Examining the efficacy of T90 mesh codends to improve catch utilization in a multispecies bottom trawl fishery

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Abstract

The U.S. West Coast groundfish bottom trawl fishery operates under a catch share program, implemented with the intention of improving the economic efficiency of the fishery, maximizing fishing opportunities, and minimizing bycatch. However, stocks with low harvest guidelines have limited fishermen's ability to maximize catch of more abundant stocks. Size-selection characteristics of 114 mm, 127 mm, and 140 mm T90 mesh, and traditional 114 mm diamond mesh codends were examined using the covered codend method. Selection curves and mean L_{50} values for two flatfish species (rex sole *Glyptocephalus zachirus*, and Dover sole *Microstomus pacificus*), and two roundfish species (shortspine thornyhead *Sebastolobus alascanus*, and sablefish *Anoplopoma fimbria*) were estimated. Mean L_{50} values were smaller for flatfishes, but larger for roundfishes in the 114 mm and 127 mm T90 codend compared to the diamond codend. The 140 mm T90 codend showed significantly different selectivities from the other codends, being most effective at reducing the catch of smaller-sized fishes, however with a considerable loss of larger-sized marketable fishes. Compared to the traditional diamond mesh codend, findings from this study indicate that 114 mm and 127 mm T90 mesh codends can improve catch utilization of flatfishes while reducing discards of juvenile and unmarketable-sized roundfishes.

Introduction

The U.S. West Coast limited entry (LE) groundfish bottom trawl fishery operates under a catch share program that allocates individual fishing quotas (IFQ) and establishes annual catch limits (ACLs) for over 30 groundfish managed units (PFMC and NMFS 2011, 2015). In this program, fishermen are allocated a proportion of the fishery ACL, are subject to full at-sea observer coverage, and are held fully accountable for all IFQ species catches whether discarded or retained.

Over the continental shelf break and upper slope of the U.S. west coast, fishermen target Dover sole, *Microstomus pacificus*, shortspine thornyhead, *Sebastolobus alascanus*, sablefish, *Anoplopoma fimbria*, and to a lesser extent rex sole, *Glyptocephalus zachirus*. In this LE trawl fishery, commonly referred to as the Dover sole/thornyhead/sablefish (DTS) fishery, sablefish are the most economically important species harvested. Ex-vessel prices for sablefish can range from US$1.10 to $9.35/kg with price increasing with fish weight. However, sablefish have become a constraining species in the DTS fishery as their 2015 shoreside trawl allocation (6,028 mt) is relatively low when compared to the Dover sole allocation (45,986 mt) (NMFS 2015). Recent catches of Dover sole have been approximately 6,251 mt (PacFIN 2015), which represents only 13% attainment of the shoreside trawl allocation. This low attainment of the Dover sole ACL is partly due to the attainment of constraining IFQ species, such as sablefish. Minimizing catches of smaller-sized shortspine thornyhead could also benefit fishermen as prices for shortspine thornyhead can range from US$0.88 to $2.42/cm, with larger-sized individuals receiving the highest price/cm. Dover sole, on the other hand, are priced at $0.99/kg regardless of length. Hence, reducing the catch rate of smaller-sized sablefish and shortspine thornyhead relative to Dover sole would allow fishermen more opportunities to capitalize on their Dover sole IFQ and increase their net economic benefits, while still attaining their quota shares of sablefish and shortspine thornyhead.

A simple technique shown to improve trawl selectivity is modifying the size and configuration of the codend mesh (Perez-Comas et al. 1998; He 2007; Madsen and Valentinsson 2010). Recently, research has focused on the development and use of T90 mesh codends (Digre et al. 2010; Wienbeck et al. 2011, 2014; Madsen et al. 2012; Herrmann et al. 2013). T90 mesh is conventional diamond mesh that has been turned 90^{o} in orientation. This configuration allows the meshes over the entire codend to remain more open than those of diamond mesh codends, improving size-selection characteristics. For diamond mesh codends, research has demonstrated that they become distorted into a bulbous shape as tension on the netting increases and catch levels accumulate (Stewart and Robertson 1985; Wileman et al. 1996). The majority of escapement occurs just ahead of the accumulating catch bulge where a few rows of meshes are more open and unblocked by fishes. The simple construction of a T90 codend, ease of repair when damaged, and its potential to improve size-selection provides some advantages over other mesh orientations used to enhance codend selectivity, such as knotless square mesh (Perez-comas et al. 1998; He 2007). This T90 mesh configuration, originally designed for use in cod, *Gadus morhua,* fisheries, has gained increased interest in other fisheries such as the Norway lobster, *Nephrops norvegicus,* otter trawl fishery in the Kattegat–Skagerrak area (Madsen et al. 2012) and in the Mediterranean Sea multispecies demersal trawl fishery (Tokaç et al. 2014).

Compared to diamond mesh codends with similar mesh sizes, T90 mesh codends have demonstrated the ability to reduce catches of smaller-sized roundfishes (Wienbeck et al. 2011; Herrmann et al. 2013; Tokaç et al. 2014).

The objective of this study was to compare the size-selection characteristics between 114 mm, 127 mm, and 140 mm T90 mesh codends, and the traditional 114 mm diamond mesh codend and evaluate if T90 mesh codends can improve catch utilization in the LE groundfish bottom trawl fishery.

Materials and Methods

Trawl Design

The chartered F/V *Last Straw*, a 23.2 m long 540 horsepower trawler, provided its two-seam trawl for sea trials. The headrope was 24.1 m in length and utilized sixteen 28.0 cm diameter deep-water floats for lift. The footrope was 24.7 m in length and covered with rubber disks 20.3 cm in diameter with 45.7 cm rockhopper discs placed approximately every 73.7 cm over the length of the footrope. The trawl sweeps were 91.4 m in length and covered with rubber discs 8.9 cm in diameter. Thyborøn type 11 standard trawl doors were used.

Codends Tested

The codends tested were nominal 114 mm (118.5 mm actual), 127 mm (127.4 mm actual), and 140 mm (139.4 mm actual) T90 mesh, and 114 mm (119.6 mm actual) diamond mesh. Actual mesh sizes were measured using an OMEGA gauge with 125 N stretching force (Fonteyne et al., 2007). Each codend was constructed within a four-seam tube of 6.0 mm double twine polyethylene netting with chafing gear protecting the aft most 50 meshes of the bottom seam. A 50 mesh length two-seam to four-seam transitional tube of netting was used to attach each codend to the trawl when tested.

Codend selectivity was measured using the covered codend method (Wileman et al. 1996). The cover was a four-seam net constructed of Ultra Cross Dyneema® knotless square mesh netting (63.5 mm center-to-center, 20 ply twine). The cover was attached to the intermediate section of the trawl 30 meshes forward of where the codend connects to the trawl. At this attachment point, the circumference of the cover was 144 squares, excluding squares in each selvedge. Moving aft, the cover then gradually angled outward over the length of 114 squares to become 296 squares in circumference and 302 squares in length before tapering to 68 squares per panel over the distance of 76 squares. Where the cover encompasses the codend, the dimensions are approximately 1.5 times the extended width and approximately 1.3 times the extended length of the codend. Chafing material (102 mm diamond mesh, 5.0 mm single twine) along the bottom seam of the cover was used to protect the aft most 227 squares from abrasion and net tearing. To keep the cover from masking the codend, a combination of trapezoidal shaped rubber kites (0.95 cm thick conveyor belt material, 61 x 31 x 31 cm in dimension) and 20.3 cm diameter floats were used. The kites were positioned along the outer and lower sides of the cover (two sets of 4 on each side) in relation to the fore and aft end of the codend, whereas the floats were positioned along the top riblines (five on each ribline) of the cover.

Sea Trials

Tests occurred off Oregon between 44°33′ and 44°55′N and between 124°33′ and 125°00′W during August 2015 and 2016. Towing occurred in the vicinity of the continental shelf break and upper slope during daylight hours, between 0600 and 2000 Pacific daylight time, at bottom depths from 366 m to 622 m. Towing speed over ground ranged from 2.2 to 2.6 knots. Tow durations were set not to exceed 105 min. so that all catches could be completely weighed and sampled.

A randomized block design was used to determine the order in which each codend was tested. Overall, 58 tows were completed with 14, 15, 13, and 16 tows made with the 114 mm diamond, 114 mm T90, 127 mm T90, and 140 mm T90 codend, respectively. After each tow, all fish caught in the cover and codend were identified to species and weighed using a motion compensated platform scale. Rex sole, Dover sole, and shortspine thornyhead from each the cover and codend were randomly selected per tow and measured to the nearest cm total length, while sablefish were measured to the nearest cm fork length. Subsampling was avoided when possible, however, time constraints and relatively large catches often required subsampling for length measurements. Tables 1 and 2 show the length data used to generate the selectivity results. During this study, the minimum market size was 31.8 cm for rex sole, 33 cm for Dover sole, and 21.6 cm for shortspine thornyhead. Sablefish did not have a minimum market size.

Selectivity Analysis

The statistical analysis software SELNET (SELection in trawl NETting) was used to analyze the data (Sistiaga et al., 2010; Herrmann et al., 2012). Selection curves were estimated by pooling data across tows. All tows and length classes caught were used in the analysis. Five models (Logit, Probit, Gompertz, Richard, and DLogit (double logistic)) were considered for estimating the average size-selection properties for each species and codend. The Logit, Probit, and Gompertz models are described by the L_{50} (length where 50% of fish have the probability of being retained) and *SR* (Selection Range, the length difference between L_{25} and L_{75}) parameters. The Richard model is described by the L_{50}, *SR*, and ($1/\delta$) selectin parameters. The Logit, Probit, Gompertz, and Richard models assume that all fish are subjected to the same size-selection process. For the DLogit model (Herrmann et al., 2016), this model assumes that a fraction of the fish encountering the codend (C_1) will be exposed to one size-selection process (i.e., towing process) and described by parameters L_{501} and SR_1, while the remaining fraction (1.0-C_1) will be exposed to another size-selection process (i.e., haulback) and described by parameters L_{502} and SR_2. The overall DLogit model L_{50} and *SR* parameters considers both C_1 and 1.0-C_1 values and are estimated using a statistical method implemented in SELNET (Sistiaga et al., 2010). The five model functions evaluated are:

$$r_{av}(l,\boldsymbol{v}) = \begin{cases} Logit(l, L50, SR) \\ Probit(l, L50, SR) \\ Gompertz(l, L50, SR) \\ Richard(l, L50, SR, 1/\delta) \\ DLogit(l, C_1, L50_1, SR_1, L50_2, SR_2) = C_1 \times Logit(l, L50_1, SR_1) + (1.0 - C_1) \times Logit(l, L50_2, SR_2) \end{cases}$$

For complete model details see Herrmann et al. (2016), Wienbeck et al. (2014), and Wileman et al. (1996).

To determine which model best describes the data, fit statistics for each model are evaluated. Fit statistics to indicate that a model can adequately describe the data are p-values >0.05, and deviance not to exceed degrees of freedom by approximately two times. Of the models with acceptable fit statistics, the model with the lowest AIC value (Akaike, 1974) is selected as the best model. Following model selection, Efron percentile 95% confidence interval (CI) limits (Efron, 1982) for L_{50} and *SR* were estimated off 1,000 bootstrap repetitions using a double bootstrapping method implemented in SELNET to account for both within-tow and between-tow variation. This approach is the same method used by Sistiaga et al. (2010) and Herrmann et al. (2012) to avoid underestimating CI limits for selectivity curves when pooling tow data. To determine if the selectivity curves differed significantly for a species between any two of the four codends, we took the following approach: For non-flatfish (sablefish and shortspine thornyhead) we assumed the L_{50} would be greater with a greater mesh size, and the 114 mm T90 would have a larger L_{50} than the 114 mm diamond codend (as has been shown in previous studies), and the p-value was calculated as the number of times out of the one million pairs of bootstrap L_{50s} that the L_{50} for Codend A was less than the L_{50} than Codend B. For a one-sided test with α=0.05, if this was less than 50,000 (5%), then the difference was deemed significant. For flatfish, we took the same approach across the three T90 codends. However, past experiments have shown that for flatfish the diamond codend has a larger L_{50} than the T90 codend for flatfish. So the one-sided test was reversed to reflect that. For the 127 mm T90 to 114 mm diamond codend test, no assumption was made about which would be expected to have a larger L_{50}, so a two-sided test was conducted, so that the threshold number of simulations with Codend A less than Codend B (or vice versa) would be 25,000.

Results

Rex sole

The mean L_{50} value of rex sole caught in the 140 mm T90 codend was significantly larger than the mean L_{50} value of the 114 mm diamond and 114 mm T90, and 127 mm T90 codends (Tables 3 and 4). The mean L_{50} value of the 114 mm T90 codend was significantly smaller than the 114 mm diamond codend. While mean selectivity curves for rex sole (Figs. 1 and 2) show selectivity confidence interval overlap (Fig. 3) between the 114 mm diamond and 114 mm T90 and 127 mm T90 codend around L_{25}, and for all three nets above L_{75}, there is clear separation of the selectivity for the 3 nets at L_{50} (Fig. 2). The 114 mm T90 and 127 mm T90 codends exhibited the narrowest selection ranges and thus the steepest selectivity curves (Table 3). Acceptable fit statistics were observed for the 114 mm diamond and 140 mm T90 codends. However, a p-value <0.05 for the 114 mm T90 codend required further assessment to determine if the model was adequately describing the data for rex sole. The assessment indicated the p-value <0.05 was due to overdispersion of the data rather than the inability of the model to adequately describe the data.

Dover sole

The mean L_{50} value of Dover sole caught in the 140 mm T90 codend was significantly larger than the mean L_{50} value of the 114 mm diamond and 114 mm T90, and 127 mm T90 codends. The mean L_{50} value for the 114 mm diamond codend was significantly larger than the 114 mm T90 codend, but not the 127 mm T90 codend (Tables 3 and 4). Mean selectivity curves for Dover sole illustrate the closer selectivity similarities between the 114 mm diamond, 114 mm T90, and 127 mm T90 codends and the larger selectivity differences from the 140 mm T90 codend (Figs. 2-4). As occurred in rex sole, the mean L_{50} value for Dover sole was smallest in the 114 mm T90 codend. In general, the T90 codends showed narrower selection ranges and steeper selectivity curves than the 114 mm diamond codend.

Shortspine thornyhead

The mean L_{50} value of shortspine thornyhead caught in the 140 mm T90 codend was significantly larger than the mean L_{50} value of the 114 mm diamond, 114 mm T90, and 127 mm T90 codends (Tables 3 and 4). While a smaller mean L_{50} value occurred in the 114 mm diamond codend than the 114 mm T90 codend, the mean L_{50} values did not differ statistically between the two codends as suggested by their substantially overlapping 95% CIs at L50 (Table 3, Fig. 3). Mean selectivity curves for shortspine thornyhead show the selectivity similarities between the 114 mm diamond, 114 mm T90, and the 127 mm T90 codend and their selectivity differences from the 140 mm T90 codend (Figs. 2 and 5). In general, the T90 codends showed narrower selection ranges and steeper selectivity curves than the 114 mm diamond codend.

Sablefish

The mean L_{50} value of sablefish caught in the 140 mm and 127 mm T90 codends were significantly larger than the mean L_{50} value of those caught in the 114 mm diamond codend (Tables 3 and 4). The mean L_{50} values of sablefish did not differ significantly between the two 114 mm codends tested, as too few fish were caught in the cover for the models to detect any significant differences (Figs. 2 and 6). Overall, the 114 mm T90 and 127 mm T90 codends had larger mean L_{50} values and narrower selection range 95% CIs than the 114 mm diamond codend, and the 140 mm T90 codend had a larger mean L_{50} value and narrower selection range 95% CIs than the 114 mm T90 codend (Table 3). As occurred in shortspine thornyhead, the mean L_{50} value for sablefish was smallest in the 114 mm diamond codend. Mean selectivity curves for sablefish for the four codends tested are shown in figures 2 and 6.

Discussion

Rotating diamond mesh 90° in orientation can affect the selection properties of a codend. In this study, mean L_{50} values for rex sole and Dover sole in general were smaller in the 114 mm T90 and 127 mm T90 codends than the 114 mm diamond codend. For shortspine thornyhead and sablefish, the opposite trend was consistently seen (Table 3), with larger mean L_{50} values occurring in the 114 mm T90 and 127 mm T90 codends than the 114 mm diamond codend. The 140 mm T90 codend showed significantly different selectivities from the other three codends for rex sole, Dover sole, and shortspine thornyhead. The mean L_{50} value for sablefish were largest in the 140 mm and 127 mm T90 codends, and were significantly different than the 114 mm diamond codend, but not from the 114 mm codend. General findings from this study noting smaller mean L_{50} values for flatfishes, but larger mean L_{50} values for roundfishes occurring in the 114 mm T90 and 127 mm T90 codends than the 114 mm diamond codend are similar to previous studies comparing diamond codends to T90 codends (Wienbeck et al. 2011; Herrmann et al. 2013; Tokaç et al. 2014), and square mesh codends (Perez-Comas et al. 1998; Wallace et al. 1996; He 2007) with similar mesh size.

Prior to this study, codend selectivity research off the U.S. west coast has focused on diamond mesh and square mesh codends. Wallace et al. (1996) and Perez-Comas et al. (1998) examined the selection properties of 114 mm, 127 mm, and 140 mm diamond, and 114 mm, and 127 mm square mesh codends. In general, their results showed total discard rates decreased with increasing mesh sizes for both diamond and square mesh codends. A drop in catch utilization also corresponded with increasing mesh size, with the highest loss occurring in the 140 mm diamond codend. In the present study, where the size-selection properties of 114 mm, 127 mm, and 140 mm T90 mesh, and 114 mm diamond mesh codends were evaluated, the 114 mm and

127 mm T90 codends showed a consistent trend of increasing the retention of flatfishes while lowering catches of smaller-sized shortspine thornyhead and sablefish than the 114 mm diamond and 140 mm T90 codends. Perez-Comas et al. (1998) observed a similar result when comparing a 114 mm square mesh codend to a 114 mm diamond codend, with more immature and unmarketable-sized flatfishes, such as rex sole and Dover sole, retained in the square mesh codend. They observed the opposite for roundfishes. Wallace et al. (1996) presented similar findings in the outer nearshore fishery (91-183 m depth), where the percentage of roundfishes is typically higher, with the 114 mm square mesh codend performing better than the 114 mm diamond codend at reducing roundfish discards. In the inner nearshore fishery (0-91 m depth), where the proportion of flatfishes is generally higher, they found the 114 mm diamond codend performed better at limiting discards. Results from the current study, indicate that the 114 mm and 127 mm T90 codends may perform better at reducing catches of smaller-sized roundfishes than the 114 mm diamond codend. In the DTS fishery, where sablefish have become a constraining species, the 114 mm and 127 mm T90 codends could potentially benefit fishermen by reducing their catch rate of smaller-sized sablefish and shortspine thornyhead, while allowing them more opportunities to catch their Dover sole IFQs. While the 140 mm T90 codend was effective at reducing catches of smaller-sized flatfishes and roundfishes, as indicated by the mean L_{50} values for this codend, this codend would be economically unfeasible for use (under current management regulations and market fish sizes) as it exhibited a considerable catch loss of marketable-sized fishes.

Although there may be clear benefits for using T90 codends in the LE groundfish bottom trawl fishery, codend circumferences other than those used in this study may improve results for trawl fishermen. In a simulated study on haddock *Melanogrammus aeglefinus* (Herrmann et al. 2007), and in a field study in the Baltic cod trawl fishery (Wienbeck et al. 2011), reducing the number of meshes in the circumference of T90 and diamond mesh codends improved size-selection characteristics (i.e., increase mean L_{50} values). While both studies demonstrated that T90 and diamond codends with reduced circumferences improved selectivity, best selection results were achieved in the T90 codends evaluated with reduced circumferences.

Identifying a particular codend mesh size and mesh configuration that can effectively reduce discards, while limiting catch loss, in multispecies groundfish bottom trawl fisheries has challenged researchers (Perez-Comas et al. 1998; Wallace et al. 1996; He 2007; Herrmann et al. 2013). In several cases, the selectivity for some species improves whereas the selectivity of other species decreases. In these fisheries, where the composition of flatfishes and roundfishes can change spatially and temporally, the use of different codend mesh sizes and mesh configurations as fishing operations change would most likely improve fishermen's ability to enhance trawl selectivity, relative to using a single codend mesh size and configuration across the whole fishery. Wallace et al. (1996) illustrated a good example of how the use of different codend mesh sizes and configurations could improve trawl selectivity in the U.S. West Coast groundfish bottom trawl nearshore fishery. In their study, square mesh codends were found to perform best at reducing total discard rates in the outer nearshore fishery (91-183 m depth) where assemblages of arrowtooth flounder *Atheresthes stomias*, Pacific cod *Gadus macrocephalus*, sablefish, lingcod *Ophiodon elongatus*, and Dover sole are targeted, whereas diamond codends of at least 114 mm did better in the inner nearshore fishery (0-91 m depth) where Pacific sanddab *Citharichthys sordidus*, English sole *Parophrys vetulus*, rex sole, and rockfishes are the main targeted species. Helping fishermen identify more selective trawl gear that can reduce retention of unmarketable-sized fishes, as well as species with relative low ACLs or allocations, will allow them to more effectively utilize their IFQs and increase their economic benefits, and be beneficial to fishermen, coastal communities, management, and the resource.

In conclusion, the size-selection characteristics of 114 mm, 127 mm, and 140 mm T90 mesh, and 114 mm diamond mesh codends were evaluated for two flatfish species and two roundfish species commonly caught over the continental shelf break and upper slope of the U.S. west coast. Compared to the traditional diamond mesh codend, findings from this study indicate that 114 mm and 127 mm T90 mesh codends can improve catch utilization of flatfishes while reducing discards of juvenile and unmarketable-sized roundfishes.

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Table 1. Length data used to model the size-selectivity for rex sole and Dover sole for each codend. DM = diamond mesh.

	Rex sole				Dover sole			
	114 DM	114 T90	127 T90	140 T90	114 DM	114 T90	127 T90	140 T90
No. of tows	13	14	12	15	14	15	13	16
No. in codend	2,073	2,746	584	503	8,064	7,674	3,860	2,657
No. in cover	3,053	3,975	570	3,114	7,228	5,194	851	6,268
Length span (cm)	21-42	19-42	23-41	22-42	25-60	24-58	26-63	23-60

Table 2. Length data used to model the size-selectivity of shortspine thornyhead and sablefish for each codend. DM = diamond mesh.

	Shortspine thornyhead				Sablefish			
	114 DM	114 T90	127 T90	140 T90	114 DM	114 T90	127 T90	140 T90
No. of tows	14	14	13	16	14	15	13	16
No. in codend	2,190	2,732	784	745	5,439	1,893	1,686	1,743
No. in cover	4,948	5,794	1,601	5,248	208	83	51	290
Length span (cm)	16-74	16-63	16-72	16-74	40-88	43-90	44-92	39-92

Table 3. Mean model selectivity results. Values in parentheses are Efron percentile bootstrap 95% confidence limits. DF = degrees of freedom; DM = diamond mesh; SSTH = shortspine thornyhead.

Species	Codend	Model	L_{50}	*SR*	P-value	Deviance	DF
Rex sole	114 DM	Logit	33.1[b] (32.3-34.9)	6.5 (5.0-8.7)	0.4338	20.4	20
	114 T90	DLogit	31.8[a] (31.2-32.4)	3.8 (3.1-4.8)	0.0051	38.5	19
	127 T90	Logit	32.7[b] (32.4-33.2)	3.7 (3.1-4.4)	0.8467	12.0	18
	140 T90	Logit	36.4[c] (35.8-37.5)	4.7 (3.8-5.8)	0.1827	24.4	19
Dover sole	114 DM	DLogit	34.9[b] (33.9-35.9)	4.5 (3.0-7.8)	0.1125	40.8	31
	114 T90	Probit	33.6[a] (33.0-34.2)	3.5 (3.2-4.0)	0.9959	15.5	33
	127 T90	DLogit	34.0[ab] (33.3-34.4)	2.4 (1.3-3.5)	0.5788	29.8	32
	140 T90	Probit	39.2[c] (38.3-40.1)	3.6 (3.0-4.2)	0.9780	21.0	36
SSTH	114 DM	DLogit	28.4[a] (27.5-30.6)	8.0 (5.9-11.7)	0.9521	28.8	43
	114 T90	DLogit	30.0[a] (28.7-31.7)	6.4 (5.1-8.2)	0.1317	50.1	40
	127 T90	Richard	31.8[b] (30.6-33.0)	5.8 (5.0-6.7)	1.0000	20.7	51
	140 T90	Richard	36.3[c] (35.0-37.4)	6.7 (5.4-7.9)	0.9563	36.8	53
Sablefish	114 DM	DLogit	42.2[a] (31.2-44.9)	2.6 (0.1-14.5)	0.9815	23.6	40
	114 T90	Gompertz	43.9[ab] (42.3-45.5)	5.1 (4.1-6.5)	0.8082	34.8	43
	127 T90	Probit	44.9[b] (43.5-46.3)	5.2 (3.9-6.5)	1.0000	15.5	45
	140 T90	DLogit	46.5[b] (42.9-48.5)	7.8 (4.4-51.5)	0.9998	17.9	44

Table 4. Significant differences (p-values) in the mean L_{50} values for rex sole, Dover sole, shortspine thornyhead (SSTH), and sablefish between the codends tested. Values in bold represent significant values. DM = diamond mesh.

	114 T90	127 T90	140 T90
Rex sole			
114 DM	**<0.05**	>0.05	**<0.05**
114 T90		**<0.05**	**<0.05**
127 T90			**<0.05**
Dover sole			
114 DM	**<0.05**	>0.05	**<0.05**
114 T90		>0.05	**<0.05**
127 T90			**<0.05**
SSTH			
114 DM	>0.05	**<0.05**	**<0.05**
114 T90		>0.05	**<0.05**
127 T90			**<0.05**
Sablefish			
114 DM	>0.05	**<0.05**	**<0.05**
114 T90		>0.05	>0.05
127 T90			>0.05

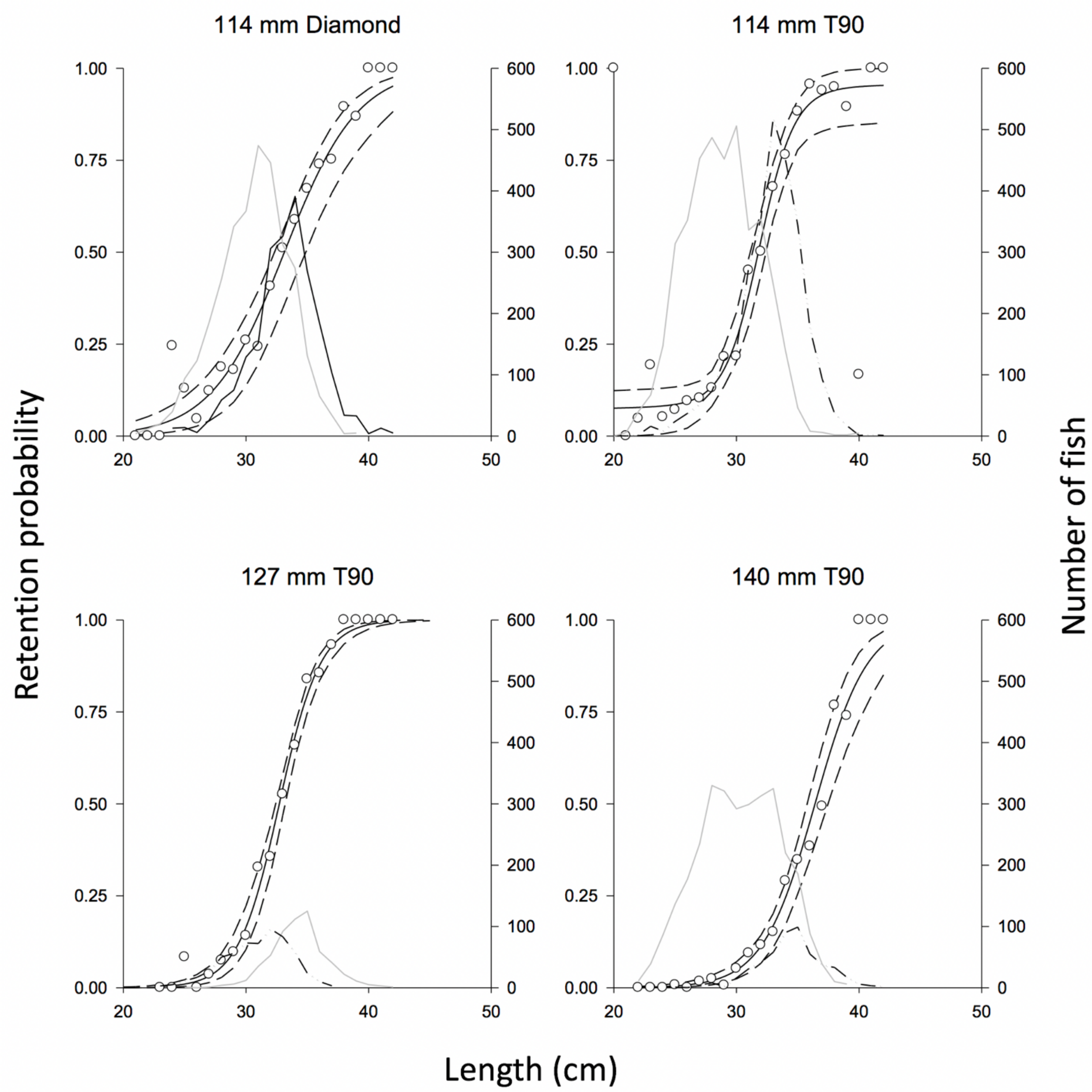

Figure 1. Mean selectivity curves modeled for rex sole. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the cover; black dashed-dot-dot lines are the number of fish caught in the codend.

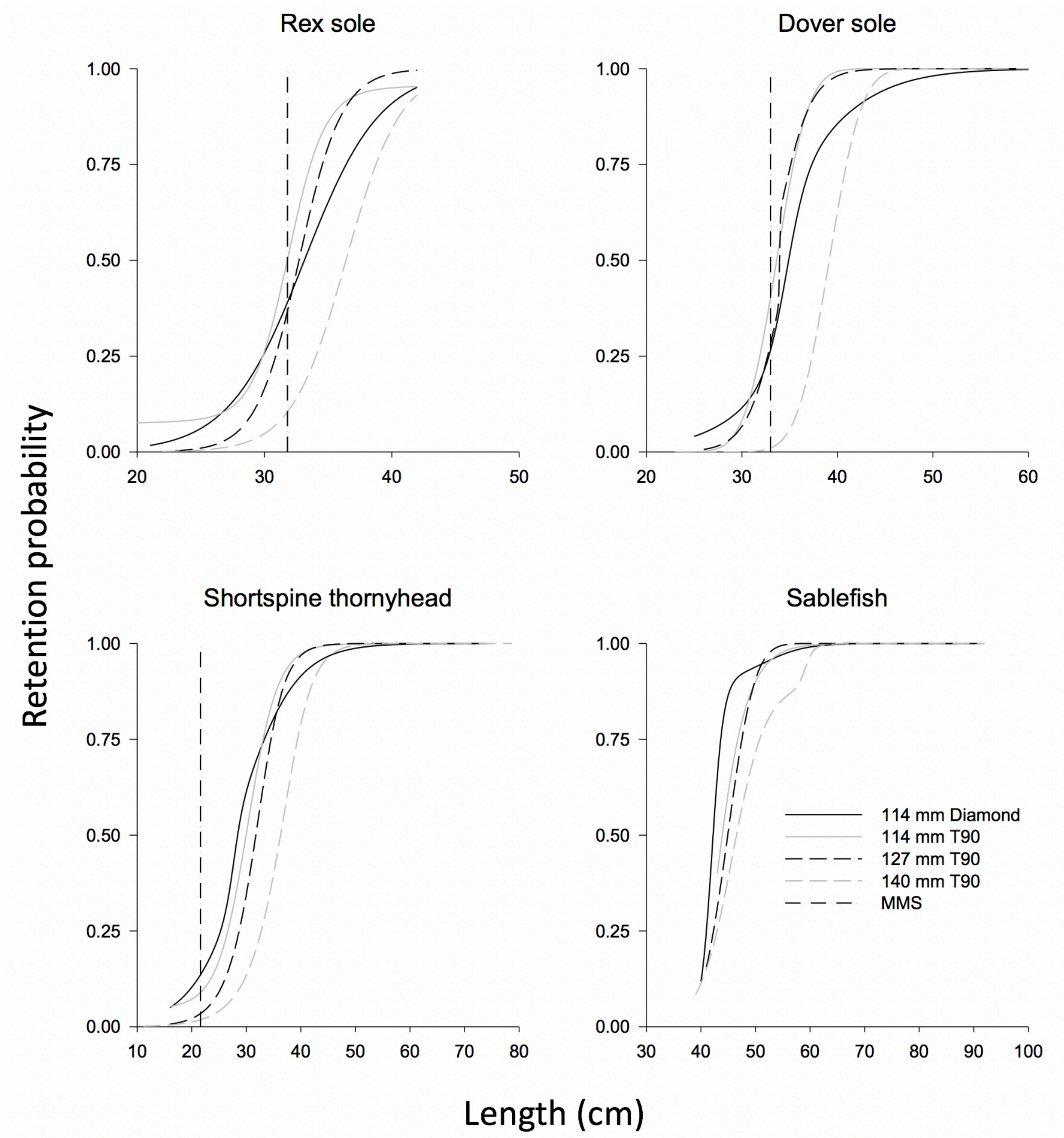

Figure 2. Comparison of the mean size-selection curves estimated for rex sole, Dover sole, shortspine thornyhead, and sablefish for each codend tested. The vertical black dashed lines represent the minimum market size (MMS).

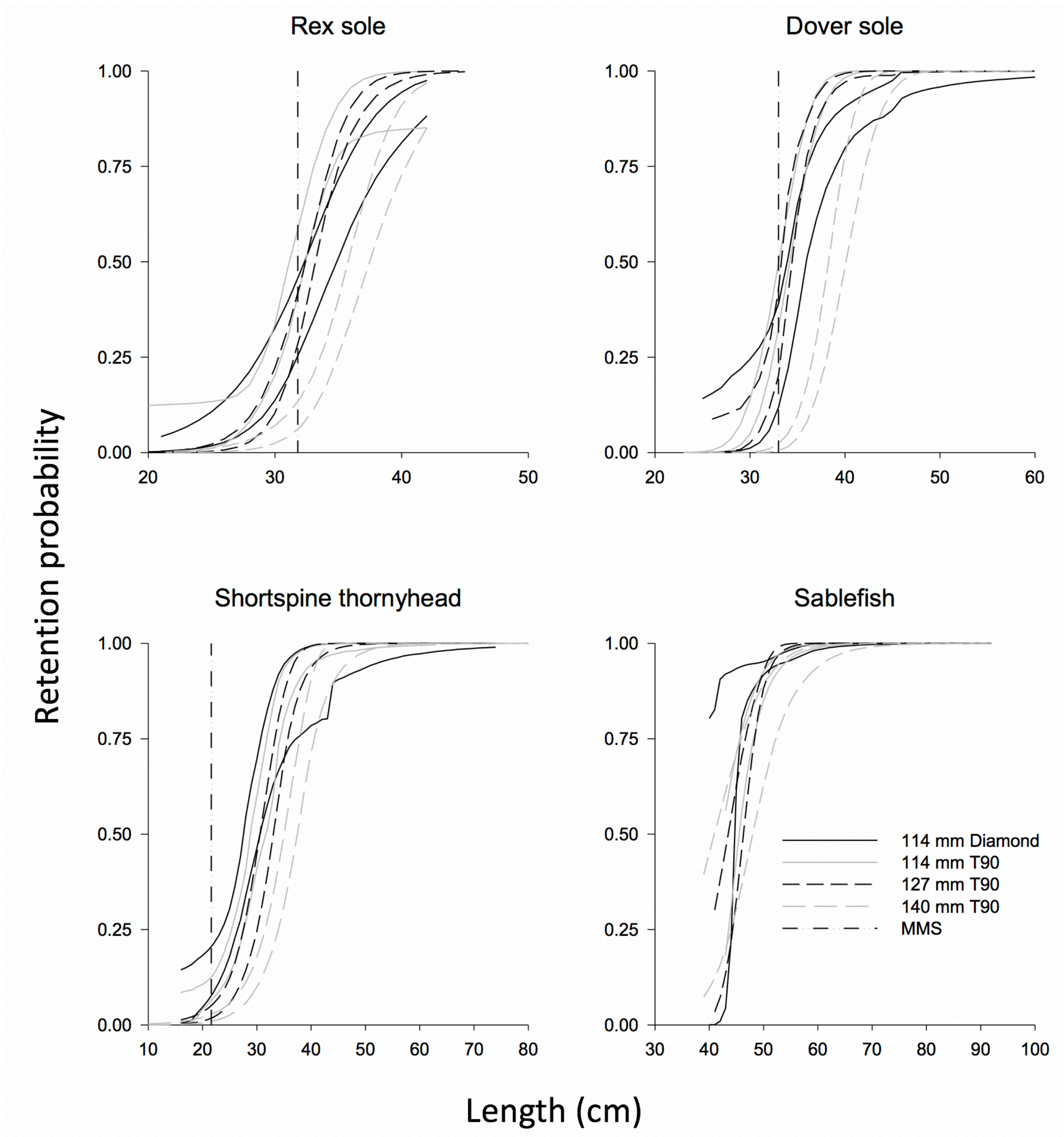

Figure 3. Comparison of the 95% confidence limits for the size-selection curves estimated for rex sole, Dover sole, shortspine thornyhead, and sablefish for each codend tested. The vertical black dashed lines represent the minimum market size (MMS).

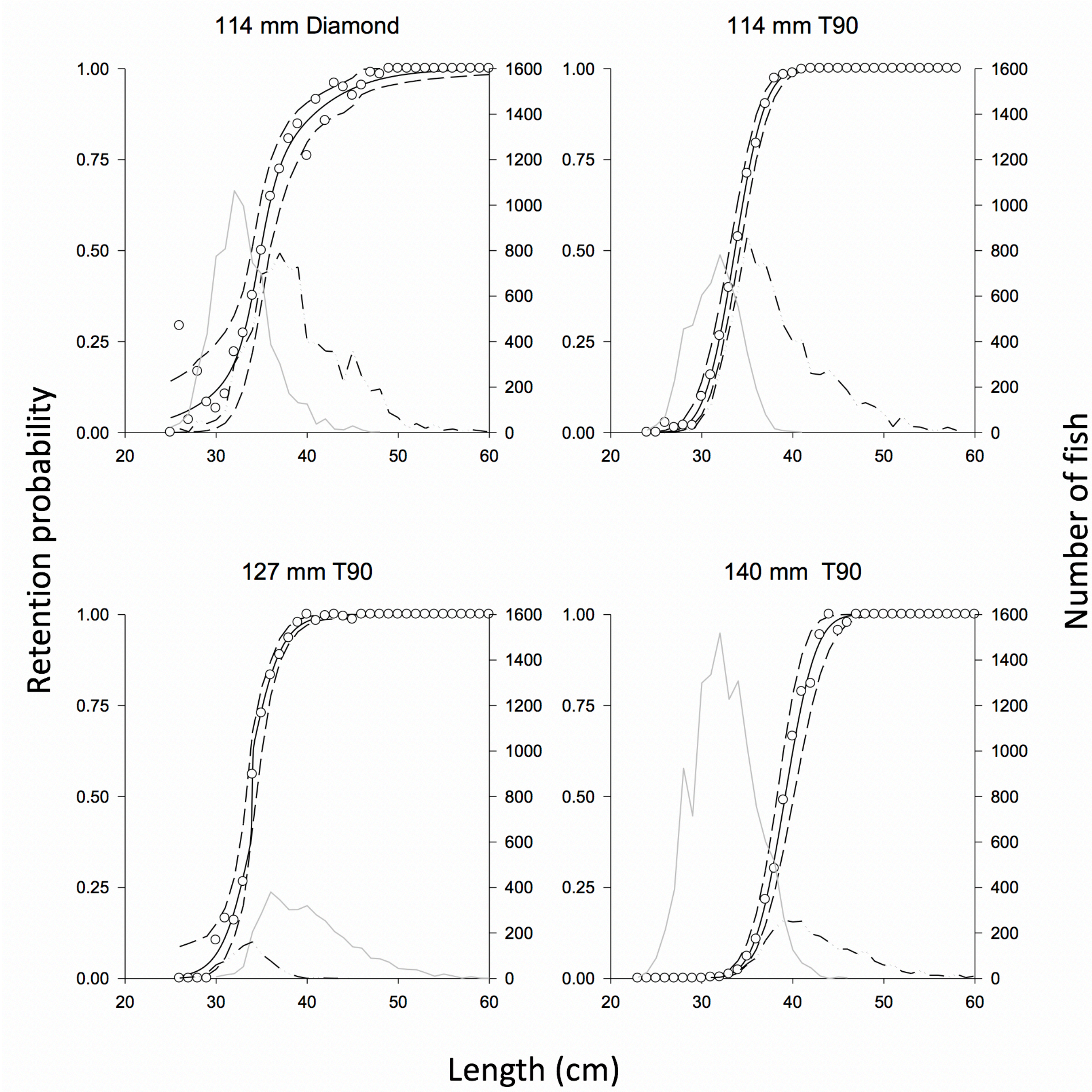

Figure 4. Mean selectivity curves modeled for Dover sole. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the cover; black dashed-dot-dot lines are the number of fish caught in the codend.

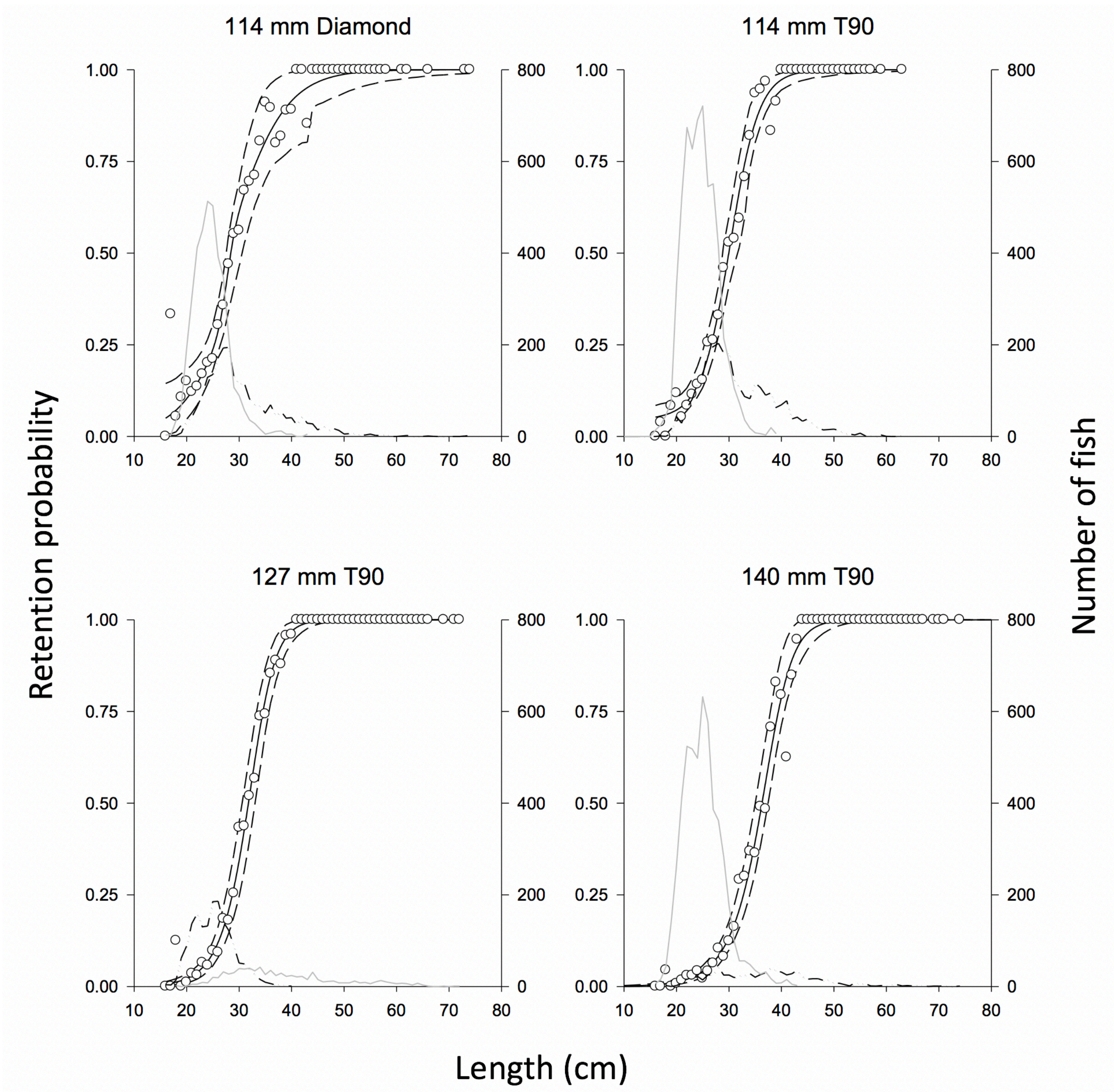

Figure 5. Mean selectivity curves modeled for shortspine thornyhead. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the cover; black dashed-dot-dot lines are the number of fish caught in the codend.

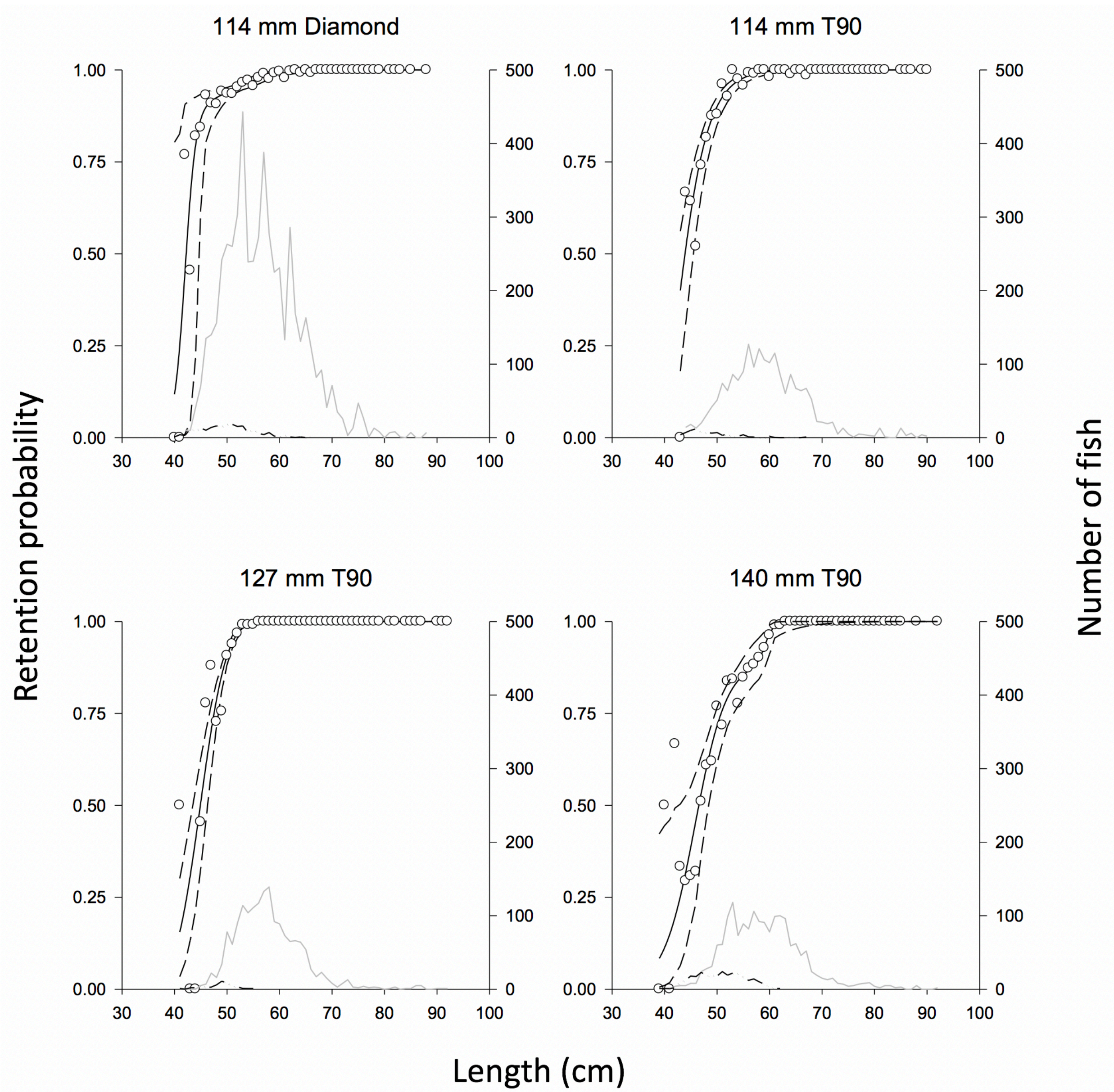

Figure 6. Mean selectivity curves modeled for sablefish. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the cover; black dashed-dot-dot lines are the number of fish caught in the codend.