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Codend Selection of Winter Flounder *Pseudopleuronectes americanus*

David G. Simpson

U.S. Department of Commerce

NOAA TECHNICAL REPORT NMFS

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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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National Marine Fisheries Service
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DAVID G. SIMPSON
Marine Fisheries Program
Connecticut Department of Environmental Protection
P.O. Box 248
Waterford, Connecticut 06385

ABSTRACT

Codend selection of winter flounder (*Pseudopleuronectes americanus*) in 76-127 mm mesh codends was examined from experiments conducted in Long Island Sound during the spring of 1986-87. The results show a slightly larger size at selection than was found in earlier work as indicated by the selection factor, 2.31 in the present study compared with 2.2 and 2.24 from previous studies. Diamond mesh was found to have a length at 50% retention about 1 cm longer (L_{50}=22.6 cm), and a selection range (3.4 cm) about 1 cm narrower, than square mesh in 102-mm codends. Tow duration varied from 1 to 2 hours using 114-mm diamond mesh. As has been found in previous studies, tow duration and L_{50} are positively related, with 1-hour tows averaging 24.6 cm and 2-hour tows averaging 26.6 cm. The importance of the slope of the selection curve was examined in yield-per-recruit analyses by comparing knife-edge and stepwise recruitment. In all mesh sizes, stepwise recruitment provides a more conservative estimate of yield in the presence of a minimum size limit. Differences in yield estimates between the two models were generally small (1-7%), except in the largest mesh size, 127 mm, where yield is overestimated by 10% when assuming knife-edge recruitment.

Introduction

The importance of mesh size, particularly codend mesh size, in determining the length at first capture was documented early in development of the otter trawl fishery (Todd 1906-1908, Russell and Edser 1926, Herrington 1935). Codend selection of winter flounder (*Pseudopleuronectes americanus*) has generally been addressed as part of larger selection experiments on several species but targeting large species such as cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Smolowitz 1983, McCracken 1963), or summer flounder (*Paralichthys dentatus*) (Anderson et al. 1983). McCracken (1963) collected data in 1954 and 1955 on natural fiber codends (untreated manila and tarred cotton) between 111 and 124 mm stretch mesh measure. Although the data were insufficient for precise estimates of length at 50% retention (L_{50}), the author suggested a selection factor, defined as L_{50} divided by the stretch mesh size, of 2.0 for double-stranded manila twine.

Smolowitz (1983) examined winter flounder selection in nylon-constructed codends of 114-mm nominal mesh (103-mm stretch measure) and 154-mm nominal mesh (133-mm stretch measure). Size selection in the 114-mm mesh was evaluated using the covered codend method only, while the 154-mm mesh codend was examined using both covered codend and alternate haul methods. Covered codend experiments gave lengths at 50% retention 2 to 3 cm shorter than the alternate haul method for 154-mm mesh. Similar results were observed for all species considered, including the other flatfish species, yellowtail flounder (*Limanda ferruginea*) and American plaice (*Hippoglossoides platessoides*).

Knife-edge recruitment is often assumed when assessing the effect of a codend mesh-size regulation on long-term yield (Gulland 1963, 1976). Gulland (1963) showed that there is little difference between the calculated yield assuming knife-edge recruitment and that estimated using approximations to the selection ogive. Gulland concluded that only basic information on codend selection (i.e., the selection factor) is required to evaluate changes in yield resulting from moderate changes in codend mesh size or fishing rate unless a large proportion of the yield comes from within the selection curve. However, no minimum legal fish size was considered in these comparisons so that all fish retained by the codend contributed to yield. Assuming knife-edge recruitment, without minimum size limits, results in a more conservative estimate of long-term yield than stepwise recruitment.

Several conditions exist today in the winter flounder fishery which may diminish the utility of yield assessments assuming knife-edge recruitment, particularly when large mesh sizes are considered, since a large proportion of the yield comes from fish within the selection range. Winter flounder are fully exploited through most of their range (NEFC 1986) with evidence of growth overfishing in some areas (NEFC 1986, Gibson 1987). Winter flounder length-frequencies have become truncated both inshore (Foster 1986) and on Georges Bank (Gabriel and Foster 1986) as landings decline in the largest market categories, "large" and "lemon sole."

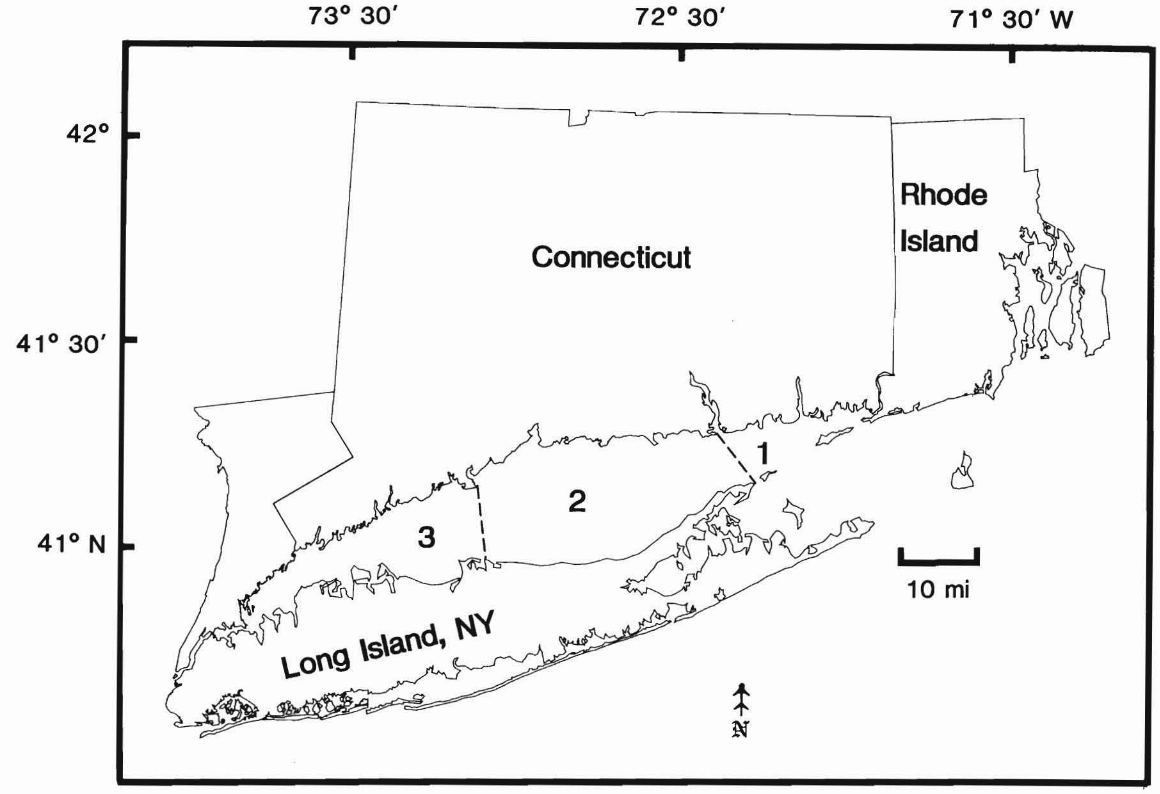

Figure 1
Long Island Sound and area subdivisions for commercial and survey catch data.

Finally, minimum fish size-regulations are enforced in many areas, both inshore and offshore. Fish below the minimum size that are retained by the trawl do not contribute to yield but are subjected to high discard mortality (Jean 1963, Lux 1968, Powles 1969).

In Long Island Sound (Fig. 1) the length-frequency of winter flounder is highly skewed to the left, with between 77% (Area 1) and 95% (Area 3) of the population (by number) below the minimum legal size (27.9 cm) at the height of the spring fishery. The proportion of fish below 21 cm ranges from 34% (Area 1) to 73% (Area 3) (by number) during the same period (CT Dep. Environ. Prot., Mar. Finfish Surv., unpubl. data 1986).

The Long Island Sound fishery is highly dependent on winter flounder near the minimum legal size with 72% (by weight) of the landed catch coming from fish between 28 and 32 cm (CT Dep. Environ. Prot., unpubl. data). Knowledge of both position and slope of the codend selection curve is critical in managing this fishery, given the abundance of small winter flounder in Long Island Sound and the dependence of the fishery on fish near the minimum size limit.

The codend selection experiments on winter flounder mentioned above (Smolowitz 1983, Anderson et al. 1983), using codends constructed of synthetic material, concentrated on large mesh codends that are generally too large for winter flounder. The smallest of these codends (114 mm) examined by Smolowitz (1983) is within the range considered reasonable for winter flounder (with a minimum size limit of 27.9 cm), but results for this mesh size are based on covered codend experiments which tend to give smaller sizes at retention than the alternate haul method. Additionally, experiments with all mesh sizes suffered from low sample sizes for fish less than 21 cm. The low availability of these small fish was particularly troubling in the 114-mm mesh codend experiments where only 50 fish, comprising the left half of the selection curve, were taken in the codends and covers from all replicates combined.

Because of the problems associated with these selection experiments (large mesh size, low availability of small fish) on winter flounder and the declining average size of these fish in many areas of the Northwest Atlantic, the Connecticut Department of Environmental Protection initiated selection experiments using a range of mesh sizes (76-127 mm nominal mesh size) considered more appropriate for the winter flounder fishery. These mesh sizes encompass the range generally used in the Southern New England mixed-species fishery and consequently reflect the mesh sizes to which winter flounder are exposed in this region.

Methods

Winter flounder (*Pseudopleuronectes americanus*) were collected only during daylight hours to reduce changes in catchability between day and night trawling during these experiments (Sissenwine and Bowman 1978). A total of 24

1-hour tows were conducted between 5 May and 8 May 1986 to examine the selection properties of four codends (76, 102, and 127-mm diamond and 102-mm square mesh). From 27 April to 7 May 1987 a total of 21 tows (12 1-hour and 9 2-hour) were made to determine the selection properties of a 114-mm diamond mesh codend and to evaluate the effect of tow duration on codend mesh selection. All codend mesh sizes cited in this document are nominal mesh size, the size (metric equivalent) referred to by the manufacturer unless otherwise noted.

All tows were made from the 12.8-m (42-ft) State of Connecticut research vessel *James P. Galligan II* using a combination sweep Wilcox "V" wing high-rise otter trawl. Trawl specifications include a 15.2-m (50-ft) headrope and an 18.3-m (60-ft) footrope. The net was constructed of No. 21 nylon with mesh size decreasing from 127 mm in the wings and belly to 102-mm, with a 76-mm tailpiece. The net was spread by 1.2-m (4-ft) steel "V" doors attached to 18.3-m (60-ft) ground wires, of 9.5-mm (⅜″) diameter, and 27.4-m (90-ft) scissors. The top legs of the scissors were 6.35-mm (¼″) diameter wire, and the bottom legs were 51-mm (2″) rubber cookies. The sweep had one strand of 6.35-mm chain in the wings and two strands of 9.5-mm chain in the belly. All tows were made at a speed of 2.8 to 3.0 knots over ground as determined by Loran C (Northstar 6000). The experimental codends were constructed of No. 84 braided nylon, while the control codend was No. 54 braided nylon. Codends were changed using a "zipper" attachment to the tailpiece of the trawl.

All winter flounder taken were measured to the nearest 1 cm total length. In 1986, 30 codend meshes were measured, at random and when wet, after the last tow of the day for that codend. Meshes were measured to 0.1 mm, stretched with moderate thumb pressure opening the SPI 30-458-4 vernier stainless steel calipers. In 1987, 20 meshes were measured wet, in the same manner as 1986, after six tows (3 1-hour and 3 2-hour duration).

Selectivity of winter flounder was compared between a 51-mm (2 in) control codend and five experimental codends—76 mm (3 in), 102 mm (4 in), 114 mm (4.5 in), and 127 mm (5 in) diamond, and 102 mm (4 in) square mesh. One experimental codend (1986 samples) or tow duration (1987 samples) was examined each day. In 1986, six tows were taken daily for four consecutive days, three tows using the experimental (E) codend for that day and three using the 51-mm control (C). Each experimental tow was paired with a control to determine a retention rate for each tow at 1-cm length intervals. Tows were ordered EC, CE, EC to minimize the number of codend changes as well as temporal variation between experimental and control tows. In order to increase the number of experimental tows each day from three to four in 1987, two experimental (114 mm-mesh) tows were compared with a single control tow. One-hour tows were then treated in two groups and ordered ECE, ECE. Three 2-hour tows were made each day resulting in a single group and ordered ECE.

The retention rate in each experimental codend tow was expressed as a percentage of the control codend catch in each 1-cm length interval (LI) (Gulland 1976). An initial retention rate was calculated for each LI and experimental tow separately, providing one observed retention rate at each LI for every experimental tow made. From these initial retention rates, a three-point moving average (Anderson et al. 1983) was then calculated for each LI (>10 cm) in each experimental tow. All observations subsequent to the first total length at which the three-point moving average reached or exceeded 100% retention were excluded. The remaining observation greater than or equal to 100% in each trial was then set to 99% to accommodate the linearized form of the sigmoid models used to calculate initial parameter estimates. An apparent increase in trawl efficiency with increasing mesh size has been observed for some species by Clark (1963) and Templeman (1963), suggesting that retention rates for large codends could exceed 100% when compared with small mesh. However, in the present investigation, the number of winter flounder larger than the length at 100% retention for the experimental codend did not differ significantly (using chi-square) between the experimental and control codends. This suggests that no increase in trawl efficiency with codend mesh size occurs for winter flounder and that an asymptotic retention rate of 100% is appropriate for this species. A logistic growth curve (Eq. 1) was fitted to the winter flounder retention data for all codends using nonlinear least squares (Ralston and Jennrich 1979). Initial parameter estimates were derived using the regression techniques of Ratkowsky (1983).

$$\text{Percent retained} = A/(1 + \exp(B + Y * TL)) \qquad (1)$$

where Percent retained = percent retained in the codend
A = asymptote (100% retention)
exp = 2.7818
B = slope at the inflection point
Y = rate of exponential decay
TL = total length interval (cm).

The codend selection factor (Jensen 1949) describes the linear relationship between L_{50} and codend mesh size. A codend selection factor can be calculated for any species from experiments with a small number of codends (Gulland 1976). The selection factor (b) (Eq. 2) for winter flounder was calculated using the mean of the stretch mesh measurements for each diamond mesh codend. The 114-mm codend selection factor is based on 1-hour tows only.

$$b = L_{50}/m \qquad (2)$$

where b = codend selection factor
L_{50} = total length at 50% retention (mm)
m = codend mesh size (mm).

Table 1

Sample sizes of winter flounder lengths for each control and experimental tow. One control tow was used for two experimental tows in 114-mm mesh tow groups.

		Winter flounder lengths (cm)		
Codend (mm)	Tow group	Experimental		Control (51 mm)
76	1		96	139
	2		145	258
102 (square mesh)	1		112	719
	2		115	606
	3		191	572
102	1		122	151
	2		93	514
	3		43	570
114 (1 h)	1	143	57	617
	2	102	58	737
	3	125	126	470
	4	95	34	311
114 (2 h)	1	137	73	1004
	2		118	764
	3	114	81	608
127	1		29	347
	2		27	411
	3		25	394

Selection curves based on data collected under controlled conditions (vessel size, trawl configuration, tow duration, geographic area, and time period) must reflect the size selection operating in the commercial fishery if they are to be useful. To evaluate the usefulness of these selection curves in describing the actual selection properties of different size codends when operating in the fishery, data on commercial length-frequencies were compared with length-frequencies from trawl survey cruises conducted monthly in Long Island Sound by the Connecticut Department of Environmental Protection using a 51-mm mesh codend. Commercial vessels measuring 11.0 to 25.3 meters using 76, 102, and 114-mm codends were sampled at sea on eight occasions (24 tows) in areas 2 and 3 of the sound (Fig. 1) between March and May, 1985-87. Survey length-frequencies were taken from April (the earliest month sampled in the survey) and May 1986. Comparisons were made during this Spring period only and examined separately by area to reduce the spatial and temporal variability associated with seasonal movements. The commercial length-frequency was expressed as the cumulative percentage of fish in each 1-cm interval for each mesh size and area. Expected length-frequencies were generated by multiplying the frequency in each 1-cm interval of the survey distribution by the probability of capture determined by the selection curve for the appropriate mesh size. This expected frequency was then expressed as a cumulative percentage to allow comparison with the observed commercial cumulative length-frequency.

Table 2

Parameter estimates and standard errors (SE) for the logistic equation, percent retained$=A/(1+\exp(B+Y*TL))$, relating winter flounder retention rate and total length by mesh size, configuration, and tow duration. Asymptote (A) equals 100%; slope at the inflection point (B) and rate of exponential decay (Y) estimated by nonlinear regression analysis.

Codend (mm)	No. of tow pairs	B	SE of B	Y	SE of Y	r^2
76	2	13.98	1.43	−0.79	0.08	0.96
102 (square mesh)	3	11.01	1.79	−0.51	0.08	0.78
102	3	14.92	1.68	−0.66	0.07	0.92
114 (1-h tows)	8	12.84	1.29	−0.52	0.05	0.83
114 (2-h tows)	5	8.78	0.81	−0.32	0.03	0.79
127	3	12.41	1.51	−0.44	0.05	0.88

Yield-per-recruit analyses were performed using Thompson and Bell's method (Ricker 1975) to assess the effect of codend mesh size on equilibrium yield-per-recruit in the winter flounder fishery. These analyses were performed twice, first assuming knife-edge recruitment at the age corresponding to L_{50} and then using a stepwise approximation to the selection ogive to simulate a gradual recruitment process. Four "steps" in recruitment were used each year based on the retention rate corresponding to the mean length-at-age at the midpoint of each quarter. Yield was also calculated quarterly, from 1,000 recruits beginning at age-1 and terminating at age-12. All fish retained which were greater than the minimum fish size limits enforced in Connecticut (25.4 cm recreational and 27.9 cm commercial) contributed to yield. The trawl fishery comprised 65% of fishing mortality, and recreational made up the remaining 35% (NEFC 1986). Natural mortality (M) was held constant at $M = 0.327$ (Gibson 1987). The average weight at the midpoint of each quarter was calculated using the von Bertalanffy length-age relationship (Eq. 3), and the length-weight relationship of Eq. 4 (NUSCo 1986).

$$Lt_i = L_{max}\,(1 - \exp(-K(Age - t_0))) \qquad (3)$$

where Lt_i = total length attained quarterly
L_{max} = 402
exp = 2.7818
K = 0.43
Age = age at the midpoint of each quarter year
t_0 = −0.485.

$$\log_{10} Wt = a + b(\log_{10} Lt_i) \qquad (4)$$

where $\log_{10}$ Wt = $\log_{10}$ weight at length Lt_i
a = −2.261
b = 3.226
Lt_i = as above.

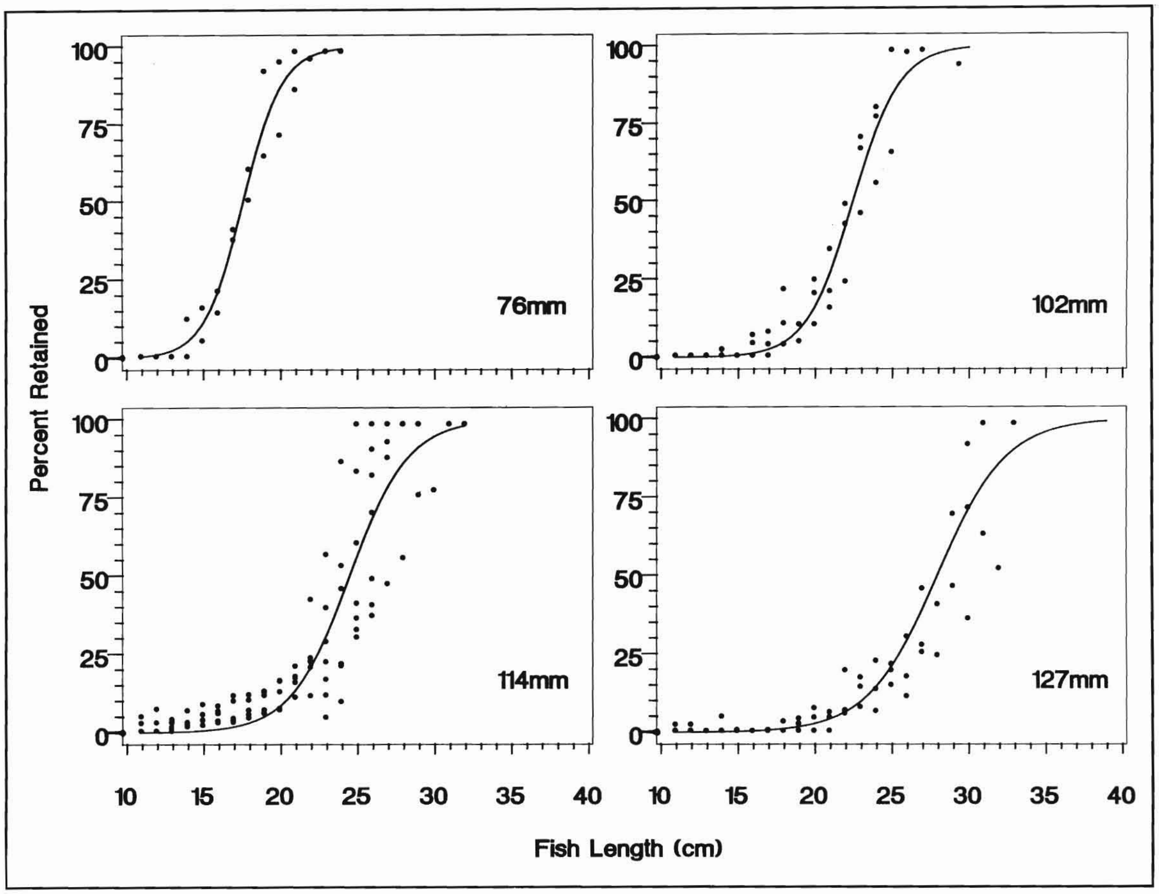

Figure 2
Selection curves for winter flounder in 76-127 mm diamond mesh codends, with plots of percent retention-at-length data.

Recruitment to the fishing grounds was assumed to be age-1. Two fishing mortality rates (*F*) were used for comparison, $F = 0.38$, and $F = 0.551$. These rates are the estimated optimum (when a Shepard stock-recruitment function is merged with yield-per-recruit, and length-at-first-capture = 280 mm) and present fishing rates, respectively (Gibson 1987). For simplicity, both fishing and natural mortality were assumed to be constant throughout the year. Two discard mortality rates (50 and 100%) were also used to evaluate the importance of this variable on yield-per-recruit.

Results

A total of 11,916 winter flounder were captured in 45 tows (19 control, 26 experimental) during mesh selection experiments in 1986 (6,142 fish/24 tows) and 1987 (5,774 fish/21 tows). Large catches in the control codends (Table 1) and a wide distribution in the length-frequencies (9-45 cm) made an adequate assessment of retention rates possible. Two experimental tows (76 mm, and 114 mm 2-hour) were excluded from analysis due to poor net performance (76 mm) and excessive mudding (114 mm 2-hour).

Winter flounder retention rates in five codends

The logistic model (Table 2) provided significant fits ($P < 0.01$) to retention data from each mesh size examined (*t*-test of correlation coefficient, Rohlf and Sokal 1969). Codend size selection of winter flounder exhibited a fairly uniform shift toward greater size at selection with the use of larger codends (Fig. 2). The selection factor varied without trend between 2.23 (127-mm codend) and 2.38 (114-mm codend) with a mean of 2.31 (Table 3). This selection factor is larger than that reported for winter flounder by Smolowitz (1983) who reported a range of selection factors from 2.04 to 2.27, and suggested an overall selection factor of 2.2. This selection factor is also larger than was found by Anderson et al. (1983) who found the selection factor to vary from 2.13 to 2.36 with a mean of 2.24.

The selection range (the difference in total length between 75% and 25%, retention) varied between 2.8 (76-mm mesh) and 5.0 cm (127-mm mesh). The selection ranges in the other codends were 4.3, 3.4, and 4.3 for 102-mm square, 102-mm diamond, and 114-mm (1-hour tow duration) mesh size codends, respectively. A significant ($r = 0.88$, $P < 0.05$) positive trend in selection range with mesh size was detected

Table 3

Codend mesh size (nominal) and mean measured stretch mesh dimensions of diamond mesh codends used in calculating the selection factor. Additionally, the winter flounder length at 50% retention (L_{50}) and the calculated selection factor.

Codend size (nominal)	Stretch mesh measure (mm)	L_{50}	Selection factor
76	74.7	177	2.36
102	98.7	226.1	2.29
114	103.9	246.9	2.38
127	126.7	282.1	2.23
		Mean	2.31

by *t*-test of correlation coefficient (Rohlf and Sokal 1969). An increase in selection range with mesh size has also been shown for several important species in the Northeast Atlantic (Robertson and Stewart 1986).

Diamond and square mesh codend configurations were compared using 102-mm mesh codends. The square mesh codend retained smaller fish than the diamond mesh, though the difference was small (0.9 cm at L_{50}). At the same time, the selection range is larger in the square mesh codend configuration than in the diamond mesh (as indicated above) resulting in a smaller size at selection at retention rates less than 75%, while the size at 75% selection or greater is similar to the 102-mm diamond mesh (Fig. 3).

The effect of tow duration on codend selection was to increase L_{50} by 2 cm (Fig. 4). The L_{50} was 24.6 cm in 1-hour tows and 26.6 cm in 2-hour tows. Clark (1957) and Beverton (1964) observed similar increases in size at selection with increased tow duration.

Comparison of observed and expected commercial length-frequencies from three codends

Agreement between observed and expected commercial length-frequencies from 76, 102, and 114 mm mesh codends was generally good (Fig. 5). Commercial length-frequencies are based on 24 tows from which a random subsample of 2,826 winter flounder were measured (Table 4). The best agreement between observed and expected catches was seen in Area 3 using 76-mm mesh codends where little deviation occurred.

Commercial catches in 102-mm mesh were compared with expected catches in two different areas. In Area 2, 50% of the commercial catch was less than 26.8 cm, 1.3 cm larger than expected (25.5 cm). The expected length-composition at first slightly underestimated the proportion each length increment contributed to the catch; then at approximately 23 cm, the contribution of each length increment was slightly overestimated.

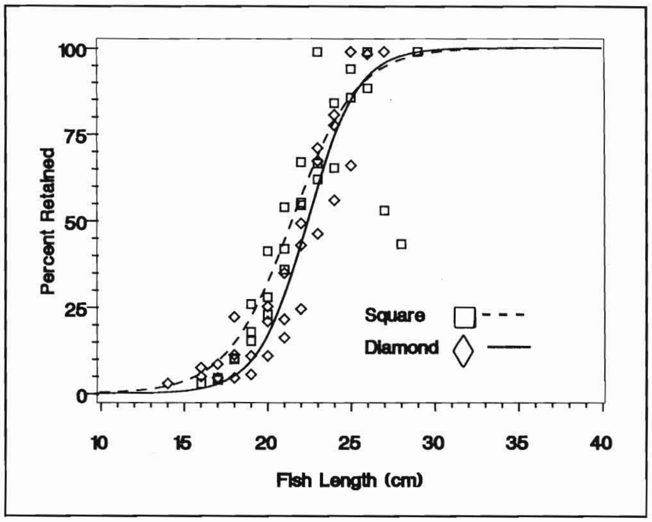

Figure 3
Selection curves for winter flounder in 102-mm diamond and 102-mm square mesh configuration codends, with plots of percent retention-at-length data.

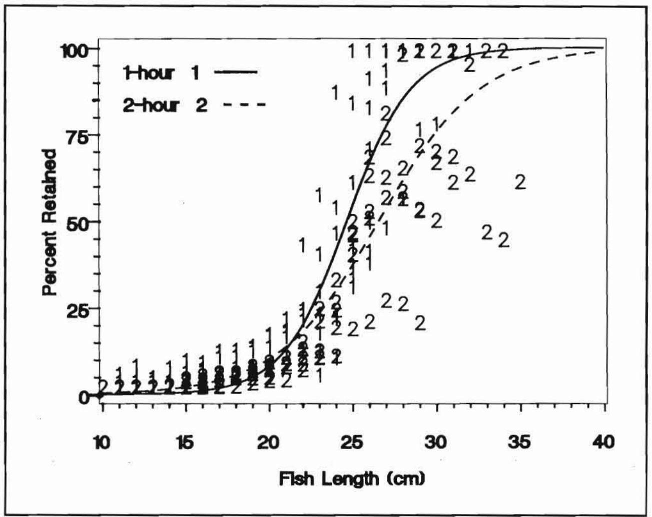

Figure 4
Selection curves for winter flounder in 1 and 2-hour tows using 114-mm mesh codends, with plots of percent retention-at-length data.

When comparisons were made with 102-mm mesh in Area 3, a bias toward underestimating the proportion of the population less than 24 cm was apparent. The observed median length in this case was 1.5 cm smaller than expected (22.5 cm observed, 24 cm expected). The observed and expected catch-compositions were in good agreement above the median length. Fish between 16 cm and 21 cm made up a larger than expected proportion of the commercial catch as evidenced by the steeper slope in the observed cumulative length-frequency in this region of the curve (Fig. 5).

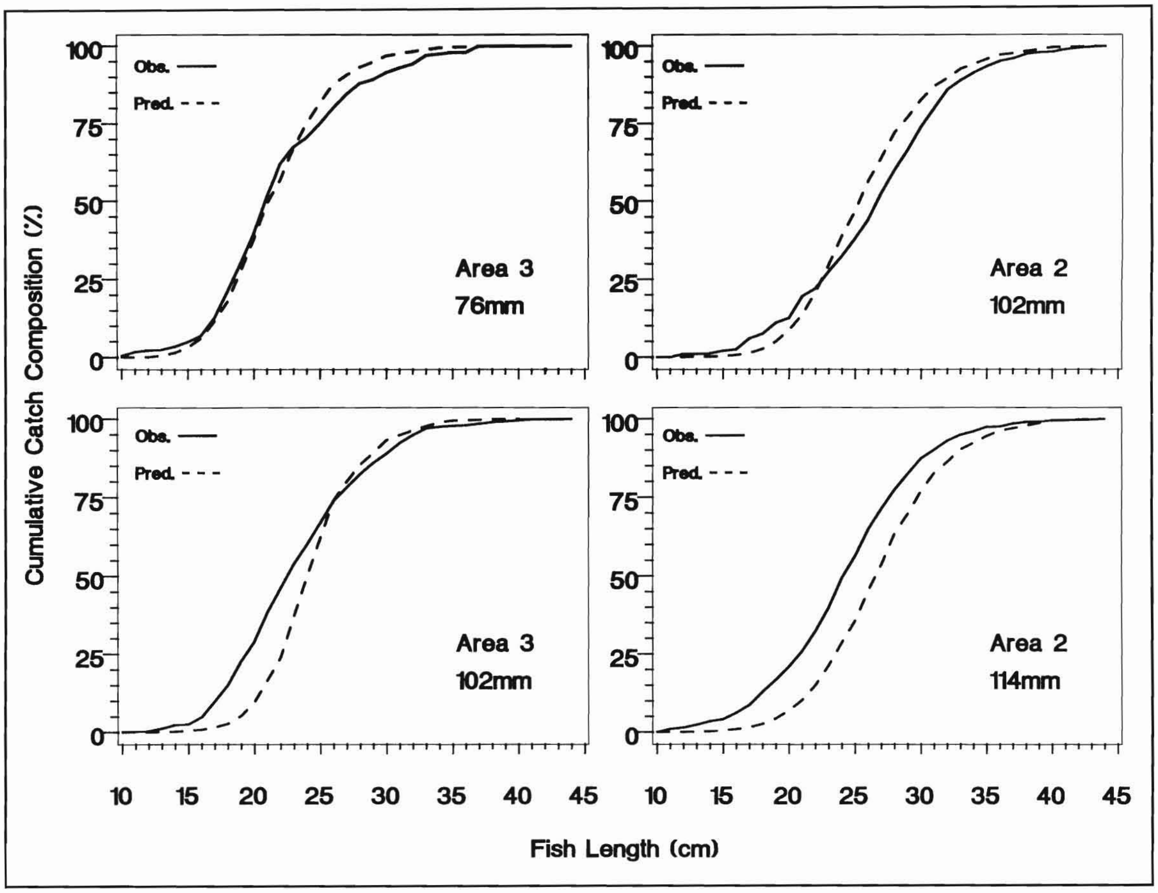

Figure 5
Observed and expected commercial length-frequency distribution from Areas 2 and 3 of Long Island Sound using 76, 102, and 114-mm mesh codends.

Two vessels were sampled on three occasions using 114-mm mesh codends. The observed median length was approximately 24 cm, 2.5 cm shorter than was expected (26.5 cm). Observed and expected catch-compositions diverge between 16 cm and 25 cm, then slowly converge thereafter. A systematic bias toward underestimating the proportion of smaller fish (<25 cm) in the catch was apparent (Fig. 5).

Yield-per-recruit

The effect of codend mesh size on yield-per-recruit was determined at two levels of discard mortality (50 and 100%) and two fishing rates ($F = 0.38$ and $F = 0.551$) using the Thompson and Bell method (Ricker 1975). Yield-per-recruit was calculated first, assuming knife-edge recruitment at the age corresponding to L_{50} for each codend, then using a stepwise approximation to the selection ogive (Table 5). Knife-edge recruitment consistently overestimated the yield-per-recruit, although the differences from stepwise recruitment were generally less than 5%. The largest difference, 10%, occurred in 127-mm mesh at the higher levels of discard and fishing mortality. No difference in yield could be detected between 102-mm square mesh and 102-mm diamond mesh using knife-edge recruitment. This is because the small increase in L_{50} (1 cm) from the former to the latter mesh configuration occurs within the quarter-year time interval used in computing yield.

The relative increases in yield-per-recruit associated with increasing mesh size were similar using knife-edge and

Table 4
Characteristics of commercial sea samples used in comparing observed and predicted winter flounder length-frequencies from trawl vessels.

Codend (mm)	Area	Vessel size (m)	Avg. tow time (h)	No. of tows	Sample size
76	3	11.6	2.0	2	188
102	2	11.0	2.0	4	383
102	2	12.2	1.0	5	360
102	3	25.3	3.5	2	234
102	3	25.3	2.5	2	393
114	2	15.2	2.5	4	485
114	2	21.9	2.5	2	304

Table 5
Effect of codend mesh size restrictions on yield-per-recruit and a comparison of differences in yield-per-recruit estimates based on assumptions of knife-edge (KR) and stepwise (SR) recruitment.

F	Discard mortality (%)	Codend mesh size (mm)	Yield (kg)		
			Knife-edge	Stepwise	KR/SR
0.38	50	76	0.095	0.093	1.02
		102 (square)	0.101	0.099	1.02
		102	0.101	0.100	1.01
		114	0.104	0.103	1.01
		127	0.110	0.106	1.04
	100	76	0.082	0.079	1.04
		102 (square)	0.092	0.088	1.05
		102	0.092	0.091	1.01
		114	0.098	0.096	1.02
		127	0.110	0.103	1.07
0.551	50	76	0.097	0.095	1.02
		102 (square)	0.106	0.103	1.03
		102	0.106	0.105	1.01
		114	0.111	0.110	1.01
		127	0.121	0.115	1.05
	100	76	0.078	0.074	1.05
		102 (square)	0.093	0.087	1.07
		102	0.093	0.091	1.02
		114	0.102	0.099	1.03
		127	0.121	0.110	1.10

stepwise recruitment except when progressing from 114 mm to 127 mm mesh, particularly at the higher fishing and discard mortality rates. In this case a 19% increase in yield is expected assuming knife-edge recruitment, while a more conservative 11% gain, is estimated from the stepwise recruitment model.

Discussion

The results of this study indicate a slightly larger selection factor (2.31) for winter flounder than the 2.2 found by Smolowitz (1983) or the 2.24 found by Anderson et al. (1983). A substantially larger L_{50} is estimated in this study using 114-mm (4.5 in.) nominal mesh than was found by Smolowitz (1983) using the same size mesh ($L_{50} = 247$ mm versus $L_{50} = 208$ mm). Much of this disparity is probably due to differences in experimental design, with Smolowitz (1983) based on the covered codend method, while this study and Anderson et al. (1983) employed the alternate haul method.

The codend mesh measurement is an important component in the calculation of the selection factor, and differences in this measurement can result in very different selection factors. The mean stretch mesh measure of the 114-mm codend (103.9 mm) was only slightly larger than the 103 mm reported by Smolowitz (1983), even though different methods were used in measuring mesh size [vernier calipers under moderate thumb pressure in this experiment, and an ICES gauge with 4 kg pressure used by Smolowitz (1983)]. The small difference in stretch mesh measure (<0.01%) between these methods for codends of the same nominal mesh size is insufficient to alter conclusions about the selection factor because of differences in measurement methods.

The logistic curve has been suggested to describe the relationship between fish length and percent retention (Holden 1971) and has been used to describe this relationship for haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) (Robertson and Stewart 1986). There are some distinct advantages to this method of curve-fitting over fitting-by-eye as is commonly done in codend selection studies. The fit of the curve to the data can be objectively evaluated, and standard errors about the parameter estimates can be calculated. Another advantage is that the logistic equation can easily be incorporated into yield-per-recruit, spawning stock biomass-per-recruit, or other models to simulate a gradual or stepwise recruitment into a fishery in order to evaluate the effect that gradual recruitment into the fishery may have on these assessments.

The significant increase in selection range with mesh size detected in this study has been observed by other researchers for haddock (*Melanogrammus aeglefinus*) (Clark et al. 1958, Holden 1971) and whiting (*Merlangius merlangus*) (Holden 1971). Jones (1963) examined factors affecting the shape of selection curves. He found the number of escape attempts and the range of mesh shapes in a codend to be among the important factors. The increase in selection range with mesh size observed with winter flounder in the present study is likely due to the increasing range of possible mesh openings that accompanies an increase in mesh size as the codend fills, changing its shape from elongated to bulbous.

The larger L_{50} in 102-mm diamond mesh compared with 102-mm square mesh is probably due to the laterally compressed shape of flounder which allows greater escapement through the elongate diamond meshes. It appears that the greater selection range observed in square mesh may be due to the greater range in mesh shape possible in square mesh versus diamond mesh. It is generally felt that square mesh has a smaller possible range in mesh shape (Robertson and Stewart 1986). However, during the first 15 minutes or so of the 1-hour tow duration used in this study, there is relatively little weight in the codend to restrict the meshes from being stretched into an elongate shape by a fish squeezing through the mesh. By the time the square mesh shape has been set by the accumulating weight in the codend, the meshes have ranged in shape from completely elongate, as when a flounder squeezes through the mesh, to square. Diamond mesh is naturally elongated at the beginning of each tow, then gradually is stretched into a less elongated diamond shape, around and just forward of the accumulating catch, never reaching the square mesh configuration. The result is the broader selection range of square mesh evident in Figure 3, where larger fish are better able to escape from square mesh early in a tow; but as the square mesh shape becomes set by the weight of the catch, fish of all sizes are retained at an increasing rate.

Increasing tow duration in experiments with a 114-mm codend acted to increase L_{50} by 2 cm. Several other investigators have observed similar results from increasing tow duration (Clark 1957, 1963; Beverton 1964; Pope and Hall 1966). The selection range also increased with tow duration, from 4.3 cm to 6.6 cm. The positive relationship between L_{50} and tow duration can be attributed to fish making repeated attempts to escape and thereby having a greater probability of escaping in a longer tow (Pope et al. 1975). The reason for the increase in selection range is less clear, but examination of the scatter plot for 2-hour tows (Fig. 4) reveals greater variability in retention rates as fish length increases. Given enough time, the greater vigor of larger fish (>30 cm) appears to allow many of them to squeeze through the meshes.

An increase in the weight of the catch in a tow can act to lower L_{50} (Clark et al. 1958, 1963), although several papers indicate little or no effect of catch weight on size at selection (McCracken 1963, Hodder and May 1964, ICES 1965, Pope and Hall 1966). Pope et al. (1975) noted that this relationship has only been observed in covered codend experiments where cover masking may play a role in lowering L_{50}. The weight of the catch had no apparent negative effect on L_{50} in these experiments between 1 and 2-hour tows as evidenced by the increase in L_{50} with tow duration noted above.

Comparisons of observed and expected commercial winter flounder length-composition are dependent on a general seasonal pattern of availability and as such are subject to error due to daily fluctuations in length-composition. Such comparisons were possible for winter flounder because their movements are not related to size, at least for adult fish (Saila 1961). Very small fish, at least to 10 cm in length, usually occur near shore (Warfel and Merriman 1944), so fish below this size were excluded from these comparisons.

The comparisons which showed the best agreement were from small vessels with average tow durations of 1 to 2 hours, while larger vessels with average tow durations of 2.5 to 3.5 hours characterized the data sets in which agreement was generally not as good (Table 4).

Vessel size and trawl size alone have been shown not to significantly affect selectivity (McCracken 1963, Pope and Hall 1966), and tow duration has already been shown to be positively related to L_{50}. However, Pope et al. (1975) suggest that a light trawl aboard a small vessel is likely to have a different selection factor than a large trawl aboard a large vessel.

It appears that the amount of chain attached to the footrope may be an important difference between small and large vessels in terms of observed and expected length-composition in this study. The small vessels uniformly used a single strand of 9.5 mm (⅜ in) chain in the wings, with two strands in the belly. The large vessels generally used two strands of 9.5 mm (⅜ in) chain in the wings with an additional length of 9.5 mm or larger chain, up to 19.1 mm (¾ in), in the belly. Sea samplers noted fish from these tows were frequently coated with mud and in poor condition. In addition to occasional clogging, the poor condition of fish in some tows may have reduced their escape response. The effect of sweep characteristics in mud bottom areas on both size selectivity and discard mortality needs further examination.

Yield-per-recruit assessments based on stepwise recruitment were found to be more conservative than assessments based on knife-edge recruitment. Stepwise and knife-edge yield calculations are equal when the products of abundance and weight on either side of the 50% retention point on the selection curve are equal. A modest difference (2 to 7%) occurs in the smallest mesh sizes considered (76-mm diamond and 102-mm square) reflecting the effect of partial fishing mortality on the numerous, rapidly growing age 1+ fish (Table 5). Little difference in yield (1 to 3%) occurs in 102-mm and 114-mm codends. The 3% difference in yield in 114-mm mesh codends is due to the escapement of some fish greater than the minimum legal size which is accounted for in the stepwise yield assessment but not the knife-edge. The greatest difference exists in 127-mm mesh comparisons (4 to 10%), particularly as discard and fishing mortality rise. Differences in 127-mm mesh appear to be caused by both ignoring discard mortality and overestimating yield in knife-edge calculations.

Estimated increases in yield with increasing mesh size are generally similar between stepwise and knife-edge models below 127-mm mesh. However, there is a greater disparity when increasing mesh size from 114 mm to 127 mm is considered. Again, differences are most notable at the high discard and fishing mortality rates which probably best characterize the fishery at present. A 19% increase is forecast in knife-edge yield, while 11% (stepwise yield) is a more realistic expectation.

The increase in yield associated with an increase in mesh size is clearly an important management consideration, influencing both the ultimate choice of mesh size and the speed with which that mesh size is to be introduced into the fishery. To evaluate short-term as well as long-term changes in yield, information on both the L_{50} and the shape of the selection curve is required. The short-term effect of a mesh-size restriction on landings cannot be evaluated at all without this information when the minimum legal size falls within the codend selection curve. At the same time, the relative increase in long-term yield expected from increasing mesh size beyond 114 mm can be greatly overestimated unless the gradual recruitment of fish into the fishery, caused by the codend selection process, is incorporated into yield assessments.

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