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

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Abstract

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

Keywords

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

1. Introduction

One of the key industries in Iceland is fishing (Sigfusson et al., 2013), and the redfish (*Sebastes spp.*) trawl fishery is one of its largest fisheries in terms of capture volume and value (FAO, 2010). Three redfish species are present in Icelandic waters: golden redfish (*Sebastes norvegicus*), Norway redfish (*S. viviparous*) and beaked redfish (*S. mentella*). Currently, golden and beaked redfish are targeted commercial species, while Norway redfish is unwanted due to its small size (MFRI, 2018a). Each species grows slowly and matures late and are difficult to differentiate due to similarities in meristic and morphological characteristics (Pampoulie and Daníelsdóttir, 2008; Christensen et al., 2018).

The Icelandic redfish fishery requires a minimum diamond-shaped codend mesh size of 135 mm (Ciccia Romito et al., 2015), and discarding is prohibited (ICNAF, 1975). Additional regulations for golden redfish include a minimum reference length (MRL) of 33 cm, where if more than 20% of the catch (in number) is below the MRL, a closure will incur on fishing grounds (MFRI, 2018b). The unwanted capture of small redfish can be problematic for fishers. Due to the discard prohibition, fishers are unable to discard small fish, and their capture can lead to a stoppage in fishing. Additionally, from a sustainable fishing perspective, the capture of large numbers of small redfish can be damaging to their population abundance due to the slow growing and late maturing nature of the species group. Additionally, when the relatively smaller Norway redfish (rarely > 30 cm; MFRI, 2018c) is mixed with the larger, targeted species, it can lead to further unwanted catch. Improvements in the size selectivity of Icelandic trawls is necessary to prevent the capture of small redfish.

Redfish size selectivity has been previously investigated, and several modifications have been attempted to improve the size selectivity of redfish trawls. Icelandic and Greenland redfish fisheries have had mesh selectivity studies dating as far back as the 1960s and 1970s (Bohl, 1961; Thorsteinsson et al., 1980). More recently, Lisovsky (2001) and Lisovsky et al. (2005)

found that mesh size can affect redfish size selectivity. Other codend size selectivity studies investigated the effects of lastridge ropes (Hickey et al., 1995), and the size selectivity of three different diamond-shaped mesh sizes in the Gulf of Maine redfish fishery (Pol et al., 2016).

Compared with conventional diamond-mesh codends, knotless codends may have better size selectivity for roundfish. The shape and opening of the traditional knotted codend may be affected by the knot, making it more difficult for juvenile or undersized fish to escape through the mesh. Without the knot, knotless netting has a larger opened area, which could potentially increase the ability for undersized fish to escape. Additionally, knotless codends may reduce abrasion and damage caused by contact with the knot, increasing selectivity and market value. The aim of this study was to compare the size selectivity and usability of a traditional diamond-shaped mesh codend versus an experimental diamond-shaped mesh knotless codend in the Icelandic redfish fishery. An improvement in selectivity could increase this fishery's capture efficiency for redfish above MRL and reduce the capture of unwanted, small redfish below MRL (both *Sebastes norvegicus and S. viviparous*).

2. Materials and Methods

2.1 Sea trials

Sea trials were conducted on the commercial stern trawler *Helga María AK-16* (length 54.4 m; gross tonnage 1469.7 t; engine power 2991 hp) from 6 to 10 May 2016 on commercial fishing grounds off southwest Iceland (Fig. 1). Fishing locations were determined based on the captain's experience and were typical for the fishery. All hauls were carried out following routine commercial fishing procedures. For each haul, fishing time, towing speeds, and fishing depth were recorded following the protocols of Wileman et al. (1996). A GPS-logger tracked the vessel's movement over the entire fishing process for each haul. A catch sensor was mounted on the codend to estimate catch size in weight, and the trawl was hauled back when the catch weight reached about 2 tons.

2.2 Gear specifications

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

2.2 Catch sampling

Catches from the codend and the cover of each haul were processed separately on board the vessel. All the catches were sorted by species, and the total number of each species were recorded for the codend and the cover separately. Total length of full or subsamples of the species was measured to the nearest cm below. The whole catches were measured if the number of individuals were below or approximately 200 in the codend or cover; otherwise random sub-sampling of 200 individuals per species was applied.

2.3 Analysis of size selection data

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

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

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

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

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

$$r_{av}(l,\boldsymbol{v}) =$$

$$\begin{cases} Logit(l,\boldsymbol{v}) \\ Probit(l,\boldsymbol{v}) \\ Gompertz(l,\boldsymbol{v}) \\ Richard(l,\boldsymbol{v}) \\ CLogit\big(l,\ C,\ \boldsymbol{v}\big) = 1.0 - C + C \times Logit\big(l,\ \boldsymbol{v}\big) \\ DLogit(l,C_1,\boldsymbol{v}) = C_1 \times Logit(l,\boldsymbol{v}_1) + (1.0-C_1)\times Logit(l,\boldsymbol{v}_2) \\ TLogit(l,C,\boldsymbol{v}) = C_1 \times Logit(l,\boldsymbol{v}_1) + C_2 \times Logit(l,\boldsymbol{v}_2) + (1.0-C_1-C_2)\times Logit(l,\boldsymbol{v}_3) \\ Poly4(l,\boldsymbol{v}) = \dfrac{exp\Big(v_0+v_1\times\frac{l}{100}+v_2\times\frac{l^2}{100^2}+v_3\times\frac{l^3}{100^3}+v_4\times\frac{l^4}{100^4}\Big)}{1.0+exp\Big(v_0+v_1\times\frac{l}{100}+v_2\times\frac{l^2}{100^2}+v_3\times\frac{l^3}{100^3}+v_4\times\frac{l^4}{100^4}\Big)} \end{cases} \qquad (2)$$

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

(1.0-C_1-C_2) probabilities of being the process that determine the codend size selection of the individual fish entering the codend (Frandsen et al., 2010). Finally, a quartic polynomial model (Poly4) was considered to estimate the codend size selection (Krag et al., 2015). For the Poly4 model, leaving out one or more of the parameters $v0 \ldots v4$ in Eqs. 2 provided 31 additional models that were also considered as potential models to describe $r_{av}(l,v)$.

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

Once the specific size selection model was identified for a particular species and codend, bootstrapping was applied to estimate the confidence limits for the average size selection. We applied the software tool SELNET (Herrmann et al., 2012) for the size selection analysis and utilized the double bootstrap method implemented in this tool to obtain the confidence limits for the size selection curve and the corresponding parameters. This bootstrapping approach is identical to the one described in Millar (1993) and takes both within-haul and between-haul variation into consideration. The hauls for each codend were used to define a group of hauls. To account for between-haul variation, an outer bootstrap resample with replacement from the group of hauls was included in the procedure. Within each resampled haul, the data for each length class was bootstrapped in an inner bootstrap with replacement to account for within-haul variation. Each bootstrap resulted in a “pooled” set of data, which was then analysed using the identified selection model. Thus, each bootstrap run resulted in an average selection curve. For each species analysed, 1000 bootstrap repetitions were conducted to estimate the Efron percentile 95% confidence limits (Herrmann et al., 2012).

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

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

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

2.4 Estimation of usability indicators

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

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

$$nP+ = 100 \times \frac{\sum_{\mathrm{j}}\{\sum_{\mathrm{l}>MRL} \mathrm{nCd}_{\mathrm{jl}}\}}{\sum_{\mathrm{j}}\{\sum_{\mathrm{l}>MRL}(\mathrm{nCd}_{\mathrm{jl}}+\mathrm{nCv}_{\mathrm{jl}})\}} \quad (6)$$

$$nRatio = \frac{\sum_{\mathrm{j}}\{\sum_{\mathrm{l}<MRL} \mathrm{nCd}_{\mathrm{jl}}\}}{\sum_{\mathrm{j}}\{\sum_{\mathrm{l}>MRL} \mathrm{nCd}_{\mathrm{jl}}\}} \qquad (7)$$

where the summation of j is over hauls with a specific codend, and l over length classes. nCd_{jl} and nCv_{jl} represents the number of individuals of length l in haul j which found in respectively the codend and in the cover. $nP-$ and $nP+$ estimate the retention efficiency of the catch below and above MRL. *nRatio* represents the landings ratio between captured fish below and above MRL of the fished populations size structure.

These indicators evaluate the effects each codend has on the specific fishery. Ideally for a target species, *nP−* and *nRatio* should be low (close to zero), while *nP+* should be high (close to 100), i.e., all individuals over MRL that enter the codend are retained. The double bootstrapping method was used to estimate the Efron percentile 95% CI for the indicator values considering the effect of between-haul variation and that of the uncertainty related to within-haul variation (Herrmann et al., 2012).

3. Results

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

3.1 Golden redfish

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

3.2 Norway redfish

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

3.3 Two species combined

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

3.4 Usability indicators

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

Codend usability was investigated for both species when combined. A MRL of 33 cm was used and assumed no difference in species (i.e. if a fish was below 33 cm it was considered only an undersized redfish, and which species was not considered). The retention of fish above MRL (*nP+*) for the traditional codend was 87.3% versus 74.0% for the experimental, but not significantly different. For fish below MRL (*nP-*), the traditional retained 83.8% and the experimental 53.8%, a difference of 30% but not significant due to CIs overlapping (Table 3). *nRatio* for the traditional was 0.70 and 0.54 for the experimental, also not significantly different.

4. Discussion

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

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

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

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

Another indicator, *nRatio*, greatly increased when comparing both species versus golden redfish alone. These increases can be considered almost entirely from the addition of Norway redfish capture due to golden redfish having *nRatio* values less than 0.02 for each codend, and values greater than 0.54 for each codend when including Norway redfish. This increase proved that both codends retained high catch amounts of small fish, and if a similar selection (morphology) between both species of equal size was considered (which has been suggested by Herrmann et al. 2012 for several redfish species), small golden redfish would have been captured if they were encountered in the fishery.

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

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

Although this study did not show any changes in size selectivity between the tested codends, reporting these results is valuable from both the management and fishing industry perspective; it enhances our understanding of fishing gear selectivity and particularly for this fishery; it 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			
				nCd	sRd	nCv	sRv	nCd	sRd	nCv	sRv
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
S. norvegicus	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**
S. viviparus	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.

	S. norvegicus		*S. viviparus*		Both species	
Codend	Traditional	Experimental	Traditional	Experimental	Traditional	Experimental
Model	TLogit	Poly4	TLogit	TLogit	Poly4	Poly4
nP+	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)
nP-	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)
nRatio	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
p-value	0.911	<0.001	0.023	<0.001	<0.001	<0.001

Figure 1

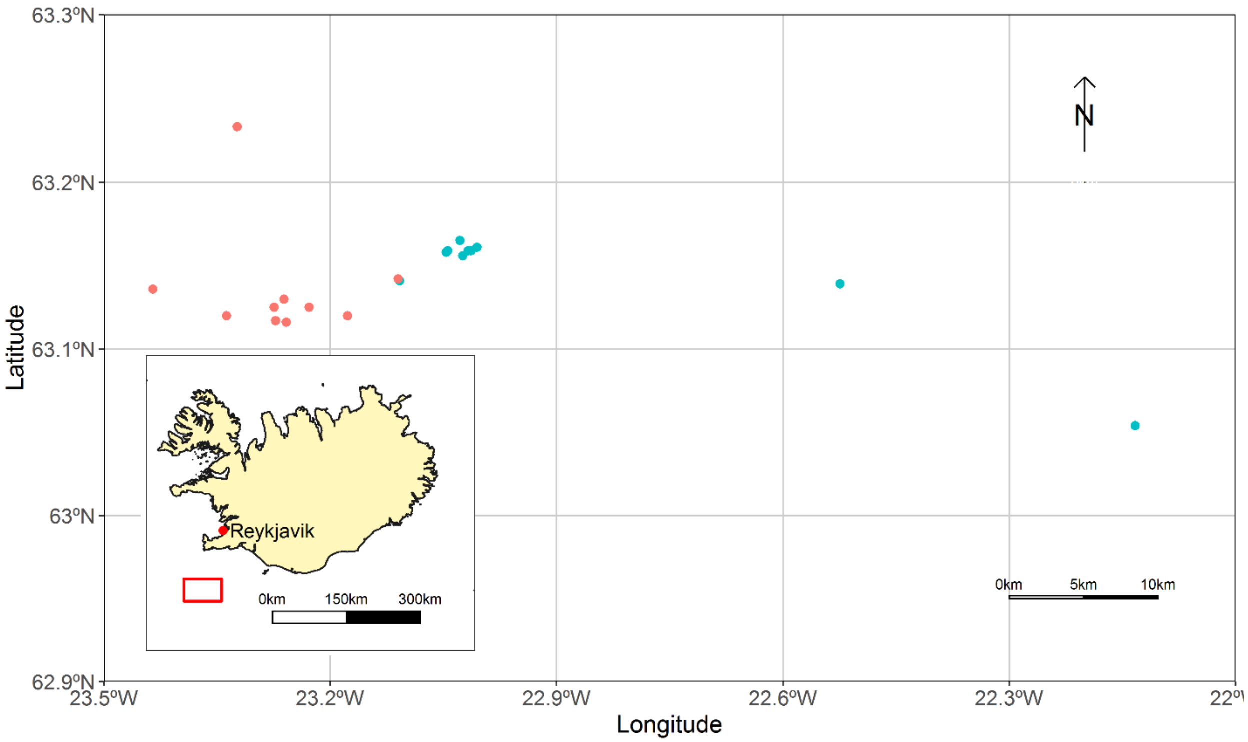

Figure 1. Location of fishing trials: green and orange spots indicate towing start points; green spots = traditional codend; orange spots = experimental codend.

Figure 2

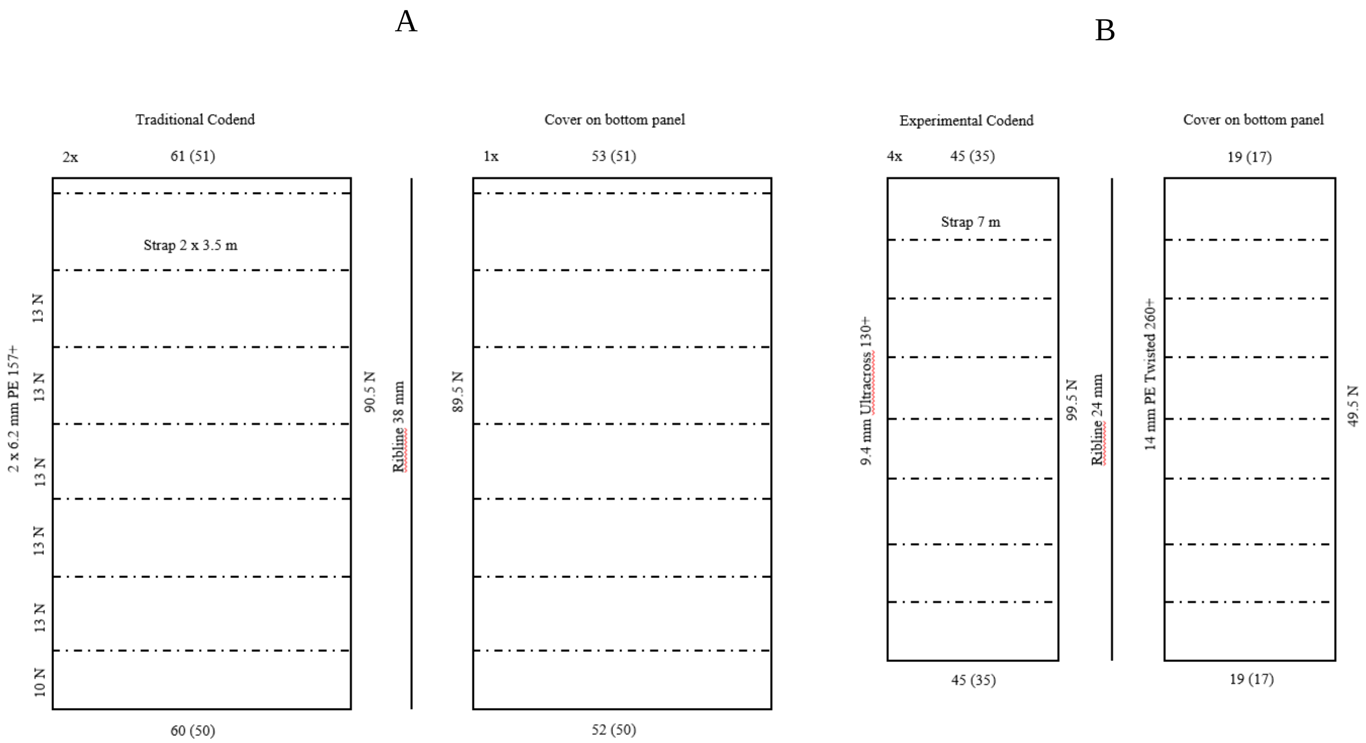

Figure 2. Schematic diagram of (A) traditional codend and (B) experiment codend (Right panel of each codend is the cover on the bottom panel; both codends are designed and constructed by Hampiðjan Iceland).

Figure 3

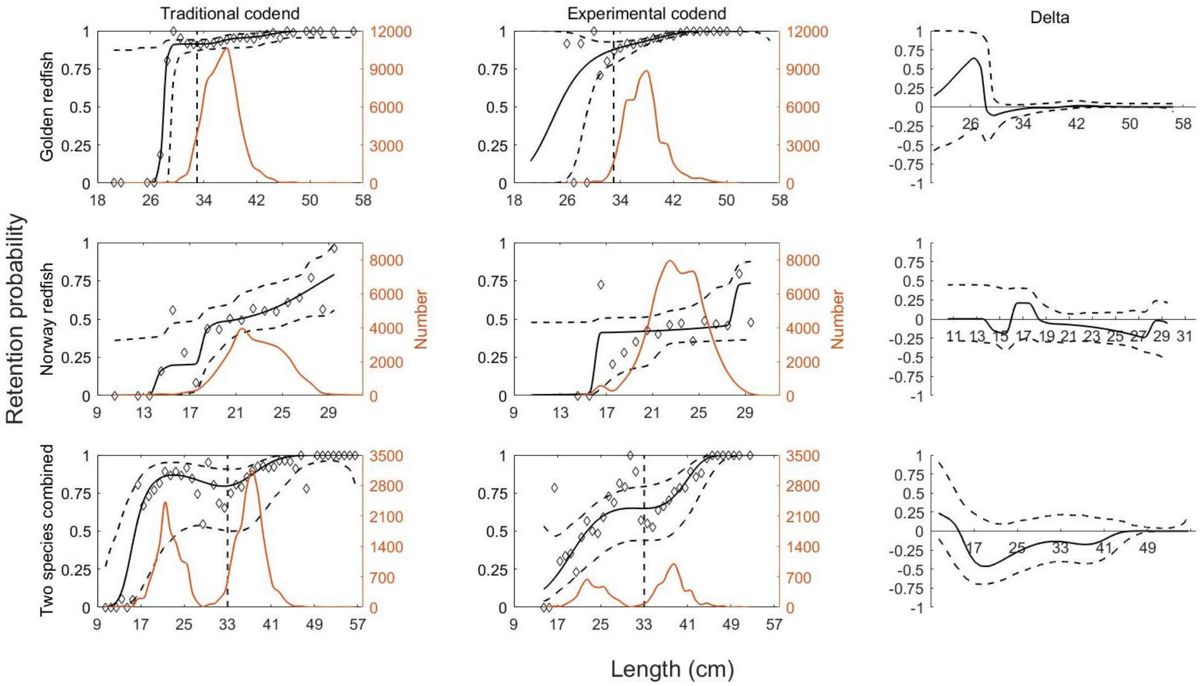

Figure 3. Size selectivity of *S. norvegicus* and *S. viviparus* in the traditional and experiment codends: Diamond symbols represent the experimental data; thick black curve indicates the fitted size selection curves; stippled curves describe the 95% confidence limits for the fitted size selection curves; 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.