedure described in Sistiaga et al. (2010). This estimation method includes a double bootstrap procedure to account for uncertainty in estimation both due to within- and between haul-variation in the selection processes in the gear. Further the method accounts for additional uncertainty due to sub-sampling of data, based on the procedure described in Eigaard et al. (2012). We applied 1000 bootstrap repetitions for the analysis.

To analyse the size selection data from the sea trials using the two compartment setup (Fig. 2b) species by species, we used the same procedure as described above for the three compartment setup with the exception that the analysis only involved the estimation of the size selection in the SMP. By quantifying the C_{SMP}, $L50_{SMP}$, SR_{SMP} parameters lead to a size selection model which is similar to the one applied for a "grid only size selection" described by Herrmann et al. (2013).

The selectivity data were analysed using the analysis tool SELNET (SELection in trawl NETting; Herrmann et al., 2012). Evaluating the ability of the model to describe the data sufficiently well was based on inspecting the fit statistics, i.e., the *p*-value and the model deviance versus the degrees of freedom (DOF), following the procedures described by Wileman et al. (1996). The *p*-value expresses the likelihood to obtain at least as big a discrepancy between the fitted model and the observed experimental data by coincidence. In case of a poor fit statistics (p-value being <0.05; deviance being >>DOF), the residuals were inspected to determine whether the poor result was due to structural problems when describing the experimental data using the model or if it was due to over-dispersion in the data (Wileman et al.,1996).

In addition to the evaluation based on the selection parameters, we also calculated the length-averaged retention probability of undersized individuals in the gear based on the three compartment trials and the length averaged escapement through the SMP of undersized individuals based on all sea trials. This estimation which was also conducted in the analysis tool SELNET follows the estimation method described in Wienbeck et al. (2014), Sala et al. (2015) and Özbilgin et al. (2015). To estimate the length-averaged retention and escapement of the undersized individuals, the minimum landing weight for pouting and red mullet was converted to length using the species-specific length-weight relationship given in Dorel (1986). The MCRSs for pouting (50 g) and red mullet (40 g) equate to lengths of approximately 16 cm and 15 cm respectively.

3. Results

3.1. Fall-through experiment

The results of the fall through experiments are summarised in Table 3 and the length distributions of the fish and the fitted curves and 95% confidence intervals for the potential size selection prop-

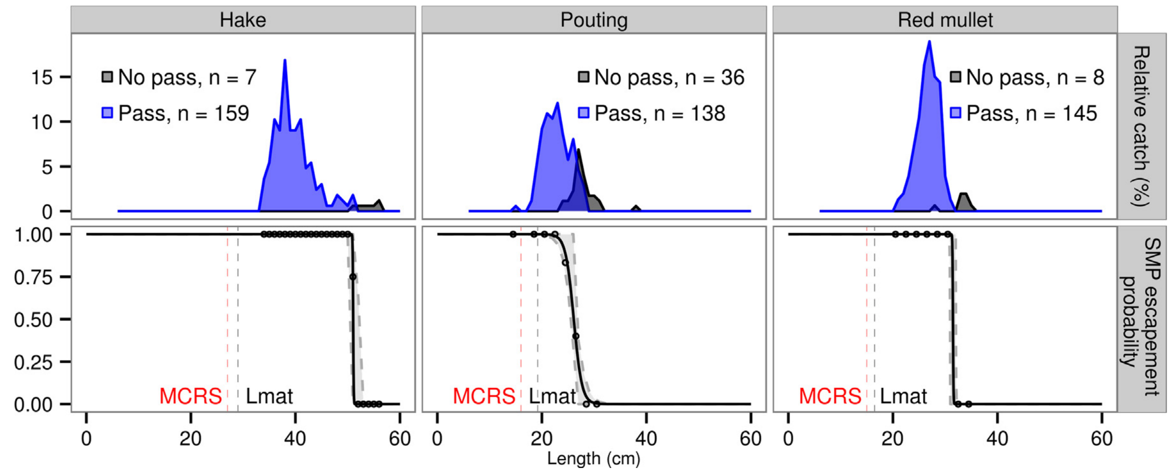

Fig. 3. Relative catch size-frequency distributions for the fall-through experiment and the fitted escapement curves (black) indicating potential SMP escapement probability with the 95% confidence intervals (grey area). Length-at-maturity (Lmat) for pouting, hake and red mullet is 19.2 cm, 29 cm and 16.5 cm on average respectively (Mahé et al., 2005; Alonso-Fernández et al., 2008 and El Habouz et al., 2011). For hake the minimum conservation reference size (MCRS) is 27 cm and for pouting and red mullet the minimum landing weights of 50 g and 40 g equate to 16 cm and 15 cm respectively.

Table 3
Results of fall-through experiments: Fitted selectivity parameters, 95% CI (in brackets) and fit statistics for each species.

	Hake	Pouting	Red mullet
$L50_{fall}$ (cm)	51.05 (50.50–52.03)	26.10 (25.58–26.50)	31.49 (31.02–31.52)
SR_{fall} (cm)	0.10 (0.10–0.10)	1.72 (0.10–2.43)	0.10 (0.10–0.10)
L_{fall} (cm)	50.41 (49.39–52.61)	23.79 (22.73–26.37)	31.36 (30.39–31.39)
deviance	<0.01	1.08	<0.01
DOF	6	6	6
p-Value	>0.99	0.98	>0.99

erties of the 100 mm square mesh are shown in Fig. 3. The *p*-value and model deviance compared to number of DOF indicate that the model describes the data adequately (Table 3). Using the values from the fitted selection curve, the lengths at which the potential probability for each species to escape through the 100 mm square mesh is 95% (L_{fall}) are estimated at 50.41 cm, 23.79 cm and 31.36 cm for hake, pouting and red mullet respectively. In the case of $L50_{fall}$, the values are estimated at 51.01 cm, 26.10 cm and 31.49 cm respectively. Since both the L_{fall} and the $L50_{fall}$ estimates are above the MCRS and the length-at-maturity (L_{mat}) for all species the SMP has the potential to release undersized and immature individuals.

3.2. Selectivity experiments

A total of 68 hauls were carried out during the three cruises (Table 1). Hauls in which fewer than 10 individuals of each species of hake, pouting and red mullet were present were excluded from the selectivity analysis. The results in terms of valid hauls, numbers and size ranges of fish retained by the codend and covers are summarised separately by cruise and species in Table 4. For those hauls where sub-sampling took place, the raised catch was used for the analysis. Over all three cruises, the length ranges of each species caught were 6–62 cm, 7–36 cm and 9–41 cm, for hake, pouting and red mullet respectively. From the total catch of each species, the proportions of fish below the average *L*mat were 73.7 %, 12.6 % and 56% for hake, pouting and red mullet respectively. Similarly, the proportion of fish below MCRS were 60%, 1.7% and 27.5% for hake, pouting and red mullet respectively. The catch of most individuals of all species studied were retained in the codend.

Table 4
Summary statistics by species for all valid hauls used for the selectivity analysis. No. retained by net compartment and No. <MCRS (sub-sample number in parentheses) and length range of all individuals caught.

	Hake	Pouting	Red mullet
Cruise 1			
No. of valid hauls	8	10	11
Length range (cm)	12–62	7–36	9–33
Total no. in CO	766 (766)	2079 (1118)	4498 (1157)
No. in CO <MCRS	356 (356)	7 (5)	932 (287)
Total no. in CC	354 (354)	324 (324)	2931 (1292)
No. in CC <MCRS	324 (324)	30 (30)	1112 (550)
Total no. in SMPC	8 (8)	13 (13)	67 (67)
No. in SMPC <MCRS	5 (5)	5 (5)	18 (18)
Cruise 2			
No. of valid hauls	22	4	7
Length range (cm)	9–60	12–33	14–39
Total no. in CL	6267 (3513)	522 (522)	311 (311)
No. in CL <MCRS	5449 (2955)	294 (294)	1 (1)
Total no. in SMPC	281 (281)	0 (0)	2 (2)
No. in SMPC <MCRS	233 (233)	0 (0)	0 (0)
Cruise 3			
No. of valid hauls	22	5	6
Length range (cm)	6–60	18–35	14–41
Total No. in CL	5321 (3783)	211 (211)	235 (235)
No. in CL <MCRS	4566 (3187)	0 (0)	3(3)
Total No. in SMPC	251 (251)	0 (0)	1 (1)
No. in SMPC<MCRS	232 (232)	0 (0)	0 (0)

3.2.1. Dual selection estimation (CO + SMP); Cruise 1

A total of 15 hauls were carried out during the first cruise designed to investigate the selective properties of the trawl gear configuration currently used by the Basque otter trawl fleet in the Bay of Biscay (Fig. 2a). For hake, pouting and red mullet, 8, 10 and 11 of the 15 hauls respectively were considered valid. The relative proportions by length retained by the CO, CC, and SMPC for hake, pouting and red mullet are shown in Fig. 4 together with the fitted selection curves and 95% confidence intervals obtained for the SMP escapement, codend escapement and dual retention (combined retention of the codend and the SMP). The results are summarized in Table 5. The *p*-value and model deviance compared to number of DOF indicate that generally the model describes the data adequately. In contrast to the results for hake and pouting, the *p*-value for modelling the selectivity data for red mullet was below 0.05 and the model deviance was far above the DOF. Such a result could indicate problems with using the dual selection model to

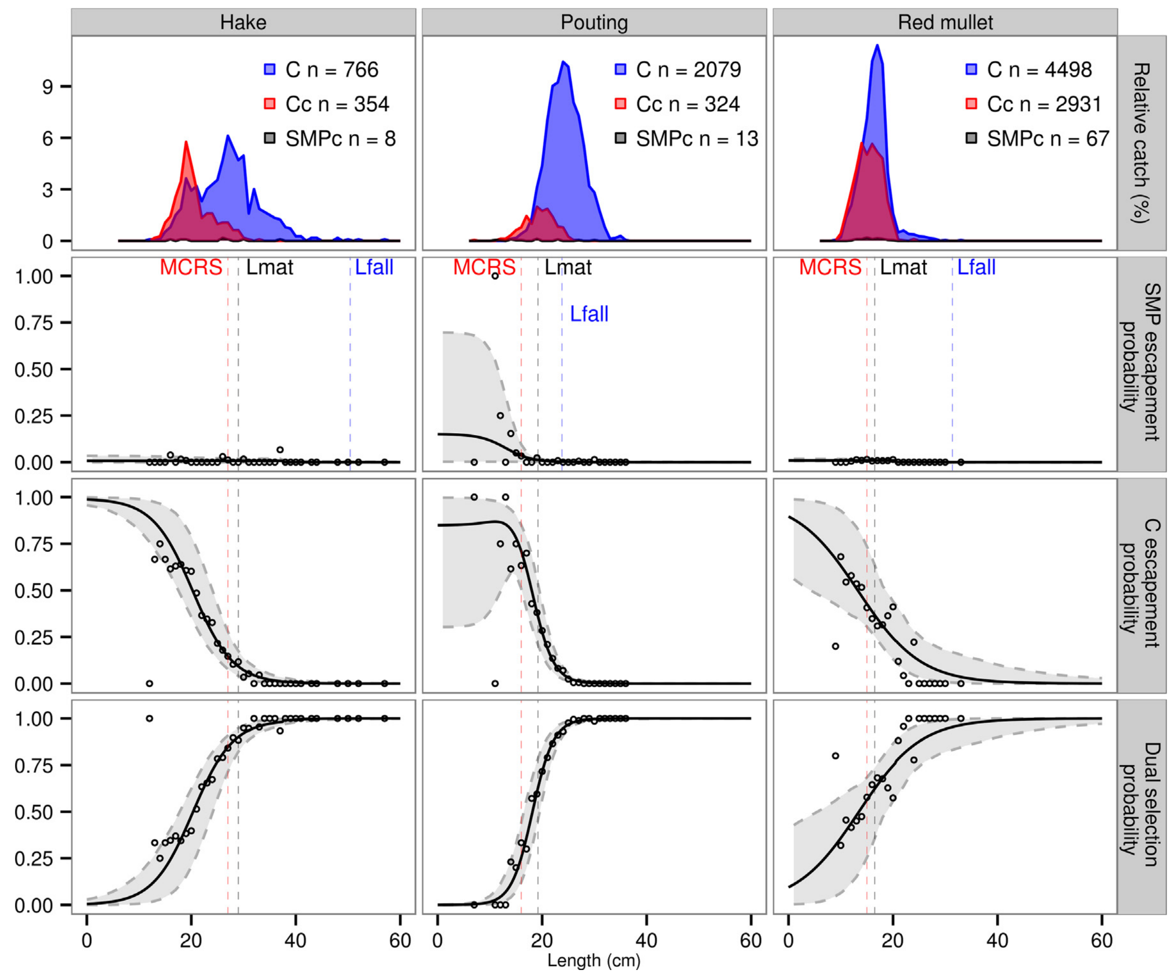

Fig. 4. Relative catch size-frequency distributions of fish retained in the codend (CO), codend cover (CC) and SMP cover (SMPC) and the mean escapement curves (black) for the SMP escapement, codend escapement and dual retention curves (combined effect of the codend and the SMP) and 95% confidence intervals (grey area) during the first cruise.

Table 5
Selectivity results from cruise 1 (3-compartment experiment): Fitted selectivity parameters, average retention/escapement probability for undersized individuals, 95% CI (in brackets) and fit statistics for each species and gear compartment.

	Hake	Pouting	Red mullet
L50 (cm)			
SMP	37.56 (25.50–37.62)	13.05 (13.05–27.52)	20.52 (16.01–20.56)
CO	20.29 (17.64–24.08)	18.08 (16.31–19.47)	13.36 (4.89–18.68)
Dual	20.34 (17.81–24.13)	18.15 (16.45–19.50)	13.47 (5.56–18.77)
SR (cm)			
SMP	0.10 (0.10–100.0)	5.51 (0.10–21.34)	0.10 (0.10–5.91)
CO	8.40 (5.59–11.73)	4.45 (3.73–5.29)	13.04 (6.31–32.80)
Dual	8.47 (5.66–11.73)	4.41 (3.73–5.18)	13.19 (6.28–33.33)
C_{SMP}	0.01 (0.00–0.03)	0.15 (0.01–0.70)	0.01 (0.01–0.02)
SMP escapement <MCRS (%)	0.73 (0.00–2.70)	11.90 (0.00–34.78)	0.87 (0.39–1.57)
CO escapement <MCRS (%)	47.30 (27.47–75.84)	71.43 (35.08–90.24)	53.93 (35.41–82.07)
Dual retention <MCRS (%)	51.97 (23.77–70.82)	16.67 (0.00–41.34)	45.20 (16.83–63.51)
Deviance	0.01	48.03	74.35
DOF	63	49	41
p-Value	0.99	0.51	0.01

describe the experimental selectivity data for red mullet. However inspection of the deviations between the observed and modelled size selectivity does not reveal any clear pattern (Fig. 4). Therefore we consider that the low *p*-value for red mullet is likely to be due to over-dispersion in the experimental data, and are therefore confident in applying the dual selection model to describe the selectivity curve for red mullet. The $L50_{SMP}$ values are estimated at 37.56 cm, 13.05 cm and 20.52 cm for hake, pouting and red mullet respectively. For all the species studied, the average $L50_{SMP}$ is estimated to be below L_{fall}, but above the MCRS for the hake and red mullet. The estimates of C_{SMP} are 0.01 for hake and red mullet, and 0.15 for pouting, meaning that only a low proportion (1% and 15%, respectively) of these species came into contact with the SMP during their drift towards the codend.

The $L50_{CO}$ values are estimated at 20.29 cm, 18.08 cm and 13.36 cm for hake, pouting and red mullet respectively. For the combination of the SMP and the codend, the $L50_{dual}$ is estimated to be 20.34 cm, 18.15 cm and 13.47 cm for hake, pouting and red mullet respectively. The differences between the estimates for $L50_{CO}$ and $L50_{dual}$, and SR_{CO} and SR_{dual} are small and not significant, which reflects that the SMP is not making an important contribution to the combined selectivity (see Table 5 and Fig. 4). Most of the individuals of the species studied that escaped from the gear did so through the codend.

Regarding catches of under-sized (<27 cm) hake, the estimated proportion retained in the codend was 51.97%, while the proportions that escaped through the codend and SMP were 47.30% and 0.73% respectively. For pouting, 16.67% of under-sized individuals were retained by the codend and 71.43% and 11.90% escaped through the codend and the SMP and for red mullet, 45.20 % of the under-sized individuals were retained by the codend and 53.93% and 0.87% escaped through the codend and the SMP (Table 5 and Fig. 4).

The above results demonstrate that the majority of undersized individuals of all species that escaped the gear did so through the codend. However, approximately half of the catch of undersized hake and red mullet and about 17% of undersized pouting was retained by the gear. It is clear that the SMP does not improve the selectivity for undersized hake and red mullet much because less than 1% of all undersized individuals escaped through the SMP. For pouting, only a marginal improvement in selectivity was attributable to the SMP (12% of undersized escapees).

3.2.2. Selection properties of the SMP alone; Cruises 2 and 3

A total of 27 and 26 hauls were carried out during the second and third cruises respectively (years 2012 and 2013), designed to investigate the selective properties of the 100 mm SMP. The numbers of valid hauls for hake, pouting and red mullet during the second cruise were 22, 4 and 7, while during the third cruise were 22, 5 and 6 respectively (Table 4). The specification of the gear used in both cruises is illustrated in Fig. 2b. The relative size-frequency distribution of individuals retained by the SMPC and the CL for the different species based on the total number of fish caught from all valid hauls is shown in Fig. 5. As observed in the three compartment experiment described above, escapement of hake, pouting and red mullet through the SMP was low in both cruises 2 and 3. The total catches of hake, pouting and red mullet were 11,950, 733 and 549 individuals respectively, but only 452 hake, 3 red mullet and not a single pouting passed through SMP into the SMPC.

Fig. 5 shows the fitted selection curves for the SMP by species for the second and third set of trials (years 2012 and 2013). Table 6 summaries the results for modelling the size selection for the SMP. Similar to the results from the dual selection modelling for red mullet, inspection of the *p*-values and the model deviance compared with the DOF for hake could indicate problems with the modelling. However, although the *p*-value for hake was below 0.05 and the model deviance was far above the DOF we could also attribute this to over-dispersion in the experimental data (Fig. 5). Using the same rationale as for red mullet we consider that it is appropriate to use the applied selection model to describe the selectivity curve for hake. For pouting the $L50_{SMP}$ could not be estimated since no fish escaped through the SMP (Table 6). For hake and red mullet, while the average estimates for $L50_{SMP}$ differed between the second and third cruises, the differences were not significant since the confidence intervals overlap (Fig. 5 and Table 6). As for cruise 1, $L50_{SMP}$ for hake and red mullet in cruises 2 and 3 are estimated to be below L_{fall}, but significantly above the MCRS and L_{mat}, which means that the SMP has the potential to allow undersized fish to escape. However, the estimated contact probabilities (C_{SMP}) were very low (zero in the case of pouting and about 5% and 1% for hake and red mullet respectively; Table 6). The estimates of C_{SMP} and the associated 95% confidence intervals for all the species studied were similar for both years, and in in line with those obtained from the three compartment experiment (Table 6).

Table 6
Selectivity results from cruises 2 and 3 (2-compartment experiments): fitted selectivity parameters, average escapement probability for undersized individuals, 95% CI (in brackets) and fit statistics for each species.

	Hake	Pouting	Red mullet
$L50_{SMP}$(cm)			
Cruise 2	49.51 (40.47–49.98)	[a]	29.56 (15.75–31.49)
Cruise 3	39.64 (26.47–46.56)	[a]	26.59 (15.75–31.49)
SR_{SMP}(cm)			
Cruise 2	0.10 (0.10–6.36)	[a]	0.10 (0.10–11.7)
Cruise 3	7.80 (0.10–20.05)	[a]	0.10 (0.10–100.0)
C_{SMP}			
Cruise 2	0.04 (0.03–0.07)	0.00	0.01 (0.00–0.02)
Cruise 3	0.05 (0.03–0.09)	0.00	0.01 (0.00–0.06)
SMP escapement <MCRS (%)			
Cruise 2	4.10 (2.29–6.83)	0.00 (0.00)	0.00 (0.00)
Cruise 3	4.84 (2.95–8.27)	0.00 (0.00)	0.00 (0.00)
Deviance			
Cruise 2	65.14	<0.01	10.08
Cruise 3	76.89	<0.01	8.23
DOF			
Cruise 2	46	18	17
Cruise 3	52	14	19
p-Value			
Cruise 2	0.03	>0.99	0.90
Cruise 3	0.01	>0.99	0.98

[a] No estimation since no fish escaped through the SMP.

It is clear that the SMP does not improve the selectivity for undersized hake because less than 5% of hake undersized individuals (4.10% and 4.83% for the second and third trial respectively) escaped through the SMP. For pouting and red mullet, the SMP was wholly ineffective at releasing undersized fish as not a single under-sized individual escaped through the SMP (Table 6 and Fig. 5).

3.3. Underwater observations

Underwater observations confirmed that the SMP meshes remained wide open during fishing (Fig. 6). However, none of the species studied seemed to react to the SMP open meshes. In the vicinity of the SMP hake individuals were observed to be passively drifting towards the codend with no apparent active escapement behaviour in relation to the SMP. Video observations showed that ground contact of the footrope constantly dislodged sand particles and sludge that created turbidity inside the trawl. Consequently, there was reduced visibility (Fig. 6), which together with the apparent affinity of pouting and red mullet to remain close to the lower panel of the trawl may explain why the SMP was not effective at releasing these species. Some pelagic species such as anchovy (*Engraulis encrasicolus*), horse mackerel and blue whiting (*Micromesistius poutassou*) were observed escaping through the SMP or swimming underneath the SMP for long periods until they became exhausted.

4. Discussion

The experimental cruises undertaken in the present study aimed to investigate the selective properties of the fishing gears used by Basque otter trawlers operating in the Bay of Biscay (ICES Divisions VIII a, b and d). The gears used are bottom otter trawls with a codend

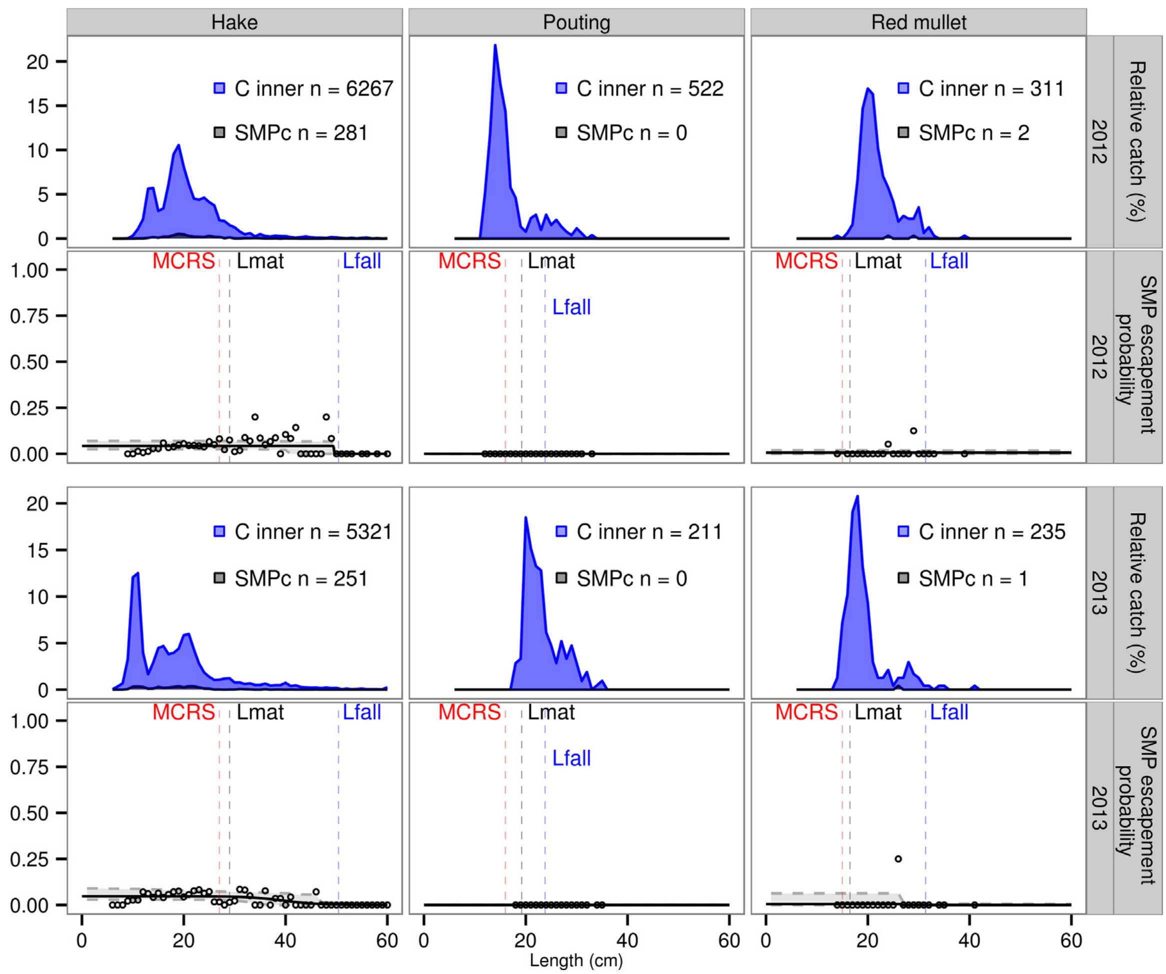

Fig. 5. Relative catch size-frequency distribution for hake, pouting and red mullet for the codend liner (CL) and square mesh panel cover (SMPC) during cruises 2 and 3 (2012 and 2013). Fitted escapement curves (solid black line) and 95% confidence intervals (grey area) are also shown.

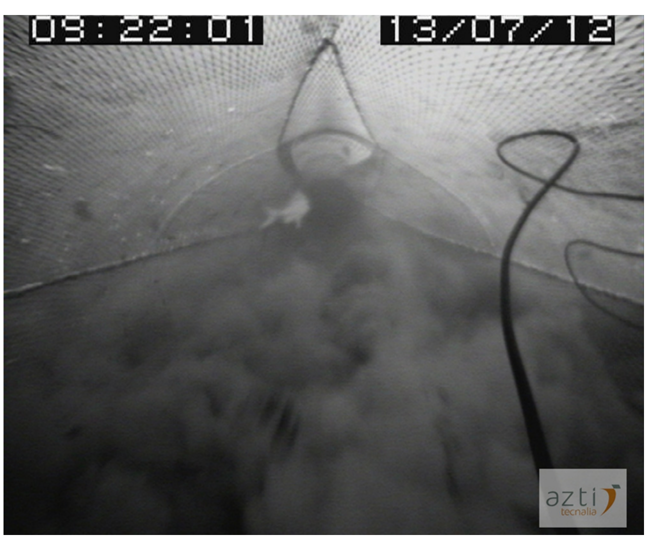

Fig. 6. Snapshot from an underwater video showing the presence of turbidity in the lower section of the net in the vicinity of the SMP.

mesh size of 70 mm, incorporating a 100 mm SMP in the extension ahead of the codend as prescribed in Council Regulation (EC) 51/2006. These provisions were introduced as an optional alternative to the mandatory use of bottom otter trawls with a 100 mm codend mesh size prescribed in (EC, 2002) and were intended primarily to improve selectivity for juvenile hake. The cruises provide an opportunity to investigate the selective properties of the SMP for hake, but also for pouting and red mullet, which are also caught in the Basque otter trawl fishery.

Results from the fall-through experiments revealed that the size-selective properties of the 100 mm SMP would potentially enable immature and undersized fish of all the species studied to escape through the SMP meshes (Table 3). The selection curves obtained from the at sea selectivity cruises also demonstrate that the value for $L50_{SMP}$ is higher than the MCRS for hake and red mullet (Tables 5 and 6). Therefore, undersized individuals of the species studied could potentially escape through the SMP. However, they show only a low probability to encounter the SMP (contact probabilities are only 1–4% for hake, between 0 and 15% for pouting, and 1% for red mullet) and hence the effectiveness of the SMP in releasing undersized individuals is very low. This is supported by the results of underwater observations made during the cruises which demonstrated that hake, pouting and red mullet did not display any active escapement behaviour in the region of the SMP and fish were simply observed to drift past the SMP towards the codend during the fishing operation. The ineffectiveness of the SMP is confirmed by comparing the differences in the estimates for $L50_{CO}$ and $L50_{dual}$, and SR_{CO} and SR_{dual}, which were small and not significant (Table 5).

While the combination of 70 mm codend mesh size and 100 mm SMP aims at improving the selectivity for juvenile hake, Nikolic et al. (2015) also concluded that release of juvenile hake with SMP is inefficient in the French *Nephrops* trawl fishery. The dual retention results for hake in the present study (Table 5) shows that approximately 52% of the catch in number of undersized hake (<MCRS = 27 cm) was retained by the codend of the trawl used by the Basque fleet. Furthermore, the majority of the undersized individuals that escaped did so through the 70 mm codend meshes (47%) and less than 1% escaped via the 100 mm SMP. Compared to a 70 mm diamond mesh codend ($L50_{CO}$ 20.3 cm), our findings reveal no improvement in size selection for hake ($L50_{dual}$ 20.3 cm) by inserting a 100 mm SMP in the extension of the trawl. The value of $L50_{CO}$ estimated for the 70 mm diamond codend is slightly higher than that estimated by Campos et al. (2003) for a 65 mm diamond codend ($L50_{CO}$ 17.0 cm), suggesting that an increase in codend mesh size can improve the selection pattern for hake, i.e., proportionally fewer smaller individuals are retained by the codend. Another effective means to improve the selection pattern for hake is the insertion of sorting grids in the extension section of trawls, as demonstrated by Fonseca et al. (2005).

The dual selection results for pouting show that approximately 17% of the catch in number of undersized pouting (<MCRS = 16 cm) was retained by the codend of the trawl used by the Basque fleet, and approximately 83% escaped (Table 5), although the majority of the undersized individuals that escaped (71%), did so through the 70 mm codend meshes. The values of $L50_{CO}$ (18.08 cm) and SR_{CO} (4.5 cm) were in the range of those estimated by Mendes et al. (2004) for a 65 mm square mesh codend (but for *Trisopterus luscus* only). The observed similarity in the results from both studies can be explained by the steepness of the estimated selection curve for pouting (Fig. 4). In contrast however, even though in our first cruise, the release potential of the SMP for undersized pouting was 12%, similar to the 10% escapement observed by Fonseca et al. (2005) using a trawl fitted with a grid with 30 mm bar spacing and a SMP located above the grid, the contact probabilities for pouting differed markedly in the other two cruises (Tables 5 and 6). Hence we are unable to conclude that the SMP is equally effective at releasing pouting as the grid-SMP combination used by Fonseca et al. (2005).

For red mullet, the dual selection results show that approximately 45% of the catch in number of undersized individuals (<MCRS = 15 cm) were retained by the codend, and less than 1% of the juvenile red mullet escaped through the 100 mm SMP. In contrast, Metin et al. (2005) found that compared to a 40 mm diamond mesh codend, selectivity experiments using a 40 mm diamond mesh codend incorporating a 40 mm SMP positioned in the forward part of the top panel of the codend significantly increased the release of juvenile red mullet. Our study estimated a similar value of $L50_{dual}$ to Metin et al. (2005) (13.5 cm vs. 12.6 cm) but a much bigger value of SR_{dual} (13.2 cm vs. 2.3 cm). The observed differences may be explained by differences in both the panel location and the length range sampled. However, and as found for hake, our estimates for $L50_{CO}$, both for pouting and red mullet, are similar to our estimates for $L50_{dual}$. Therefore, the combined selectivity of the gear is mainly attributable to the escapement of individuals through the codend.

The low escapement of these demersal species through the SMP can be attributed to the fact that they did not display any active escape behaviour in the region of the SMP, as confirmed by our underwater observations. These observations are also in line with the findings of Briggs (1992), Frandsen et al. (2009), and Rosen et al. (2012) for cod. Furthermore, Fonseca et al. (2005) demonstrated that compared to pelagic species, the escape behaviour of demersal species was much less active in the area of the SMP. However, previous studies have shown that other factors, such as the location if the SMP can also affect escapement through the SMP of species that exhibit less active escape behaviour. For example, in selectivity trials undertaken by Graham and Kynoch (2001), no significant differences in the *L50*s for haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) were found between trials using trawls fitted with a 100 mm diamond mesh codend, and trawls with a 3 m long, 80 mm SMP inserted in the extension section ahead of a 100 mm diamond mesh codend. However, when the 80 mm SMP was inserted in the codend, it significantly improved the selectivity of the gear. Furthermore, other studies also on haddock, whiting and cod have proved that when SMPs are positioned in the codend, closer to the catch accumulation zone, both the selectivity for small fish and the survival of escapees is improved (Graham et al., 2003, 2004; Madsen and Staehr, 2005; Bullough et al., 2007; Grimaldo et al., 2007; Herrmann et al., 2015).

Glass and Wardle (1995) found that the selectivity and survival of the escapees of demersal fish can be dramatically affected by using visual stimuli to raise their vertical position in the trawl. In their study, the proportion of haddock and whiting escaping through the SMP increased from 20 to 60% with addition of a black tunnel in the extension section of the trawl behind the SMP. Fish appeared reluctant to enter the tunnel and preferred to escape through the open meshes that the SMP offered. However, underwater observations made during trawling in the present study, demonstrated that even though the SMP may have offered enhanced light penetration compared to the adjacent, almost closed diamond meshes; hake, pouting and red mullet rarely exhibited active escape behaviour inside the gear and tended to remain closer to the bottom panel of the trawl. Furthermore, bottom otter trawling by the Basque fleet is carried out at a relatively high speed of about 4 knots, which creates conditions of reduced visibility due to the presence of high densities of particulate matter in suspension. Such conditions may have influenced the ability of the fish to locate the SMP, thereby inhibiting their ability to escape the open meshes.

Currently the Basque bottom otter trawl fleet in the Bay of Biscay is complying with existing regulations by adopting the 70 mm diamond codend with the 100 mm SMP rather than opting for the alternative permissible configuration of 100 mm diamond mesh codend. Whatever the reasons for choosing the 70 mm codend plus SMP configuration, our results demonstrate that incorporation of the SMP, positioned in the extension section of the trawl, does not result in any significant improvement in the selectivity for small hake over and above that achieved by the 70 mm codend. Consequently, we conclude that this gear configuration does not effectively achieve the intended objective of releasing undersized hake and ideally its ability to do so should have been assessed before the measures were implemented. Hence we agree with Suuronen and Sarda (2007) that before implementation, gear-specific regulations should be carefully thought through and thoroughly tested in all the fisheries to which they are to apply.

We have demonstrated that under normal fishing operations, the selective properties of the trawls deployed by the Basque bottom otter trawl fleet in the Bay of Biscay, retains approximately half of undersized hake and red mullet that enter the trawl and approximately 17% of undersized pouting. To comply with current minimum size regulations, catches of undersized individuals must be discarded and the vast majority will be returned to the sea dead. However, with the implementation of the landing obligation (Article 15 of the CFP; EU, 2013), discarding of undersized quota species (hake in this case study) will no longer be permitted. Such catches will have to be retained on board and landed, will be counted against quota and shall be restricted to purposes other than direct human consumption. Whether they are discarded or landed, they are unwanted catches that reduce future potential yield and spawning stock biomass. A potential solution to avoid unwanted catches is to improve the selective properties of the fishing gear so that undersized individuals can escape. The conservation benefits of escapement of juvenile individuals depends on the survival rate. In absence of information on the survival rates of hake, pouting or red mullet following escapement from trawls the conservation benefits cannot be predicted with any certainty. If the long-term survival rate is 100%, juveniles escaping from fishing gears have the potential to make a significant contribution to the future spawning potential of the stock. However if the survival rate is close to 0%, then the future conservation benefits will be minor. In either of these cases, there is a double incentive for skippers to avoid catching undersized individuals, both from the potential conservation benefits that might accrue to the stock and to avoid having to land undersized individuals under the landing obligation.

The introduction of the landing obligation shifts the emphasis from prescribing the fishing gears that are permissible, to a results-based system where the onus is on the fishers to develop gears that will avoid unwanted catches. Such a shift to a results-based system, presents both a challenge and an opportunity to the Basque trawl fleet to develop alternative more-selective gears in the Bay of Biscay fishery to avoid unwanted catches of undersized hake and other species. Reverting to using a 100 mm diamond mesh codend in the Basque bottom otter trawl fishery may provide a partial solution to mitigate the potential impact of the landing obligation. However such a measure may also lead to losses in marketable catch and reductions in revenue that make the fishery unviable in the short-term and perhaps in the long-term. Should adoption of a 100 mm codend prove to be economically unviable or fail to reduce unwanted catches, fishers will be incentivised to develop alternative gears or adapt their fishing behaviour to mitigate the full impact of the landing obligation.

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References

Alonso-Fernández, A., Domínguez-Petit, R., Bao, M., Rivas, C., Saborido-Rey, F., 2008. Spawning pattern and reproductive strategy of female pouting *Trisopterus luscus* (Gadidae) on the Galician shelf of north-western Spain. Aquat. Living Resour. 21, 383–393.

Bellido, J.M., Santos, M.B., Pennino, M.G., Valeiras, X., Pierce, G.J., 2011. Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? Hydrobiologia 670 (1), 317–333.

Briggs, R.P., 1992. An assessment of nets with a square mesh panel as a whiting conservation tool in the Irish Sea Nephrops fishery. Fish. Res. 13, 133–152.

Broadhurst, M.K., 2000. Modifications to reduce by catch in prawn trawls: a review and framework for development. Rev. Fish Biol. Fish. 10, 27–60.

Bullough, L.W., Napier, I.R., Laurenson, C.H., Riley, D., Fryer, R.J., Ferro, R.S.T., Kynoch, R.J., 2007. A year-long trial of a square mesh panel in a commercial demersal trawl. Fish. Res. 83, 105–112.

Campos, A., Fonseca, P., Erzini, K., 2003. Size selectivity of diamond and square mesh cod ends for four by-catch species captured in the crustacean fishery of the Portuguese south coast. Fish. Res. 60, 79–97.

Catchpole, T.L., Revill, A.S., 2008. Gear technology in Nephrops trawl fisheries. Rev. Fish Biol. Fish. 18, 17–31.

Daan, N., 1997. TAC management in North Sea flatfish fisheries. Neth. J. Sea Res. 37, 321–341.

Dorel, D., 1986. Poissons de l'Atlantique Nord-est Relations Taille-pods. Institut Francais de Recherche pour l'Exploitation de la Mer, Nantes, France, pp. 165.

EC, 1996. Council Regulation (EC) No. 2406/96 of 26 November 1996 laying down common marketing standards for certain fishery products. Official Journal of the European Communities L344/1.

EC, 2002. Commission Regulation (EC) No. 494/2002 of 19 March 2002 establishing additional technical measures for the recovery of the stock of hake in ICES subareas III, IV, V, VI and VII and ICES Divisions VIII a, b, d, e. Official Journal of the European Communities L77/8.

EC, 2006. Council Regulation (EC) No. 51/2006 of 22 December 2005 fixing for 2006 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where catch limitations are required. Official Journal of the European Union L (16) 148-149.

EU, 2013. Regulation (EU) No 1380/2013 of the European Parliament and Council of 11 December 2013 on the Common Fisheries Policy. Official Journal of the European Union, L 354/22.

Eigaard, O., Herrmann, B., Nielsen, J.R., 2012. Influence of grid orientation and time of day on grid sorting in a small-meshed trawl fishery for Norway pout (*Trisopterus esmarkii*). Aquat. Living Resour. 25, 15–26.

El Habouz, H.L., Recasens, L., Kifani, S., Moukrim, A., Bouhaimi, A., El Ayoubi, S., 2011. Maturity and batch fecundity of the European hake (*Merluccius merluccius*, Linnaeus, 1758) in the eastern central Atlantic. Sci. Mar. 75 (3), 447–454.

Feekings, J., Bartolino, V., Madsen, N., Catchpole, T., 2012. Fishery discards: factors affecting their variability within a demersal trawl fishery. PLoS One 7 (4), e36409, http://dx.doi.org/10.1371/journal.pone.0036409.

Fonseca, P., Campos, A., Mendes, B., Larsen, R.B., 2005. Potential use of a Nordmore grid for by-catch reduction in a Portuguese bottom-trawl multispecies fishery. Fish. Res. 73, 49–66.

Fonteyne, R., Polet, H., 2002. Reducing the benthos by-catch in flatfish beam trawling by means of technical modifications. Fish. Res. 55, 219–230.

Fonteyne, R., Buglioni, G., Leonori, I., O'Neill, F.G., Fryer, R.J., 2007. Laboratory and field trials of OMEGA, a new objective mesh gauge. Fish. Res. 85, 197–201.

Frandsen, R.P., Holst, R., Madsen, N., 2009. Evaluation of three levels of selective devices relevant to management of the Danish Kattegat–Skagerrak Nephrops fishery. Fish. Res 97, 243–252.

Glass, C.W., Wardle, C.S., 1995. Studies on the use of visual stimuli to control fish escape from codends II. The effect of a black tunnel on the reaction behaviour of fish in otter trawls codends. Fish. Res. 23, 165–174.

Garcia, S.M., Cochrane, K.L., 2005. Ecosystem approach to fisheries: a review of implementation guidelines. ICES J. Mar. Sci. 62, 311–318.

Graham, N., Kynoch, R.J., 2001. Square mesh panels in demersal trawls: some data on haddock selectivity in relation to mesh size and position. Fish. Res. 49, 207–218.

Graham, N., Kynoch, R.J., Fryer, R.J., 2003. Square mesh panels in demersal trawls: further data relating haddock and whiting selectivity to panel position. Fish. Res. 62, 361–375.

Graham, N., O'Neill, F.G.O., Fryer, R.J., Galbraith, R.D., Myklebust, A., 2004. Selectivity of a 120 mm diamond codend and the effect of inserting a rigid grid or a square mesh panel. Fish. Res. 67, 151–161.

Graham, N., Ferro, R.S.T., Karp, W.A., MacMullen, P., 2007. Fishing practice, gear design, and the ecosystem approach—three case studies demonstrating the effect of management strategy on gear selectivity and discards. ICES J. Mar. Sci. 64, 744–750.

Grimaldo, E., Larsen, R.B., Holst, R., 2007. Exit windows as an alternative selective system for the Barents Sea demersal fishery for cod and haddock. Fish. Res. 85, 295–305.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Eliott, M., Feld, C.K., Heiskanen, A.S., Moe, J., Pont, D., Solheim, A.L., de Bund, W.V., 2010. The European water framework directive at the age of 10: a critical review of the achievements with recommendations for the future. Sci. Total Environ. 408 (19), 4007–4019, http://dx.doi.org/10.1016/j.scitotenv.2010.05.031.

Herrmann, B., Krag, L.A., Frandsen, R.P., 2009. Prediction of selectivity from morphological conditions: methodology and a case study on cod (*Gadus morhua*). Fish. Res. 97, 59–71.

Herrmann, B., Sistiaga, M., Nielsen, K.N., Larsen, R.B., 2012. Understanding the size selectivity of redfish (*Sebastes* spp.) in North Atlantic trawl codends. J. Northwest Atl. Fish. Sci. 44, 1–13.

Herrmann, B., Sistiaga, M., Larsen, R.B., Nielsen, K.N., 2013. Size selectivity of redfish (*Sebastes* spp.) in the Northeast Atlantic using grid-based selection systems for trawls. Aquat. Living Resour. 26, 109–120.

Herrmann, B., Wienbeck, H., Karlsen, J.D., Stepputtis, D., Dahm, E., Moderhak, W., 2015. Understanding the release efficiency of Atlantic cod (*Gadus morhua*) from trawls with a square mesh panel: effects of panel area, panel position, and stimulation of escape response. ICES J. Mar. Sci. 72, 686–696.

Iriondo, A., Prellezo, R., Santurtún, M., Garcia, D., Quincoces, I., Mugerza, E., 2008. Basque trawl metier definition for 2003–2007 period. In: Working Document for the ICES WGHMM 2008, (Copenhagen, Denmark 30 April 6 May 2008).

Iriondo, A., Prellezo, R., Santurtún, M., Garcia, D., Quincoces, I., Mugerza, E., 2010. A multivariate approach for metier definition: a case study of Basque Country trawlers. Rev. Invest. Mar. 17 (6), 2010.

Larsen, R.B., Isaksen, B., 1993. Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). ICES Mar. Sci. Symp. 196, 178–182.

Madsen, N., Holst, R., Foldager, L., 2002. Escape windows to improve the size selectivity in the Baltic cod trawl fishery. Fish. Res. 57, 223–235.

Madsen, N., Staehr, K.J., 2005. Selectivity experiments to estimate the effect of escape windows in the Skagerrak roundfish fishery. Fish. Res. 71, 241–245.

Madsen, N., 2007. Selectivity of fishing gears used in the Baltic Sea cod fishery. Rev. Fish Biol. Fish. 17, 517–544.

Mahé, K., Destombes, A., Coppin, F., Koubbi, P., Vaz, S., 2005. Le rouget barbet de roche *Mullus surmuletus* (L. 1758) en Manche orientale et mer du Nord. Final report, pp. 186.
McClanahan, T.R., 2010. Effects of fisheries closures and gear restrictions on fishing income in a Kenyan Coral Reef. Conserv. Biol. 24 (6), 1519–1528, http://dx.doi.org/10.1111/j.1523-1739.2010.01530.
Mendes, B., Fonseca, P., Campos, A., 2004. Cod end selectivity for six fish species of the Portuguese southwest coast. Relat. Cient. Téc. Inst. Invest. Pescas Mar., no. 11, 18 pp. In Portuguese with an English abstract. (http://ipimar-iniap.ipimar.pt/edicoes/relatorios/relatoriosdigitais.html).
Metin, C., Özbilgin, H., Tosunoğlu, Z., Gökçe, G., Aydın, C., Metin, G., Ulaş, A., Kaykaç, H., Lök, A., Düzbastılar, F.O., Tokaç, A., 2005. Effect of square mesh escape window on codend selectivity for three fish species in the Aegean Sea. Turk. J. Vet. Anim. Sci. 29, 461–468.
Nikolic, N., Diméet, J., Fifas, S., Salaün, M., Ravard, D., Fauconnet, L., Rochet, M.J., 2015. Efficacy of selective devices in reducing discards in the Nephrops trawl fishery in the Bay of Biscay. ICES J. Mar. Sci., http://dx.doi.org/10.1093/icesjms/fsv036.
O'Neill, F.G., Kynoch, R.J., Fryer, R.J., 2006. Square mesh panels in North Sea demersal trawls: separate estimates of panel and cod-end selectivity. Fish. Res. 78, 333–341.
Özbilgin, H., Eryaşar, A.R., Gökçe, G., Özbilgin, Y.D., Bozaoğlu, A.S., Kalecik, E., Herrmann, B., 2015. Size selectivity of hand and machine woven codends and short term commercial loss in the north eastern Mediterranean. Fish. Res. 164, 73–85.
Rochet, M.J., Arregi, L., Fonseca, T., Pereira, J., Pérez, N., Ruiz, J., Valeiras J., 2014. Demersal discard atlas for the South Western Waters. pp. 121. (http://www.ccr-s.eu/Upload/ES/Agenda/DocsAnnexes/discard_atlas_SWW_def.pdf). (accessed 24.11.15.).
Rosen, S., Engas, A., Ferno, A., Jørgensen, T., 2012. The reaction of shoaling adult cod to a pelagic trawl: implications for commercial trawling. ICES J. Mar. Sci. 69, 303–312.
Sala, A., Lucchetti, A., Perdichizzi, A., Herrmann, B., Rinelli, P., 2015. Is square-mesh better selective than larger mesh? A perspective on fisheries management for Mediterranean trawl fisheries. Fish. Res. 161, 182–190.
Santurtún, M., Prellezo, R., Arregi, L., Iriondo, A., Aranda, M., Korta M., Onaindia, I., Garcia, D., Merino, G., Ruiz, J., Andonegi, E., 2014. Characteristics of multispecific fisheries in the European Union. https://www.researchgate.net/publication/266082516_Characteristics_of_multispecific_fisheries_in_the_European_Union._STUDY_IPBPECHIC2013_088 (accessed 24.11.15.).
Sistiaga, M., Herrmann, B., Grimaldo, E., Larsen, R.B., 2010. Assessment of dual selection in grid based selectivity systems. Fish. Res. 105, 187–199.
Suuronen, P., Sarda, F., 2007. The role of technical measures in European fisheries management and how to make them work better. ICES J. Mar. Sci. 64, 756–771.
Tschernij, V., Suuronen, P., 2002. Improving trawl selectivity in the Baltic. Utokning av tralselektion i Ostersjon. TemaNord 512, 56.
Uhlmann, S.S., van Helmond, A.T.M., Stefánsdóttir, E.K., SigurÐardóttir, S., Haralabous, J., Maria Bellido, J., Carbonell, A., Catchpole, T., Damalas, D., Fauconnet, L., Feekings, J., Garcia, T., Madsen, N., Mallold, S., Margeirsson, S., Palialexis, A., Readdy, L., Valeiras, J., Vassilopoulou, V., Rochet, M.J., 2013. Discarded fish in European waters: general patterns and contrasts. ICES J. Mar. Sci. 71, 1235–1245.
Wienbeck, H., Herrmann, B., Feekings, J.P., Stepputtis, D., Moderhak, W., 2014. Comparative analysis of legislated and modified Baltic Sea trawl codends for simultaneously improving the size selection of cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*). Fish. Res. 150, 28–37.
Wileman, D.A., Ferro, R.S.T., Fonteyne, R., Millar, R.B., (Ed.), 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Coop. Res. Rep. No. 215.
Zuur, G., Fryer, R.J., Ferro, R.S.T., Tokai, T., 2001. Modelling the size selectivities of a trawl codend and an associated square mesh panel. ICES J. Mar. Sci. 58, 657–671.