GILL NET MESH SELECTION CURVES FOR PACIFIC SALMON ON THE HIGH SEAS

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ABSTRACT

Gill net mesh selection curves of normal distribution were developed and applied to Pacific salmon caught by research vessels on the high seas of the North Pacific Ocean and the Bering Sea. Mesh selection curves were constructed for pink, sockeye, and chum salmon for each of four mesh sizes, 2½-, 3¼-, 4½-, and 5¼-inch. Catch efficiency curves for combined mesh sizes show that the range for salmon lengths was covered, although the coverage was not equal for all lengths. The length-frequency distribution of each species was adjusted for effect of gill net selectivity. Adjustments were minor.

The Bureau of Commercial Fisheries fishes experimentally for salmon with surface gill nets on the high seas of the North Pacific Ocean and the Bering Sea. Salmon samples taken by gill nets are used to estimate abundance, distribution, racial identity, and growth of salmon populations in the ocean. Accurate estimates of abundance, distribution, racial identity, and growth require unbiased samples from salmon populations in the ocean. Gill nets are selective; a particular mesh size of gill net selects a particular size range of fish.

To cover the range of fish sizes, four gill net mesh sizes, 2½-, 3¼-, 4½-, and 5¼-inch, stretched measure, of multifilament nylon twine are used in the fishing. Selectivity studies are necessary to assess the adequacy of this coverage and to adjust the salmon size frequencies for any bias caused by selectivity. Determining the shape and extent of the mesh selection curve for each mesh size and for combined mesh sizes is necessary before size frequencies can be adjusted for possible bias.

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A METHOD FOR DETERMINING GILL NET SELECTIVITY

Holt (1957) described a method for determining gill net mesh selection curves with normal frequency distributions. He developed normal mesh selection curves for Fraser River sockeye salmon (from Peterson, 1954) and for North Sea herring (from Hodgson, 1933). He used the ratio of catches from adjacent pairs of mesh sizes at different length classes to develop parameters for the normal curve. The following formulations were abstracted from Holt (1957) and McCombie and Fry (1960):

$$C_L = nP_L p_m \cdot e^{-(L-L_m)^2/2S^2} \qquad (1)$$

where C_L is the number of fish of length L caught, n the number of operations or the fishing duration, P_L the number of fish of length L liable to capture, p_m the fishing power of the mesh at the mean selection length, e the base of natural logarithms, L_m the mean selection length caught, and S the standard deviation of distribution. The ratio of catches for two meshes (A and B), differing slightly in size and fishing together, can be described by an equation of the linear form, $y=bL+a$:

$$\log \frac{{}_B C_L}{{}_A C_L}=\frac{({}_B L_m-{}_A L_m)\cdot L}{S^2}+\frac{{}_A L^2_m-{}_B L^2_m}{2S^2}+\log \frac{B^P_m}{A^P_m} \quad (2)$$

in which ${}_B C_L$ is the catch of length L taken in mesh B, ${}_B L_m$ is the mean selection length of mesh B, B^P_m is the fishing power of mesh B, etc. The log $\frac{B^P_m}{A^P_m}$ term will cancel; i.e., log 1=0, by assuming that the two nets have equal fishing power for their respective mean lengths. If the terms from equation (2) are used, $\log \frac{{}_B C_L}{{}_A C_L}=y$, $\frac{{}_B L_m-{}_A L_m}{S^2}=b$ (the slope), and $\frac{{}_A L^2_m-{}_B L^2_m}{2S^2}=a$ (the y intercept). When equation (2) holds true, a plot of $\log \frac{{}_B C_L}{{}_A C_L}$ against various values of L gives a straight line, and the assumption is justified that the mesh selection curve is normal.

The selection curve parameters, ${}_A L_m$, ${}_B L_m$, and S, are obtained as follows:

$$a/b=\frac{{}_A L_m{}^2-{}_B L^2_m}{2S^2}\Big/\frac{{}_B L_m-{}_A L_m}{S^2}$$

$$-2a/b={}_B L_m+{}_A L_m$$

Assume that L_m is proportional to mesh size (θ). Assign a proportionality constant (K). Then, ${}_A L_m+{}_B L_m=-2a/b=K({}_A\theta A_B\theta)$, from which ${}_A L_m$ and ${}_B L_m$ can be derived. S can be found from either a or b. With these values and a table of ordinates for normal distribution (Snedecor, 1956), mesh selection curves can be constructed.

APPLICATION OF METHOD TO SALMON GILL NET CATCHES

I have applied the above analytical procedure to length frequencies of three salmon species: pink, sockeye, and chum. To illustrate the method, I have used catch data for 1957 and 1959. In these years the three species were well represented in the gill net catches of the research vessels. Catch data on sockeye and chum salmon for 1956, 1958, and 1960 were used in part of the analysis. Table 1 shows the number of the three species caught and measured during 1956 to 1960. The catches were made during May to September on the high seas of the North Pacific Ocean (north of lat. 45° N.) and the Bering Sea.

PINK SALMON

Table 2 gives the length-frequency distributions of pink salmon taken by the 3¼-, 4½-, and 5¼-inch mesh gill nets in 1957. Table 3 gives similar data for 1959. Catches were confined to three mesh sizes; the 2½-inch mesh did not catch pink salmon. Since more of the 4½-inch mesh than of the 3¼- and 5¼-inch meshes was used in a fishing set, catches of the 4½-inch mesh were reduced to equalize fishing effort. A 1:3 reduction was necessary in 1957; a 1:6 reduction in 1959. Length frequencies were grouped by 3-cm. length classes. Fork length is related to mesh size.[1]

Tables 2 and 3 also give catch ratios of adjacent mesh sizes, 4½/3¼-inch and 5¼/4½-inch. The catch ratio at each length class is limited to a combined sample size of 50 or more fish for the paired mesh sizes. By establishing a minimum sample size of 50, I was able to omit smaller samples that may not have been representative

TABLE 1.—*Gill net catches of pink, sockeye, and chum salmon by U.S. research vessels in the North Pacific Ocean and the Bering Sea, 1956–60*

Species [1]	Number of salmon caught and measured				
	1956	1957	1958	1959	1960
Pink	431	3,129	174	4,202	1,049
Sockeye	3,224	3,584	1,177	6,462	8,296
Chum	3,565	4,678	3,744	6,082	5,816

[1] Coho and chinook salmon are excluded because of small catches.

TABLE 2.—*Catch by mesh size and catch ratio of adjacent mesh sizes, pink salmon, 1957*

Fork length (midpoint of length class)	Catch by mesh size [1]				Catch ratio	
	2½-inch	3¼-inch	4½-inch	5¼-inch	log 4½/3¼-inch	log 5¼/4½-inch
Centimeters	*Number*	*Number*	*Number*	*Number*		
35	----------	2	----------	----------	----------	----------
38	----------	14	1	----------	----------	----------
41	----------	148	69	1	−0.76	−4.27
44	----------	192	363	13	+.64	−3.32
47	----------	42	300	32	+2.00	−2.24
50	----------	3	109	47	+3.51	−.84
53	----------	1	19	22	----------	----------
56	----------	----------	8	5	----------	----------
59	----------	1	1	1	----------	----------

[1] Original catches of the 4½-inch mesh were 3 times as large as shown; they were divided by 3 to equalize fishing effort between mesh sizes.

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[1] Mesh size as shown is factory-labeled size. During the 1960 fishing operations about 400 meshes from the four mesh sizes were measured. The average measured size was either identical to the factory-labeled size or slightly oversize.

Table 3.—*Catch by mesh size and catch ratio of adjacent mesh sizes, pink salmon, 1959*

Fork length (midpoint of length class)	Catch by mesh size [1]				Catch ratio	
	2½-inch	3¼-inch	4½-inch	5¼-inch	log 4½/3¼-inch	log 5¼/4½-inch
Centimeters	*Number*	*Number*	*Number*	*Number*		
32		1				
35		3				
38		7				
41		38	26		−0.39	
44		16	201	6	+2.53	−3.51
47		6	236	14	+3.67	−2.83
50		1	135	51	+4.90	−0.97
53		1	46	49		+0.07
56		1	14	30		
59			3	3		
62		1		3		

[1] Original catches of the 4½-inch mesh were 6 times as large as shown; they were divided by 6 to equalize fishing effort between mesh sizes.

The natural logarithm of the catch ratio is directly related to the length of pink salmon for 1957 and 1959 (fig. 1). The straight lines are fitted by the least squares method. The relation in both years is approximately linear. Holt showed in equation (2) that this relation must be linear if the mesh selection curve is normal. With replicating evidence for 2 years, I feel justified in assuming that the mesh selection curve for pink salmon is approximately normal.

To obtain the normal frequency curve for each mesh size, the mean selection length and the standard deviation of the curve were needed. The estimation of these parameters for 1959 pink salmon is shown in table 4 and the determination of the normal curve in table 5.

A further step in applying the method was to construct a composite selection curve from the mesh selection curves of the three mesh sizes (fig. 2). This composite curve was obtained by summing at each length class the ordinate heights of the individual curves (table 6), as was done by McCombie and Fry (1960). The composite curve can be called a "catch efficiency curve" because

Table 4.—*Estimation of mean selection length and standard deviation of mesh selection curves, pink salmon, 1959*

Mesh sizes	Sum of mesh sizes	Sum of mean selection lengths (−2a/b)	Mean selection length	Standard deviation of selection curve
	Centimeters	*Centimeters*	*Centimeters*	*Centimeters*
3¼-inch (8.26 cm.)			34.8	
3¼ and 4½-inch	19.69	81.36		4.9
4½-inch (11.43 cm.)			48.1	
4½ and 5¼-inch	24.77	105.65		4.4
5¼-inch (13.34 cm.)			56.2	
Mean	22.23	93.50		

$K = 93.50/22.23 = 4.21$.

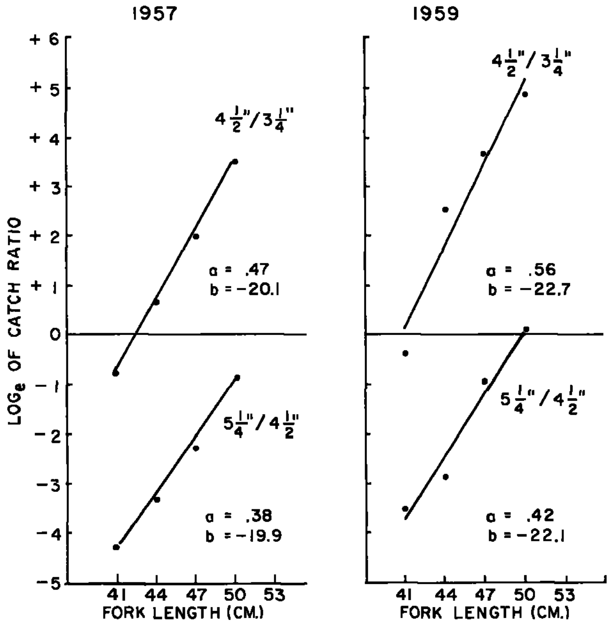

Figure 1.—Catch ratio of adjacent mesh sizes by fork length, pink salmon, 1957 and 1959.

Table 5.—*Determination of ordinate heights of normal curve for each mesh size, pink salmon, 1959*

Fork length (midpoint of length class)	3¼-inch mesh L_m=34.8, S=4.9 [1]		4½-inch mesh L_m=48.1, S=4.6 [2]		5¼-inch mesh L_m=56.2, S=4.4	
	$\frac{L-L_m}{S}$	Ordinate height	$\frac{L-L_m}{S}$	Ordinate height	$\frac{L-L_m}{S}$	Ordinate height
Centimeters						
32	0.57	0.339	3.50	0.001		
35	.04	.399	2.85	.007		
38	.65	.323	2.20	.036	4.23	0
41	1.27	.178	1.54	.122	3.55	.001
44	1.88	.068	.89	.268	2.77	.009
47	2.49	.018	.24	.388	2.09	.045
50	3.10	.003	.41	.367	1.41	.148
53	3.71	0	1.07	.225	.73	.306
56			1.72	.091	.05	.398
59			2.37	.024	.64	.325
62			3.02	.004	1.32	.167

[1] L_m=mean selection length (cm.), S=standard deviation (cm.).
[2] Mean of 4.9 and 4.4.

Table 6.—*Summation of ordinate heights of three mesh selection curves, pink salmon, 1959*

Fork length (midpoint of length class)	Ordinate height (by mesh size)			Sum of ordinate heights
	3¼-inch	4½-inch	5¼-inch	
Centimeters				
32	0.339	0.001		0.340
35	.399	.007		.406
38	.323	.036	0	.359
41	.178	.122	.001	.301
44	.068	.268	.009	.345
47	.018	.388	.045	.451
50	.003	.367	.148	.518
53	0	.225	.306	.531
56		.091	.398	.489
59		.024	.325	.349
62		.004	.167	.171

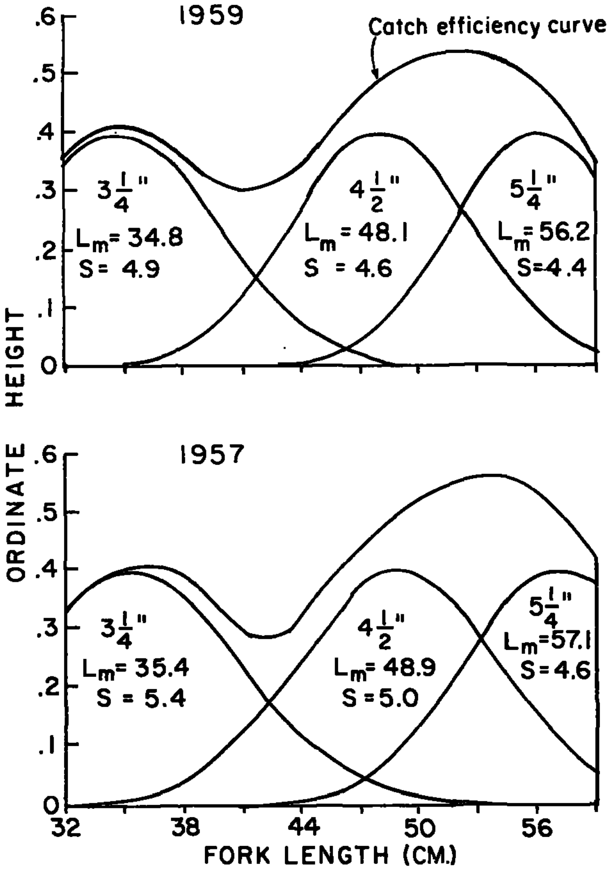

FIGURE 2.—Catch efficiency curve (sum of ordinate heights at each length) for three mesh sizes combined, pink salmon, 1957 and 1959.

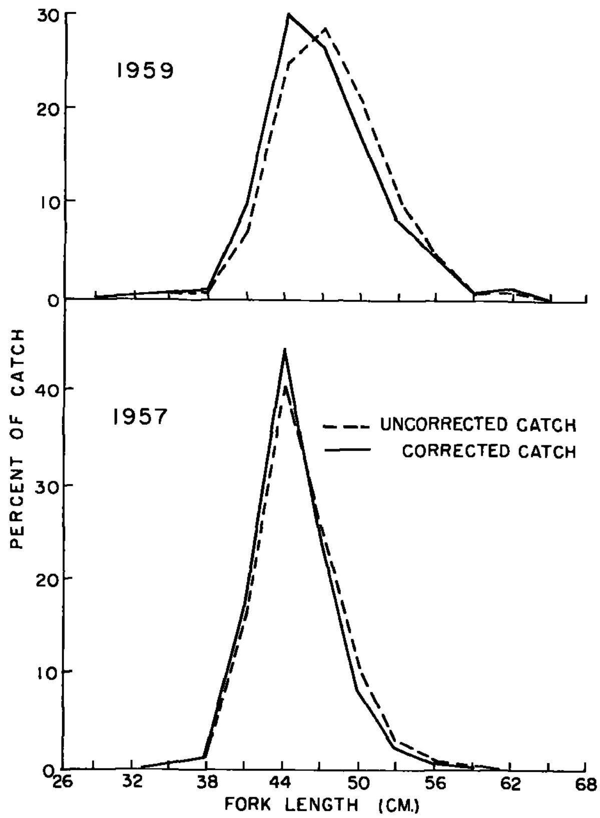

FIGURE 3.—Length frequency distribution of pink salmon adjusted for effect of gill net selectivity, 1957 and 1959.

it shows a relative catch efficiency of gill nets over fish length range. Curves for 1957 and 1959 are shown.

In both years the catch efficiency curves show a dip at 41 cm. Catch efficiency at 41 cm. is lower because of the 1¼-inch gap between the 3¼- and 4½-inch mesh sizes. The gap between the 4½- and 5¼-inch meshes is ¾ inch.

The final step in applying the method was to reconstruct the length frequency curve of the available fish population, adjusting for effect of gill net selectivity. The uncorrected catch was divided by the sum of ordinates at each length class (table 7). The corrected catch for all length classes was the length frequency curve adjusted for effect of gill net selectivity.

When the uncorrected and the corrected length frequency distributions of pink salmon taken by combined mesh sizes of gill net in 1957 and 1959 are plotted, a single mode of maturing 2-year-old fish is evident (fig. 3).

Adjustments for gill net selectivity in 1957 were minor. In the uncorrected catches the 41-cm. and 44-cm. length classes were slightly under-represented and the 47-cm., 50-cm., and 53-cm. classes were slightly over-represented. The corrected catch curve adjusts for these conditions. The mode, after I adjusted for selectivity, remains unchanged at 44 cm.

In 1959 the amount of correction was somewhat greater than in 1957. As in 1957, the 41-cm. and 44-cm. lengths were under-represented, the 47-cm., 50-cm., and 53-cm. lengths over-represented. Adjustments in 1959 changed the position of the mode from 47 cm. to 44 cm.

SOCKEYE SALMON

Least squares lines were fitted to the catch ratios of sockeye salmon taken in 1959 by the four gill net mesh sizes (fig. 4). Catch data are in table 8. Catch ratios were computed for

Table 7.—*Adjustment of 1959 catches of pink salmon for effect of gill net selectivity*

Fork length (midpoint of length class)	Uncorrected	Sum of ordinate heights	Corrected	Uncorrected	Corrected
Centimeter	*Number*		*Number*	*Percent*	*Percent*
32	1	0.340	3	0.1	0.1
35	3	.406	7	.3	.3
38	7	.359	19	.8	.9
41	64	.301	213	7.2	10.0
44	223	.345	646	25.0	30.3
47	256	.451	568	28.7	26.7
50	187	.518	361	21.0	16.9
53	96	.531	181	10.8	8.5
56	45	.489	92	5.0	4.3
59	6	.349	17	.7	.8
62	4	.171	23	.5	1.1

samples of 50 or more fish, as was done for pink salmon. Sockeye salmon catch ratios for each pair of mesh sizes showed approximate linearity over the greater part of the range of fish lengths, but not at the extremes of the range. Approximate linearity extended from 29 cm. to 38 cm. for the 3¼/2½-inch mesh sizes, from 38 cm. to 53 cm. for the 4½/3¼-inch mesh sizes, and from 47 cm. to 62 cm. for the 5¼/4½-inch mesh sizes. Least squares lines were fitted in these ranges. The procedure of discarding extremes in line-fitting previously was used by Garrod (1961).

Figure 5 shows a similar picture for 1957 (data are in table 9). Catch ratios were approximately linear except at the extremes. In 1957 and 1959 similar length ranges were used in line-fitting, except for extending the range to 41 cm. for the 3¼/2½-inch mesh sizes in 1957.

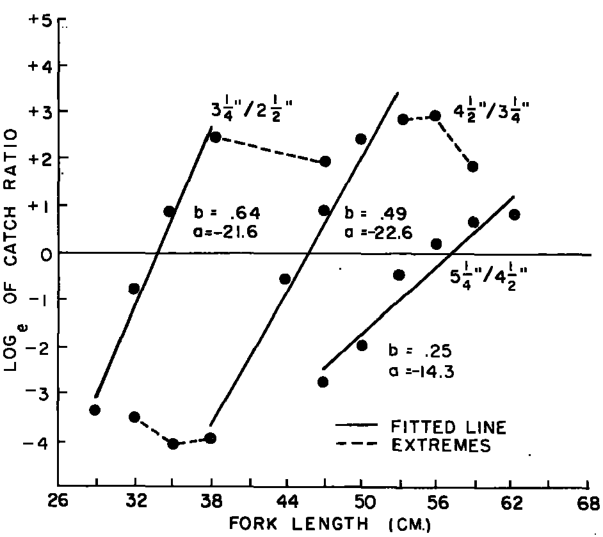

Figure 4.—Catch ratio of adjacent mesh sizes by fork length, sockeye salmon, 1959.

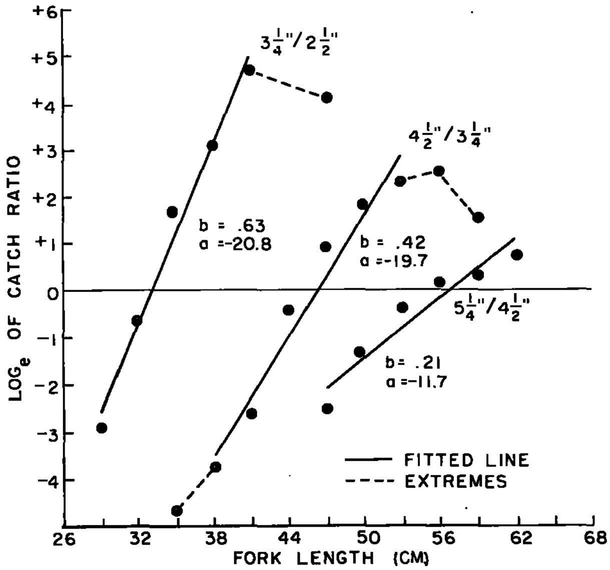

Figure 5.—Catch ratio of adjacent mesh sizes by fork length, sockeye salmon, 1957.

Table 8.—*Catch by mesh size and catch ratio of adjacent mesh sizes, sockeye salmon, 1959*

Fork length (midpoint of length class)	Catch of sockeye by mesh size [1]				Catch ratio		
	2½-inch	3¼-inch	4½-inch	5¼-inch	log 3¼/2½-inch	log 4½/3¼-inch	log 5¼/4½-inch
Centimeters	*Number*	*Number*	*Number*	*Number*			
26	9						
29	88	3			−3.38		
32	293	139	4	4	−.75	(−3.54)	
35	279	648	9	7	+.85	(−4.27)	
38	22	268	5	2	+2.50	−3.96	
41	1	34	2			−2.85	
44	1	41	23	2		−.58	
47	6	44	111	7	(+1.99)	+.92	−2.76
50	1	16	161	23		+2.40	−1.94
53	3	9	155	97		+2.84	−.47
56		9	118	144		(+2.94)	+.19
59	3	9	59	116		(+1.88)	+.68
62		6	22	51			+.82
65	2	4	4	22			
68	1		1	5			
74				1			

[1] Original catches of the 4½-inch mesh were 6 times as large as shown; they were divided by 6 to equalize fishing effort between mesh sizes.

Note.—Catch ratios in parentheses were not used. See text.

Catch ratios showing the linear relation represent mainly fish which were enmeshed (gilled) around the head and gill cover by the net twine. Catch ratios departing from the straight line at either end were discarded because they represent large fish snagged or small fish tangled in the gill nets.

In the 1959 sockeye catch ratios of the 4½/3¼-inch mesh sizes (fig. 4), the discarded catch ratios at 32 cm. and 35 cm. and at 56 cm. and 59 cm. curve away from the fitted line, giving the effect of a tipped S-shaped curve. At 32 cm. and 35 cm. the fish in the 4½-inch mesh were probably

Table 9.—*Catch by mesh size and catch ratio of adjacent mesh sizes, sockeye salmon, 1957*

Fork length (midpoint of length class)	Catch of sockeye by mesh size [1]				Catch ratio		
	2½-inch	3¼-inch	4½-inch	5¼-inch	log 3¼/2½-inch	log 4½/3¼-inch	log 5¼/4½-inch
Centimeters	*Number*	*Number*	*Number*	*Number*			
23	4						
26	36	1					
29	55	3			−2.90		
32	54	29	1	1	−.62		
35	32	168	2	1	+1.66	(−4.62)	
38	8	176	4	1	+3.09	−3.77	
41	1	108	8		+4.68	−2.60	
44		46	31	3		−.40	
47	1	57	133	11	(+4.04)	+.85	−2.49
50	3	34	194	50		+1.74	−1.36
53	4	15	146	100		+2.28	−.38
56	3	9	108	121		(+2.48)	+.11
59	3	20	84	114		(+1.44)	+.31
62	2	11	26	54			+.73
65		4	6	20			
68	1	1	1	1			
71				1			

[1] Original catches of the 4½-inch mesh were 3 times as large as shown; they were divided by 3 to equalize fishing effort between mesh sizes.

Note.—Catch ratios in parentheses were not used. See text.

tangled rather than gilled. At 56 cm. and 59 cm. the fish in the 3¼-inch mesh were mainly snagged rather than gilled. Some fish within the 38-cm. to 53-cm. length range also were snagged or tangled, but the numbers were so small that the linear relation between fish length and log of catch ratio was unaffected.

The procedure for developing mesh selection curves and a catch efficiency curve for sockeye salmon followed that for pink salmon. Table 10 shows the summation of the ordinate heights of the mesh selection curves for the four mesh sizes. The composite curve was used to adjust for selectivity effect (table 11).

A comparison of the uncorrected and corrected length frequency distributions of sockeye salmon in 1957 and 1959 shows that the 44-cm. and 47-cm. fish are under-represented, the 53-cm. to 59-cm. over-represented in the uncorrected catches (fig. 6). Over most of the length range, adjustments were quite minor.

Adjustments for the effect of gill net selectivity changed slightly the shape of the length-frequency distribution curve of sockeye salmon. The length-frequency distributions in 1957 and 1959 were bimodal. Mode 1 consisted of small fish (highly abundant in 1959) that had spent one winter at sea. Mode 2 consisted of large fish that

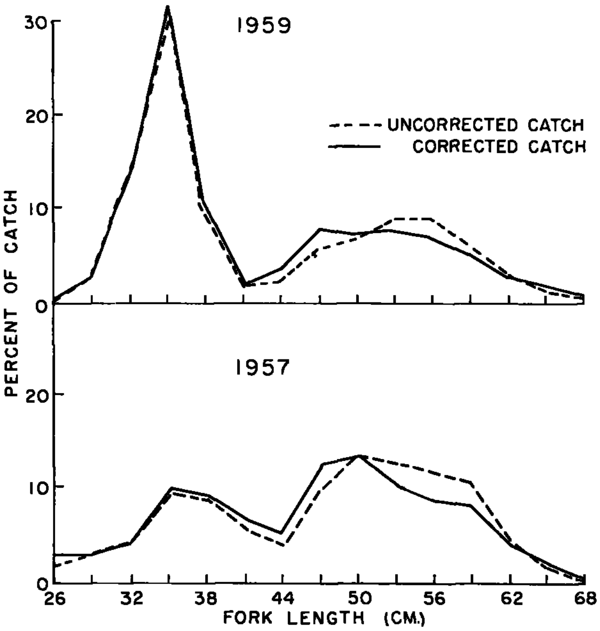

Figure 6.—Length frequency distributions of sockeye salmon adjusted for effect of gill net selectivity, 1957 and 1959.

Table 10.—*Summation of ordinate heights of four mesh selection curves, sockeye salmon, 1959*

Fork length (midpoint of length class)	Ordinate height (by mesh size)				Sum of ordinate heights
	2½-inch	3¼-inch	4½-inch	5¼-inch	
Cm.					
26	0.268	0.013			0.281
29	.398	.056			.454
32	.306	.165	0		.471
35	.122	.319	.003		.444
38	.025	.391	.014	0	.430
41	.003	.327	.049	.001	.380
44	0	.176	.124	.005	.305
47		.062	.242	.019	.323
50		.014	.357	.060	.431
53		.002	.398	.142	.542
56		0	.337	.259	.596
59			.216	.365	.581
62			.106	.398	.504
65			.039	.335	.374
68			.011	.218	.229

Table 11.—*Adjustment of the 1959 catches of sockeye salmon for effect of gill net selectivity*

Fork length (midpoint of length class)	Uncorrected	Sum of ordinate heights	Corrected	Uncorrected	Corrected
Centimeter	*Number*		*Number*	*Percent*	*Percent*
26	9	0.281	32	0.3	0.5
29	91	.454	201	2.9	2.9
32	440	.471	944	14.2	13.8
35	943	.444	2,158	30.5	31.4
38	297	.430	678	9.6	9.9
41	37	.380	97	1.2	1.4
44	67	.305	218	2.2	3.2
47	168	.323	525	5.4	7.6
50	201	.431	472	6.5	6.9
53	264	.542	491	8.5	7.2
56	271	.596	455	8.8	6.6
59	187	.581	321	6.0	4.7
62	79	.504	156	2.6	2.3
65	32	.374	85	1.0	1.2
68	7	.229	30	.2	.4
74	1	(.044)			

Note.—Length class 74 cm. was omitted.

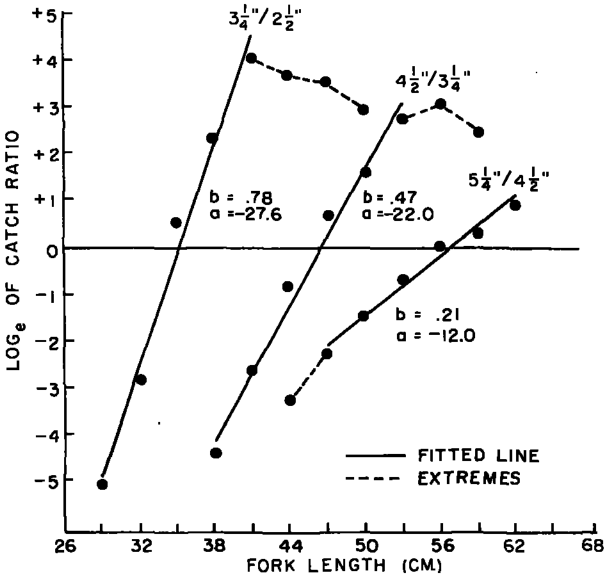

FIGURE 7.—Catch ratio of adjacent mesh sizes by fork length, chum salmon, 1957.

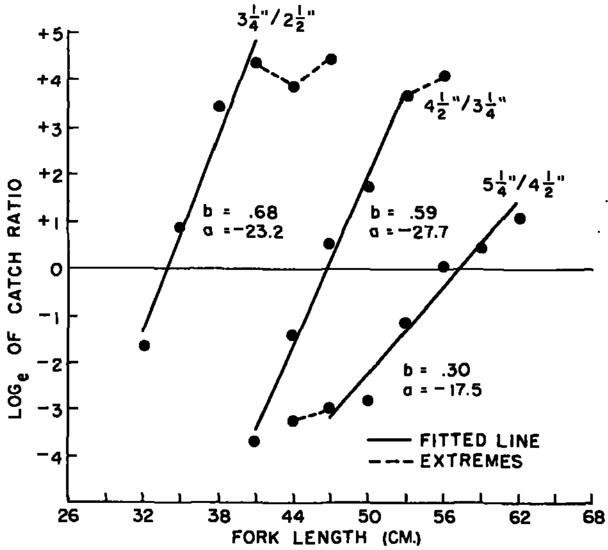

FIGURE 8.—Catch ratios of adjacent mesh sizes by fork length, chum salmon, 1959.

had spent mainly two and three winters at sea. Mode 1 did not change position, but mode 2 shifted to smaller fish when adjusted for selectivity. This change occurred in both years.

Chum salmon

The problems encountered for chum salmon and the results obtained are almost identical to those for sockeye salmon. As with sockeye, chum salmon catch ratios of a minimum 50-fish sample for each pair of mesh sizes were approximately linear over a greater part of the range of fish lengths but not at the extremes. The length ranges for chum salmon were identical to those established for sockeye. Least squares lines were fitted to the 1957 and 1959 catch ratios of the three pairs of mesh sizes (figs. 7 and 8). Catches on which these lines were based are given in tables 12 and 13. Table 14 sums up the ordinate heights for the four mesh sizes.

Figure 9 and table 15 show the uncorrected and corrected length-frequency distributions of chum

TABLE 12.—*Catch by mesh size and catch ratio of adjacent mesh sizes, chum salmon, 1957*

Fork length (mid-point of length class)	Catch of chum by mesh size [1]				Catch ratio		
	$2\frac{1}{2}$-inch	$3\frac{1}{4}$-inch	$4\frac{1}{2}$-inch	$5\frac{1}{4}$-inch	log $3\frac{1}{4}$/$2\frac{1}{2}$-inch	log $4\frac{1}{2}$/$3\frac{1}{4}$-inch	log $5\frac{1}{4}$/$4\frac{1}{2}$-inch
Centimeters	*Number*	*Number*	*Number*	*Number*			
26	5						
29	330	2	1	1	−5.12		
32	523	28		2	−2.92		
35	52	89		1	+.54		
38	8	78	1		+2.28		
41	2	109	8		+4.00		
44	3	119	52	2	(+3.68)	−0.83	(−3.27)
47	3	100	191	21	(+3.50)	+.65	−2.21
50	3	58	285	64	(+2.96)	+1.59	−1.49
53	1	13	203	105		+2.75	−.66
56		6	117	105		(+2.97)	−.01
59	1	4	46	66		(+2.44)	+.36
62			16	41			+.94
65			5	15			
68			2	10			
71				1			
74				1			

[1] Original catches of the $4\frac{1}{2}$-inch mesh were 3 times as large as shown; they were divided by 3 to equalize fishing effort between mesh sizes.

NOTE.—Catch ratios in parentheses were not used. See text.

TABLE 13.—*Catch by mesh size and catch ratio of adjacent mesh size, chum salmon, 1959*

Fork length (mid-point of length class)	Catch of chum by mesh size [1]				Catch ratio		
	$2\frac{1}{2}$-inch	$3\frac{1}{4}$-inch	$4\frac{1}{2}$-inch	$5\frac{1}{4}$-inch	log $3\frac{1}{4}$/$2\frac{1}{2}$-inch	log $4\frac{1}{2}$/$3\frac{1}{4}$-inch	log $5\frac{1}{4}$/$4\frac{1}{2}$-inch
Centimeters	*Number*	*Number*	*Number*	*Number*			
29	9						
32	57	11		1	−1.64		
35	18	44	1		+ .89		
38	3	93		1	+3.42		
41	2	156	4		+4.36		
44	4	196	48	2	(+3.89)	−3.65	(−3.22)
47	1	84	160	8	(+4.43)	−1.41	−3.00
50	1	37	232	14		+.53	−2.81
53	2	5	195	67		+1.78	−1.08
56		2	113	116		+3.66	+.03
59			59	95		(+4.03)	+.50
62		2	14	45			+1.17
65			4	24			
68				4			
71				2			

[1] Original catches of the $4\frac{1}{2}$-inch mesh were 6 times as large as shown; they were divided by 6 to equalize fishing effort between mesh sizes.

NOTE.—Catch ratios in parentheses were not used. See text.

Table 14.—*Summation of ordinate heights of four mesh selection curves, chum salmon, 1959*

Fork length (midpoint of length class)	Ordinate height (by mesh size)				Sum of ordinate heights
	2½-inch	3¼-inch	4½-inch	5¼-inch	
Cm.					
26	0.242	0.006	----------	----------	0.248
29	.393	.033	----------	----------	.426
32	.319	.122	0	----------	.441
35	.130	.280	.001	----------	.411
38	.026	.395	.005	----------	.426
41	.003	.341	.024	0	.368
44	0	.180	.078	.001	.259
47	----------	.060	.187	.007	.254
50	----------	.012	.323	.030	.365
53	----------	.001	.398	.091	.490
56	----------	0	.352	.201	.553
59	----------	----------	.223	.331	.554
62	----------	----------	.102	.398	.500
65	----------	----------	.033	.352	.385
68	----------	----------	.008	.228	.236

salmon. In 1957 and 1959 the corrected catches increased at 44 cm. and 47 cm. and decreased at 53 cm. to 59 cm. As with sockeye, the mode of the large chum salmon shifted to smaller fish when adjusted for selectivity.

SELECTIVITY COMPARED FOR THE THREE SPECIES

The catch efficiency of the combined mesh sizes was compared for pink, sockeye, and chum salmon (fig. 10). Curves were given for sockeye and chum salmon ranging in length from 29 cm. to 62 cm. and for pink salmon from 38 cm. to 56 cm.; these covered 98 percent of the samples. Chum and sockeye curves are similar and show a dip in catch efficiency at 44 cm. and 47 cm., resulting from the 1¼-inch gap between the 3¼- and 4½-inch mesh sizes. Both curves show peak catch efficiency at 56 cm. and 59 cm. The mode for sockeye is about 56 cm., for chum about 57 cm. The pink salmon curve shows peak catch efficiency at 53 cm. and lowest catch efficiency at 41 cm.

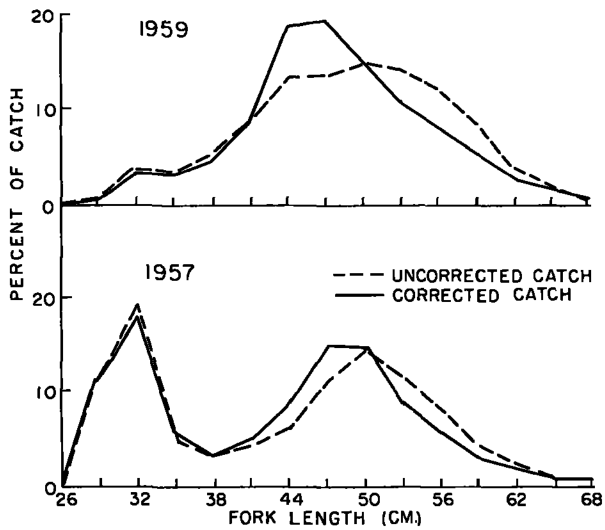

Figure 9.—Length frequency distribution of chum salmon adjusted for effect of gill net selectivity, 1957 and 1959.

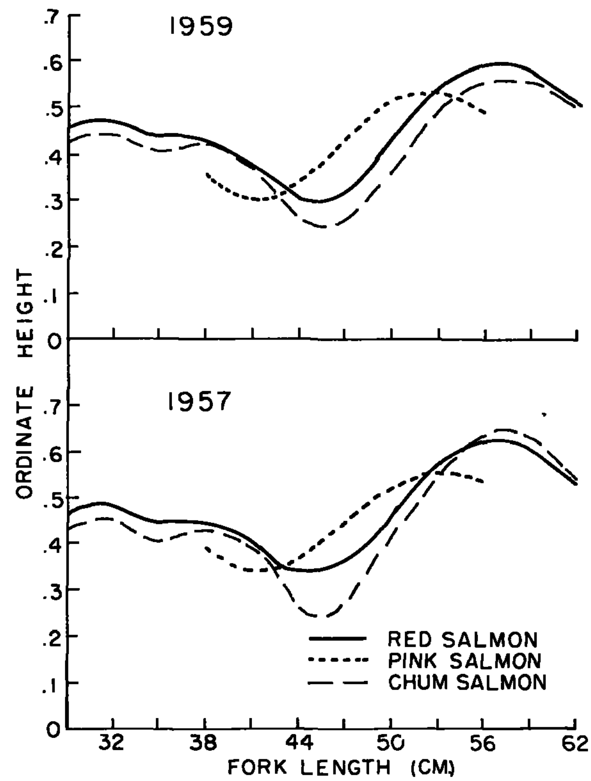

Figure 10.—Comparison of catch efficiency of combined mesh sizes on pink, sockeye, and chum salmon, 1957 and 1959.

Table 15.—*Adjustment of the 1959 catches of chum salmon for effect of gill net selectivity*

Fork length (midpoint of length class)	Uncorrected	Sum of ordinate heights	Corrected	Uncorrected	Corrected
Centimeters	*Number*		*Number*	*Percent*	*Percent*
29	9	0.426	21	0.5	0.4
32	69	.441	156	3.6	3.0
35	63	.411	153	3.3	2.9
38	97	.426	228	5.0	4.4
41	162	.368	440	8.4	8.5
44	250	.259	965	12.9	18.6
47	253	.254	996	13.1	19.2
50	284	.365	778	14.7	15.0
53	269	.490	549	13.9	10.6
56	231	.553	418	11.9	8.0
59	154	.554	278	8.0	5.4
62	61	.500	122	3.2	2.3
65	28	.385	73	1.4	1.4
68	4	.236	17	.2	.3
71	(2)	(.176)	----------	----------	----------

Note.—Length class 71 cm. was omitted.

The shape of the catch efficiency curves for sockeye and chum salmon between 44 cm. and 62 cm. and for pink salmon between 38 cm. and 56 cm. is somewhat similar. The pink salmon curve is displaced to shorter fish. Pink salmon probably have greater girth per given length than the other two species, although no girth measurements of pink salmon were taken to verify this. Differences shown in figure 10 probably result from girth/length differences among the three species.

DISCUSSION

Certain assumptions in applying Holt's method were considered. One assumption was that standard deviations of selection curves should be similar. A computation of the *S* values for each year from 1956 to 1960 checked this assumption. Table 16 lists *S* values for each pair of mesh sizes. Sockeye and chum salmon *S* values are given for all years. Pink salmon *S* values were computed only for odd-numbered years; catches were small in even-numbered years.

Standard deviations of selection curves within each species were reasonably similar in at least the larger mesh sizes, 3¼-, 4½-, and 5¼-inch. Pink salmon had slightly higher *S* values and sockeye slightly lower *S* values in the paired 3¼- and 4½-inch mesh sizes than in the 4½- and 5¼-inch (table 16). Chum salmon also varied only slightly between these sizes. In the 2½- and 3¼-inch pair of mesh sizes, however, the *S* values for sockeye and chum salmon were low. The small 2½-inch mesh was probably the main cause of these low values.

TABLE 16.—*Standard deviation of mesh selection curves for pink, sockeye, and chum salmon by year*

Salmon species	Year	Standard deviation (paired mesh sizes)		
		2½-inch and 3¼-inch	3¼-inch and 4½-inch	4½-inch and 5¼-inch
		Centimeters	*Centimeters*	*Centimeters*
Pink	1957	----	5.4	4.6
Do	1959	----	4.9	4.4
Sockeye	1956	3.5	5.5	6.1
Do	1957	3.7	5.9	6.5
Do	1958	3.1	5.1	6.1
Do	1959	3.9	5.5	5.9
Do	1960	4.0	5.4	6.3
Chum	1956	3.6	5.6	5.3
Do	1957	3.4	5.6	6.5
Do	1958	3.7	4.4	5.5
Do	1959	3.6	5.0	5.4
Do	1960	3.8	5.2	5.1

Another assumption was that the mean selection length of salmon is proportional to mesh size. Mesh size (perimeter) is directly related to the fish's girth. Lander (1963) showed that the girth and length of sockeye and chum salmon of the high seas have a linear relation. Thus, the relation of length of salmon and mesh size warrants using proportionality constants (*K* values).

K values within species varied remarkably little annually (table 17). Between species, *K* values for pink salmon were lower than those for sockeye and chum salmon, probably because pink salmon have greater girth per given length. As shown in table 17, mean selection lengths had lower values in pink salmon than in the other two species.

All investigators did not use normal distribution for the mesh selection curve. Some used a skewed mesh selection curve, tailing off to the right, rather than a normal curve. Olsen (1959), working with Newfoundland herring data, found that logs of catch ratios followed a parabolic line better than a straight line. His selection curves, thus, are slightly skewed rather than normal. Ishida (1962) used a mesh-size ratio method in developing skewed selectivity curves for salmon from the North Pacific. Gulland and Harding (1961), using gill net catches of the African catfish *Clarias*, obtained a skewed selection curve with a long upper tail. The shape of *Clarias* (long fish with a large bony head) and the method of its capture (entanglement in

TABLE 17.—*Proportionality constants and mean selection lengths for pink, sockeye, and chum salmon*

Salmon species	Year	K[1]	Mean selection length by mesh size			
			2½-inch 6.35 cm.	3¼-inch 8.26 cm.	4½-inch 11.43 cm.	5¼-inch 13.34 cm.
			cm.	*cm.*	*cm.*	*cm.*
Pink	1957	4.28	27.2	35.4	48.9	57.1
Do	1959	4.21	26.7	34.8	48.1	56.2
		Mean	27.0	35.1	48.5	56.6
Sockeye	1956	4.53	28.8	37.4	51.8	60.4
Do	1957	4.62	29.3	38.2	52.8	61.6
Do	1958	4.49	28.5	37.1	51.3	59.9
Do	1959	4.62	29.3	38.2	52.8	61.6
Do	1960	4.60	29.2	38.0	52.6	61.4
		Mean	29.0	37.8	52.3	61.0
Chum	1956	4.63	29.4	38.2	52.9	61.8
Do	1957	4.68	29.7	38.7	53.5	62.4
Do	1958	4.68	29.7	38.7	53.5	62.4
Do	1959	4.67	29.7	38.6	53.4	62.3
Do	1960	4.73	30.0	39.1	54.1	63.1
		Mean	29.7	38.7	53.5	62.4

[1] K=Proportionality constant of fish length divided by mesh size.

several meshes) are thought to cause the asymmetry.

Other investigators besides Holt used normal distribution for mesh selection curves. McCombie and Fry (1960), working with Lake Huron whitefish data, concluded that normal distribution best describes the mesh selection curve. Using nylon gill net catches of *Tilapia* from Lake Victoria, East Africa, Garrod (1961) showed that normal distribution applies over most of the selection range of fish lengths but not at the extremes of this range. Garrod used the normal curve obtained from linear regression after discarding the extremes where the relation departs from linear. I also used the procedure of discarding the extremes and then applying the normal curve.

SUMMARY

1. A method for determining gill net selectivity described by Holt (1957) was applied to experimental gill net catches of pink, sockeye, and chum salmon from the high seas of the North Pacific Ocean and Bering Sea. This method develops mesh selection curves for gill nets of different mesh sizes from catch ratios at various fish lengths.

2. A normal mesh selection curve, representing relative catch efficiency of the mesh for different length classes of fish, was constructed for each mesh size, 2½-, 3¼-, 4½- and 5¼-inch, for each species. Normal distribution can be used validly when extreme sizes of fish caught by snagging and tangling rather than gilling are omitted.

3. A composite curve of relative catch efficiencies for combined mesh sizes shows that the four mesh sizes cover the range of salmon lengths. All length classes were not caught with equal efficiency. A lower catch efficiency at 44 cm. of 47 cm. for sockeye and chum salmon and 41 cm. for pink salmon, resulted from the larger (1¼-inch) gap between the 3¼- and 4½-inch mesh sizes. The gap between other adjacent mesh sizes was three-quarter inch.

4. The composite curve for each species was used to adjust gill net catches for selectivity effect. Adjustments were minor.

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