

1 Comparing size selectivity of traditional and knotless diamond-mesh codends in the Iceland redfish
2 (*Sebastes spp.*) fishery

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16 **Abstract**

17 The size selectivity and usability of two diamond mesh codends, a traditional two-panel
18 codend versus an experimental four-panel ultra-cross knotless mesh codend, were compared
19 using the covered codend method in the Iceland redfish (*Sebastes norvegicus* and *S.*
20 *viviparous*) fishery. Results showed that there was no significant difference in size selectivity
21 between the codends at lengths greater than 29 cm for *S. norvegicus* and 19 cm for *S.*
22 *viviparous*. At smaller lengths, size selectivity was undetermined due to small catches at those
23 sizes. For *S. norvegicus*, both codends demonstrated a high retention ratio (93.4 and 92.9%,
24 respectively) above the minimum reference length (MRL; 33 cm), but also had a high
25 retention below MRL (90.9 and 83.4%, respectively). However, the actual proportion of catch
26 below MRL was low due to few small fish on fishing grounds. Since these fish are difficult to
27 tell apart and have similar morphologies, we investigated the size selectivity of the two
28 codends for both species combined, resulting in similar results of no difference in size
29 selectivity, but a large increase in actual catches below MRL, which were primarily *S.*
30 *viviparous*. This study concludes that the experimental codend does not improve the size
31 selectivity or usability in the Iceland redfish fishery and both codends will retain large
32 proportions of undersized fish if present on fishing grounds; however, few undersized fish
33 were present in the study area.

34

35 *Keywords*

36 Codend selectivity, codend usability, redfish, *Sebastes norvegicus*, *Sebastes viviparous*,
37 Iceland

38 **1. Introduction**

39 One of the key industries in Iceland is fishing (Sigfusson et al., 2013), and the redfish
40 (*Sebastes spp.*) trawl fishery is one of its largest fisheries in terms of capture volume and
41 value (FAO, 2010). Three redfish species are present in Icelandic waters: golden redfish
42 (*Sebastes norvegicus*), Norway redfish (*S. viviparous*) and beaked redfish (*S. mentella*).
43 Currently, golden and beaked redfish are targeted commercial species, while Norway redfish
44 is unwanted due to its small size (MFRI, 2018a). Each species grows slowly and matures late
45 and are difficult to differentiate due to similarities in meristic and morphological
46 characteristics (Pampoulie and Daníelsdóttir, 2008; Christensen et al., 2018).
47 The Icelandic redfish fishery requires a minimum diamond-shaped codend mesh size of 135
48 mm (Ciccía Romito et al., 2015), and discarding is prohibited (ICNAF, 1975). Additional
49 regulations for golden redfish include a minimum reference length (MRL) of 33 cm, where if
50 more than 20% of the catch (in number) is below the MRL, a closure will incur on fishing
51 grounds (MFRI, 2018b). The unwanted capture of small redfish can be problematic for fishers.
52 Due to the discard prohibition, fishers are unable to discard small fish, and their capture can
53 lead to a stoppage in fishing. Additionally, from a sustainable fishing perspective, the capture
54 of large numbers of small redfish can be damaging to their population abundance due to the
55 slow growing and late maturing nature of the species group. Additionally, when the relatively
56 smaller Norway redfish (rarely > 30 cm; MFRI, 2018c) is mixed with the larger, targeted
57 species, it can lead to further unwanted catch. Improvements in the size selectivity of
58 Icelandic trawls is necessary to prevent the capture of small redfish.
59 Redfish size selectivity has been previously investigated, and several modifications have been
60 attempted to improve the size selectivity of redfish trawls. Icelandic and Greenland redfish
61 fisheries have had mesh selectivity studies dating as far back as the 1960s and 1970s (Bohl,
62 1961; Thorsteinsson et al., 1980). More recently, Lisovsky (2001) and Lisovsky et al. (2005)

63 found that mesh size can affect redfish size selectivity. Other codend size selectivity studies
64 investigated the effects of lastridge ropes (Hickey et al., 1995), and the size selectivity of
65 three different diamond-shaped mesh sizes in the Gulf of Maine redfish fishery (Pol et al.,
66 2016).
67 Compared with conventional diamond-mesh codends, knotless codends may have better size
68 selectivity for roundfish. The shape and opening of the traditional knotted codend may be
69 affected by the knot, making it more difficult for juvenile or undersized fish to escape through
70 the mesh. Without the knot, knotless netting has a larger opened area, which could potentially
71 increase the ability for undersized fish to escape. Additionally, knotless codends may reduce
72 abrasion and damage caused by contact with the knot, increasing selectivity and market value.
73 The aim of this study was to compare the size selectivity and usability of a traditional
74 diamond-shaped mesh codend versus an experimental diamond-shaped mesh knotless codend
75 in the Icelandic redfish fishery. An improvement in selectivity could increase this fishery's
76 capture efficiency for redfish above MRL and reduce the capture of unwanted, small redfish
77 below MRL (both *Sebastes norvegicus* and *S. viviparous*).

78 **2. Materials and Methods**

79 *2.1 Sea trials*

80 Sea trials were conducted on the commercial stern trawler *Helga María AK-16* (length 54.4
81 m; gross tonnage 1469.7 t; engine power 2991 hp) from 6 to 10 May 2016 on commercial
82 fishing grounds off southwest Iceland (Fig. 1). Fishing locations were determined based on
83 the captain's experience and were typical for the fishery. All hauls were carried out following
84 routine commercial fishing procedures. For each haul, fishing time, tows speeds, and
85 fishing depth were recorded following the protocols of Wileman et al. (1996). A GPS-logger
86 tracked the vessel's movement over the entire fishing process for each haul. A catch sensor

87 was mounted on the codend to estimate catch size in weight, and the trawl was hauled back
88 when the catch weight reached about 2 tons.

89 *2.2 Gear specifications*

90 The traditional codend was made of double 6.2 mm diameter mesh in a two-panel
91 configuration and the measured mesh size (stretched inside mesh opening between opposite
92 knots) was 131 mm. The experimental codend was made of 9.4 mm diameter ultra-cross
93 knotless mesh in a four-panel configuration, and the measured mesh size (stretched inside
94 mesh opening between opposite knots) was 127 mm (Fig. 2). The mesh size of the two
95 codends was measured with an ICES OMEGA gauge prior to the sea trials (Fonteyne, 2005).
96 Both codends were made by a local fishing company, Hampiðjan Iceland, and were in use in
97 the local redfish (*Sebastes. spp*) fisheries before the sea trials of this research were carried out.
98 The covered codend method was used for estimating the codend selectivity (Wileman et al.,
99 1996). The dimensions of the cover were kept in line with the recommendations of Wileman
100 et al. (1996). The cover attached to the codend had 50 mm mesh sizes. To avoid the masking
101 effect of the cover, flexible kites made of PVC-coated canvas (Grimaldo et al., 2009) were
102 attached to the front, middle front and back parts of the cover, 16 kites in total (4x4). The
103 trawl system used in the sea trials was similar with commercial trawls fishing in the area. The
104 codends were the only difference between traditional and experimental gear, and differed in
105 presence of knots, material, and number of panels (Fig. 2).

106 *2.2 Catch sampling*

107 Catches from the codend and the cover of each haul were processed separately on board the
108 vessel. All the catches were sorted by species, and the total number of each species were
109 recorded for the codend and the cover separately. Total length of full or subsamples of the
110 species was measured to the nearest cm below. The whole catches were measured if the

111 number of individuals were below or approximately 200 in the codend or cover; otherwise
112 random sub-sampling of 200 individuals per species was applied.

113 *2.3 Analysis of size selection data*

114 The applied experimental design enabled analysis of the collected catch data as binominal
115 data, where individuals either are retained by the codend cover or by the codend itself, and are
116 used to estimate the size selection in the codend (i.e., length-dependent retention probability).
117 The probability of finding a fish of length l in a codend in haul j is expressed by the function
118 $r_j(l)$. The purpose of the analysis is to estimate the values of this function for all relevant
119 sizes and species individually. Thus, the analysis is conducted separately for each species and
120 codend following the description below.

121 Between hauls with the same codend, the value of $r_j(l)$ is expected to vary (Fryer, 1991). In
122 this study, we were interested in the length-dependent values of $r(l)$ averaged over hauls with
123 the same codend, since this would provide information about the average consequences for
124 the size selection process when applying the codend in the fishery. Thus, it was assumed that
125 the size selective performance of the codend, for the hauls conducted, was representative of
126 how the codend would perform in a commercial fishery (Millar, 1993; Sistiaga et al., 2010).
127 Estimation of the average size selection over hauls $r_{av}(l)$ involves pooling data from the
128 different hauls (Herrmann et al., 2012). Since we tested different parametric models for $r_{av}(l)$,
129 we write $r_{av}(l, \mathbf{v})$, where \mathbf{v} is a vector consisting of the parameters of the model. The purpose of
130 the analysis is to estimate the values of the parameter \mathbf{v} that make experimental data (averaged
131 over hauls) most likely to be observed, assuming that the model is able to describe the data
132 sufficiently well. Therefore, expression (1) was minimized with respect to parameters \mathbf{v} ,
133 which is equivalent to maximizing the likelihood for the observed data in form of the length-
134 dependent number of fish retained in the codend (nR_{jl}) versus those escaping to the cover
135 (nE_{jl}):

$$136 \quad - \sum_{j=1}^m \sum_l \left\{ \frac{nR_{jl}}{qR_j} \times \ln(r_{av}(l, \mathbf{v})) + \frac{nE_{jl}}{qE_j} \times \ln(1.0 - r_{av}(l, \mathbf{v})) \right\} \quad (1)$$

137 Where the outer summation is over the m hauls conducted and the inner over length classes l .
 138 qR_j and qE_j are the sampling factors for the fraction of the fish length measured in the codend
 139 and cover respectively.

140 Four basic selectivity models were tested to describe $r_{av}(l, \mathbf{v})$ for each codend and species
 141 individually: Logit, Probit, Gompertz and Richard (Eqs. 2), which assume that all individual
 142 fish entering the codend are subjected to the same size selection process. More information
 143 about the four selection models can be found in Wileman et al., (1996).

$$144 \quad r_{av}(l, \mathbf{v}) =$$

$$145 \quad \left\{ \begin{array}{l} \text{Logit}(l, \mathbf{v}) \\ \text{Probit}(l, \mathbf{v}) \\ \text{Gompertz}(l, \mathbf{v}) \\ \text{Richard}(l, \mathbf{v}) \\ \text{CLogit}(l, C, \mathbf{v}) = 1.0 - C + C \times \text{Logit}(l, \mathbf{v}) \\ \text{DLogit}(l, C_1, \mathbf{v}) = C_1 \times \text{Logit}(l, \mathbf{v}_1) + (1.0 - C_1) \times \text{Logit}(l, \mathbf{v}_2) \\ \text{TLogit}(l, C, \mathbf{v}) = C_1 \times \text{Logit}(l, \mathbf{v}_1) + C_2 \times \text{Logit}(l, \mathbf{v}_2) + (1.0 - C_1 - C_2) \times \text{Logit}(l, \mathbf{v}_3) \\ \text{Poly4}(l, \mathbf{v}) = \frac{\exp\left(v_0 + v_1 \times \frac{l}{100} + v_2 \times \frac{l^2}{100^2} + v_3 \times \frac{l^3}{100^3} + v_4 \times \frac{l^4}{100^4}\right)}{1.0 + \exp\left(v_0 + v_1 \times \frac{l}{100} + v_2 \times \frac{l^2}{100^2} + v_3 \times \frac{l^3}{100^3} + v_4 \times \frac{l^4}{100^4}\right)} \end{array} \right. \quad (2)$$

146
 147 Additional models tested include the CLogit model (Eqs. 2), where C represents the assumed
 148 length-independent contact probability with the codend meshes that provides fish with a
 149 length-dependent chance of escape (Bayse et al., 2016). C is a value from 0.0-1.0, and if $C =$
 150 1.0, all fish were able to have sufficient contact with the codend meshes. For the double
 151 logistic model (DLogit), C_1 represents the fraction of fish entering the codend will be
 152 subjected to one logistic size selection process with parameters \mathbf{v}_1 while the remaining
 153 fraction $(1.0 - C_1)$ will be subjected to an additional logistic size selection process with
 154 parameters \mathbf{v}_2 (Lipovetsky, 2010). Compared with DLogit, the triple logistic model (TLogit)
 155 introduces an additional size selection process, totaling three different processes C_1 , C_2 and

156 (1.0- C_1 - C_2) probabilities of being the process that determine the codend size selection of the
157 individual fish entering the codend (Frandsen et al., 2010). Finally, a quartic polynomial
158 model (Poly4) was considered to estimate the codend size selection (Krag et al., 2015). For
159 the Poly4 model, leaving out one or more of the parameters $v_0 \dots v_4$ in Eqs. 2 provided 31
160 additional models that were also considered as potential models to describe $r_{av}(l, v)$.

161 The capacity of a model to describe the data was inspected following the procedure of
162 inspecting goodness-of-fit as described by Wileman et al. (1996). Therefore, the p -value
163 representing the likelihood to obtain at least as big a discrepancy between the fitted model and
164 the observed data by coincidence should not be below 0.05. In case of a poor statistical fit (p -
165 value < 0.05), the residuals were inspected to determine whether the poor result was due to
166 structural problems when modelling the experimental data using the different selection curves
167 or if it was due to overdispersion in the data (Wileman et al., 1996). The most appropriate
168 model for each species and codend was selected based on comparing Akaike information
169 criterion (AIC) values, where the selected model had the lowest AIC (Akaike, 1974).

170 Once the specific size selection model was identified for a particular species and codend,
171 bootstrapping was applied to estimate the confidence limits for the average size selection. We
172 applied the software tool SELNET (Herrmann et al., 2012) for the size selection analysis and
173 utilized the double bootstrap method implemented in this tool to obtain the confidence limits
174 for the size selection curve and the corresponding parameters. This bootstrapping approach is
175 identical to the one described in Millar (1993) and takes both within-haul and between-haul
176 variation into consideration. The hauls for each codend were used to define a group of hauls.
177 To account for between-haul variation, an outer bootstrap resample with replacement from the
178 group of hauls was included in the procedure. Within each resampled haul, the data for each
179 length class was bootstrapped in an inner bootstrap with replacement to account for within-
180 haul variation. Each bootstrap resulted in a “pooled” set of data, which was then analysed

181 using the identified selection model. Thus, each bootstrap run resulted in an average selection
 182 curve. For each species analysed, 1000 bootstrap repetitions were conducted to estimate the
 183 Efron percentile 95% confidence limits (Herrmann et al., 2012).

184 To compare the difference in length-dependent selectivity of the codends, $\Delta r(l)$ was
 185 estimated:

$$186 \Delta r(l) = r_{Kt}(l) - r_{Td}(l) \quad (4)$$

187 where $r_{Kt}(l)$ is the size selectivity of the knotless codend, and $r_{Td}(l)$ is the selectivity of
 188 traditional codend. The 95% confidence intervals (CI) for $r_{Kt}(l)$ were estimated based on the
 189 bootstrap population results by the method described in Herrmann et al. (2018). The
 190 inspection of length class with a lack of overlap between 95% CI and 0.0 was conducted to
 191 determine whether there were any significant differences between codends.

192 2.4 Estimation of usability indicators

193 To evaluate how the tested codends would affect the specific fishery, three codend usability
 194 indicators, $nP-$, $nP+$ and $nRatio$ (Eqs 5-7) were calculated for species or species groups with a
 195 MRL. Contrary to the size selection properties, which provide information that is independent
 196 of the size structure of the population encountered by the gear, the indicators directly depend
 197 on the size structure of the population encountered during the sea trials providing additional
 198 information for the evaluation of the catch performance of each codend.

$$199 nP- = 100 \times \frac{\sum_j \{ \sum_{l < MRL} nCd_{jl} \}}{\sum_j \{ \sum_{l < MRL} (nCd_{jl} + nCv_{jl}) \}} \quad (5)$$

$$200 nP+ = 100 \times \frac{\sum_j \{ \sum_{l > MRL} nCd_{jl} \}}{\sum_j \{ \sum_{l > MRL} (nCd_{jl} + nCv_{jl}) \}} \quad (6)$$

$$201 nRatio = \frac{\sum_j \{ \sum_{l < MRL} nCd_{jl} \}}{\sum_j \{ \sum_{l > MRL} nCd_{jl} \}} \quad (7)$$

202 where the summation of j is over hauls with a specific codend, and l over length classes. nCd_{jl}
 203 and nCv_{jl} represents the number of individuals of length l in haul j which found in
 204 respectively the codend and in the cover. $nP-$ and $nP+$ estimate the retention efficiency of the

205 catch below and above MRL. $nRatio$ represents the landings ratio between captured fish
206 below and above MRL of the fished populations size structure.
207 These indicators evaluate the effects each codend has on the specific fishery. Ideally for a
208 target species, nP^- and $nRatio$ should be low (close to zero), while nP^+ should be high (close
209 to 100), i.e., all individuals over MRL that enter the codend are retained. The double
210 bootstrapping method was used to estimate the Efron percentile 95% CI for the indicator
211 values considering the effect of between-haul variation and that of the uncertainty related to
212 within-haul variation (Herrmann et al., 2012).

213 **3. Results**

214 A total of twenty-one hauls were carried out during the sea trials, eleven with the traditional
215 codend and ten with the experimental codend. The water depth of the towed area ranged from
216 290 to 396 m, the towing speed varied between 3.3 and 3.8 knots (average 3.6 knots), and the
217 average towing duration was 54 min (26 - 115 min). Golden redfish and Norway redfish were
218 the predominantly captured species for all hauls, with few other captured species, therefore
219 they were the only species analysed (Table 1).

220 *3.1 Golden redfish*

221 For golden redfish, the best model describing the size selection properties of the traditional
222 codend was the TLogit, and the Poly4 model was the most appropriate model for the knotless
223 codend (Table 2). Confidence intervals for the selection curves were very wide for lengths
224 less than 29 cm (Fig. 3). This was related to the relatively low number of small individuals
225 captured by the codend and cover during sea trials. The selectivity performance of both
226 codends could not be determined for these lengths. However, for lengths above 29 cm, CIs
227 were narrow and Delta plots contained 0.0 within the CI, which means there was no
228 significant difference in selectivity between codends (Fig. 3).

229 3.2 Norway redfish

230 For Norway redfish, size selectivity for the traditional and experimental codends was best
231 described by the TLogit model (Table 2). Similar to golden redfish, high CIs were observed
232 for small length classes (< 19 cm). Therefore, size selectivity of these length classes could not
233 be determined. For lengths greater than 19 cm, CIs were relatively smaller, and the Delta plot
234 contained 0.0, showing that there was no significant difference between codends (Fig. 3).

235 3.3 Two species combined

236 Since these two species have similar morphological features, and are difficult to tell apart,
237 especially when mixed together on the same fishing grounds, we combined both species to
238 understand the size selectivity observed under commercial fishing operations, where species
239 identification is not a priority. The best fit model for both codends was the Poly4 (Table 2).
240 The population structure contained two modes (Fig. 3), and this represents the difference in
241 size between the two species with little overlap in the fished population. Confidence intervals
242 were quite large throughout most of the length classes (< 49 cm), and the Delta plot contained
243 0.0 showing no significance in size selectivity between codends.

244 3.4 Usability indicators

245 For golden redfish, the traditional codend retained 93.4% of individuals above MRL whereas
246 the experimental codend retained 92.9% ($nP+$; Table 3). Both codends showed a high
247 retention ratio for fish below MRL ($nP-$; 83.4 and 90.9%, respectively). The ratio of catches
248 under MRL to catches over MRL was near 0.0 for each codend ($nRatio$; 0.01 and 0.02,
249 respectively). No significant differences between usability indicators were observed for
250 golden redfish. Codend usability could not be determined for Norway redfish since they do
251 not have a MRL.

252 Codend usability was investigated for both species when combined. A MRL of 33 cm was
253 used and assumed no difference in species (i.e. if a fish was below 33 cm it was considered

254 only an undersized redfish, and which species was not considered). The retention of fish
255 above MRL ($nP+$) for the traditional codend was 87.3% versus 74.0% for the experimental,
256 but not significantly different. For fish below MRL ($nP-$), the traditional retained 83.8% and
257 the experimental 53.8%, a difference of 30% but not significant due to CIs overlapping (Table
258 3). $nRatio$ for the traditional was 0.70 and 0.54 for the experimental, also not significantly
259 different.

260 **4. Discussion**

261 Size selectivity and usability of the traditional and experimental codends was compared for
262 golden and Norway redfish separately, and combined in Iceland waters. According to the
263 selection curves and delta plots, no difference in size selectivity was observed between the
264 codends. For golden redfish, both codends presented a high retention ratio of catch above
265 MRL ($np+$; above 80%) and low discard-to-landings ratios ($nRatio$; less than 0.03), both the
266 aim of a commercial fishery. This scenario can be explained by two factors. First, both
267 codends caught mostly golden redfish above MRL, retaining more than 85%. Second,
268 juvenile and undersized golden redfish were rarely encountered in the fished population,
269 which led to the small $nRatios$.

270 The measured codend meshes had similar openings (131 vs. 127 mm), but differed in material
271 and the presence of knots. Differences in twine diameter can affect selectivity (Herrmann and
272 O'Neill, 2006). While twine diameter was arranged differently between codends, double vs
273 single twine, the practical size of each twine's diameter was very similar. The experimental
274 twine diameter was 9.4 mm, and the traditional twine diameter was 6.2 mm of double twine.
275 According to O'Neill et al. 2005, to estimate double twine diameter requires applying the
276 formula $1 + 2/\pi$ to the single twine diameter, which in this case equals 10.1 mm, a difference
277 of only 0.7 mm, which likely had a negligible effect on size selectivity. These results should
278 be interpreted as the difference between two codends, not simply the difference between the

279 presence or absence of knots. However, each codend had similar mesh openings and twine
280 diameters, therefore were made practically similar in these regards.

281 Due to current limitations of fishing gears and technology, golden and Norway redfish cannot
282 be targeted separately, and are often mixed on fishing grounds. Therefore, fishers regard the
283 two species as one for practical purposes. Additionally, fishers are not concerned with
284 identifying redfish to the species level – interest is only on size. Thus, combining and
285 analysing the two species together is of practical significance. Based on the selection curves
286 and delta plots of the combined species, the size selectivity of the traditional codend trended
287 higher for all size classes < 44 cm, but the difference was not significant due to the CIs
288 containing 0.0. The lack of significance could be due to the small overlap between the length
289 classes for each species on the fishing grounds. From 28 to 32 cm, few redfish of either
290 species were captured. These lengths represent the maximum length of Norway redfish, which
291 are rarely captured, and combined with few captured golden redfish less than 33 cm leads to
292 more complicated selectivity models that allow curves, or bends, due to changes in selectivity
293 and likely lead to lower confidence estimations when combined with the multimodal
294 distribution.

295 Codend usability indicators, nP^- and nP^+ , for the combined species analysis decreased when
296 compared with analysis for just the golden redfish. Although the addition of Norway redfish
297 did not lead to significant changes in codend usability between codends, each value did drop
298 when compared to the golden redfish analysis, with the experimental codend having the
299 largest decrease, 29% less nP^- and 19% less nP^+ than for the golden redfish alone. This
300 comparison presents a clearer indication of the bycatch that is incurred in this fishery, since
301 the Norway redfish and small golden redfish are unwanted catch.

302 Another indicator, $nRatio$, greatly increased when comparing both species versus golden
303 redfish alone. These increases can be considered almost entirely from the addition of Norway

304 redfish capture due to golden redfish having *nRatio* values less than 0.02 for each codend, and
305 values greater than 0.54 for each codend when including Norway redfish. This increase
306 proved that both codends retained high catch amounts of small fish, and if a similar selection
307 (morphology) between both species of equal size was considered (which has been suggested
308 by Herrmann et al. 2012 for several redfish species), small golden redfish would have been
309 captured if they were encountered in the fishery.

310 The research to date on trawl selectivity for redfish (*Sebastes spp.*) using knotless netting was
311 limited. One study compared a 122 mm knotless mesh codend made of “Perlon” for redfish
312 versus several other knotted codends of varying size and material in the Denmark Strait (Bohl,
313 1961). While results were positive for this codend compared to braided Perlon codends and
314 manila codends of larger mesh sizes, these results suffer from low sample sizes (5 hauls) and
315 are difficult to compare with our work using modern material and analytical techniques.

316 The experimental codend did not improve the selectivity in the Icelandic redfish fishery, nor
317 did it capture significantly less commercial-sized redfish. Thus, these codends should be
318 considered equal in terms of selectivity of redfish and the transition to knotless mesh should
319 only be considered for positive gains in fuel efficiency or to reduce damage to fish from
320 contact with the knot, neither of which were investigated in this study. Further, future
321 research should be concentrated on avoiding the capture of Norway redfish and small golden
322 redfish due to the lack of selectivity observed in this study for small-sized redfish.

323 Although this study did not show any changes in size selectivity between the tested codends,
324 reporting these results is valuable from both the management and fishing industry perspective;
325 it enhances our understanding of fishing gear selectivity and particularly for this fishery; it
326 provides guidance on what fishing strategies can be used to limit the capture of small redfish.

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Table 1. Overview of 21 hauls with towing depth, duration, and number of length measurements obtained for each species. *indicates that data were not available. *nCd* is the number of individuals in the codend; *nCv* is the number of individuals in the cover; *sRd* is the sampling ratio of the codend; *sRv* represents the sampling ratio of the cover.

Haul ID	Codend	Depth (m)	Towing duration (min)	Golden redfish				Norway redfish			
				<i>nCd</i>	<i>sRd</i>	<i>nCv</i>	<i>sRv</i>	<i>nCd</i>	<i>sRd</i>	<i>nCv</i>	<i>sRv</i>
1	Traditional	337	44	250	0.403	34	1.000	201	0.282	203	0.510
2	Traditional	290	115	200	0.104	182	1.000	43	0.112	107	0.294
3	Traditional	310	34	220	0.014	203	0.501	166	0.719	101	0.564
4	Traditional	311	44	200	0.027	200	0.188	4	0.085	101	0.168
5	Traditional	297	57	219	0.030	200	0.284	79	0.026	100	0.029
6	Traditional	304	48	209	0.030	206	0.530	4	0.029	159	0.513
7	Traditional	312	49	203	0.024	199	0.505	136	0.070	120	0.093
8	Traditional	310	68	203	0.377	212	0.555	99	0.066	107	0.053
9	Traditional	317	51	180	0.052	206	0.904	133	0.049	164	0.406
10	Traditional	318	51	186	0.048	200	0.475	55	0.044	164	0.139
11	Traditional	342	92	185	0.310	182	1.000	67	0.072	110	0.137
12	Experimental	338	61	190	0.107	29	1.000	110	0.060	110	0.224
13	Experimental	336	26	200	0.028	145	1.000	138	0.052	161	0.095
14	Experimental	303	43	222	0.733	62	1.000	92	0.526	196	0.269
15	Experimental	*	31	156	0.223	29	0.058	10	0.222	131	0.102
16	Experimental	329	51	186	0.032	187	0.588	72	0.032	174	0.072
17	Experimental	329	68	170	0.034	204	0.586	90	0.034	185	0.066
18	Experimental	396	76	159	0.017	196	0.359	57	0.017	122	0.042
19	Experimental	318	29	133	0.009	130	0.115	59	0.009	100	0.009
20	Experimental	310	52	171	0.083	152	1.000	33	0.180	117	0.047
21	Experimental	*	52	188	0.049	199	0.337	83	0.146	143	0.080

Table 2. Akaike's information criterion (AIC) for each model for each species or species group. Selected model in bold.

Species	Codend	Logit	Probit	Gompertz	Richard	DLogit	TLogit	CLogit	Poly4
<i>S. norvegicus</i>	Traditional	31,976	31,975	31,976	31,977	31,902	31,887	31,977	31,962
	Experimental	26,839	26,823	26,843	26,818	26,792	26,799	26,812	26,788
<i>S. viviparus</i>	Traditional	31,845	31,844	31,834	31,837	31,756	31,730	31,847	31,783
	Experimental	63,407	63,408	63,409	63,406	63,250	63,203	63,371	63,372
Both species	Traditional	23,832	23,893	23,769	23,618	23,206	23,094	23,420	22,972
	Experimental	11,094	11,089	11,097	11,062	10,943	10,949	11,066	10,929

Table 3. Codend usability indicators with fit statistics for each species. “Na” means data are not available since there is no MRL for *S. viviparus*. Numbers in () represent the 95% CI for the estimated data.

Codend Model	<i>S. norvegicus</i>		<i>S. viviparus</i>		Both species	
	Traditional TLogit	Experimental Poly4	Traditional TLogit	Experimental TLogit	Traditional Poly4	Experimental Poly4
<i>nP+</i>	93.4(88.6-96.3)	92.9(89.9-96.0)	Na	Na	87.3(55.5-93.7)	74.0(50.4-86.7)
<i>nP-</i>	90.9(82.2-96.3)	83.4(65.0-95.6)	Na	Na	83.8(41.6-93.8)	53.8(29.1-67.6)
<i>nRatio</i>	0.02(0.01-0.03)	0.01(0.00-0.01)	Na	Na	0.70(0.32-0.81)	0.54(0.36-0.59)
DOF	22	22	11	9	41	34
Deviance	13.7	58.1	22.1	41.5	190.8	133.0
<i>p</i> -value	0.911	<0.001	0.023	<0.001	<0.001	<0.001

Figure 1

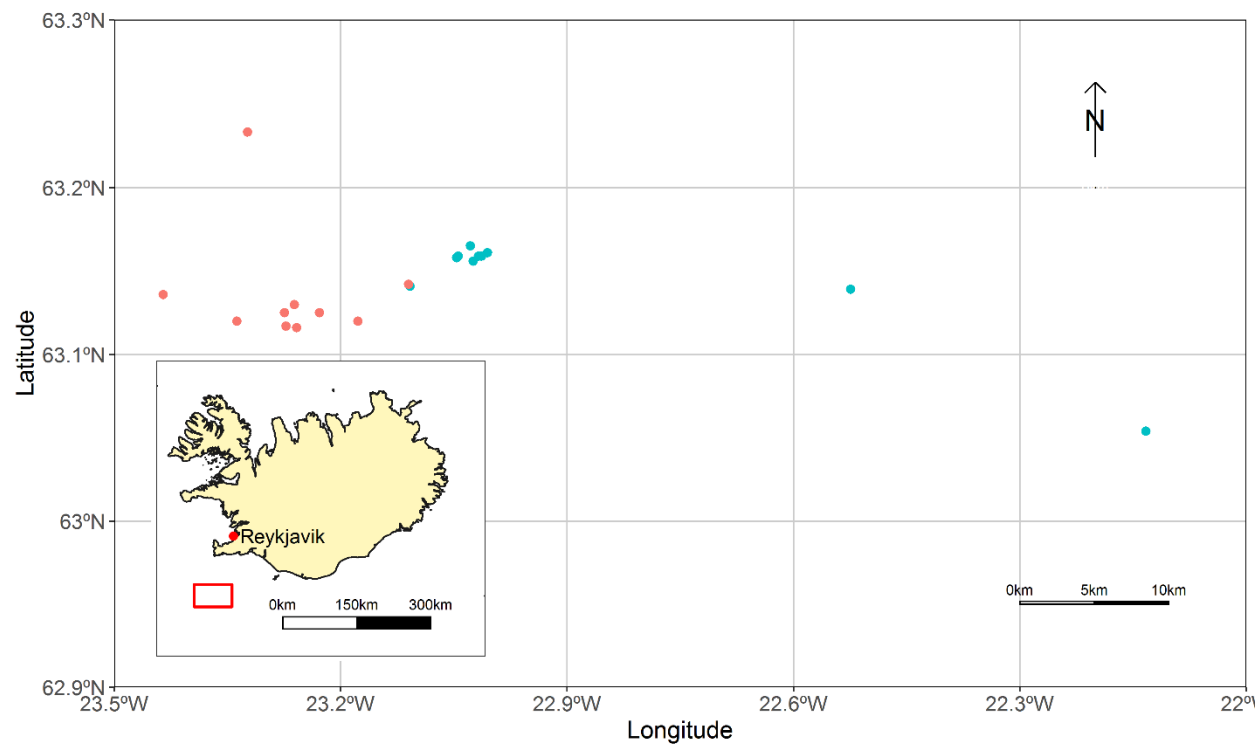


Figure 1. Location of fishing trials: green and orange spots indicate towing start points; green spots = traditional codend; orange spots = experimental codend.

Figure 2

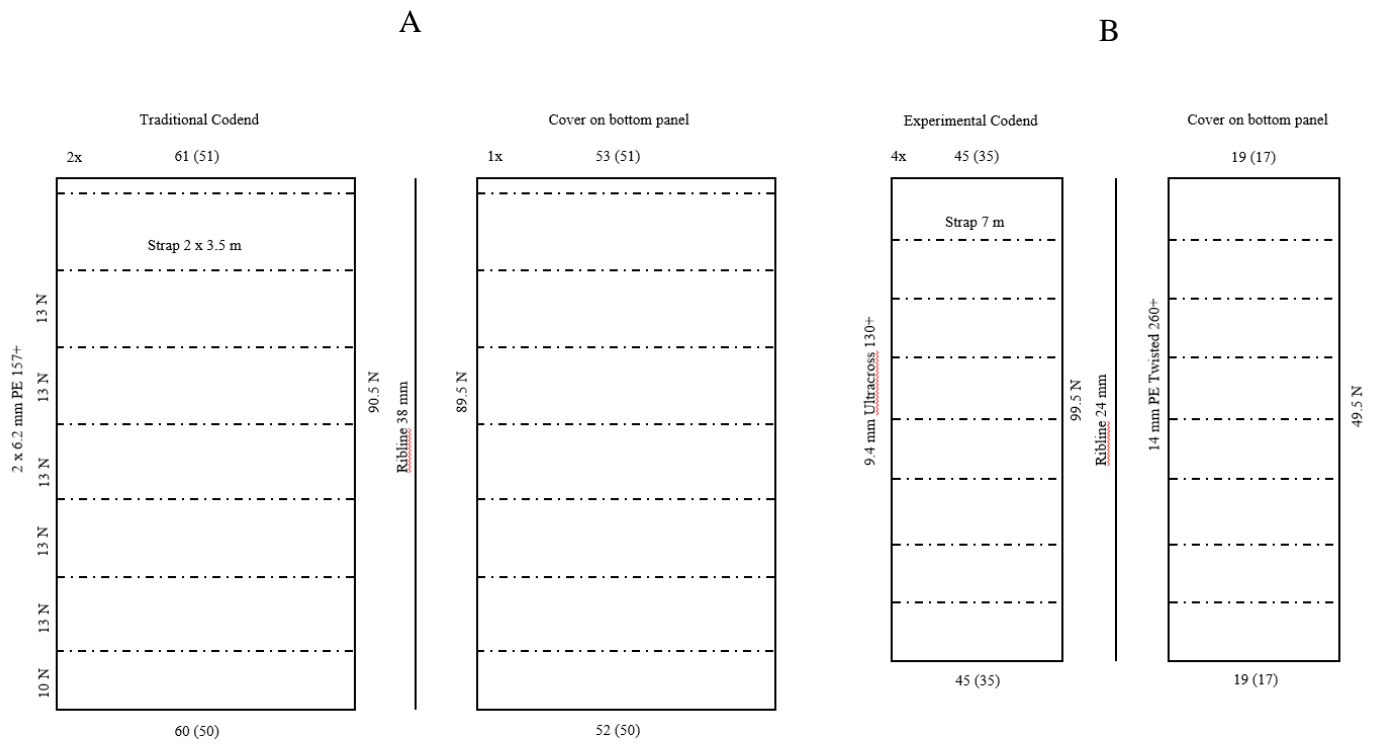


Figure 2. Schematic diagram of (A) traditional codend and (B) experiment codend (Right panel of each codend is the cover on the bottom panel; both codends are designed and constructed by Hampiðjan Iceland).

Figure 3

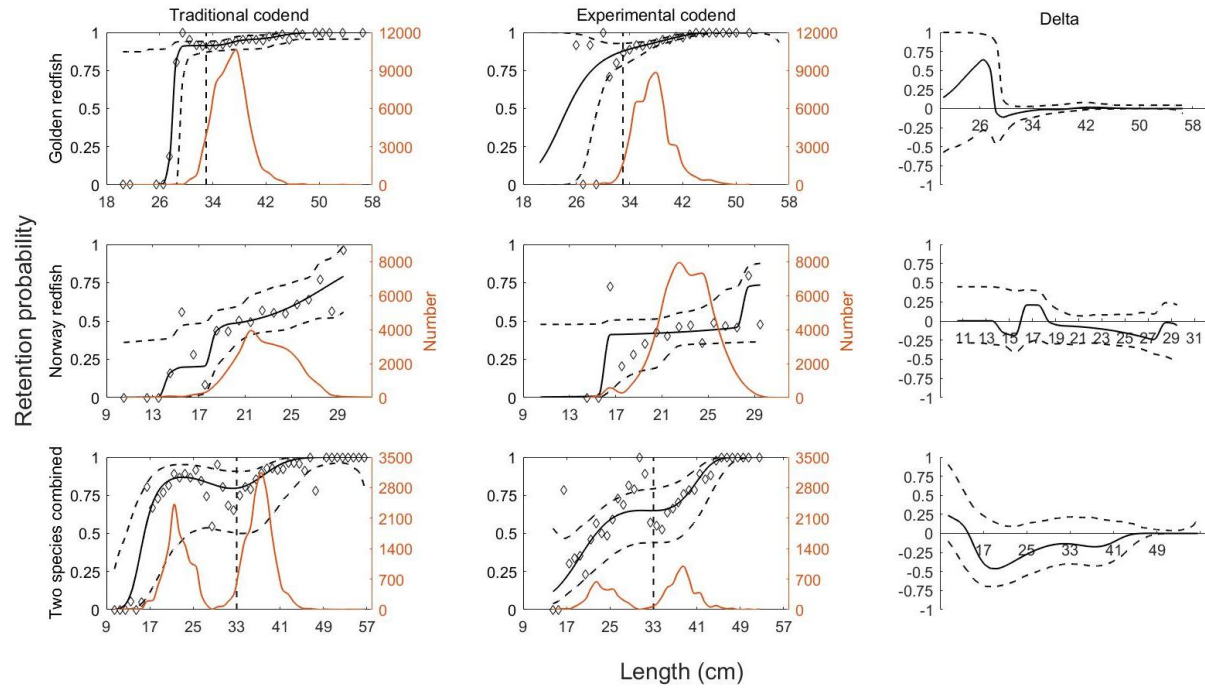


Figure 3. Size selectivity of *S. norvegicus* and *S. viviparus* in the traditional and experiment codends: Diamond symbols represent the experimental data; thick black curve indicates the fitted size selection curves; stippled curves describe the 95% confidence limits for the fitted size selection curves; vertical stippled line represents the MRL (minimum reference length) for *S. norvegicus*; brown curves shows the size distribution of the population encountered during sea trials.