

1 **Stimulating release of undersized fish through a square mesh panel in the Basque otter**
2 **trawl fishery**

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Abstract

18 Discards of regulated species in the Basque mixed trawl fishery are a challenge. In 2006, a square mesh
19 panel (SMP) was introduced in the fishery to increase the release efficiency of undersized fish. However,
20 studies have shown that the selectivity in this fishery is based on codend selectivity and the release
21 through the SMP is inefficient due to low contact between fish and the SMP. In order to improve contact,
22 we tested four different gear configurations that use different stimulators to lead fish to the panel: without
23 stimulation, with stimulation based on ropes, with stimulation based on ropes and floats, and with
24 stimulation based on LED lights. The experiment was carried out on three of the potential choke species
25 for the fishery: hake (*Merluccius merluccius*), horse mackerel (*Trachurus trachurus*), and blue whiting
26 (*Micromesistius poutassou*). The results showed that stimulators did not significantly improve the release
27 efficiency of hake and horse mackerel through the panel. For blue whiting, stimulation with floats had a
28 significant positive effect on release efficiency, whereas LED light-based stimulation had the opposite
29 effect. In general, the contribution of the SMP to the overall release efficiency of the selective system
30 (SMP+codend) was low. Underwater recordings confirmed that the stimulators generally were not able to
31 lead fish towards the SMP.

32 **Keywords:** Square mesh panel (SMP); Basque bottom otter trawl; Release efficiency; Contact probability

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34 1. Introduction

35 Fisheries in general have great social and economic implications for coastal communities
36 in the Basque Country (Haig, 2008), which is a region located in the north of Spain. Basque
37 bottom trawling began in the early twentieth century, and its productivity peaked in the late
38 1970s when 53% of the Spanish trawling fleet fishing in EU community waters (ICES VIab,
39 VIIbcghj, VIIIabd) was Basque. The demersal trawl fishery in this area is a multispecies fishery
40 that includes more than 100 different species (Rochet et al., 2014), but hake (*Merluccius*
41 *merluccius*), megrim (*Lepidorhombus* spp.), and anglerfish (*Lophius* spp.) are the main target
42 species. However, other species such as horse mackerel (*Trachurus trachurus*), blue whiting
43 (*Micromesistius poutassou*), and mackerel (*Scomber scombrus*) can be important as choke
44 species (Schrope, 2010) depending on the fishing ground, season, quota availability, and
45 commercial value (Iriondo et al., 2008, 2010; Rochet et al., 2014).

46 Awareness about discard reduction in fisheries has increased worldwide (Catchpole et
47 al., 2005; Gillespie, 2000; Santurtún et al., 2014). Discards in fisheries can occur for several
48 reasons, including capture of individuals below minimum legal size, exhaustion of quota, low
49 commercial value, damaged or degraded individuals in the catch, or high grading (Anderson,
50 1994; Pascoe, 1997). Since 1980, several technical regulations have been implemented in the
51 EU with the aim of reducing discards (Franco, 2007; Santurtún et al., 2014). However,
52 discarding is still a common practice in some European fisheries (Uhlmann et al., 2013). Rochet
53 et al. (2014) analyzed available data from observer discard monitoring, catch landings, and/or
54 nominal fishing effort from 2011 to 2013 and found that the total discard of the Spanish fleet
55 operating in ICES VIIIabd was around 60–65% of the total catch. Thus, unwanted catches and
56 discards constitute a substantial waste that negatively affects the sustainable exploitation of
57 marine resources (Kelleher, 2005). This perception has motivated the establishment of the
58 Landing Obligation (LO) under the provisions of Article 15 of the 2013 reform (EU, 2013). Its
59 main objective is to eliminate discards of commercially exploited stocks. By 2019, all EU
60 fisheries are obliged to land the catches of regulated species to be counted against the quota.

61 In recent decades, several fishing regulations have been implemented specifically to
62 stimulate the recovery of hake (EC, 2001a; 2001b; 2002; 2004). In 2002 (EC, 2002), the
63 minimum codend mesh size for trawlers fishing the northern stock of European hake in the Bay
64 of Biscay was changed from 70 mm to 100 mm diamond mesh. In 2006 (EC, 2006), fishermen
65 were given the alternative of using a 70 mm diamond mesh codend combined with a square
66 mesh panel (SMP) (2 m long, 1 m wide, 100 mm mesh size) inserted in the upper panel of the
67 extension piece of the trawl instead of a 100 mm diamond mesh codend. Currently, the gear
68 composed of the SMP with a 70 mm diamond mesh codend is the one most used by the fleet.

69 Several studies have investigated the functionality and release efficiency potential of
70 SMPs (Briggs, 1992; Santos et al., 2016; Zuur et al., 2001). In general, results show that even if
71 some species manage to escape through SMPs, less active species, such as hake, do not manage
72 to escape through it efficiently (Alzorriz et al., 2016). In most cases, the authors concluded that
73 the low release efficiency of the panel is a consequence of the low contact between the fish and
74 the panel (Alzorriz et al., 2016; Brčić et al., 2017; Herrmann et al., 2014). To improve the
75 contact, some mechanical (Kim and Whang, 2010) and visual stimulators (Glass and Wardle,
76 1995; Grimaldo et al., 2017) have been used to guide fish towards SMPs or netting walls
77 (Grimaldo et al., 2018; Herrmann et al., 2014).

78 The main goal of the present study was to determine if the release efficiency of the SMP
79 used in a demersal trawl in the Bay of Biscay could be improved by adding ropes, floats, and
80 LED light-based stimulators. The study focused on individuals of hake, horse mackerel, and
81 blue whiting, which may compromise the activity of the fleet due to their potential as choke
82 species. Specifically, we aimed to answer the following research questions:

- 83 • What is the release efficiency of the selection system composed of a SMP and 70 mm
84 diamond mesh codend for hake, horse mackerel, and blue whiting?
- 85 • What are the contributions of the SMP and the 70 mm diamond mesh codend to the
86 combined selectivity of the system?

- 87 • Can the release efficiency of the SMP be improved by adding different stimulators
88 based on ropes, floats, or LED lights for the three species investigated?

89

90 **2. Material and methods**

91 *2.1. Sea trials and data collection*

92 The sea trials were carried out on board the oceanographic vessel *Emma Bardan* (29 m
93 length overall; 900 Kw) from 8 to 19 June 2017. The fishing was carried out in a specific area
94 within ICES divisions VIIIc and VIIIb that correspond to Spanish and French waters (Figure 1).
95 This area normally contains high densities of hake juveniles at this time of year and therefore
96 was considered to be suitable for the experiments. During the experimental period, 32 valid
97 hauls were conducted at depths that varied between 106 and 128 m.

98 **Figure 1**

99 The gear used in the experiments was a four-panel bottom trawl called GOC73
100 (Bertrand et al., 2000). This trawl is built according to the standard bottom trawl survey manual
101 for the Mediterranean (MEDITS, 2016). The headline, sideline, and fishing line were 35.7, 7.4,
102 and 40.0 m long, respectively. The trawl was rigged with a set of Morgère doors (Morgère WH
103 S8 type, 2.6 m²; 350 Kg), 100 m sweeps, and a light rockhopper ground gear (with 3 × 40 Kg
104 chain + 15 Kg chain on the bosom). While fishing, the trawl had a horizontal opening of 16 m
105 and a vertical opening between 2.7 and 3.2 m. The towing speed during the cruise was 3.0–3.3
106 knots which was the maximum for the vessel.

107 In this study, we used a SMP (mesh size 82.7 mm) inserted into the upper panel of the
108 extension piece of the trawl, 1 m in front of the joint between the codend and the extension
109 piece (Figure 2). A previous study carried out with a 100 mm SMP (Alzorritz et al., 2016)
110 showed that the low release efficiency of the panel was due to poor contact between the fish and
111 the panel rather than to an inappropriate mesh size. In fact, the results of the study showed that
112 fish over Minimum Conservation Reference Size (MCRS) that managed to contact the panel

113 were able to escape through it. Therefore, and in order to avoid the loss of valuable catch, the
114 mesh size of the panel used in the present study was reduced to 82.7 mm (3 mm polyamide (PA)
115 twine) (Table 1). The codend, used together with the panel, was 7.0 m long and made of 72.8
116 mm meshes (4 mm PA double twine). All meshes were measured with an electronic OMEGA
117 mesh gauge (Fonteyne et al., 2007) according to the guidelines described in regulation EC,
118 2008.

119 The selectivity data were collected using the dual-cover method (Figure 2) described in
120 Zuur et al. (2001) and Sistiaga et al. (2010). The cover used over the SMP was 13 m long with
121 26.1 mm mesh size (1.2 mm PA twine). It was built based on the design of Larsen and Isaksen
122 (1993) and was equipped with nine floats (N-50/8 type; 135 mm diameter; 0.760 Kg buoyancy
123 each) to ensure its expansion. The cover over the codend was 9 m long and constructed of 26.5
124 mm mesh size (1.3 mm PA twine) (Table 1; Figure 2). To expand the codend cover we used
125 nine pairs of floats (N-25/5 type; 100 mm diameter; 0.300 Kg buoyancy each), eight kites (four
126 per panel), and four chains (1 Kg each) in the lower panel. Table 1 summarizes details about the
127 specifications of the different parts of the trawl.

128 **Table 1**

129 **Figure 2**

130 We tested four different gear configurations:

- 131 1. No-stimulation: used as baseline, consisted on the SMP with no stimulators added
132 (Figure 3a);
- 133 2. Stimulation by ropes: consisted of six inclined elastic ropes attached on one side to the
134 bottom panel of the square mesh section and on the other side to the upper panel at the
135 end of the SMP. The purpose was to partially obstruct the passage of fish toward the
136 codend, guiding them upwards towards the SMP (Figure 3b);

- 137 3. Stimulation by floats: this configuration added oval plastic floats to the inclined ropes
138 described in the former configuration (3-4 floats on each rope, T80/5 type, 118x52 mm,
139 0.085 Kg buoyancy each). The floats provided vibration to the guiding ropes while
140 towing (Figure 3c);
- 141 4. Stimulation by LED lights: ten blue LED lights (CENTRO Power Light, Standard
142 model SW2) were placed over the SMP to attract fish towards the panel and increase
143 contact probability (Figure 3d).

144 **Figure 3**

145 Each haul was carried out with one configuration at a time, completing a total of eight
146 hauls for each configuration. The species included in the data analysis were hake (*Merluccius*
147 *merluccius*), horse mackerel, (*Trachurus trachurus*) and blue whiting (*Micromesistius*
148 *poutassou*). After each haul, these species were measured to the nearest centimeter below. When
149 the catch exceeded a maneuverable quantity in terms of the available time and crew for
150 processing the fish, randomly selected subsamples of the catch were taken, and the subsample
151 ratio was calculated. In some specific hauls, once the subsample was sorted, and if the
152 representation of some species was still too big to handle, a randomly selected sample from the
153 sorted subsample was taken. Consequently, we expected that in those specific hauls the less
154 abundant species would be weakly represented. Therefore, we established a protocol for
155 acceptance, meaning that the hauls that did not pass the limits established in the protocol were
156 discarded. The haul protocol acceptance was based on two conditions: 1) sampling factor for a
157 compartment had to be at least 0.05 and 2) in case of subsampling in a compartment, the
158 product of the number measured in the compartment and the compartment sampling factor
159 needed to be at least 4.

160 Underwater recordings were carried out to check the correct performance of the gear
161 and collect information about fish behavior relative to the stimulators tested. The camera

162 (Camera type: GoPro Hero 3) was attached at different locations in the trawl (Table 2) together
163 with a CREE underwater torch (Brinyte DIV01; CREE XM-L2(U2) LED; max 1000 lm).

164 **Table 2**

165 *2.2. Selectivity model for the gear*

166 In the experimental setup used in this study, fish entering the trawl first encountered the
167 SMP and could escape if they swam up to it and if their body size, shape, and orientation
168 allowed them to pass through the meshes. If any of these requirements were not met, the fish
169 entered the size selective codend, where a further selection process took place. If the fate of
170 each individual fish is assumed to be independent of the others, the number of fish of length l
171 retained in the three compartments, codend (CD), SMP cover (PC), and codend cover (CC)
172 (Fig. 2), can be modelled using a multinomial distribution with length-dependent probability of
173 being retained in the codend $r_{comb}(l)$; escapement through the SMP $e_{SMP}(l)$; and escapement
174 through the codend $e_{codend}(l)$. The combined retention can be modelled as:

$$r_{comb}(l) = 1 - e_{SMP}(l) - e_{codend}(l), \quad (1)$$

175 where l represents fish length. This type of model has been previously used in several studies to
176 investigate combined selection of SMPs and diamond mesh codends (Alzorritz et al., 2016;
177 Brčić et al., 2017; O'Neill et al., 2006; Zuur et al., 2001).

178 The first selection process takes place when a fish encounters the SMP zone, where it
179 can be size-selected if it makes contact with the panel. The contact parameter (C) quantifies the
180 fraction of fish entering the selectivity area that makes contact with the device and, therefore, is
181 subjected to a size-dependent probability of escaping through it. In this case, we assume that the
182 probability for fish to come into contact with the panel can be modelled with the length-
183 independent parameter C_{SMP} . This parameter can take values from 0.0 to 1.0 depending on the
184 fraction of individuals contacting the panel. If C_{SMP} is equal to 1.0, all fish come into contact

185 with the panel, whereas if C_{SMP} is equal to 0.0, none do. This leads to the following model for
 186 $e_{SMP}(l)$:

$$e_{SMP}(l) = C_{SMP} \times (1 - rc_{SMP}(l, \mathbf{v}_{SMP})), \quad (2)$$

187 where $rc_{SMP}(l, \mathbf{v}_{SMP})$ is the selection model for fish making contact with the SMP and having a
 188 suitable orientation to achieve a size-dependent probability of passing through the SMP mesh,
 189 and \mathbf{v}_{SMP} are the parameters of model $rc_{SMP}(l, \mathbf{v}_{SMP})$ and therefore, represented by a vector. A
 190 further assumption is that the probability $rc_{SMP}(l, \mathbf{v}_{SMP})$ can be described by standard S-shaped
 191 size selection models for trawl gears. We considered four S-shaped size selection curves: *Logit*,
 192 *Probit*, *Gompertz*, and *Richard*. Further information about these models, their respective
 193 parameters \mathbf{v} , and estimation of the selectivity parameters $L50$ and SR ($L50$ is the length at
 194 which a fish has a 50% chance of being retained by the gear, whereas SR is the difference
 195 between $L75$ and $L25$) can be found in Wileman et al. (1996).

196 To model the size-dependent codend retention probability $rc_{codend}(l, \mathbf{v}_{codend})$, it was
 197 assumed that every fish entering the codend came into contact with the codend meshes and that
 198 $rc_{codend}(l, \mathbf{v}_{codend})$, like $rc_{SMP}(l, \mathbf{v}_{SMP})$, could be modelled by a *Logit*, *Probit*, *Gompertz*, or *Richard*
 199 model. Estimation of codend escape involves the fish that have not escaped through the SMP.
 200 The above considerations led to the following model for $e_{codend}(l)$:

$$e_{codend}(l) = (1 - rc_{codend}(l, \mathbf{v}_{codend})) \times (1 - e_{SMP}(l, C_{SMP}, \mathbf{v}_{SMP})) \quad (3)$$

201 2.3. Model estimation

202 The values of C_{SMP} , \mathbf{v}_{SMP} , and \mathbf{v}_{codend} for selection models (1)–(3) are species-specific and
 203 depend on the gear configuration. Therefore, the values were obtained separately for each
 204 species and gear configuration using Maximum Likelihood Estimation (MLE) by pooling the
 205 experimental data over the hauls j (1 to m) with the specific gear configuration and minimizing:

$$\begin{aligned}
& - \sum_l \sum_{j=1}^m \left\{ \frac{nCD_{lj}}{qCD_j} \times \ln(r_{comb}(l, C_{SMP}, v_{SMP}, v_{codend})) + \frac{nPC_{lj}}{qPC_j} \times \ln(e_{SMP}(l, C_{SMP}, v_{SMP})) \right. \\
& \quad \left. + \frac{nCC_{lj}}{qCC_j} \times \ln(e_{codend}(l, C_{SMP}, v_{SMP}, v_{codend})) \right\}
\end{aligned} \tag{4}$$

206 where for each haul j and length class l , nCD_{lj} , nPC_{lj} , and nCC_{lj} are the numbers of individuals
207 length-measured in the CD , PC , and CC , respectively; and qCD_j , qPC_j , and qCC_j are their
208 respective subsampling factors (ratio of length-measured to total number of fish in each
209 compartment). In total, 16 models were considered to describe the overall trawl size selectivity
210 based on the combination of the four S-shaped functions considered for $r_{SMP}(l)$ and $r_{codend}(l)$.
211 The 16 models were tested against each other and the one with the lowest AIC value (Akaike's
212 Information Criterion; Akaike, 1974) was selected. MLE using equation (4) with (1) to (3)
213 requires pooling experimental data over hauls. This results in stronger data for average size-
214 selectivity estimation at the expense of not considering explicit variation in selectivity between
215 hauls (Fryer, 1991). To account correctly for the effect of between-haul variation when
216 estimating uncertainty in size selection, a double bootstrap method was used (Herrmann et al.,
217 2012). We estimated the 95% Efron percentile confidence intervals (95% CIs) (Efron, 1982) for
218 the parameters in equations (1)–(3) and for the resulting $e_{SMP}(l)$, $e_{codend}(l)$, and $r_{comb}(l)$ curves. To
219 estimate the 95% CIs, 1000 bootstrap iterations were carried out. All analyses were done using
220 the software tool SELNET (Herrmann et al., 2012).

221 The models were validated based on p-value estimations and model deviance versus
222 degrees of freedom (Wileman et al., 1996). When the p-value was < 0.05 and deviance was
223 much bigger than the degrees of freedom, the residuals were inspected to determine whether the
224 discrepancy between model and experimental data was the result of overdispersion.

225 To infer the effect on the length-dependent SMP escape probability, $e_{SMP}(l)$ and on the
226 combined retention, $r_{comb}(l)$, when changing from the no-stimulation configuration to a specific
227 stimulation configuration, the difference in the estimated value for $p(l)$ was calculated as
228 follows:

$$\Delta p(l) = p_{stim}(l) - p_{base}(l), \quad (5)$$

229 where $p_{base}(l)$ represents the value for $e_{SMP}(l)$ or $r_{comb}(l)$ for the no-stimulation design and
 230 $p_{stim}(l)$ is for the stimulator design. Efron 95% CIs for $\Delta p(l)$ were obtained based on the two
 231 bootstrap populations of results (1000 bootstrap repetitions in each) for both $p_{base}(l)$ and
 232 $p_{stim}(l)$. As they are obtained independently, a new bootstrap population of results was created
 233 for $\Delta p(l)$ by:

$$\Delta p(l)_i = p_{stim}(l)_i - p_{base}(l)_i \quad i \in [1 \dots 1000], \quad (6)$$

234 where i denotes the bootstrap repetition index. As the bootstrap resampling was random and
 235 independent for the two groups of results, it is valid to generate the bootstrap population of
 236 results for the difference based on (6) using the two independently generated bootstrap files
 237 (Herrmann et al., 2018). Based on the bootstrap population, Efron 95% CIs can be obtained for
 238 $\Delta p(l)$ as described above.

239 *2.4. Estimation of exploitation pattern indicators*

240 The effect of the SMP on the exploitation pattern of the gear was quantified by estimating the
 241 values for a number of indicators (described in detail below) using the data collected during the
 242 fishing trials. To quantify to what extent the experimental gear supports a sustainable and
 243 efficient fishery, the average percentage of retained individuals below (rP_-) and above (rP_+)
 244 MCRS were estimated for each species individually based on the population size structure for
 245 the different species entering the gear during the experimental fishing. The Minimum
 246 Conservation Reference Size (MCRS) for hake and horse mackerel are 27 and 15 cm length,
 247 respectively. For blue whiting, which does not have MCRS, we used its estimated marketable
 248 size limit, 18 cm length. This length is based on a regulation that establishes a maximum of 30
 249 individuals of blue whiting per kilo for commercialization (Dorel, 1986; EC, 1996).

250 The formulae used to calculate rP_- and rP_+ values are as follows (Brčić et al., 2017):

$$\begin{aligned}
rP_- &= 100 \times \frac{\sum_j \sum_{l < MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} \right\}}{\sum_j \sum_{l < MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} + \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}}, \\
rP_+ &= 100 \times \frac{\sum_j \sum_{l > MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} \right\}}{\sum_j \sum_{l > MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} + \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}},
\end{aligned} \tag{7}$$

251 where the outer summation in (7) is over hauls j over the hauls with the specific gear
252 configuration and the inner summation is over length classes l .

253 The indicators rP_- and rP_+ quantify the effect of fishing on the population structure of
254 the target species with the specific gear. A small value of rP_- means that the gear retains only a
255 small fraction of individuals below MCRS. High rP_+ values, preferably close to 100, would
256 mean that most individuals over MCRS that enter the gear are retained. To quantify the extent to
257 which the SMP releases the fish that entered the trawl, the averaged percentage of individuals
258 below (esP_-) and above (esP_+) MCRS that escaped through the panel compared to those
259 entering were estimated for the species investigated. The formulae used to calculate esP_- and
260 esP_+ values are as follows:

$$\begin{aligned}
esP_- &= 100 \times \frac{\sum_j \sum_{l < MCRS} \left\{ \frac{nPC_{jl}}{qPC_j} \right\}}{\sum_j \sum_{l < MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} + \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}}, \\
esP_+ &= 100 \times \frac{\sum_j \sum_{l > MCRS} \left\{ \frac{nPC_{jl}}{qPC_j} \right\}}{\sum_j \sum_{l > MCRS} \left\{ \frac{nCD_{jl}}{qCD_j} + \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}}
\end{aligned} \tag{8}$$

261 For the SMP to have a positive effect on the exploitation pattern of the targeted species,
262 esP_- should be significantly above zero and esP_+ close to zero. Furthermore, to quantify the
263 SMP contribution to the overall escapement that occurs during the experimental fishing, an
264 average percentage of individuals below ($resP_-$) and above ($resP_+$) MCRS escaping through the
265 SMP, compared to the overall escapement, were estimated for the investigated species. The
266 formulae used to calculate $resP_-$ and $resP_+$ values are as follows:

$$\begin{aligned}
resP_- &= 100 \times \frac{\sum_j \sum_{l < MCRS} \left\{ \frac{nPC_{jl}}{qPC_j} \right\}}{\sum_j \sum_{l < MCRS} \left\{ \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}} \\
resP_+ &= 100 \times \frac{\sum_j \sum_{l > MCRS} \left\{ \frac{nPC_{jl}}{qPC_j} \right\}}{\sum_j \sum_{l > MCRS} \left\{ \frac{nCC_{jl}}{qCC_j} + \frac{nPC_{jl}}{qPC_j} \right\}}
\end{aligned} \tag{9}$$

267 For the SMP to have any major effect on the exploitation pattern for the fishing gear, at least
268 one of the parameters in (9) should have a value much higher than zero. The 95% confidence
269 bands for rP_- , rP_+ , esP_- , esP_+ , $resP_-$ and $resP_+$ values were estimated using the double bootstrap
270 method described above, taking into account between-haul variation and within-haul variation
271 in the exploitation pattern.

272 3. Results

273 3.1. Overview of the sea trials

274 During the experimental period, 32 hauls were carried out and length measurements for
275 5852 hake, 5720 horse mackerel, and 7524 blue whiting were taken (Table 3). However, based
276 on the acceptance protocol established, the final pool of hauls included in the analysis consisted
277 of 28 hauls for hake, 25 for horse mackerel, and 23 for blue whiting. The number of fish
278 captured and length-measured in each of the configurations and species are provided in Table 3.

279 Table 3

280 3.2. Release efficiency

281 Table 4 summarizes the model combinations resulting in the lowest AIC value for each
282 configuration tested. In some cases, there were alternative models with identical AIC values,
283 meaning that the support for these other models was equally strong. In those cases, the simplest
284 model was chosen. The fit statistics showed that, for hake and horse mackerel, models (2) and
285 (3) were able to describe the experimental data well for most configurations (Table 4; Figures 4,
286 5). In the case with stimulation by floats, the low p-value associated with horse mackerel was
287 attributed to overdispersion of the data because there was no clear pattern in the deviations

288 between the experimental data and the fitted escape probability curve (Figure 5). This
289 overdispersion was probably caused by the heavy subsampling in the data collection process.

290 **Table 4**

291 Among the tested configurations, the SMP release efficiency of hake and horse
292 mackerel in the Bay of Biscay was low (Figures 4, 5), with an estimated escape below 1% in
293 most cases (Table 4). The only exception was the LED light treatment for horse mackerel, in
294 which the release efficiency was close to 4% for the smallest sizes (Figure 5j). This was also
295 manifested in the C_{SMP} values obtained, which were estimated to be 0.01 for hake in every
296 configuration and below 0.03 for horse mackerel in every case, meaning that only a low
297 proportion of these fish made contact with the SMP (1 and 3%, respectively) (Table 4). Figures
298 4 and 5 show that most of the individuals of these species that escaped did so through the
299 codend. Even so, in the case of hake, $L50_{comb}$ was around 17 cm (Table 4), and for individuals of
300 27 cm length (hake's MCRS) the retention probability was above 90% for every configuration.

301 **Figure 4**

302 **Figure 5**

303 **Figure 6**

304 The modelling enabled comparison of gear selectivity with and without stimulation. The
305 results showed that the release efficiency of the panel with stimulation did not significantly
306 differ from no-stimulation situation (Figure 7a, c, e). The release efficiency through the SMP
307 for horse mackerel did not differ significantly among configurations (Figure 8a, c, e). However,
308 the overall retention of this species was significantly lower when using rope stimulation (Figure
309 8b), reaching an estimated effect of 40% less escape for some length classes (between 12 and 20
310 cm in size). Differences in codend size selectivity when using ropes caused these differences in
311 gear retention, as the $L50_{CD}$ for the rope configuration was significantly different from that of
312 the baseline design (Table 4).

313 For blue whiting, the panel contact values were higher than for hake and horse mackerel
314 in all configurations tested (between 20 and 53%), but the wide 95% confidence intervals made
315 the inference for blue whiting uncertain (Table 4; Figure 6). $L50_{comb}$ values were estimated to be
316 over its marketable size (18 cm; this species does not have a MCRS) in all configurations, and
317 because the selection ranges (SR) were quite narrow, individuals below 18 cm had low
318 probability of being retained. The poor p-values for almost all treatments (Table 4) were
319 probably due to overdispersion in the data created by heavy subsampling ratios, as the
320 experimental data and the fitted escape probability curve showed no clear deviation patterns.

321 The results show that the configuration with floats significantly improved the release of
322 blue whiting through the SMP for a range of lengths (10–15 cm) (Figure 9c). However, the
323 improved release of this configuration was not manifested in the combined retention of the gear
324 (Figure 9d). In this case, $L50_{CD}$ values (between 19.3–22.4; Table 4) show that the small fish not
325 released in the first selection process through the panel would escape anyway in the second
326 process through the codend due to its selection properties. In contrast, LED lights over the SMP
327 had a statistically significant negative effect on the release of this species through the panel
328 (between 15 and 27 cm; Figure 9e). Consequently, the combined retention of blue whiting
329 between 21 and 27 cm was significantly higher (Figure 9f).

330 **Figure 7**

331 **Figure 8**

332 **Figure 9**

333 Regarding the exploitation pattern, the values obtained for rP_- and rP_+ show that the
334 exploitation pattern of the selective system, consisting of SMP and codend, was species-
335 dependent (Table 5). For hake, rP_+ was high (above 96.0%) for every configuration, although
336 rP_- was estimated to be relatively high too, meaning that a large fraction of small hake was also
337 retained (around 46% for ropes and floats stimulation treatments and around 41% for LED light
338 stimulation). For blue whiting, rP_- was estimated to be below 1.3% for every configuration. In

339 contrast, for horse mackerel with no-stimulation and LED light treatments rP_- values were
340 estimated to be 27.8% (CI: 12.2–46.6%) and 22.1% (CI:17.4–27.3%), respectively, implying
341 that a larger fraction of undersized individuals of these species entering the gear were retained.
342 For horse mackerel, the rP_+ value was relatively high, as the retention rate was above 69.7% for
343 every configuration, except for rope stimulation (40.5% (CI: 16.9–64.1)). Blue whiting above
344 18 cm had a retention of almost 90% when lights were used, but it was below 66% for the rest
345 of the tested configurations.

346 The results show that the SMP does not affect the exploitation pattern of hake or horse
347 mackerel much, as the values for esP_- and esP_+ for every configuration were low. For
348 undersized hake, the estimated values (esP_-) were below 1%, with the upper confidence limit
349 never exceeding 2%. For undersized horse mackerel, the estimated values never exceeded 3%,
350 and upper confidence limit was always below 7%. $resP_-$ and $resP_+$, which quantify how much
351 the SMP contributes to the total escape, also demonstrated the low effect of the panel. The
352 estimated $resP_-$ values for hake were below 1.5%, and the upper confidence limit never
353 exceeded 3.7%. $resP_-$ and $resP_+$ for horse mackerel also show the low effect of the SMP on the
354 total escape, and especially for sizes below MCRS, the estimated value never exceeded 3.9%
355 with the upper confidence limit always below 8.6%. However, the contribution of the SMP to
356 the overall escapement of legal sizes of horse mackerel was higher, reaching 17.5% (CI: 6.4–
357 29.2%) when LED light-based stimulation was used. In contrast to hake and horse mackerel, a
358 higher proportion of small blue whiting escaped through the SMP, with esP_- estimated to be
359 between 19.9 and 52.6% depending on configuration.

360 **Table 5**

361 *3.3. Underwater observations*

362 Underwater video recordings showed that the SMP and codend meshes remained open
363 during the recorded trials (Table 2) and that the covers did not mask the meshes. Further, they
364 showed that the stimulation devices were physically functioning as intended. With respect to

365 fish behavior in relation to the SMP, none of the configurations seemed to affect fish behavior
366 differently from the no-stimulation treatment. Hake individuals usually swam next to the
367 bottom, passively drifted backwards towards the codend, and did not show any reaction to the
368 SMP. Horse mackerel and blue whiting exhibited more active behavior, mostly swimming in the
369 towing direction along the extension piece (close to the SMP area) until they became exhausted
370 and drifted towards the codend. In addition, blue whiting showed more active and erratic
371 behavior in front of the SMP; many of these individuals turned and swam quickly either towards
372 the panel or the codend. This behavior resulted in greater physical contact with the SMP,
373 although most of the time they were not properly oriented and therefore most of them did not
374 manage to escape through it.

375 **4. Discussion**

376 The LO represents a big challenge for multi-species trawl fisheries (De Vos et al., 2016)
377 such as the Basque bottom otter trawl fishery. It has been shown that undersized fish release
378 efficiency through the 70 mm diamond mesh codend and the SMP is low (Rochet et al., 2014)
379 due to low contact with the panel (Alzorriz et al., 2016). In the present study, we aimed to
380 increase contact of fish. We attempted to stimulate escape behavior of hake, horse mackerel,
381 and blue whiting through a panel made of 82.7 mm square meshes.

382 In general, the results obtained in this study showed that the stimulators, based on ropes,
383 floats, or LED lights, barely increased the contact probability of the species tested with the
384 SMP. For hake, escape probability was low for all stimulators tested, and it was not significantly
385 different compared to the treatment without stimulation. Herrmann et al. (2014) and Krag et al.
386 (2016a) reported that to improve fish escapement in non-tapered netting sections, additional
387 stimuli are needed because in the absence of these stimuli, most fish drift towards the codend
388 without seeking escape through the selection device. However, in the present study, despite the
389 implementation of different stimuli, hake had very low probability of encountering the SMP.
390 This, together with the SMP's release efficiency curves, underscores the low effectiveness of the

391 SMP in releasing undersized individuals of this species when inserted in the upper panel of the
392 extension piece and regardless of the presence of the stimuli. In addition, underwater
393 observations made during the cruise demonstrated that hake did not display any active escape
394 behavior; instead they fell back through the extension piece until reaching the aft end of the
395 gear. This behavior and the observed preference for swimming close to the lower panel, also
396 observed in other species (e.g. cod (*Gadus morhua*)) (Sistiaga et al., 2011, 2017), makes it
397 difficult to improve the efficiency of the SMP (Alzorritz et al., 2016; Nikolic et al., 2015).
398 Previous research (Grimaldo et al., 2017) also documented the low effectiveness of similar
399 stimulators on the release efficiency of cod through a square mesh section.

400 Horse mackerel showed a contact probability of between 0 and 3% for the different
401 configurations tested. Thus, the estimated release efficiency of the SMP for this species was low
402 and not significantly different from the no-stimulation treatment. Earlier studies (Herrmann et
403 al., 2014; Krag et al., 2016b) showed that escape stimulation by similar floats through a SMP,
404 placed on the upper part of the codend and the extension piece, respectively, significantly
405 improved the escapement of cod. Grimaldo et al. (2017) also indicated that the use of
406 mechanical stimulation based on floats could improve the release efficiency of 40 cm haddock
407 (*Melanogrammus aeglefinus*) through a square mesh section by 50% (although these results
408 were not statistically significant). In this study, we observed that fish tried to avoid contact with
409 the stimulators based on ropes and floats by swimming in front of them until reaching
410 exhaustion and then drifting towards the codend.

411 Blue whiting, compared to hake and horse mackerel, showed higher contact probability
412 with the panel, which was between 20 and 26% for no-stimulation, stimulation by ropes, and
413 LED light-based stimulation treatments. In general, and supported by underwater observations,
414 their active swimming behaviour seemed to increase the contact probability with the SMP. In
415 particular, when stimulation by floats was used to trigger fish escape, blue whiting showed
416 higher contact probability (53%), and the estimated release efficiency of the SMP for
417 individuals below 18 cm was between 47.6 and 53.1%. Compared to the treatment without

418 stimulation, the estimated release efficiency for blue whiting between 10 and 15 cm was
419 significantly improved, by almost 30%. However, this effect had no impact on codend size
420 selectivity because codend selection properties would release any small individual retained in
421 the first selection process by the panel. Therefore, any change in panel selectivity for small blue
422 whiting would not be evident in the combined retention probability. Additionally, the
423 assessment of the release efficiency with float stimulation was based on few hauls (3 hauls). The
424 hauls not included were heavily subsampled, which would have highly affected the results. This
425 resulted in a weaker experimental base for these results, which is reflected in the wider
426 confidence bands for the size selection curves obtained. Therefore, following the protocol
427 established, the analyses were carried out with a considerably lower number of hauls. Even if
428 limiting the number of hauls in the analysis meant using fewer hauls than often applied for such
429 assessment, we considered this as the most correct approach. The number of hauls with these
430 configurations was lower than we would normally recommend for making definitive
431 conclusions. Therefore, our results for these designs should be considered as preliminary, but
432 still relevant.

433 Our results also suggest that blue LED light stimulation decreased the escape probability
434 through the SMP of blue whiting individuals between 15 and 27 cm. In general, blue LED light
435 affected the escape probability of blue whiting negatively, although these results were only
436 significant for a specific length range. This effect was reflected in the combined retention of the
437 trawl, which was significantly higher for some length classes. Quality of the underwater images
438 for the light treatment was not sufficient to analyze fish behaviour, but active behavior of this
439 species was observed in the other three treatments when light was used to obtain underwater
440 images (Table 2). The behavior of blue whiting could be compared with what Grimaldo et al.
441 (2017) described for haddock when they got close to the green light stimulators placed on the
442 extension piece of the trawl. These haddocks exhibited erratic behaviour when approaching the
443 LED lights, which led them to hit the netting in a way that did not allow them to make contact
444 with the SMP. This could explain the low release efficiency of blue whiting when LED lights

445 were used compared to no-stimulation treatment. Many studies have demonstrated that visual
446 stimulation may affect fish behaviour and the selective properties of trawl gear (Hannah et al.,
447 2015; Larsen et al., 2018; Lomeli and Wakefield, 2014; Ryer and Olla, 2000; Walsh and
448 Hickey, 1993). The processes through which light affects marine fish are still not completely
449 understood because being attracted or repulsed by light depends on many factors, including
450 species, ontogenetic development, ecological factors, light intensity, and light wavelength
451 (Marchesan et al., 2005). In this study, lights were used during many hauls to illuminate the
452 recordings (Table 2), which could have affected fish behaviour. However, lights were needed to
453 check for adequate performance of the trawl and the research trials were time limited, thus we
454 could not repeat these hauls to include non-illuminated hauls in the data analysis.

455 For all species and treatments, most of the escape was observed in the codend, and the
456 contribution of the SMP was low. These results are in agreement with the observations of Brčić
457 et al. (2016, 2018), who concluded that a SMP inserted in front of the codend had little effect on
458 the escapement of hake, horse mackerel, and other species in a Mediterranean bottom trawl
459 fishery. Alzorritz et al. (2016) also reported 47% escape of undersized hake through the codend,
460 and less than 1% through the SMP. Our findings revealed no improvement in size selection for
461 hake by inserting a SMP together with any of the stimulators and that individuals below their
462 MCERS still had a high probability of being retained by the gear.

463 Previous studies on Portuguese crustacean trawl fishery (Campos and Fonseca, 2004)
464 showed that a window made of 100 mm square meshes positioned in the upper panel of the
465 belly section, 3.3 m before the codend, was efficient at excluding blue whiting but not horse
466 mackerel. Graham et al. (2003) found that moving the panel closer to the codline increased the
467 *L50* for haddock. Herrmann et al. (2014) found that the release efficiency of the SMP in the
468 BACOMA codend largely depended on how close the panel was to the catch-accumulation zone
469 (0–6 m from the codline). Compared to these studies, the panel distance from the codline in our
470 study (10 m) may have been one of the reasons for the poor efficiency of the panel, as fish in the
471 extension piece had no chance to change direction and swim up through the panel meshes even

472 if stimulated. Other researchers also have mentioned that fish are exhausted when they reach the
473 SMP area, so they are unable to attempt active escape (Winger et al., 2010) or may be reluctant
474 to change swimming direction to save energy (Peake and Farrell, 2006). Besides, the towing
475 speed during the hauls in our study was around 3 knots, whereas in real conditions a commercial
476 trawl would tow at 4 knots, which could lead to greater exhaustion when the catch arrives in the
477 extension piece.

478 Alzorritz et al. (2016) demonstrated that under commercial fishing operations, the
479 selective properties of the trawls deployed by the Basque bottom otter trawl fleet in the Bay of
480 Biscay did not satisfactorily release undersized individuals due to low contact. In the present
481 study, we showed that the stimulators used to increase contact probability with the SMP were
482 mostly ineffective, and the retention of undersized fish was still high. Hake did not react
483 significantly to any of the stimulation treatments, whereas a significantly higher proportion of
484 horse mackerel and blue whiting escaped through the SMP. These results indicate a clear
485 behavioral difference compared to hake. Although this study provided greater understanding of
486 fish behaviour inside the trawl, the contribution of the SMP to overall escape was
487 unsatisfactory. Considering the new CFP, unwanted catches still represent a major challenge for
488 this fishery. In order to comply with the LO, this may have a direct influence on each vessel's
489 ability to optimize its economic revenue. Therefore, future studies should focus on maximizing
490 SMP contact probability or improving codend release efficiency. Alternatively, future studies
491 could also consider investigating the applicability of other bycatch reduction devices like
492 sorting grids in this fishery.

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1 **TABLES**2 **Table 1.** Specifications of the gear used during the cruise.

	Codend (CD)	Codend cover (CC)	SMP	SMP cover (PC)	Extension piece
Twine material	Doubled braided Polisteel	Single braided PA	Single braided PA	Single braided PA	Single braided PE
Thickness (mm)	4	1.3	3	1.3	3
Mesh size* (mm)	72.8	26.5	82.7	26.1	75.3
Length (m)	7	9	2.2	13	5
Width (m)	-	-	1.2	-	-

3 *Measured with an OMEGA gauge (Fonteyne et al., 2007) according to EC, 2008.

4

5

6 **Table 2.-** Camera specifications corresponding to each haul and configuration tested. Light color corresponds to the
7 light attached to the camera.

Haul n°	Stimulator	Position of the cameras (light color: red (R) or white (W) or none (N))
8	None	Lower panel, joint between codend and extension piece (W)
13	Ropes	Lower panel, behind the SMP (W).
14	Ropes	Lower panel, behind the SMP (W).
15	Ropes	Lower panel, behind the SMP (W).
16	Ropes	Lower panel, behind the SMP (W) and Upper panel, before the SMP (R).
18	Ropes	Lower panel, behind the SMP (W).
23	LED lights	Upper panel, before the SMP (N).
25	LED lights	Over the codend, in between the codend cover and the codend (W).
26	LED lights	Over the codend, in between the codend cover and the codend (W) and Upper panel, before the SMP (W).
28	Floats	Lower panel, behind the SMP (W).
31	Floats	Upper panel, before the SMP (W).
32	Floats	Over the codend cover (W) and Lower panel, behind the SMP (W).
34	Floats	In the codend (W) and on the float line, behind the floats (W).
35	Floats	On the float line, behind the floats (W).
36	None	Over the codend, in between the codend cover and the codend (W) and over the codend cover (W).
37	None	On the float line, behind the floats (W).

8

9

10 **Table 3.** Summary of hauls used, no. of individuals retained in the codend (*CD*), codend cover (*CC*), and SMP cover
 11 (*PC*), no. of individuals < MCRS, and length range of all individuals caught. The number of fish measured is given in
 12 brackets. ¹MCRS for hake: 27 cm; ²MCRS for horse mackerel: 15 cm; ³blue whiting does not have a MCRS but it has
 13 a minimum marketable size of 30 individuals/Kg (EC, 1996). This is equivalent to 18 cm in length according to the
 14 weight-length ratio for this species (Dorel, 1986).

Stimulation/design	No-stimulation	Ropes	Floats	LED lights
Hake				
No. of hauls used	8	6	6	8
Length range (cm)	7-58	7-56	8-58	7-60
Total no. in <i>CD</i>	1015 (1015)	543 (543)	832 (832)	1045 (1045)
No. in <i>CD</i> < MCRS ¹	621 (621)	325 (325)	412 (412)	497 (497)
Total no. in <i>CC</i>	986 (986)	375 (267)	473 (473)	697 (647)
No. in <i>CC</i> < MCRS ¹	983 (983)	367 (263)	465 (465)	695 (645)
Total no. in <i>PC</i>	16 (16)	6 (6)	11 (11)	11 (11)
No. in <i>PC</i> < MCRS ¹	10 (10)	4 (4)	7 (7)	7 (7)
Horse mackerel				
No. of hauls used	7	5	6	7
Length range (cm)	10-35	10-36	10-35	10-39
Total no. in <i>CD</i>	1222 (926)	2378 (465)	1344 (876)	1745 (768)
No. in <i>CD</i> < MCRS ²	292 (235)	300 (65)	419 (245)	502 (257)
Total no. in <i>CC</i>	839 (644)	6500 (476)	3839 (838)	1886 (496)
No. in <i>CC</i> < MCRS ²	733 (564)	3491 (249)	3442 (739)	1705 (440)
Total no. in <i>PC</i>	37 (37)	69 (69)	19 (19)	106 (106)
No. in <i>PC</i> < MCRS ²	23 (23)	23 (23)	13 (13)	68 (68)
Blue whiting				
No. of hauls used	8	6	3	6
Length range (cm)	7-31	8-31	10-32	10-31
Total no. in <i>CD</i>	1619 (936)	1037 (556)	333 (333)	1209 (513)
No. in <i>CD</i> < MCRS ³	47 (40)	21 (11)	17 (17)	67 (39)
Total no. in <i>CC</i>	5512 (1033)	2894 (544)	2132 (533)	4290 (471)
No. in <i>CC</i> < MCRS ³	5184 (914)	2570 (459)	2016 (504)	4213 (461)
Total no. in <i>PC</i>	2387 (1015)	1227 (609)	2438 (598)	1121 (383)
No. in <i>PC</i> < MCRS ³	1914 (606)	926 (395)	2258 (550)	1060 (358)

15

16

17 **Table 4.** Selected models based on the lowest AIC values, selectivity results and fit statistics are shown for the
 18 different species, configuration, and compartment (square mesh panel (*SMP*); codend (*CD*) and combined effect of
 19 the codend and the *SMP* (Comb)). 95% CIs (in brackets).

		Hake			
Stimulation/Design		No-stimulation	Ropes	Floats	LED lights
Models	<i>SMP</i> <i>CD</i>	<i>CLogit</i> <i>Richard</i>	<i>CLogit</i> <i>Gompertz</i>	<i>CLogit</i> <i>Gompertz</i>	<i>CLogit</i> <i>Logit</i>
<i>L50</i> (cm)					
<i>SMP</i>		37.07 (21.22–37.10)	30.03 (0.10–30.07)	36.06 (0.10–36.08)	29.99 (24.05–30.04)
<i>CD</i>		16.95 (16.02–17.92)	17.32 (15.43–19.53)	17.37 (16.18–18.28)	17.35 (16.20–18.40)
Comb		16.98 (16.05–17.95)	17.36 (15.45–19.59)	17.42 (16.21–18.32)	17.37 (16.23–18.44)
<i>SR</i> (cm)					
<i>SMP</i>		0.10 (0.10–7.42)	0.10 (0.10–19.16)	0.10 (0.10–0.10)	0.10 (0.10–0.10)
<i>CD</i>		4.37 (3.45–5.11)	5.88 (3.58–8.02)	5.51 (4.33–7.00)	3.71 (2.90–4.34)
Comb		4.41 (3.48–5.17)	5.96 (3.60–8.11)	5.59 (4.43–7.03)	3.74 (2.92–4.38)
<i>C_{SMP}</i>		0.01 (0.00–0.02)	0.01 (0.00–0.03)	0.01 (0.00–0.02)	0.01 (0.00–0.02)
Deviance		59.29	82.57	53.72	44.51
DOF		82	77	77	89
p-Value		0.972	0.311	0.980	1.000
		Horse mackerel			
Stimulation/Design		No-stimulation	Ropes	Floats	LED lights
Models	<i>SMP</i> <i>CD</i>	<i>CLogit</i> <i>Gompertz</i>	<i>CLogit</i> <i>Gompertz</i>	<i>CPogit</i> <i>Gompertz</i>	<i>CProbit</i> <i>Logit</i>
<i>L50</i> (cm)					
<i>SMP</i>		28.00 (0.10–56.70)	23.04 (17.58–61.92)	24.05 (15.03–62.02)	30.01 (0.10–30.02)
<i>CD</i>		14.11 (13.23–14.69)	16.96 (15.61–20.13)	15.48 (14.24–16.49)	14.77 (14.48–15.09)
Comb		14.16 (13.34–14.74)	16.99 (15.65–20.13)	15.49 (14.25–16.49)	14.84 (14.54–15.18)
<i>SR</i> (cm)					
<i>SMP</i>		0.10 (0.10–53.69)	0.10 (0.10–6.34)	0.10 (0.10–6.67)	0.10 (0.10–43.11)
<i>CD</i>		2.71 (2.26–3.38)	3.94 (2.67–6.22)	3.03 (2.47–4.06)	2.61 (2.16–3.24)
Comb		2.80 (2.30–3.48)	3.99 (2.72–6.18)	3.05 (2.50–4.10)	2.70 (2.23–3.36)
<i>C_{SMP}</i>		0.02 (0.01–0.66)	0.01 (0.00–0.02)	0.00 (0.00–0.01)	0.03 (0.01–0.32)
Deviance		45.57	36.45	67.61	53.82
DOF		47	35	45	49
p-Value		0.532	0.401	0.016	0.295
		Blue whiting			
Stimulation/Design		No-stimulation	Ropes	Floats	LED lights
Models	<i>SMP</i> <i>CD</i>	<i>CGompertz</i> <i>Richard</i>	<i>CGompertz</i> <i>Logit</i>	<i>CGompertz</i> <i>Richard</i>	<i>CGompertz</i> <i>Logit</i>
<i>L50</i> (cm)					
<i>SMP</i>		27.62 (23.14–34.76)	30.59 (0.10–38.43)	25.75 (11.77–94.93)	20.57 (0.10–25.14)
<i>CD</i>		20.76 (19.06–21.59)	21.36 (20.36–22.20)	22.42 (21.44–22.99)	19.31 (16.77–20.76)
Comb		21.70 (20.47–22.25)	22.33 (21.12–23.63)	23.73 (21.81–25.45)	19.74 (17.09–21.20)
<i>SR</i> (cm)					
<i>SMP</i>		8.99 (0.10–15.73)	15.48 (0.10–66.87)	10.93 (0.10–60.27)	6.12 (1.80–14.75)
<i>CD</i>		3.44 (2.67–4.41)	3.94 (2.87–4.59)	3.16 (1.87–4.35)	3.71 (2.88–4.25)
Comb		4.81 (3.26–10.56)	5.55 (3.65–7.58)	5.05 (2.56–69.53)	3.98 (3.06–4.61)
<i>C_{SMP}</i>		0.27 (0.21–0.38)	0.26 (0.10–0.86)	0.53 (0.46–1.00)	0.20 (0.13–0.90)
Deviance		105.10	105.10	51.84	79.07
DOF		40	40	34	31
p-Value		<0.001	<0.001	0.026	<0.001

20

21

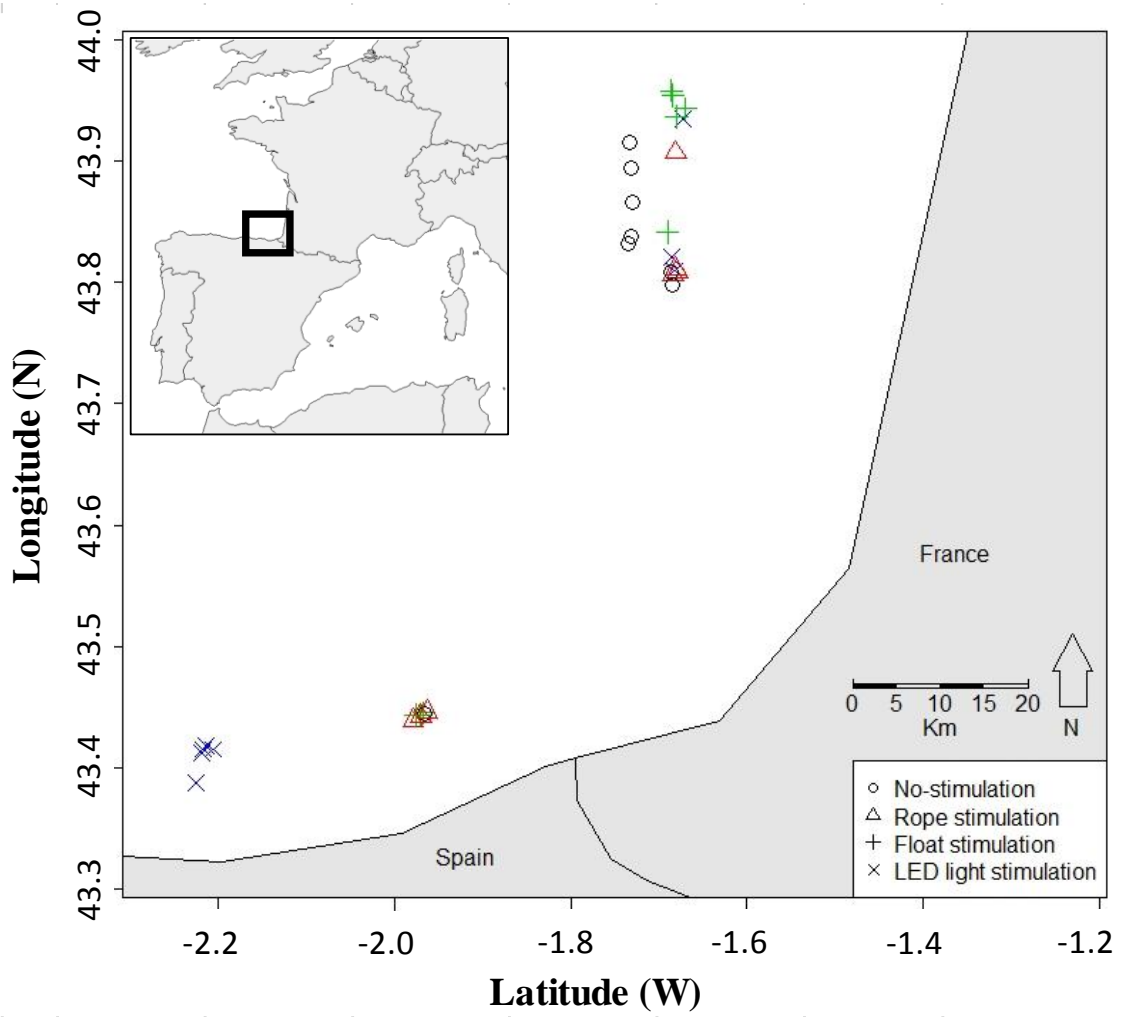
22

23 **Table 5.** Values of exploitation pattern indicators and their 95% CIs (in brackets) for all species in the different panel
 24 configurations. ¹MCRS for hake: 27 cm; ² MCRS for horse mackerel: 15 cm; ³blue whiting does not have a MCRS
 25 but it has a minimum marketable size of 30 individuals/Kg (EC, 1996), and this is equivalent to 18 cm in length
 26 according to the weight:length ratio for this species (Dorel, 1986).

Hake¹				
Stimulation/Design	No-stimulation	Ropes	Floats	LED lights
<i>rP-</i>	38.48 (34.76–41.81)	46.63 (32.94–61.78)	46.61 (36.40–55.16)	41.45 (30.31–54.30)
<i>rP+</i>	97.77 (95.61–99.45)	96.04 (87.14–100)	97.22 (94.07–98.82)	98.92 (97.33–100.00)
<i>esP-</i>	0.62 (0.22–1.15)	0.57 (0.00–1.41)	0.79 (0.00–1.93)	0.58 (0.09–1.13)
<i>esP+</i>	1.49 (0.25–3.19)	0.88 (0.00–3.14)	0.93 (0.00–1.86)	0.72 (0.00–2.44)
<i>resP-</i>	1.01 (0.36–1.86)	1.08 (0.00–3.18)	1.48 (0.00–3.61)	1.00 (0.16–1.93)
<i>resP+</i>	66.67 (12.50–100)	22.22 (0.00–100)	33.33 (0.00–88.89)	66.67 (0.00–100.00)
Horse mackerel²				
Stimulation/Design	No-stimulation	Ropes	Floats	LED lights
<i>rP-</i>	27.77 (12.17–46.57)	7.87 (2.18–16.34)	10.81 (4.23–34.91)	22.12 (17.35–27.33)
<i>rP+</i>	88.57 (84.04–94.69)	40.48 (16.92–64.09)	69.65 (53.35–85.19)	85.13 (74.30–90.87)
<i>esP-</i>	2.19 (0.56–4.64)	0.60 (0.21–1.51)	0.34 (0.03–0.82)	2.99 (1.14–6.82)
<i>esP+</i>	1.33 (0.43–2.25)	0.90 (0.43–1.75)	0.45 (0.06–1.13)	2.60 (1.21–4.31)
<i>resP-</i>	3.04 (0.86–7.50)	0.65 (0.23–1.66)	0.38 (0.03–0.93)	3.83 (1.46–8.56)
<i>resP+</i>	11.67 (5.31–20.75)	1.51 (0.76–4.57)	1.49 (0.17–5.88)	17.51 (6.38–29.17)
Blue whiting³				
Stimulation/Design	No-stimulation	Ropes	Floats	LED lights
<i>rP-</i>	0.66 (0.26–1.57)	0.60 (0.06–1.19)	0.40 (0.00–1.09)	1.25 (0.37–4.21)
<i>rP+</i>	66.29 (61.03–72.01)	61.95 (54.12–71.75)	51.63 (36.17–84.38)	89.36 (80.32–98.35)
<i>esP-</i>	26.78 (20.98–37.25)	26.34 (4.87–38.81)	52.62 (45.41–63.87)	19.87 (9.93–29.94)
<i>esP+</i>	19.96 (13.42–30.30)	18.35 (11.14–25.85)	29.41 (0.00–42.75)	4.69 (0.69–8.95)
<i>resP-</i>	26.96 (21.06–37.57)	26.49 (4.92–38.87)	52.83 (45.44–64.56)	20.12 (10.26–30.54)
<i>resP+</i>	59.20 (40.77–84.42)	48.24 (34.79–69.38)	60.81 (0.00–71.54)	44.12 (17.33–84.38)

27

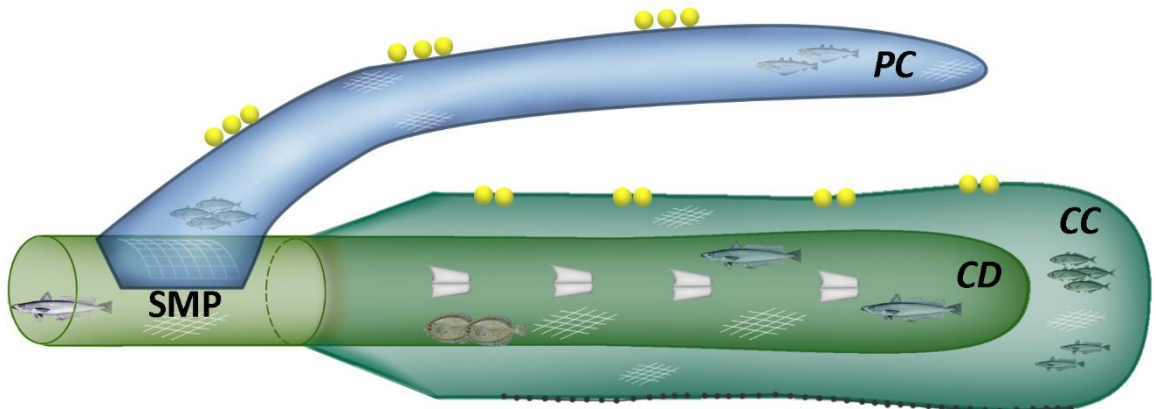
1 FIGURES



2

3 Figure 1. Sampling area and fishing position for all hauls conducted during the cruise.

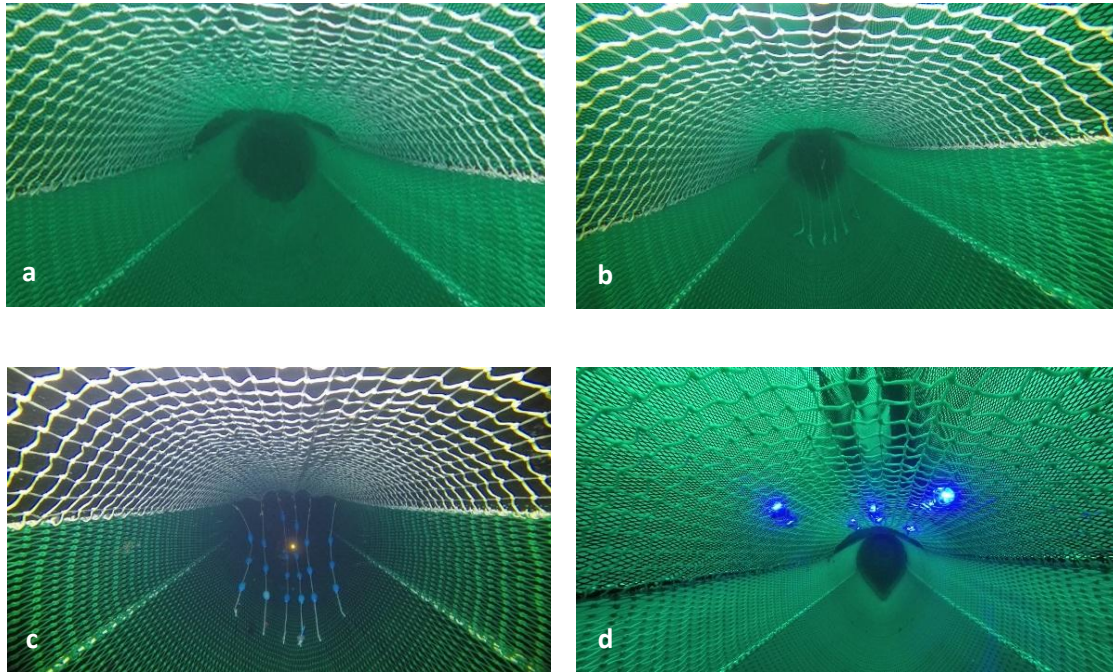
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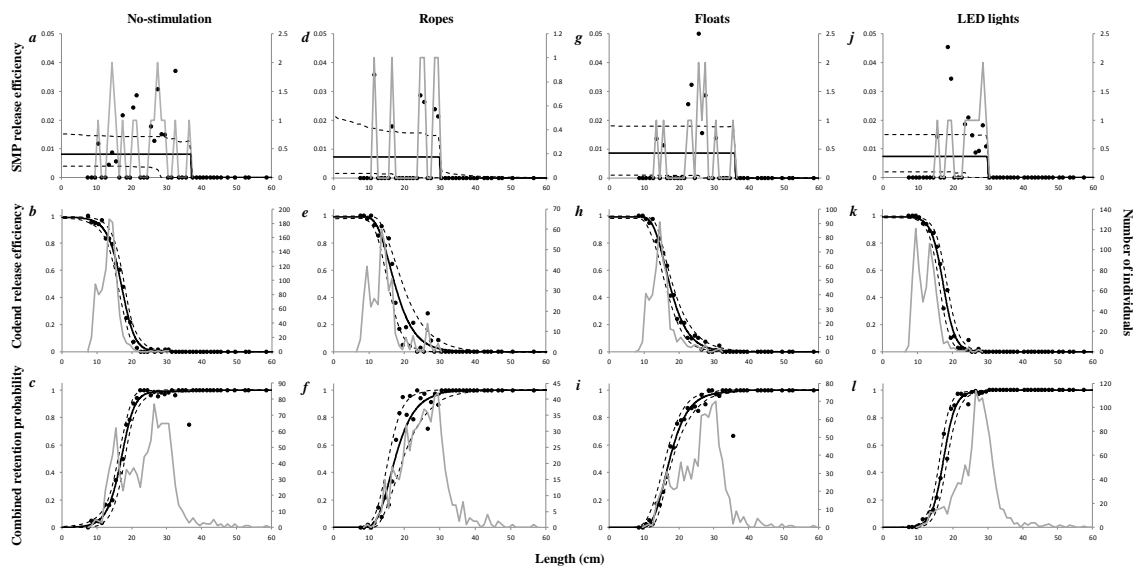
5

6 **Figure 2.** Scheme of the module built with the square mesh panel (SMP), codend (CD), and the different net covers
 7 (SMP cover (PC) and codend cover (CC)) used to collect the escapement.

8



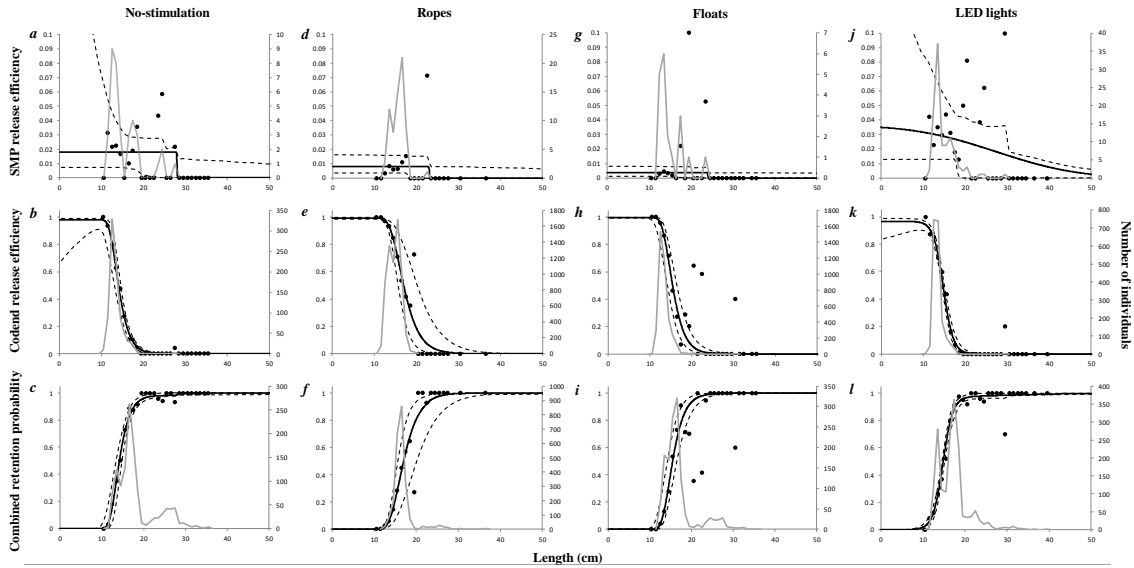
9 **Figure 3.** Different configurations tested on the SMP: (a) no-stimulation; (b) stimulation by ropes; (c) stimulation by
 10 floats; (d) LED light-based stimulation.



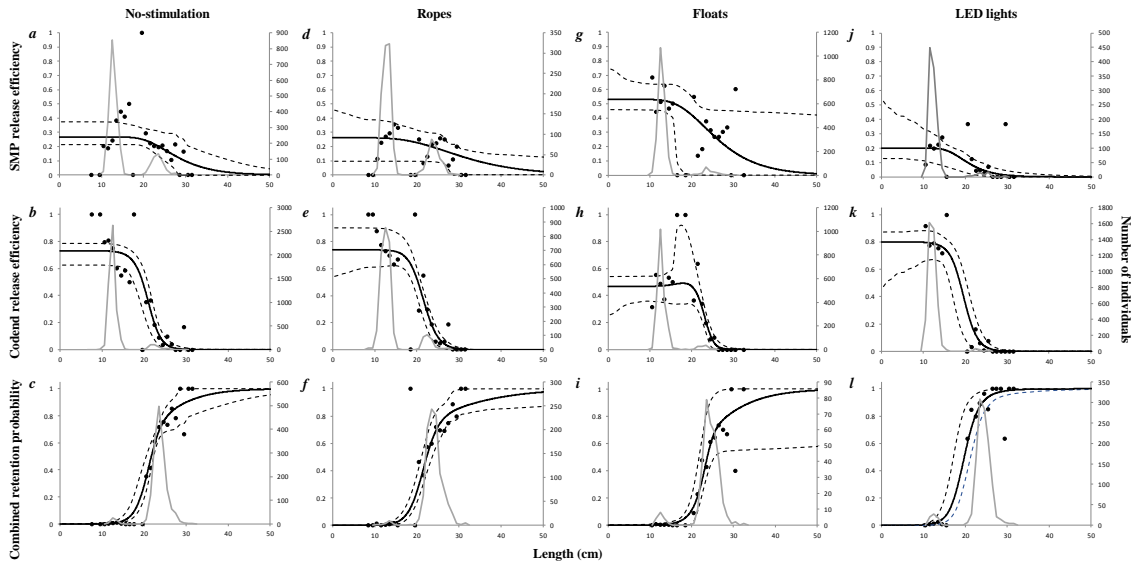
11

12 **Figure 4.** Relative catch size-frequency distributions (grey lines) of hake retained in the codend (CD), codend cover
 13 (CC), and SMP cover (PC), the mean escapement curves (solid black lines) for SMP escapement (a, d, g, j), codend
 14 escapement (b, e, h, k), and combined retention (combined effect of the codend and the SMP) (c, f, i, l). All of them

15 show 95% CIs (dashed lines). *Note that the y-axis for SMP release efficiency has a different order of magnitude in
 16 order to properly observe the data.



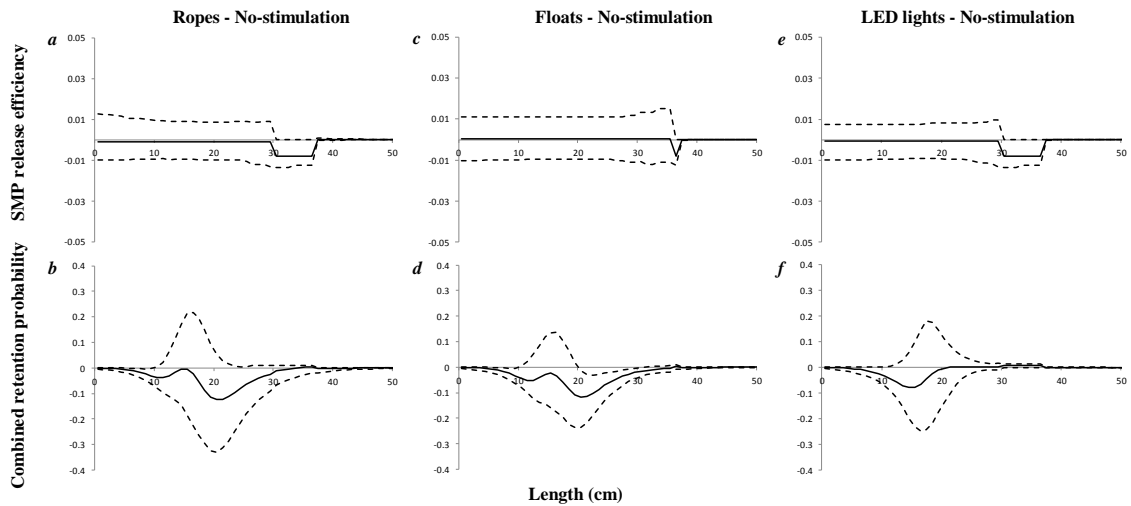
17
 18 **Figure 5.** Relative catch size-frequency distributions (grey lines) of horse mackerel retained in the codend (CD),
 19 codend cover (CC), and SMP cover (PC), the mean escapement curves (solid black lines) for SMP escapement (a, d,
 20 g, j), codend escapement (b, e, h, k), and combined retention (combined effect of the codend and the SMP) (c, f, i, l).
 21 All of them show 95% CIs (dashed lines). *Note that the y-axis for SMP release efficiency has a different order of
 22 magnitude to properly observe the data.



23
 24 **Figure 6.** Relative catch size-frequency distributions (grey lines) of blue whiting retained in the codend (CD), codend
 25 cover (CC), and SMP cover (PC), the mean escapement curves (solid black lines) for SMP escapement (a, d, g, j),

26 codend escapement (*b, e, h, k*), and combined retention (combined effect of the codend and the SMP) (*c, f, i, l*). All of
27 them show 95% CIs (dashed lines).

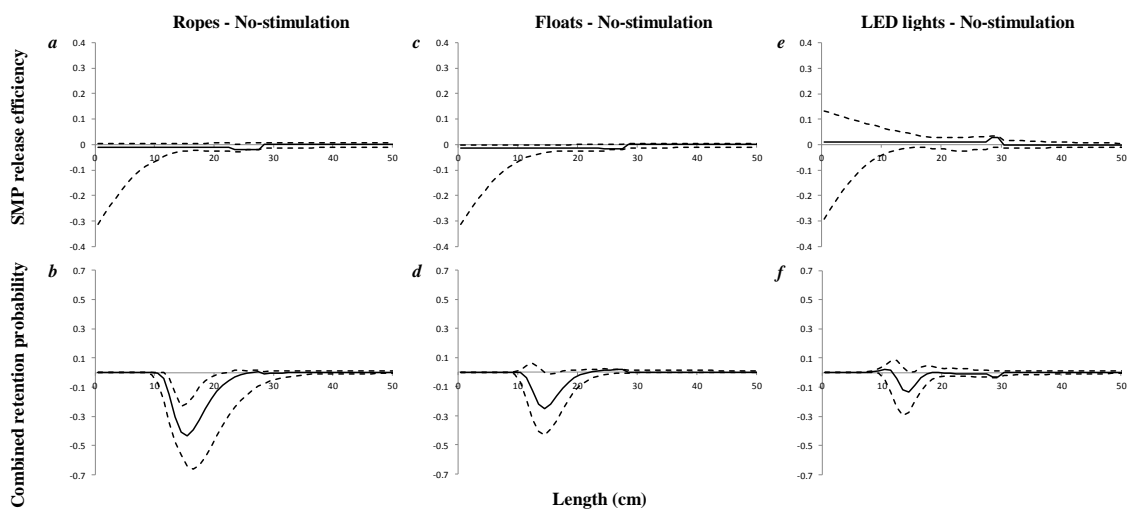
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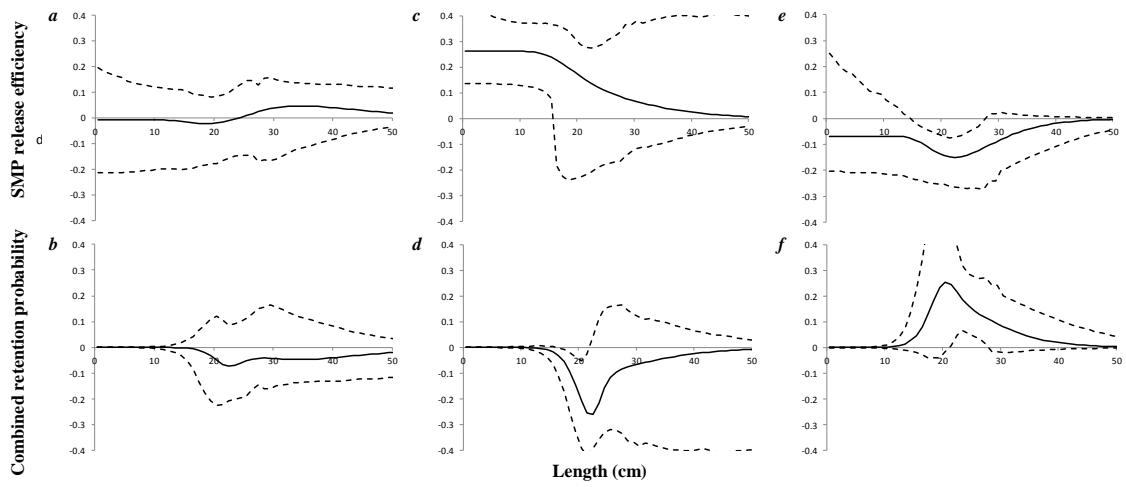
30 **Figure 7.** Change in SMP release efficiency (*a, c, e*) and in combined retention (*b, d, f*) for hake. Dashed lines
31 represent 95% CIs. * Note that the y-axis for SMP release efficiency has a different order of magnitude to properly
32 observe the data.

33



34

35 **Figure 8.** Change in SMP release efficiency (*a, c, e*) and in combined retention (*b, d, f*) for horse mackerel. Dashed
36 lines represent 95% CIs. * Note that the y-axis for SMP release efficiency has a different order of magnitude to
37 properly observe the data.



39

40 **Figure 9.** Change in SMP release efficiency (*a, c, e*) and in combined retention (*b, d, f*) for blue whiting. Dashed lines
 41 represent 95% CIs. * Note that the y-axis for SMP release efficiency has a different order of magnitude to properly
 42 observe the data.