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GEAR SELECTION AND PACIFIC HALIBUT

BY

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FOREWORD

The 1953 Convention between Canada and the United States requires that the International Pacific Halibut Commission develop the stocks of halibut to those levels which will permit the maximum sustainable yield and maintain them at those levels. To attain such objectives it is necessary that the halibut be taken at or near their optimum harvesting size. Accordingly, the selection properties of the gear used for the taking of halibut has been a matter of long-standing study by the Commission.

This report defines some of the selection characteristics of trawl net gear of various codend mesh sizes. The selection properties of the setline gear commonly used in the North American setline halibut fishery are also described. The sustainable yields of halibut that could be produced by fisheries employing these gears are examined.

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INTRODUCTION

In principle a fishery will take the maximum yield from a fish stock if each year class is harvested when it attains its maximum weight. At such time the average individual in the year class will have reached its optimum age and size for harvesting. Such a scheme is impractical for two reasons. First, to maximize the yield from a fish stock on a sustained basis an adequate spawning stock must be maintained to assure future year classes of adequate size, even if achieved at the expense of some immediate yield. Second, a fishery intensive enough to take all fish above a given age or size in one year would cost more than the catch would be worth.

A practical alternative is to regulate the fishing intensity and the minimum harvesting age (or size) to levels which will in fact permit the maximum sustainable yield. The more intensive the fishery the closer the minimum harvesting size should approach the optimum harvesting size, and vice versa.

Even before management of the Pacific halibut fishery began in 1932, the Commission recognized that the so-called "baby" halibut required protection if increased yields were to be achieved (Babcock, Found, Freeman and O'Malley, 1928, 1931). Public hearings held by the Commission to explain its scientific findings showed industry support for measures to protect such small halibut (Anonymous, 1927).

Regulations in 1932 and thereafter included provisions designed to restrict the capture of halibut to those sizes which would permit the greatest sustainable yield (IFC, 1948; Bell, 1956). For example, in 1932 nursery areas were established in areas known to be inhabited by large numbers of small halibut and these areas were closed to halibut fishing.

Since 1935 setline fishing with dory vessels has been prohibited in waters south of Cape Spencer, Alaska (Figure 1) because the proportion of small halibut caught by such vessels was unduly high. In 1944 dory gear was prohibited in all convention waters. The high proportion of small fish in dory vessel catches may have been a consequence of the light-weight gear used as well as of the fishing grounds frequented.

Since 1940 a minimum size limit has been in force, below which halibut must not be retained. The present minimum size limit is 26 inches or 5 pounds dressed weight which for reasons mentioned above is much below the optimum size for harvesting halibut. Although North American halibut setline gear catches relatively few fish as small as 26 inches, the adequacy of the present minimum size limit is under investigation by the Commission.

In 1938 the Commission prohibited the use of bottom set nets on the basis that studies in Norway had shown this gear to be highly selective for large halibut (Devold, 1938). Such gear could have posed a threat to the stock of mature halibut upon which future recruitment depended, a matter of considerable concern at that time (Thompson and Van Cleve, 1936).

The European trawl fishery had long demonstrated that small halibut were particularly vulnerable to capture by that gear (Jespersen, 1917; German Fisheries Yearbooks). This information was supported by Commission observations on the size composition of Pacific halibut landed by the rapidly expanding trawl fishery on the Pacific Coast. In 1944 the Commission prohibited the use of that gear for catching halibut. Further investigations by the Commission (IFC, 1948; Bell, 1956) and by others (Jespersen, 1948; McIntyre, 1952, 1956) have supported this decision.

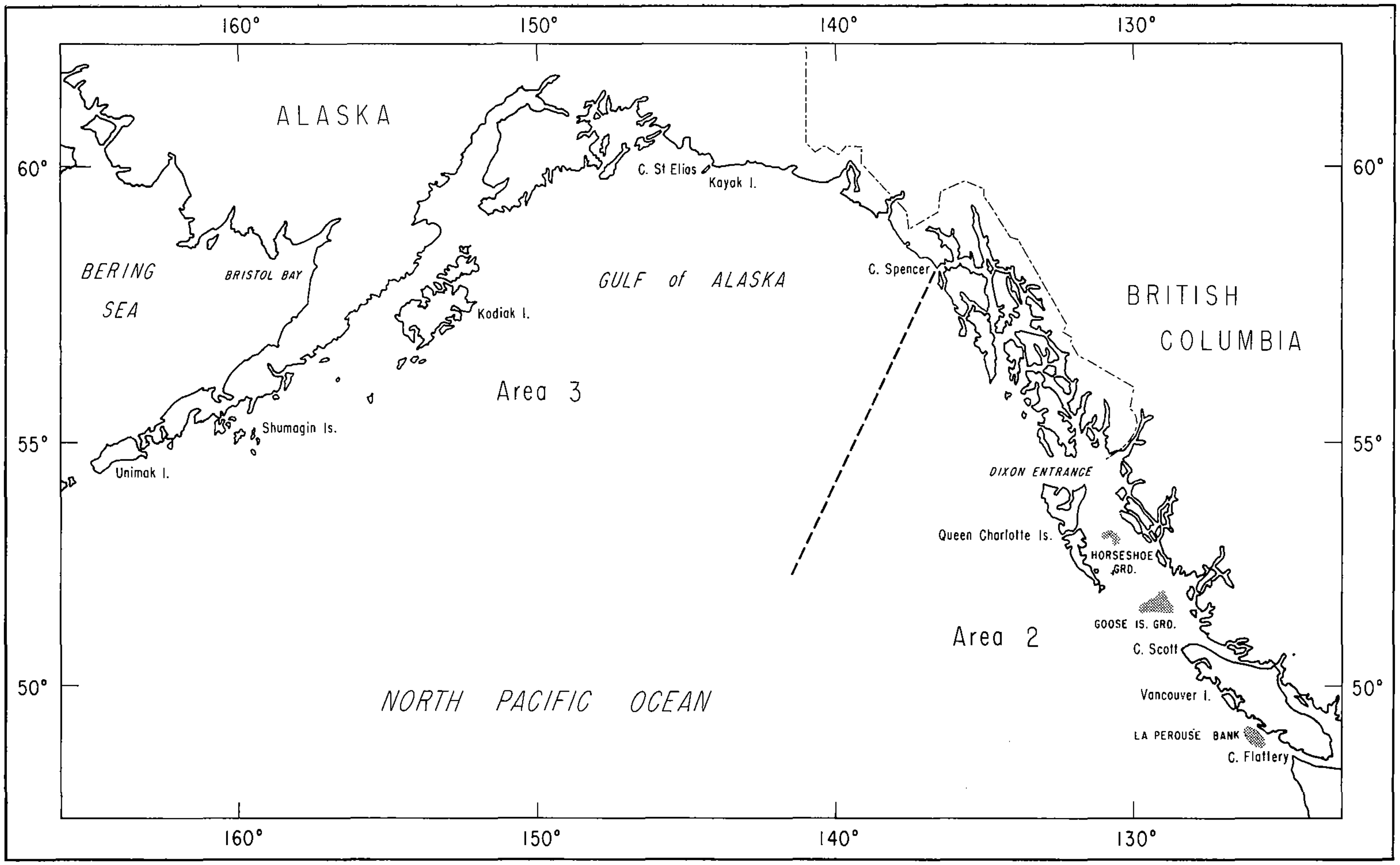

Figure 1. Map of the Pacific Coast showing locations where gear selection experiments were conducted.

Since the late 1950's increasing numbers of foreign vessels have been fishing off the Pacific Coast of North America. Although halibut is not of primary interest to these vessels, they are known to catch halibut inadvertently while seeking other bottomfish species. North American trawlers, which operate south of Dixon Entrance, have increased their landed catches of bottomfish species other than halibut since 1960. Although prohibited from retaining inadvertently-caught halibut under Halibut Commission regulations, it is known that some released halibut do not survive.

The Halibut Commission recognized that increased trawling both by foreign and North American trawlers would reduce the share of the halibut productivity available to North American fishermen. It also recognized that the full impact of these fisheries would depend upon the characteristics of the trawl gear employed as well as on where, when and how it was fished.

This report describes the selection characteristics of trawl nets of different codend mesh sizes and of commercial halibut setline gear. This information is used in a mathematical model to predict the relative yield of halibut that could be taken by each type of gear when fished alone and by a fishery using both setline and trawl net gear simultaneously.

METHODS OF ANALYSIS

Trawl Net Selection

Studies on the selection characteristics of trawl net gear date back to the late 19th Century with the work of T. W. Fulton (1893). Since that time an extensive literature has accumulated describing methods of measuring the selection properties of bottom trawl net gear and describing the characteristics of the more common types of such gear. Useful references on the subject will be found in Davis (1934), Herrington (1935), Beverton and Holt (1957), ICNAF (1963) and ICES (1964).

The selection characteristics of a fishing gear refers to the ability of the gear to capture and retain certain individual fish while permitting others to escape. Selection is usually measured in relation to fish length. Selection characteristics are determined by the design of the gear, the material used in its construction and the conditions under which it is fished. Because species vary markedly in size, shape, behavior and swimming ability, the selection properties of fishing gear differ for different species.

The selection range has been defined as the range of fish lengths over which a fishing gear exercises selection (Clark, 1963). With respect to trawl nets, selection can occur because small fish are able to escape through the meshes; it can also occur because stronger swimming fish are able to avoid the gear as was observed by McIntyre (1956) and by High, Ellis and Lusz (1969). The terms selection range and selection curve are frequently applied to the sizes of fish caught below the length of maximum retention and it is assumed that retention is uniformly high for all sizes above that length. For halibut this assumption cannot be satisfied so the entire selection range is considered. Consequently reference will be made to the upper and lower selection curve, division being at the size of maximum retention.

The selection curve for a particular unit of gear is determined from the proportion of the fish of different sizes in the population that are caught and retained by the gear. Two basic methods can provide the required information: comparison of catches by gears having different selection curves and by tagged fish recoveries.

Three techniques which may be used for obtaining comparable catches by trawl nets of dissimilar codend mesh size are by fishing both nets in a parallel manner, by using a divided or "trouser" codend with different mesh sizes on each "leg", or by lacing a small mesh cover over the large mesh codend. Although the methods differ in principle, the results have shown reasonably good agreement when compared. The parallel fishing method has been used in the present study.

The selection curve is approximated by calculating for each length class the retention ratio for the gear being studied using the equation

$$P_i = \frac{C_i}{T_i} \qquad [1]$$

where P_i is the retention ratio for length class i, C_i is the number of fish in length class i retained by the gear under study and T_i is the number of fish of length class i from which C_i was taken. For example, T_i might be the number caught by the smaller mesh net during parallel fishing operation. The selection curve will be obtained when the series of retention ratios are plotted against length.

Much of the effect of statistical variation can be removed by smoothing the ratios by a moving average of three and connecting the points thus obtained by straight line segments. The smoothed ratio, $\overline{P}_i$, is obtained from the equation

$$\overline{P}_i = \frac{P_{i-1} + P_i + P_{i+1}}{3} \qquad [2]$$

and the corresponding length, $\overline{L}_i$, is obtained from the equation

$$\overline{L}_i = \frac{L_{i-1} + L_i + L_{i+1}}{3} \, . \qquad [3]$$

Smoothing tends to spread the selection curve over a range of sizes which is greater than that for unsmoothed data. This bias decreases with decrease in width of the length classes used. It also tends toward zero near the middle of the selection range.

The selection properties of nets of different mesh sizes are best compared by calculating their 50% selection length, that is, the length at which 50% of the fish passing into the net are retained, the remainder presumably escaping through the meshes. A generally satisfactory estimate of the 50% selection length is readily computed from the smoothed selection curve by linear interpolation between the ratios on either side of the 50% point and their corresponding lengths. Thus suppose the smoothed ratio at 47.0 cm. is 0.455 and that at 50.0 cm. is 0.581, then the lower 50% selection length is estimated at 48.1 cm.

The comparable haul method for determining the lower selection range for a trawl net requires several assumptions. One assumption is that the numbers of fish caught by each net at each length above the size of maximum retention are proportional to the number in the population. This assumption will fail if the ability of fish to avoid the net increases with fish size as postulated by Beverton and Holt (1957). This avoidance will not be detected in the likely event that both nets are subject to the same escape-by-size relationship.

If uniform catches are not obtained above the point of maximum retention for each gear the calculated ratio of catches will not remain at the level of maximum retention but will exhibit an increasing or decreasing slope for sizes above that point depending upon the reason for the change in proportionality. Davis (1934) and Beverton and Holt (1957) observed this phenomenon and the latter authors suggested using the slope of the upper ratios to adjust the entire curve to approach an upper asymptote of unity. Such adjustment is futile since any curve adjusted to eliminate the effect of gear avoidance by the fish does not reflect the true selection characteristics of the gear.

Another assumption made is that the lower selection range of the large- and small-mesh nets does not overlap. Failure of this assumption will result in a distortion of the selection curve for the larger mesh net. Beverton and Holt (ibid) suggested an ogive-ratio method for estimating the true 50% selection length for the larger mesh net in such a case.

Finally, it is assumed that fish of sizes spanning the lower selection range of the large mesh net are present in the population. If not, the catch composition of the two nets will tend to merge and the ratios of catches will not define the selection curve of the large mesh net. An example of this situation is described later in this report.

Tagging data can also be used to construct the selection curve and to locate the 50% selection length. In this case tagged fish releases comprise the population and the percentage recovered at each length represents the relative degree of selection at that length. In other words, for each length class i,

$$\frac{n_i}{T_i} = S_i q_i f \qquad [4]$$

where n_i is the number recovered, T_i is the number released, q_i is the catchability of the fishing gear for fish of size i and f is the number of units of fishing effort expended. S_i is the ratio of annual total mortality to instantaneous total mortality so S_i changes relatively little with change in q_i for all i. The percentage recovery can be adjusted to range from 0 to 1.0 and the 50% selection length can be located as before. The data may be smoothed if necessary to aid in locating the 50% selection length.

In using this method it is assumed that the recoveries are drawn randomly (representatively) from the released population. This assumption will fail if tagging mortality, emigration or growth occur between tagging and recovery and if these rates vary with length of fish. Of course, the effect of emigration and growth will be minimized if recoveries are made soon after tagging. A length-related tagging mortality will occur whenever the proportion of fatal injuries increases with decrease in fish length. Its effect will be to overestimate the sizes of fish falling within the lower selection range.

The nets used in this study were of the 400-mesh Eastern design except that the 1¼-inch net was made at about 2/3 scale. Construction details are given in the Appendix of this study.

Unless otherwise cited the codend mesh sizes referred to are those specified by the manufacturer. Measurements of average stretched mesh size were made for each of the nets after the experiments had been completed rather than after each haul as is sometimes prescribed. Although the mesh openings may have changed to some extent between tows, it is deemed unlikely that such changes would have altered the fishing or selection characteristics of the nets enough to have affected the conclusions reached.

Two measurements were made for each net; the actual mesh size which was the stretched distance from the middle of one knot to the middle of the opposite knot and the inside measurement which was the length of the opening when stretched between opposite knots. Ten randomly selected meshes were measured to obtain the average inside measurement while four randomly selected groups of five meshes were measured to obtain the actual mesh size. Although the web was stretched by hand, an effort was made to apply uniform tension for each measurement. The average measurements are given in the following table:

Manufacturer's Stated Mesh Size (inches)	Actual Mesh Size (inches)	Inside Measurement (inches)
1¼	1.3	1.1
3½	3.4	2.8
7	6.5	6.1
9	8.9	8.4

Setline Selection

The determination of selection curves and of the 50% selection point for setline gear can be achieved by the same method as were described above for trawl nets. However, use of the simultaneous fishing method will require comparison of setline catches with trawl catches as was done by McCracken (1963) and Saetersdal (1963). This makes fully comparable catches more difficult to obtain because of basic differences in the fishing action of the two gears. A particular problem in comparing trawl and setline catches is that the upper selection range for the two gears differs which complicates detection of the point of maximum retention. The wide range of lengths achieved by halibut tends to aggravate this problem. Although the same situation can occur between catches of two trawl nets, the differences are not likely to be so great.

The recovery of tagged fish can provide a more reliable measure of utilization by length provided the length composition of the tagged population from which the recoveries are drawn is essentially the same as the composition of the releases.

The factors which determine whether or not a fish is caught on setline gear are not as well known as is the case for trawl gear. Hook size and bait size affect the selection characteristics of setline gear (Thompson, 1926; McCracken, 1963; Saetersdal, 1963; Fisheries Agency of Japan, 1966), probably because capture requires that the fish be able to take the baited hook into its mouth. Fish behavior may be more important in setline selection than in trawl selection since capture requires action on the part of the fish in addition to its presence. Allen (1963) suggested that territorial behavior might result in larger fish being captured first. On the other hand, a hook small enough to capture small fish may not be strong enough to hold large fish.

The unit of setline gear commonly used in the North American commercial halibut fishery is known as a "skate". The groundline now usually consists of about 250 to 300 fathoms of 28- to 32-pound nylon rope. Attached to the groundlines at 13-, 18- or 21-foot intervals are lighter branch lines or "gangions" of braided nylon about five feet long. Prior to the early 1960's natural fibers were used in place of nylon for groundlines and gangions. At the end of each gangion is a barbed, offset, eyed hook, usually Mustad No. 6283.

Skates are usually tied together in "sets" or "strings" of from four to twelve skates depending on the location and type of bottom. At the end of each set is an anchor with a buoy-line leading to the surface where it is attached to a float and flag pole.

Baits consist of fresh or frozen fish purchased at the start of the fishing trip or of fish taken incidentally during fishing. Herring, octopus, true cod, blackcod and salmon are the main species used as bait. The cut baits vary in size with an approximate average length of six inches and width of two inches.

GEAR SELECTION PROPERTIES

Trawl Net Gear

In 1963 and 1965 the Commission operated a trawler on the flats in southeastern Bering Sea to study the distribution and relative abundance of halibut in that region. Two sizes of trawl nets were used, a 3½-inch codend net and a 1¼-inch codend net. The number of pairs of comparable hauls made in 1963 and 1965 were 14 and 47 respectively.

The average duration of hauls with the 1¼-inch net in the two years was 15.7 minutes and 14.8 minutes respectively. The average duration of hauls with the 3½-inch net in the two years was 44.2 minutes and 60.3 minutes respectively. Owing to the small numbers of fish involved in each year's catches, the 1963 and 1965 data were combined. The length frequency of catches by the two nets in the two years and the actual smoothed and adjusted* ratios are given in Table 1. The lower selection curve is shown as the solid line in Figure 2. The 50% selection length for the 3½-inch mesh net is estimated at 26.1 cm.

*Halibut of lengths from 37 to 72 cm. were judged to be fully retained by the gear. An adjustment factor of 0.217 was used to adjust these ratios to an average of 1.0. The same factor was used to adjust the ratios for larger and smaller classes.

Table 1. Length composition of catches by the 1¼-inch and 3½-inch mesh nets during parallel fishing operations in Bering Sea in 1963 and 1965 and calculated ratios.

Length in cm.	Number Caught		Ratios		
	1¼-in.	3½-inch	Actual	Smoothed	Adjusted
7-12	39	0	0	0.240	0.052
13-18	25	18	.720	0.604	0.132
19-24	239	261	1.092	1.439	0.313
25-30	91	228	2.505	2.570	0.558
31-36	106	436	4.113	4.160	0.904
37-42	80	469	5.862	4.975	1.081
43-48	41	203	4.951	5.630	1.223
49-54	13	79	6.076	4.131	0.897
55-60	6	82	1.366	3.763	0.817
61-66	13	50	3.846	3.682	0.800
67-72	6	35	5.833	5.448	1.183
73-78	3	20	6.666	5.433	1.180
79-84	5	19	3.800		
85-90	1	12	12.000		
91-96		7	undefined		
97-102		5	undefined		
103-108		3	undefined		
Total	668	1927			

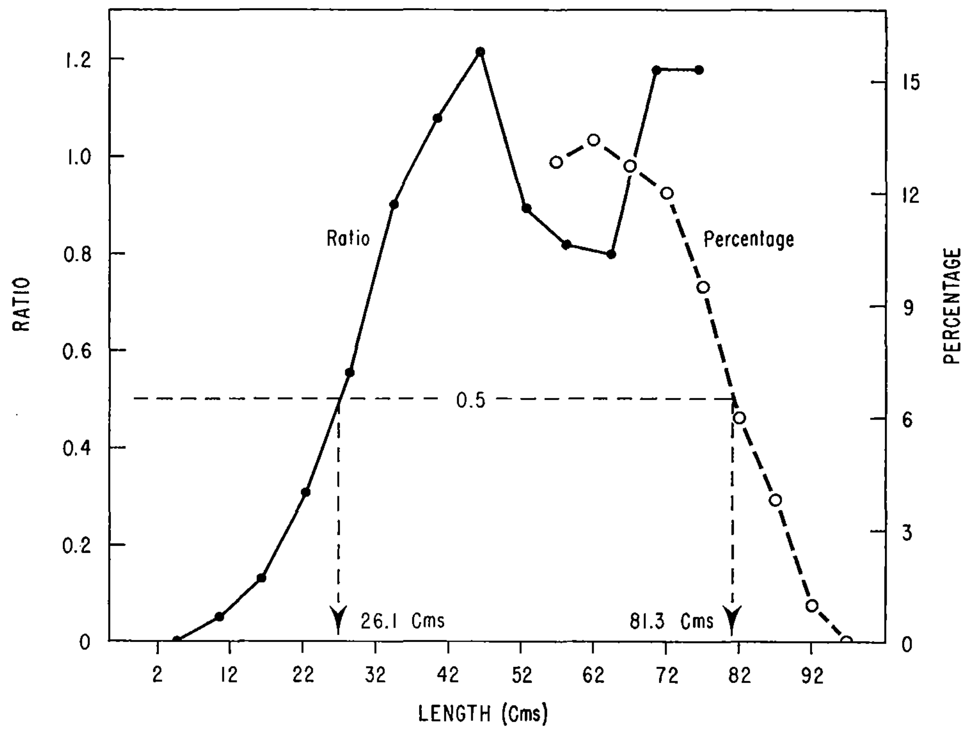

Figure 2. Lower selection curve (solid) for the 3½-inch codend mesh net from parallel fishing data and upper selection curve (broken) for the same gear from tagging data with both lower and upper 50% selection lengths.

Information on the selection curve of trawl nets of the type commonly used by the North American trawl fishery operating in British Columbia and Washington water was also obtained from tagging data. Fish for tagging were obtained from catches on Goose Islands grounds in British Columbia waters by the chartered commercial trawler *Don Edwards* in 1966 using a 3½-inch mesh net. Recoveries were taken by North American trawlers fishing in the same general region with nets which usually have a 3½-inch mesh net in the codend. Only 1966 and 1967 recoveries were used to minimize the effect of growth.

The numbers released and recovered at each 5 cm. length class are given in Table 2. The relationship between percentage recovery and length at tagging is also shown in Figure 2 by the broken line. The lower selection range does not appear because fish of lengths in that size range were not tagged. A declining recovery with increase in length is shown in the upper selection range, beginning at about 65 cm. On the basis of these data the upper 50% selection length is 81.3 cm. Although halibut larger than 90 cm. (15 pounds) are caught by commercial trawlers using present fishing methods and gear, their capture is relatively infrequent according to the above data. Captures of tagged fish by setline gear prove that these large fish are present on the fishing grounds as is shown below.

The total selection curve for the 3½-inch codend net is implied by the area of overlap of the upper and lower selection curves (Figure 2). Halibut having lengths between about 37 and 72 cm. are judged to be within the range of maximum retention for this gear.

Table 2. Percentage recovery by release length for halibut tagged on Goose Islands grounds in 1966 and recovered in 1966 and 1967 by North American commercial trawlers.

Length Class	Released Number	Recovered by Trawl: Number	Percentage	Smoothed Percentage	Adjusted Percentage
45-49	2				
50-54	21	3	14.2		
55-59	84	13	15.5	12.8	0.988
60-64	126	11	8.7	13.4	1.034
65-69	107	17	15.9	12.7	0.980
70-74	163	22	13.5	12.0	0.926
75-79	138	9	6.5	9.5	0.733
80-84	71	6	8.4	6.0	0.463
85-89	32	1	3.1	3.8	0.293
90-94	12	0	0	1.0	0.077
95-99	7	0	0		
100-104	4				
105-109	1				
110-114	1				
115-119	3				
Total	772	82			

During a trawl survey conducted by the Commission in the Gulf of Alaska in the years 1961-1963, a series of comparable hauls was made to study the relationship between codend mesh size and the lengths of halibut caught. The tests were conducted on grounds near Kayak Island in the central Gulf of Alaska during late August and early September of 1962. This location was selected because it appeared to provide an adequate amount of trawlable bottom for the planned series of hauls and because a wide range of sizes of halibut was known to inhabit the area. The work was done in late summer when weather conditions would likely permit completion of the series of hauls.

Table 3. Length frequencies of halibut caught during comparable hauls made near Kayak Island, Alaska and retention ratios for nets having 7-inch and 9-inch mesh codends.

Length in cm.	Numbers caught by mesh size: 3½"	7"	9"	Retention Ratios: 7-inch Net: Actual	Smoothed	Adjusted	9-inch Net: Actual	Smoothed	Adjusted
15-19	1								
20-24	29			0	0.008	0.011	0		
25-29	86	2		0.023	0.020	0.026	0	0.004	0.004
30-34	78	3	1	0.038	0.036	0.048	0.013	0.004	0.004
35-39	65	3	0	0.046	0.070	0.093	0	0.004	0.004
40-44	39	5	0	0.128	0.152	0.202	0	0.016	0.016
45-49	41	12	2	0.292	0.362	0.480	0.049	0.026	0.025
50-54	33	22	1	0.666	0.574	0.761	0.030	0.026	0.025
55-59	34	26	0	0.765	0.723	0.959	0	0.053	0.052
60-64	23	17	3	0.739	0.751	0.996	0.130	0.160	0.157
65-69	20	15	7	0.750	1.274	1.689	0.350	0.493	0.483
70-74	6	14	6	2.333	1.130	1.498	1.000	0.681	0.667
75-79	13	4	9	0.308	1.047	1.388	0.692	1.008	0.988
80-84	6	3	8	0.500	0.686	0.910	1.333	1.008	0.988
85-89	4	5	4	1.250	0.783	1.038	1.000	1.044	1.023
90-94	5	3	4	0.600			0.800		
95-99	0	0	1	*			*		
100-104	4	0	1	*			*		
105-109	2	1	1	*			*		
Total	489	135	48						

* Ratios based on meagre data are omitted.

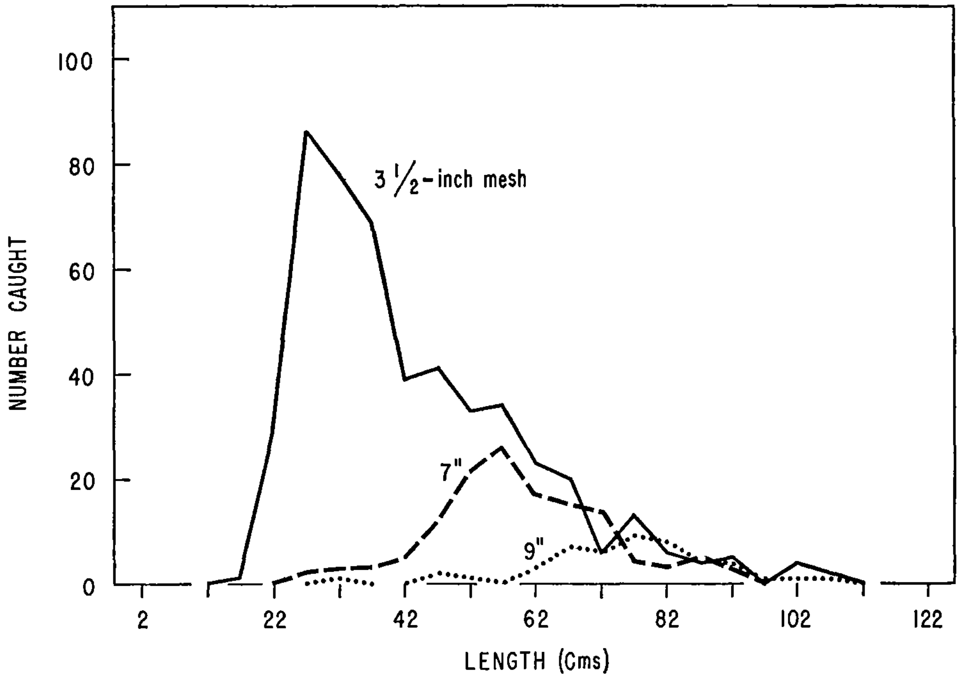

Figure 3. Length frequency in numbers of halibut caught by the 3½-inch, 7-inch and 9-inch codend nets in parallel hauls made near Kayak Island, Alaska.

Three series of nine hauls were made in which each vessel made a haul with the 3½-, 7-, and 9-inch net. The total number of hauls made in the test was 27. The nets were exchanged between vessels after each haul so that the same nets were used by each vessel. The length frequencies in numbers of halibut caught by each net in the series of hauls are given in Table 3 and shown in Figure 3.

The relative fishing capability of the vessels was tested in a series of nine comparable hauls made by the three boats with 3½-inch nets. Although the number of halibut caught in successive hauls by each boat varied widely, no difference was found between vessels in the numbers of halibut caught on matched hauls ($F = 0.026$, $df = 2{,}24$). These observations provide evidence that catches taken by the three vessels when fishing in a parallel manner are indeed comparable.

The ratio of catches at each 5 cm. length class by the 3½-inch and 7-inch mesh net and the ratios for the 3½-inch and 9-inch mesh nets are presented in Table 3 as are the smoothed and adjusted ratios. The selection curves are plotted for each net in Figure 4. The lower 50% selection points for the 7-inch and the 9-inch nets were 47.4 and 67.5 cm. respectively.

Further information on the selection characteristics of the 9-inch mesh net is provided by data obtained from experiments conducted by the trawler *Karen T* during four fishing trips in 1968 while under charter to the Commission. The fishing location on trip one was La Perouse Bank, off Cape Flattery, Washington, while Horseshoe Ground in British Columbia waters was the location for trip three. The fishing locations for trips two and four were the Cape Scott-Goose Islands grounds in British Columbia waters. At each of these locations halibut are caught frequently by North American trawlers while fishing for other species.

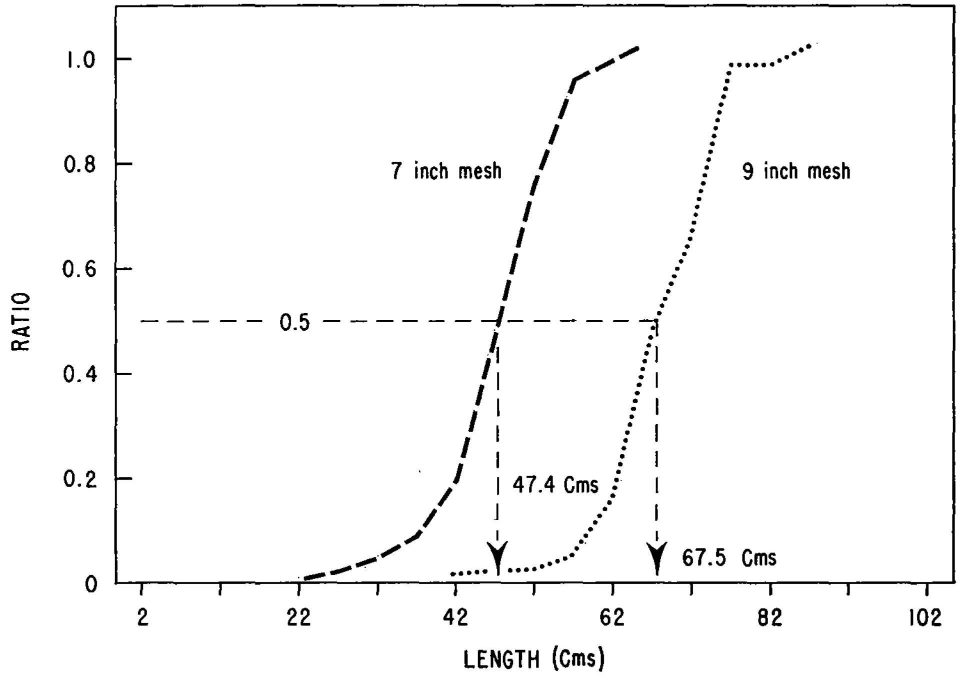

Figure 4. Lower selection curves and the 50% selection lengths for 7-inch and 9-inch codend mesh nets from comparable hauls made near Kayak Island, Alaska.

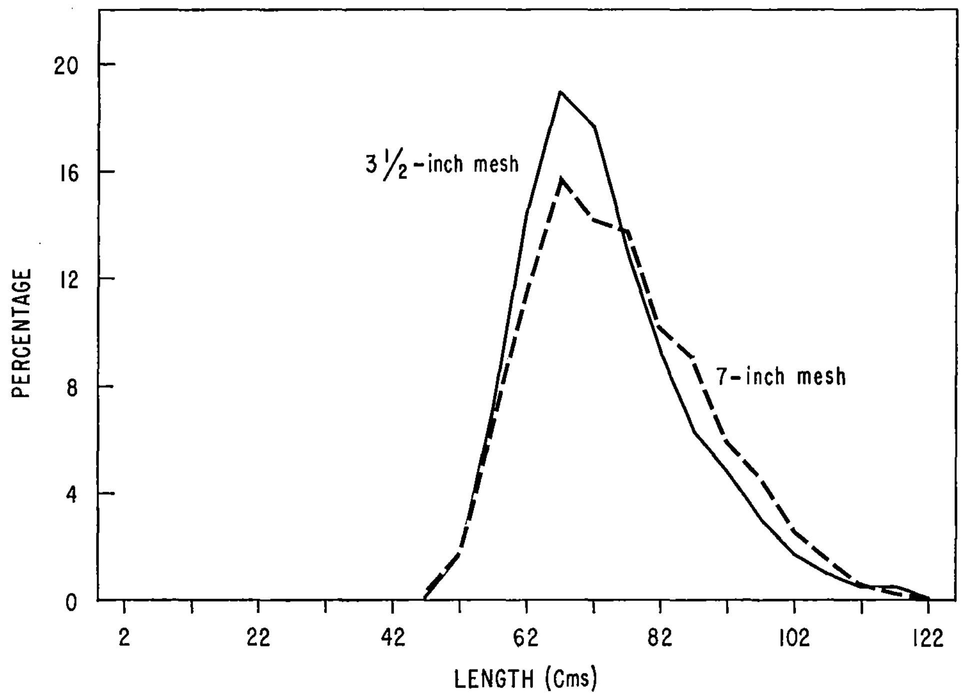

Figure 5. Length frequencies of halibut caught in 3½- and 7-inch codend mesh nets during KAREN T Trip I on La Perouse Bank, 1968.

Nets having codend meshes of 3½-, 7- and 9-inches were fished in a comparable manner to provide mesh selection information. In addition, some one- and two-hour hauls were made to test the effect of haul duration on selection by the nets.

During operations of the *Karen T,* two noteworthy observations were made concerning catches by the 3½-inch mesh net. First, on several hauls on La Perouse Bank this net became heavily burdened by stones which prevented it from fishing properly. For this reason, several hauls with the 3½-inch mesh net at La Perouse Bank were rejected as noneffective. The 7- and 9-inch mesh nets fished normally since the stones could pass through the mesh openings. At the other locations stones were not a problem and all nets appeared to fish normally.

Second, at all three locations, the size composition of halibut taken by the 3½-inch and 7-inch nets were nearly the same, as shown by a sample of catches from La Perouse Bank (Figure 5). This similarity of catch is probably explained by a near absence of halibut less than 50 cm. in length at these locations since the lower selection range for these two nets do not overlap (Figures 2 and 4). Thus part of the lower selection range of the 3½-inch mesh net is missing from the catches. As a consequence usable estimates of the lower selection curve of the 7-inch mesh net are not available from these data.

Table 4. Length frequency of parallel hauls with 3½-inch and 9-inch codend mesh nets and calculated ratios by trips for 1968 KAREN T. experiments.

Length in cm.	Trip 1			Trip 2			Trip 3			Trip 4		
	Numbers			Numbers			Numbers			Numbers		
	3½″	9″	Ratio	3½″	9″	Ratio	3½″	9″	Ratio	3½″	9″	Ratio
45-49				2	0	0.026	13	0	0.005			
50-54	2	0	0.020	16	2	0.027	29	1	0.011	6	0	0.010
55-59	16	2	0.066	83	3	0.069	89	4	0.038	43	3	0.021
60-64	53	15	0.149	149	30	0.176	183	33	0.144	187	14	0.097
65-69	69	44	0.436	146	93	0.432	134	99	0.387	233	125	0.263
70-74	53	96	0.661	156	191	0.557	124	206	0.619	239	295	0.573
75-79	39	66	0.900	106	135	0.854	96	165	0.860	101	227	0.922
80-84	23	49	0.936	73	115	0.915	46	108	0.898	48	143	1.164
85-89	23	47	1.278	37	56	1.010	35	67	0.978	27	79	1.054
90-94	12	46	1.402	22	38	1.006	15	34	1.104	25	37	0.978
95-99	10	29		15	21		11	35		9	22	
100-104	5	20		4	12		6	12		4	9	
105-109	1	12		1	3		4	6		3	1	
110-114	3	4		3	2		4	2		3	1	
115-119	0	1						3			3	
120-124	1							2				
125-129												
130-134											1	
135-139		1			1							
140-144												
145-149				1								
Total	310	432		814	702		789	777		928	960	

The *Karen T* data were analyzed by trip to show the consistency of results with respect to location. Length frequencies of paired catches by the 3½-inch and 9-inch mesh nets at each location are given in Table 4 and shown in Figure 6. Smoothed lower selection curves for the 9-inch mesh net are given in Table 4 and shown in

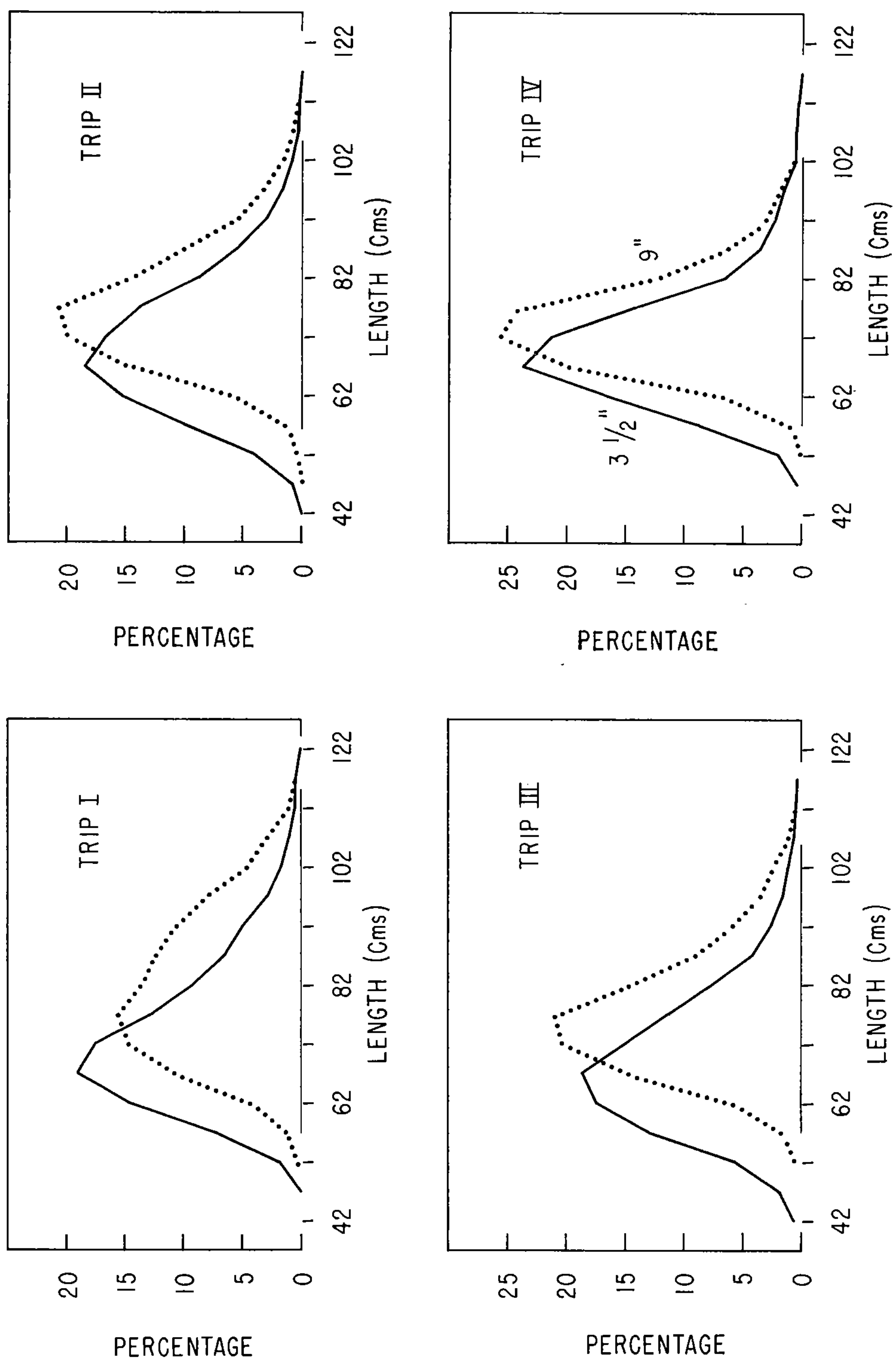

Figure 6. Smoothed length frequencies of catches taken during the 1968 KAREN T operations, Trips I to IV, and used in the computation of selection curves for the 9-inch mesh net.

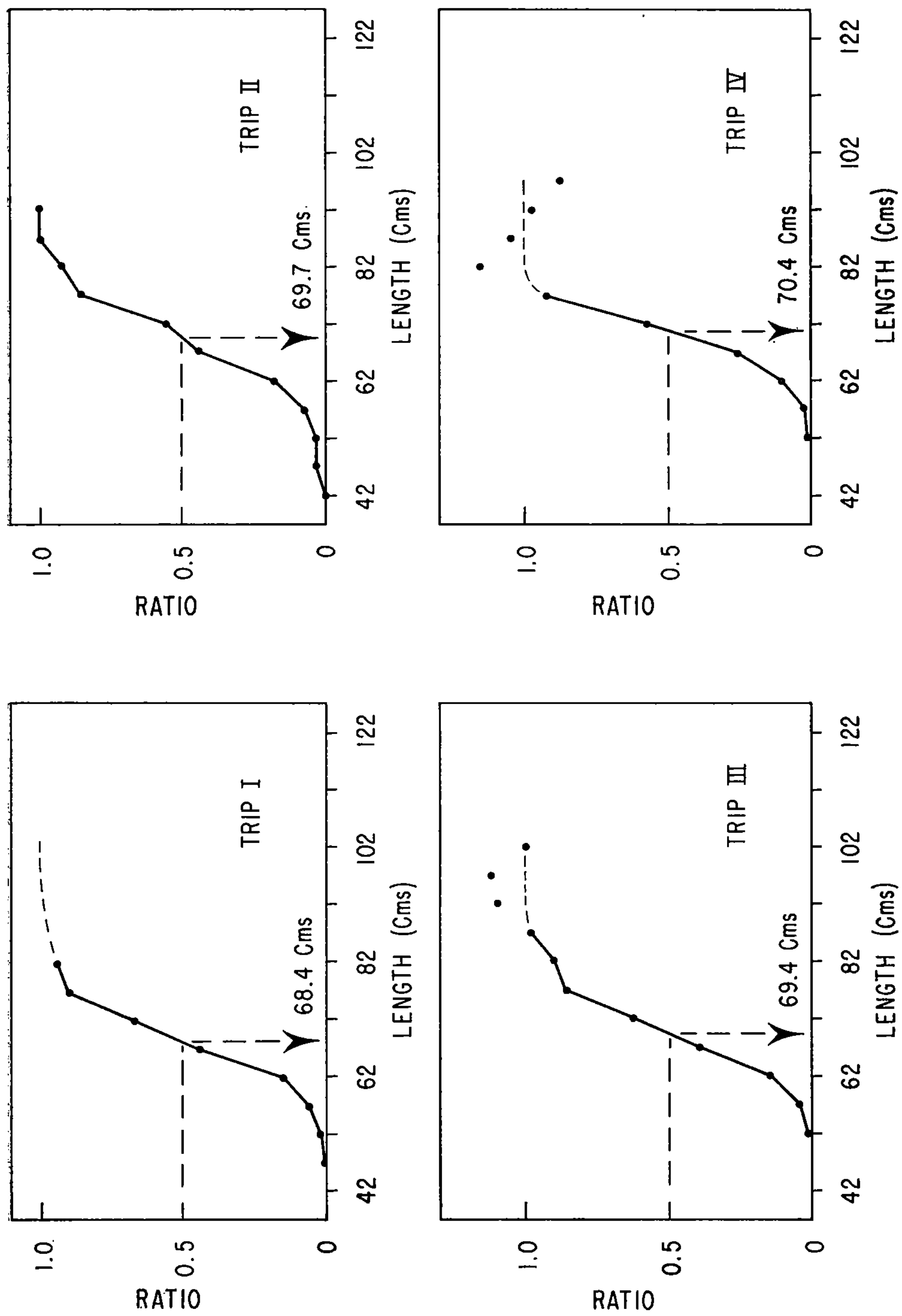

Figure 7. Lower selection curves and 50% selection lengths for the 9-inch mesh net obtained from four fishing trips by the KAREN T between Cape Flattery, Washington and middle Hecate Strait, British Columbia.

Figure 7. The lower 50% selection length for the 9-inch mesh net was remarkably consistent between each of the four trips as shown in the following table:

Trip	Location	50% Selection Length (cm.)	Number of Paired Hauls
1	La Perouse Bank	68.4	11
2	Cape Scott-Goose Is.	69.7	12
3	Horseshoe	69.4	13
4	Cape Scott-Goose Is.	70.8	16

The estimate of the lower 50% selection length from La Perouse Bank catches is less reliable than the others because of difficulty in locating the point of maximum retention. Reference to Figure 6 shows that the 9-inch mesh net tended to catch more than expected of the fish above 80 cm. in length. This condition caused the ratios to continue increasing instead of levelling off in the 80-90 cm. size range as expected (Table 4). Since fish above 77 cm. appeared to be fully available to the gear as indicated by the declining right limb of the length frequency curve, the point of maximum retention was judged to be in the 80-90 cm. range. The ratios for the 82 and 87 cm. classes were therefore averaged to compute the adjustment factor and the lower 50% selection length was computed in the usual manner.

The shape of the entire selection curve for the 7- and 9-inch mesh nets can be calculated from parallel catches with the 3½-inch mesh net provided allowance is made for the declining right limb of the selection curve for the smaller mesh net. To do this, the retention ratio is calculated from equation (1) as for the lower selection curve and the result is in turn multiplied by the appropriate retention ratio from the selection curve for the 3½-inch net as calculated above.

Total catches for each of the 3½-, 7- and 9-inch mesh nets during parallel hauls by the *Karen T* in 1968 and resulting adjusted ratios for the 7- and 9-inch nets are given in Table 5. The total selection curves for the three nets are shown in Figure 8.

Table 5. Calculation of the total selection curves for the 7-and 9-inch codend mesh nets.

		Catches in Paired Hauls					
Length	3½-inch net selection curve	Catch 3½-inch net	Catch 7-inch	Smoothed Ratio	Catch 3½-inch net	Catch 9-inch	Smoothed Ratio
40-44	1.000	0	0	0.066	0	0	0.000
45-49	1.000	5	1	0.250	15	0	0.016
50-54	1.000	30	17	0.569	51	3	0.030
55-59	1.000	95	93	0.802	215	10	0.072
60-64	1.000	173	158	0.999	519	77	0.227
65-69	0.980	155	185	1.001	513	317	0.565
70-74	0.926	172	183	0.982	519	690	0.884
75-79	0.733	113	132	0.750	303	527	1.000
80-84	0.463	92	91	0.518	167	366	0.820
85-89	0.293	61	57	0.259	99	202	0.495
90-94	0.077	33	27	0.110	62	109	0.208
95-99		25	18	0.021	35	78	0.038
100-104		17	13		14	33	
105-109		2	4		8	10	
110-114		2	4		10	5	
115-119		2	1			6	
120-124		0	1			2	
125-129		0	0			0	
130-134		1	1			1	
135-139		0				1	
140-144		1					
Total		979	986		2530	2437	

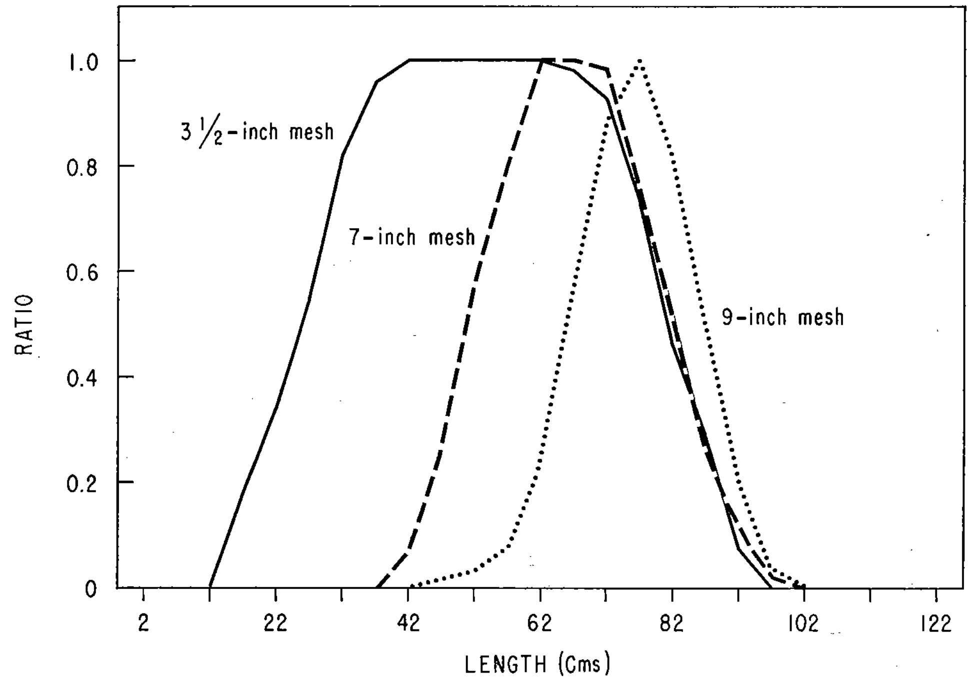

Figure 8. Calculated total selection curves for trawl nets having 3½-, 7- and 9-inch codend meshes.

The major difference between the selection properties of the three nets is in the lower selection curve due to the retention of smaller fish by the smaller meshed codends. Although the 9-inch net appeared to catch slightly more large fish than did the 3½- and 7-inch nets, the difference was not great. If the upper selection curve is a manifestation of the ability of halibut to avoid the net, similar curves should be expected since the nets differed only in the size of mesh used in the codend. However, modifications in net design and in hauling speed might alter the shape of the upper selection curve without changing the lower selection curve.

Setline Gear

Data for examining the lower selection curve for setline gear were obtained during parallel fishing operations of two Commission-chartered vessels on Goose Islands grounds in 1966. A setline vessel, *Chelsea,* fished with conventional halibut setline gear while the *Don Edwards,* an otter trawler, used a trawl net with a 3½-inch mesh codend. Comparability was obtained by having the trawler tow its net between and around the sets of line gear. The length frequencies of halibut caught by the two gears are given in Table 6. The size of maximum retention for setline gear is not indicated by these data since there was no range of sizes within which catches by the two gears were proportional. This is not unexpected since tagging data have shown that trawl gear has a declining upper selection curve. Consequently the ratio of catches by the 3½-inch net and by setline gear was adjusted for the upper selection curve of the 3½-inch net.

The steps in the calculation are given in Table 6 and the resulting curve is shown in Figure 9. The lower 50% selection length obtained from this curve was

Table 6. Length frequencies of halibut caught on Goose Islands grounds with the 3½-inch codend net and with setline gear and the lower selection curve for setline gear.

Length in cms.	3½-inch net Selection Curve	3½-inch net Catch	Setline Catch	Ratio	Adjusted Ratio
40-44	1.00	2	0	.000	0.000
45-49	1.00	21	1	.048	0.011
50-54	1.00	84	4	.048	0.011
55-59	1.00	126	15	.119	0.026
60-64	1.00	107	34	.318	0.070
65-69	0.980	163	126	.759	0.168
70-74	0.926	138	279	1.872	0.415
75-79	0.733	71	385	3.969	0.880
80-84	0.463	32	320	4.776	1.059
85-89	0.293	12	174	4.244	0.941
90-94	0.077	7	108	1.187	
95-99		4	64		
100-104		1	43		
105-109		1	25		
110-114		3	17		
115-119			13		
120-124			11		
125-129			4		
130-134			3		
135-139			3		
140-144			0		
145-149			3		
150-154			2		
155-159			1		
160-164			0		
165-169			0		
170-174			1		
175-179			1		
180-184			1		
Total		772	1638		

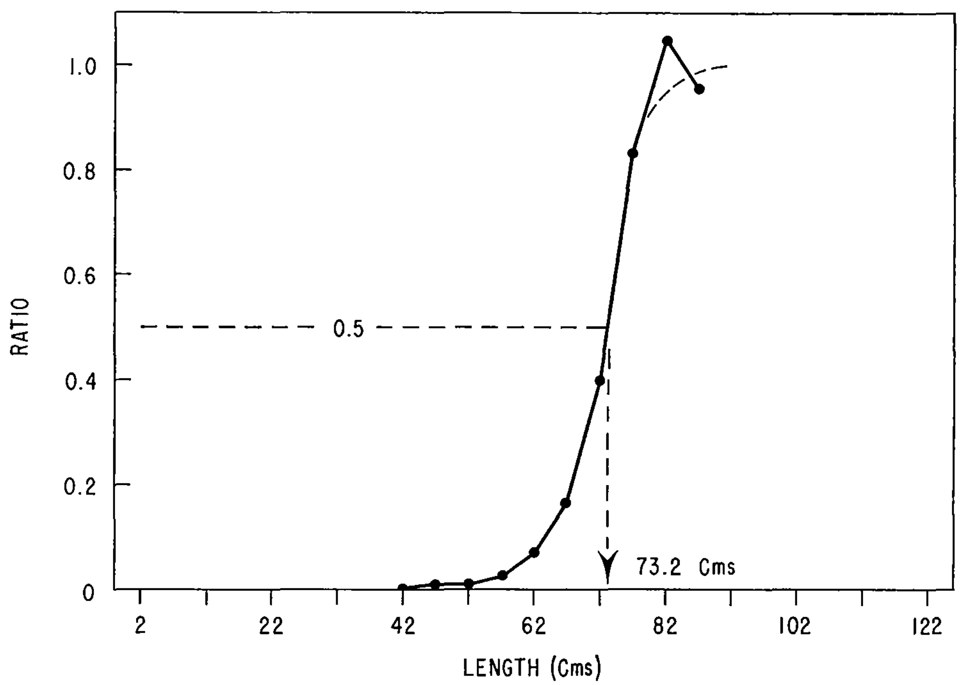

Figure 9. Lower selection curve for setline gear on Goose Islands grounds based on adjusted catches by the 3½-inch codend mesh net.

73.2 cm. The upper 50% selection length was not obtained because the 3½-inch net did not catch sufficient numbers of the larger fish.

Additional information on the selection curve of setline gear is provided by the percentage recovery of tagged fish. For comparability, data are presented from a tagging experiment conducted on Goose Islands grounds by the setliner *Chelsea* in 1966 while fishing in parallel manner with the trawler *Don Edwards.* These experiments produced data used earlier for determining the selection curve of the 3½-inch trawl net.

The numbers tagged by the *Chelsea* in 1966 and the numbers and percentage recovered by setline gear in 1966 and 1967 are presented in Table 7. The smoothed percentage recovery by length at tagging is shown in Figure 10 by the solid line. Taking the modal length of 87 cm. as the point of maximum retention the lower 50% selection length for setline gear on Goose Islands grounds is estimated at 74.3 which agrees well with the 73.2 estimated from the results of parallel fishing on the same grounds. A significant feature of this curve is the declining right limb which indicates that this group of tagged fish became somewhat less vulnerable to capture by setline gear with increase in length above about 87 cm.

Table 7. Number released in 1966 and recovered in 1966 and 1967 by length at tagging from Goose Islands grounds tagging data.

Length in cm.	Number Released	Setline Recoveries		
		Number	Percent	Smoothed Percent
50-54	4			
55-59	12			
60-64	38			1.4
65-69	137	2	1.4	2.6
70-74	298	19	6.4	5.6
75-79	409	37	9.0	9.7
80-84	264	36	13.6	12.4
85-89	149	22	14.8	14.5
90-94	99	15	15.2	13.9
95-99	51	6	11.8	10.7
100-104	39	2	5.1	10.2
105-109	22	3	13.6	6.2
110-114	14	0	0	8.6
115-119	15	2	13.3	7.4
120-124	11	1	9.1	7.4
125-129	3			
130-134	2			
135-139	5			
140-144	0			
145-149	2			
150-154	1			
155-159	0			
>159	2			
Total	1577	145		

An example of the selection characteristics of setline gear in Area 3, i.e. in the Gulf of Alaska West of Cape Spencer, Alaska (Figure 1), is provided by data from a tagging experiment conducted between Kodiak Island and the Shumagin Islands in western Alaska in 1964. This tagging was conducted by the chartered setliner *Eclipse* while fishing on a grid of predetermined stations. The numbers of tagged fish released and the numbers and percentages recovered by setline gear in 1964 and 1965 by length at tagging are presented in Table 8. The smoothed percentages recovered by length at tagging are shown in Figure 10 by the broken line.

Table 8. Numbers tagged in the Kodiak Island-Shumagin Islands Region in 1964 and recovered by setline gear in 1964 and 1965 by length at tagging.

Length in cm.	Number Tagged	Recoveries		
		Number	Percent	Smoothed Percent
40-44	4			
45-49	14			
50-54	53			0.7
55-59	101	2	2.0	0.7
60-64	148	0	0.0	1.4
65-69	182	4	2.2	1.5
70-74	221	5	2.3	1.7
75-79	217	1	0.5	1.4
80-84	271	4	1.5	1.7
85-89	333	10	3.0	2.5
90-94	346	10	2.9	2.8
95-99	349	9	2.6	2.7
100-104	341	9	2.6	2.6
105-109	350	9	2.6	3.0
110-114	295	11	3.7	3.0
115-119	268	7	2.6	3.4
120-124	237	9	3.8	3.5
125-129	236	10	4.2	3.7
130-134	216	7	3.2	4.5
135-139	184	11	6.0	5.1
140-144	131	8	6.1	6.7
145-149	114	9	7.9	5.6
150-154	68	2	2.9	4.3
155-159	46	1	2.2	3.5
160-164	37	2	5.4	7.7
165-169	26	4	15.4	9.5
170-174	13	1	7.7	7.7
175-179	10			2.6
180-184	1			
185-189	4			
> 189	2			
Total	4818	145		

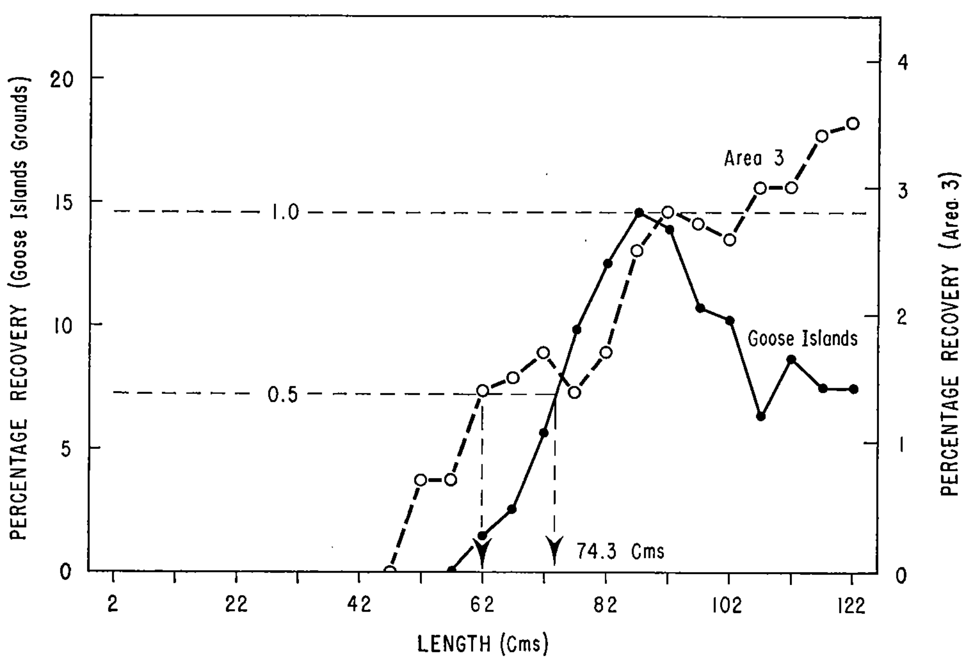

Figure 10. Setline selection curves for Goose Islands grounds in Area 2 (solid line) and for Area 3 (broken line) and 50% selection points based upon tagged fish experiments.

The Area 3 selection curve shows two important differences when compared with the curve from Goose Islands grounds. First, the Area 3 curve extends down to about 47 cm. while the smallest sizes in the curve for Goose Islands grounds were about 62 cm. Thus the selection curve for setline gear on the latter grounds is truncated for smaller sizes as was observed for the selection curve for the 3½-inch mesh trawl net.

Second, the setline selection curve for Area 3 is essentially a line with no significant change in slope throughout its length. Thus there is no indication of a size of maximum retention, without which the lower and upper 50% selection lengths cannot be estimated by the methods used heretofore.

A possible explanation for the divergent results for Goose Islands grounds and Area 3 data is that fishermen exercise some size selection in choosing how, when and where they fish. The natural choice will be to increase their catch of the larger and more valuable halibut by placing their gear where it will more likely catch those sizes of fish. Such selection will be superimposed upon that of the gear itself and thus distort the upper part of the curve. It is also possible that in the competition for food the larger fish are more successful and hence more of them get caught as was suggested by Allen (1963).

The Goose Islands grounds data provide a distorted lower selection curve for setline gear because of the scarcity of halibut at the lower limit of the selection range for that gear. Area 3 data also provide a distorted lower selection curve because the point of maximum retention is not defined. Under the circumstances a tentative best estimate of the lower 50% selection length is obtained as a composite of the two curves. Taking 47 cm., the lower limit of the Area 3 curve, and 87 cm., the point of maximum retention in the Goose Islands grounds curve, the lower 50% selection length is estimated to be about 67.0 cm., i.e. at the midpoint. Assuming the lower selection curve reaches a maximum at 87 cm., the 50% selection lengths for the Goose Islands grounds and Area 3 data would be 73.4 cm. and 62.0 cm. respectively which encompass the estimate of 67.0 cm.

The divergent upper selection curves for different grounds shown in Figure 10 suggest that there is no single upper selection curve for setline gear. Until the reasons for the observed differences can be determined it is probably justifiable to assume that, on the average, the upper selection curve is essentially constant for all sizes of halibut above 87 cm.

SELECTION FACTOR FOR HALIBUT

A useful proportionality called the selection factor exists between the lower 50% selection size and the size of codend mesh. This proportionality is expressed by the equation

$$\text{Selection Factor} = \frac{\text{Lower 50\% Selection Length}}{\text{Mesh Size}} \qquad [5]$$

This statistic is useful in predicting the selection characteristics of trawls of various mesh sizes.

The lower 50% selection size calculated by the parallel fishing method for the different mesh sizes are plotted in Figure 11 against both the manufacturers stated mesh size (solid dots) and the average inside measurements (open dots) given earlier

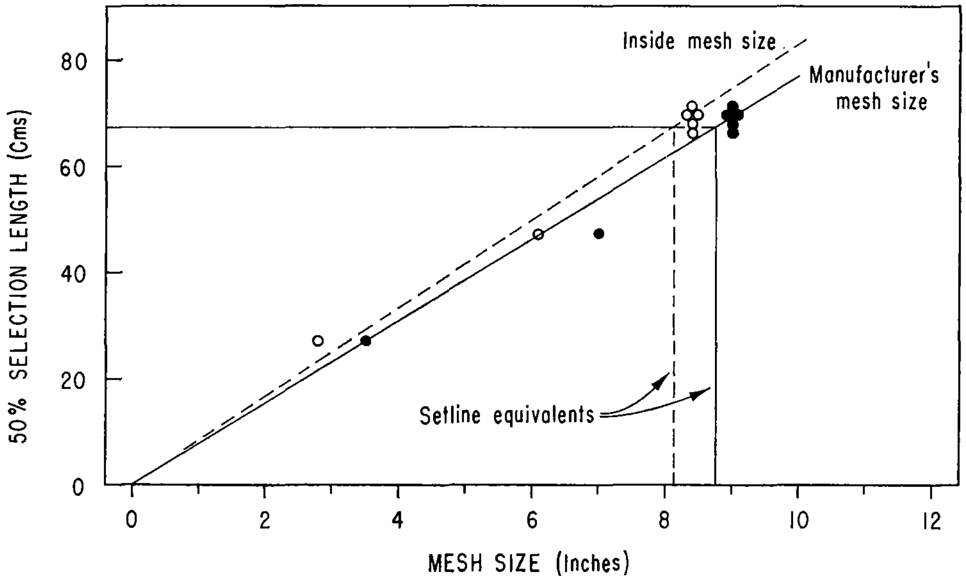

Figure 11. Relationship between lower 50% selection length and codend mesh size based on manufacturers stated mesh size (solid line and solid dots) and inside mesh measurements (broken line and open dots).

in this report. Forcing the line through the origin, the slope of the regression line for inside measurements is 8.2 cm. of fish length per inch of codend mesh opening.

From this relationship it is estimated that the lower 50% selection length for setline gear would be approximately the same as that of a trawl net having a codend with an inside mesh size of 8.2 inches or a manufacturers stated mesh size of 8.8 inches. Converting inside mesh sizes to centimeters the average selection factor for halibut is 3.2 when caught in trawls constructed and fished in the manner described above.

Comparable estimates of the selection factor for Atlantic halibut are lacking but selection factors for other species of flatfish have been reported to range from 2.0 to 2.5 depending upon the species and on net materials (Buchanan-Wollaston, 1933; Beverton and Holt, 1957; Clark, McCracken and Templeman, 1958; Best, 1961; and Ketchen and Forrester, 1966). Although the above estimate for halibut is greater than those for other flatfish species, the differences can probably be attributed to differences in body shape, behavior and swimming power of halibut.

SUSTAINABLE YIELD BY GEAR

The Halibut Convention provides that in managing the fishery to produce the maximum sustainable yield, the Commission may specify the size and character of halibut fishing appliances to be used in any area. Although the Commission had determined many years ago that the use of commercial trawl net gear to catch halibut was inimical to the attainment of its management objectives, the extent of the losses which would result from the trawl capture of halibut was not known. The foregoing information on the selection properties of trawl and setline gear provide a basis for estimating the possible effect the use of such gears would have on the sustainable yield of halibut.

The yield tables of Beverton and Holt (1964) provide a convenient method for computing relative yields from a population with specified growth and mortality characteristics when fished with gear of specified selection characteristics. For present purposes growth parameters of L_∞ and K of 152 cm. and 0.10 respectively and a natural mortality rate of 0.175 were assumed. These values conform with previous estimates of halibut growth (Southward, 1967) and mortality (IPHC, 1960; Chapman, Myhre and Southward, 1962).

Selection by each gear was introduced on a knife-edge basis. Setline gear was assumed to catch no fish below 73 cm. in length and to be uniformly effective for catching all halibut above that size. Although the 50% selection length for setline gear in the Gulf of Alaska was 67 cm., this difference was not important in the present comparisons.

The 3½-inch mesh net was assumed to catch no halibut below 26 cm. which was the lower 50% selection size observed in Bering Sea where catches contained halibut much smaller than that size. The 3½-inch net was also assumed to catch no halibut above 90 cm. The 9-inch mesh net was assumed to catch no halibut below 69 cm. or above 100 cm.

The foregoing upper selection sizes for trawl nets are somewhat greater than what was observed from inadvertent trawl catches of halibut discussed earlier in the report. The increase was made on the assumption that if halibut were sought after commercially the trawl gear would be fished in a manner to increase the proportion of the larger and more valuable sizes.

Insofar as the natural mortality, growth and gear selection estimates used are representative of the respective parameters for halibut the relative yields for each type of gear at different levels of fishing mortality will be as shown in Figure 12. At all levels of fishing mortality, setline gear is found to produce the higher sustainable yield. The yield indicated for the 9-inch mesh net is greater than that for the 3½-inch

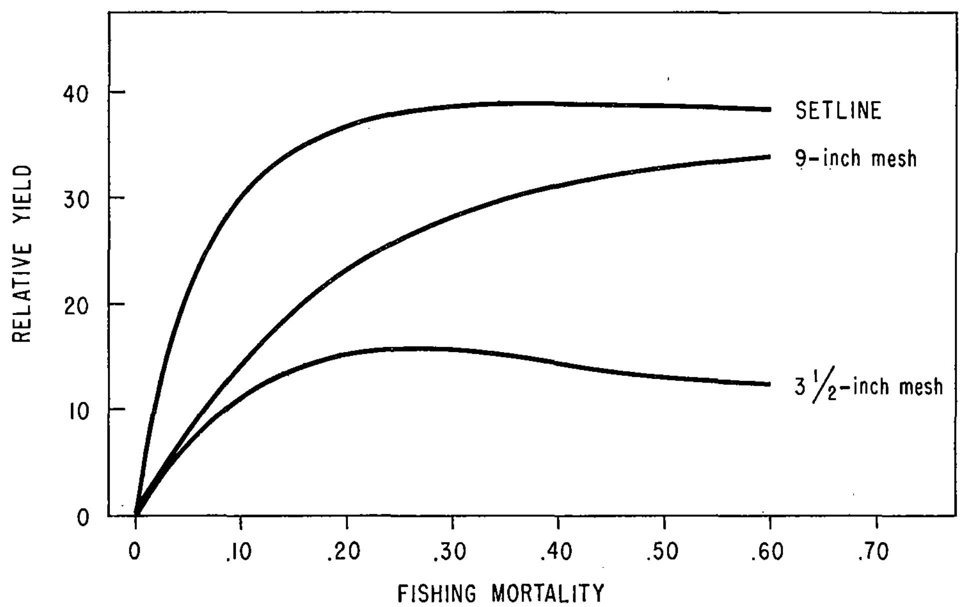

Figure 12. Relationship between relative sustainable yield of halibut and fishing mortality for different gears.

mesh net because the larger mesh net permits the small fast-growing sizes to escape through the mesh openings.

Some grounds South of Cape Spencer, Alaska, have relatively few halibut below 50 cm. in length. For example, length frequency data from the *Karen T* catches indicate that for the grounds fished a knife-edge recruitment at a size of about 60 cm. would be appropriate. Obviously the sustained yield curve for the 3½-inch mesh net on such grounds would more nearly resemble the curve for the 9-inch mesh net. Thus the importance of gear selection characteristics may vary from ground to ground.

The difference in relative yields for setline gear and for the 9-inch mesh net is attributable to the ability of the larger halibut to avoid capture by the latter gear. It is probable that a large mesh net could be designed to be more effective for catching large halibut than was the gear used in the above experiments. It is likely that for trawl gear the upper selection curve is more amenable to adjustment than is the lower selection curve for a given mesh size.

In calculating the above yields, allowance was not made for the present minimum size limits for halibut. Such limits would not alter the curves for setline or for the 9-inch mesh net since these gears were assumed to catch no fish less than 66 cm., the present minimum. The minimum size limit would raise the yield curves for the 3½-inch net if growth of survivors more than compensated for the weight loss of non-survivors. More detailed study of this problem is beyond the scope of this paper.

To approximate the yield of a mixed trawl and setline fishery the upper selection size for the 3½-inch mesh net and the lower selection size for setline were each set at 80 cm. Setline gear was assumed to catch all sizes greater than 80 cm. Knife-edge recruitment for the 3½-inch mesh net was set at two lengths, 26 cm. and 60 cm. Fishing intensity for the setline fishery was fixed at the maximum sustainable yield

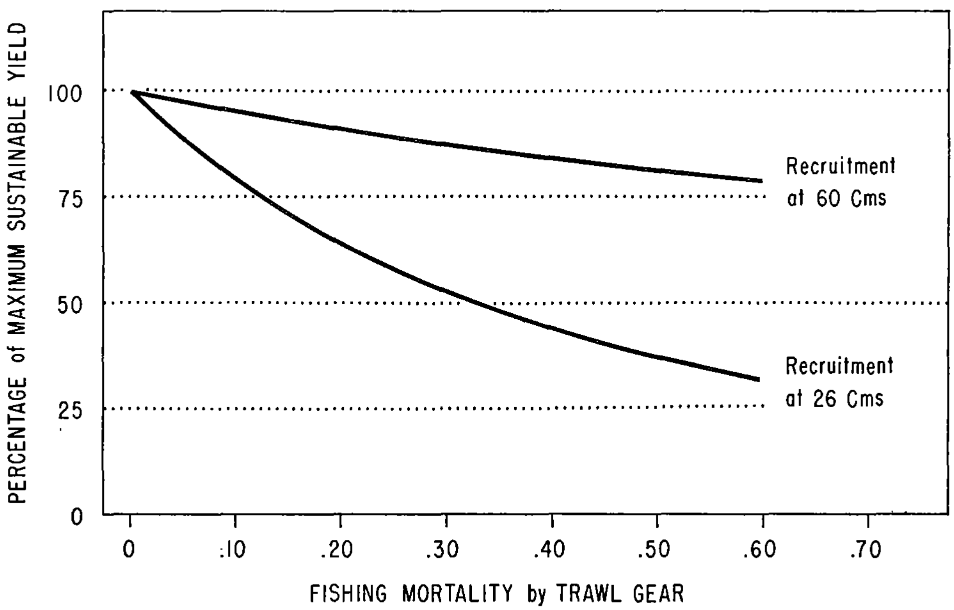

Figure 13. Percentage of maximum sustainable yield from a commercial fishery using both setline gear and 3½-inch mesh trawl gear with halibut recruited at 26 cm. and 60 cm. and with fishing mortality by trawl variable.

level while the intensity of the trawl fishery was allowed to vary over a range of values. In other words, the model indicates the total yield produced when the setline fishery makes maximum use of all halibut which survive the trawl fishery.

The resulting yields are shown in Figure 13 as a percentage of the maximum sustainable setline yield for setline gear. For both curves the total yield decreases continuously with increase in fishing mortality by trawl. Thus the total sustainable yield will be greatest when there is no trawl fishery for halibut. Furthermore a trawl fishery operating in areas where halibut down to 26 cm. are caught as is the case on grounds west of Cape Spencer, Alaska will reduce the sustainable yield more sharply than a similar fishery operating where halibut less than 60 cm. are lacking.

SUMMARY

The halibut selection characteristics of trawl and setline gear are examined with respect to fish length. Two parts of the selection curve are defined, a lower part in which the proportion caught increases with size and an upper part in which the proportion caught may be constant or may decline with further increase in size. Both parts of the selection curve are important from the standpoint of maximum sustainable yield from a fishery.

The parallel fishing method and the results of tagging experiments were used to determine the selection characteristics of trawl net codends of various mesh sizes and of setline gear of the type commonly used in the North American setline fishery for Pacific halibut.

A close relationship was found between codend mesh size and the lower 50% selection length for halibut. The lower and upper 50% selection lengths for halibut taken in a trawl net having a 3½-inch mesh codend was estimated at 26.1 centimeters and 81.3 cm. respectively. On some grounds catches by this gear contained few fish less than 50 cm. because halibut of such sizes are relatively scarce. The upper selection curve may be modified by changes in net construction and in method and location of fishing.

Trawl nets having 7- and 9-inch mesh codends were found to have lower 50% selection lengths of 47.4 and 69.1 cm. respectively. Upper 50% selection lengths for the larger mesh nets were not estimated but were close to that for the 3½-inch mesh net.

Selection curves for setline gear were also obtained from the results of parallel fishing with trawl gear and from tagging data. However both the upper and lower selection curves showed considerable variability between grounds due to differences in halibut size composition. The lower 50% selection length for setline gear was tentatively estimated to be 67 cm. Differences in the upper selection curve for setline gear from ground to ground may be attributed to a tendency for fishermen to seek large fish on grounds where such fish are relatively abundant. Thus there is reason to believe that in areas where larger halibut are present the upper selection curve of setline gear can be assumed to be nearly uniform for all sizes.

The lower selection factor for trawl net gear was estimated at 3.2 which is much higher than has been reported for other flatfish. The difference may be due to the body shape, behavior or swimming power of halibut compared with other flatfish species. On the basis of the selection factor, the lower selection curve for halibut is estimated to be equivalent to that of a trawl net with a codend having an inside mesh size of about 8.2 inches.

It was concluded by means of a model that setline gear would produce a greater sustainable yield than 3½-inch or 9-inch codend mesh trawl nets when each gear was fished by itself. It was also concluded that in a mixed fishery where setline gear was fished at the maximum sustained yield level, the greatest total yield would be produced when there was no trawl fishery for halibut. A trawl fishery using 3½-inch codend mesh nets would reduce the halibut yield far less when operating on grounds not frequented by small halibut.

Insofar as modifications in gear and fishing methods may alter the selection characteristics of trawl and setline gear, the above results and conclusions are subject to change.

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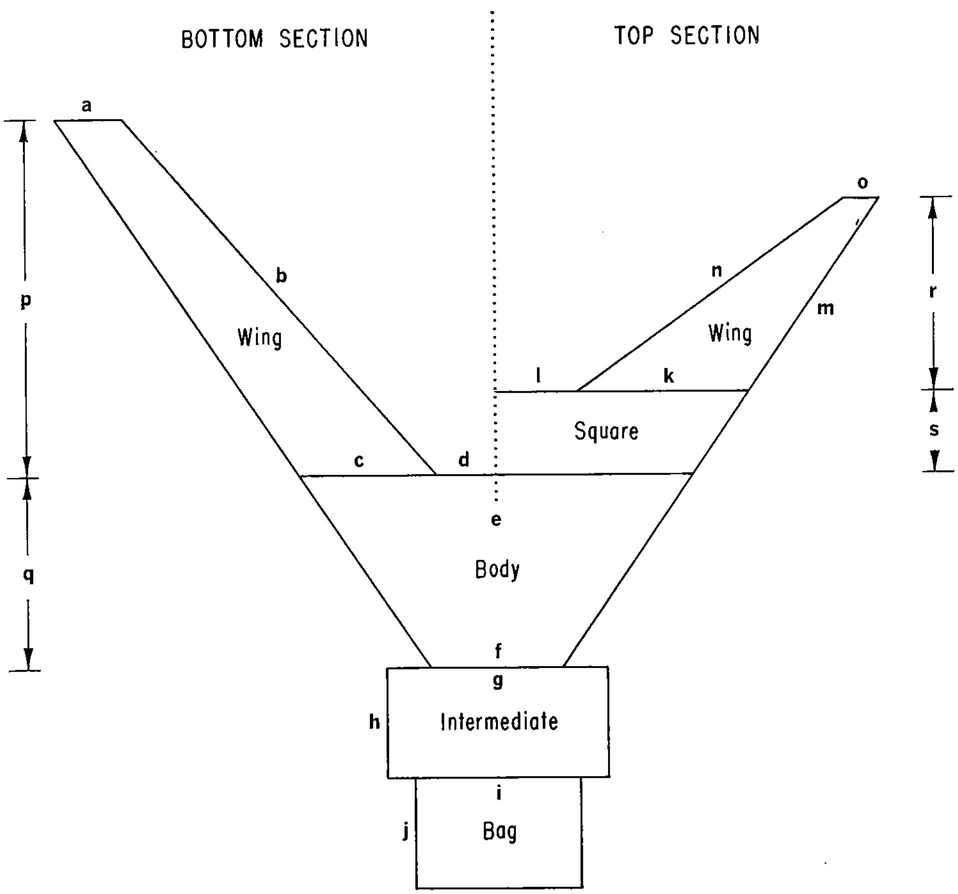
APPENDIX

The trawl nets used in the present study were of the 400-Eastern design except that the 1¼-inch codend net was constructed to about a two-thirds scale. The figure and table below show the construction details for each net. The individual measurements indicated on the figure by the alphabetical letters are given for each net in the table.



Dimensions of trawl nets used by codend mesh size

Measurement	1 1/4-inch	3 1/2-inch	7-inch	9-inch
a	33M	31M	25M	18M
b	26 1/4 ft.	42 ft.	42 ft.	42 ft.
c	82M	68M	54M	39M
d	4.5 ft.	10 ft.	10 ft.	10 ft.
e	412M	207M	166M	118M
f	145M	64M	51M	36M
g	120M	110M	88M	63M
h	100M	60M	48M	34M
i	120M	100M	70M	50M
j	100M	60M	42M	30M
k	273M	272M	218M	155M
l	11 ft.	15 ft.	15 ft.	15 ft.
m	78M	68M	54M	39M
n	18 ft.	28 ft.	28 ft.	28 ft.
o	20M	15M	12M	8M
p	150M	133M	106M	76M
q	200M	100M	80M	57M
r	90M	80M	64M	46M
s	50M	45M	36M	26M
Material				
Wings and Square	18 thread 2 1/2" nylon	36 thread 4" nylon	48 thread 7" nylon	48 thread 9" nylon
Body	15 thread 1 1/4" nylon	36 thread 4" nylon	48 thread 7" nylon	60 thread 9" nylon
Intermediate		60 thread 4" nylon	60 thread 7" nylon	
Bag	21 thread 1 1/4" nylon	96 thread 3 1/2" nylon	120 thread 7" nylon	120 thread 9" nylon
Headrope	47 feet 3/8" wire rope	71 feet 7/16" wire rope	71 feet 7/16" wire rope	71 feet 7/16" wire rope
Footrope	57 feet 1/2" wire rope	94 feet 1/2" wire rope	94 feet 1/2" wire rope	94 feet 1/2" wire rope