A New Technique for Estimation of Gillnet Selectivity and Re-analysis of Data for Several Fish Species

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Abstract

A model is proposed for calculating gillnet selectivities based on the assumption that selection curves are normally distributed. Arbitrary starting selectivities are chosen for two gillnets whose catch curves overlap. The "goodness of fit" of the two selection curves is estimated from three points whose relative values are known from the smoothed catch frequencies. The selection curves are adjusted, through their means and standard deviations, until the fit is considered satisfactory.

A review of the theory of gillnet selectivity and an extensive bibliography provide useful background material. A series of definitions is given for gillnet selectivity, and case studies are examined for Atlantic cod, *Gadus morhua*, Atlantic herring, *Clupea harengus*, Arctic char, *Salvelinus alpinus*, sockeye salmon, *Oncorhynchus nerka*, and pink salmon, *O. garbuscha*.

Introduction

Fishing with gillnets is one of the oldest, simplest and easiest forms of passive fish harvesting. In order to utilize gillnet catch data for quantitative population dynamics, the selectivity and efficiency of the net must be known to allow the correction of the catch to give an unbiased estimate of the population. Baranov (1914) provided the first detailed description of gillnet fishing and selectivity undertaken prior to 1920. Since then, especially in the last 20 years, several scientists have utilized mathematical techniques to describe the selectivity of gillnets (McCombie, 1961; Holt, 1963; Regier and Robson, 1966; Hamley and Regier, 1973). The present study reviews previous theory of gillnet operation and attempts to show how gillnets can be used as random sampling tools. Regier and Robson (1966) provided a detailed review of the mathematical models used to calculate gillnet selectivity, and this aspect will not be repeated here.

The terminology used in this paper is based on the following definitions, some of which have been adopted from otter-trawl selectivity studies (Pope *et al.*, 1975):

a) Selectivity — the relative likelihood that a fish of any given size encountering a unit of gear will be retained by it, the value being generally normalized to some standard, usually 100%.

b) Availability — the likelihood that a fish of any given size will encounter the fishing gear, this being controlled by the distribution and behavior of the gear, fish and fishermen.

c) Partial recruitment — the absolute probability of capture of any member of the population whether or not the fish encounters the gear, it being expressed as the product of availability and selectivity.

d) Efficiency — the selectivity of one gillnet relative to another. An overlapping range of selectivities is required for nets of different mesh sizes to permit the calculation of relative fishing efficiencies; these are generally normalized to the highest value.

e) Selection curve — a model or mathematical expression of gillnet selection with the highest (modal) point usually normalized to 100%. This curve is often represented by a normal or Gaussian distribution and will have the same four moments as the efficiency curve.

f) Modal length — the length of fish at the highest point of the selection curve (also the mean length when the selection curve is normal).

g) Selection range — the range of lengths between the points at which 25% (relative to the modal size) of the fish are retained.

h) Selection factor — the ratio of the modal length of fish to the stretched mesh size, both being measured in the same units.

i) Relative fishery efficiency — the difference in catch between two or more units of gear that cannot solely be attributed to gear efficiency. This

value is affected by the advantage that one unit of the gear may be given over another.

Background to Theory of Gillnet Selectivity

Gillnet fishing

Fish are caught in gillnets by two methods, gilling or wedging and tangling. The latter is of negligible importance with respect to the capture of smooth-bodied fish, such as Atlantic cod, *Gadus morhua*, and herring, *Clupea* sp. However, for species with spines, such as the African catfish, *Clarias gariepinus* (Gulland and Harding, 1961), and for fish with large teeth, such as the walleye, *Stizostedion vitreum*, (Hamley and Regier, 1973), tangling may result in a large proportion of the catch.

Gillnets catch fish of varying size with unequal success. Baranov (1948) showed how the size of mesh and the body form of the fish are very important in controlling the ability of an individual net to retain a particular fish. For each species, there is an optimum size of fish that will be retained by a net of a particular mesh size. Above and below this optimum length, the ability of the net to retain fish decreases. The smaller fish, in the extreme, pass freely through the meshes, and as they increase in size they are able to squeeze through the meshes with varying degrees of success, due to twine elongation and body compression. Fish larger than the optimum size meet resistance and are often able to avoid becoming entangled.

The gillnet selection has long been assumed to approximate a normal or Gaussian curve (Baranov, 1948; McCombie, 1961; Holt, 1963). Baranov noted that the relationship between the bar measure of the mesh (B) and the modal length (L_m) is: $B = K \times L_m$. He found that constant (K) to be 0.125 for herring, *Clupea* sp., and 0.150 for roach, *Rutilis* sp. After further work, he found the relationship ($B = k \times G_m$) to be superior, the parameter (G_m) being the girth of the modal group and the constant (k) being the same for different species. This, in principle, indicates that fish of the same girth are caught equally well in the same net, irrespective of the species. The premise that girth is the controlling factor of selectivity (at least for the gilled portion of the catch) leads to the conclusion that the girth/selectivity relationship must be normal. Baranov (1948) found that modal girth was approximately 1.25 times the mesh size. As the girth distribution for any fish length is normal, the assumption that selection of fish about the modal length in a gillnet catch approximates a normal curve is sound.

Since the time of Baranov, the results of two further studies (Rollefsen, 1953; Richardson, MS 1956) indicated that gillnet selectivity follows a normal pattern. In each of these studies, a gear presumed to be unselective was used in the same area as gillnets, and a comparison between catch and presumed population indicated a normal-type selection curve for gillnets.

Factors affecting gillnet efficiency

Four major factors affect the fishing behavior of gillnets: (a) twine size and elasticity, (b) twine color, (c) mode of hanging the net, and (d) duration of set.

The first of these has been studied by many authors since the first theoretical analysis by Baranov (1948). Hansen (1974) found that a thin monofilament twine caught significantly larger fish than a thicker monofilament twine of the same mesh size, and postulated that this was due to the greater elasticity of the thinner twine. He did not find a trend in efficiency (i.e. increase in catch per unit effort) with gillnets of thinner twine, whereas Baranov (1948) reported a fivefold decrease in catch with thicker twine. This difference may be due to the fact that the thickest twine used by Hansen (1974) was less than one-half of the the diameter of the thinnest twine used by Baranov (1948). It is possible that, as twine diameter decreases, the efficiency increases to a maximum for a particular twine size, below which only an increase in the number of fish encountering the net will increase the catch rate. Baranov (1948) pointed out the important concern regarding the trade-off between fishing efficiency and the strength of the net. Compromises on the most suitable twine size are required for different fisheries.

Associated with twine size is twine type. Collins (1979), Larkins (1963, 1964), Pristas and Trent (1977), and Washington (1973) compared the efficiency of monofilament and multifilament gillnets of the same mesh size, and found that monofilament twine was more efficient for some species and not for others. Collins (1979) found that efficiency of the two twine types varied throughout the fishing season but with no apparent trend, the modal size and age of fish being the same for both twine types, whereas Washington (1973) reported that monofilament nets caught slightly larger fish. Earlier comparisons between cotton and nylon gillnets found nylon to be more efficient, but opinions differed as to the effect of the twine types on selectivity (Atton, 1955; Hewson, 1951; Lawler, 1950; Pycha, 1962).

The fishing behavior of gillnets is affected by the color of the twine. Visibility of nets in the water is a function of water clarity, illumination, and wave length of light reflected by the twine. Hunter and Wisby (1964) indicated that fish learn to avoid nets, and Steinberg (1964) showed that water clarity influences catch efficiency, which differs according to the visual acuity of individual species. For this reason, gillnets are used mainly (and most effectively) from dusk to dawn. Many studies, such as that of Libosvarsky (1970), arrived at

confusing results regarding color of twine due to the alteration of more than one parameter at a time. Baranov (1948) observed that often the most efficient color of a net was similar to the color of the dorsal region of the fish. Protective coloration of fish conceals them in their local environment, and it is likely that the same (dorsal) color is most efficient for concealing the net.

Collins (1979) and Quartier (1975) found that fish catches are related to lunar phases. This relationship is attributed to increased illumination during moonlight, thus making the nets more visible and increasing their avoidance by fish (Blaxter and Parrish, 1965). Molin (1953) suggested that the invisible nature of monofilament twine was the major factor in improved fishing efficiency over that for multifilament nylon. Collins (1979) did not note any difference in the relative efficiency of monofilament and multifilament twine during various lunar phases but did note a decrease in catch during full moon with both twine types. In some cases, therefore, the variation in catch may be more attributable to changes in fish activity (Lawler, 1969; Ryder, 1977) than to a change in avoidance of the net.

The fishing behavior of gillnets is affected by the method of 'hanging', which relates to the attachment of the webbing to the mainlines or cords framing the net. Baranov (1969) explained it as the change in the dimensions of a stretched piece of netting due to the spread of the meshes. In practice, the value given to 'hanging' is calculated by the formula, $P = 1 - A/2B$, where P is the hanging coefficient, A is the horizontal distance between two opposite knots of a mesh, and B is the bar measure of the mesh. A net 'hung' by 1/2 has a final length of 0.5 times the length of the stretched netting, and a net 'hung' by 1/3 has a final length of 0.667 times the length of the stretched netting. Although the method of hanging affects the fishing characteristics of a gillnet, little work has been done to study the degree of this effect (Mohr, 1965). Jackson et al. (1963) concluded that one measurable advantage was the area of the net, the maximum occurring with a hanging coefficient of 0.707. They considered that the most efficient mounting of the twine might depend on the cross-sectional shape of the species for which the net is to be used, i.e. a hanging coefficient of 0.5 for salmon (Peterson, 1954) and 0.7 for the catfish, Bagrus sp. (Jackson et al., 1963).

The fishing behavior of gillnets is affected by the duration of the set. Kennedy (1951) found that high levels of catch reduced the fishing efficiency of gillnets over time. Baranov (1948) also commented on the saturation level of the catch, and both Kennedy (1951) and Pycha (1962) indicated the necessity of calculating effective fishing effort by assessing the duration of the set in relation to saturation limits.

Kennedy (1951) noted that the catch efficiency may be reduced by the presence of rotting fish in gillnets which are set for long periods of time.

Selectivity

Studies on gillnet selectivity involve consideration of three curves (Fig. 1). The easiest to measure is the catch curve which is the frequency distribution of fish retained by the gillnet. The other two curves (selection and population) are initially unknown, but, once the selection curve has been estimated, the population curve can be calculated. The selectivity, or the 'relative fishing efficiency' (Baranov, 1948), is the unknown which one attempts to estimate. (The term 'population' is used throughout this paper to denote the population structure by size groups over the range of fish sizes available to the gillnet.)

Indirect methods are generally used to estimate gillnet selectivity. Most authors (Baranov, 1948; McCombie and Fry, 1960; Holt, 1963) have suggested that two or more nets with different mesh sizes be fished concurrently. Some of the basic requirements, as outlined by Baranov (1948), are that the gillnets should be hung in the same manner, made of the same material, fished at the same time, and have similar-shaped selection curves (assumed to be 'normal' in this paper). Suppose that two selection curves, S_1 and S_2, have mean or modal values X_1 and X_2 for gillnets with mesh sizes a_1 and a_2 (Fig. 2). If the difference in mesh size is not great (15-20%) and the adjacent limbs overlap, the common point of the selection curves will have the same selectivity at fish length for both nets. If these nets are fished identically, the catches will be the same at this common point. However, grouping by length intervals could cause difficulty in identifying the common point. The relative inaccuracies due to random causes are inversely proportional to the square root of the size of the sample at each interval, and Baranov (1969) suggests that at least 500 fish
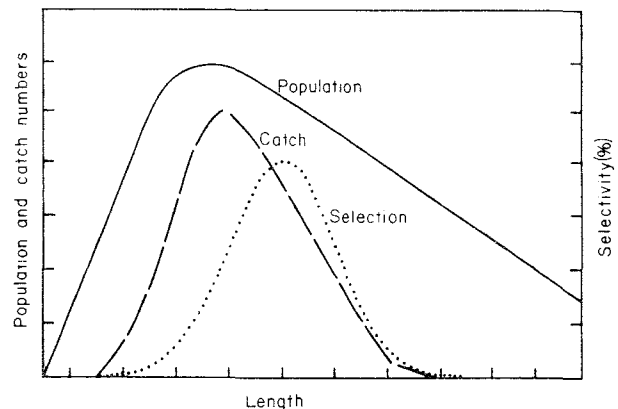

Fig. 1. The three curves involved in a gillnet selectivity study. The catch is known but the population and selection curves are to be calculated.
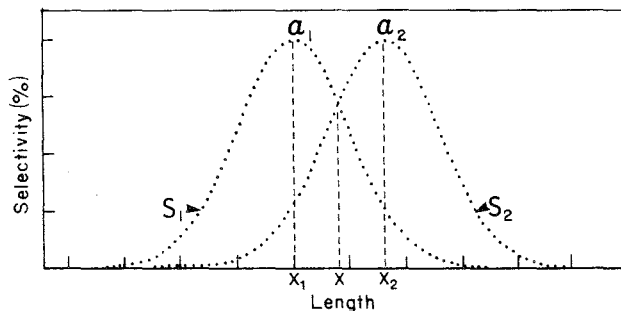
Fig. 2. Hypothetical gillnet selection curves (S_1 and S_2) for mesh sizes a_1 and a_2, modal lengths X_1 and X_2, and a common point X.

should be sampled by each net. He pointed out that the simplest approach is to plot the length frequencies and draw a smooth curve through the points. The intersection of the two smoothed curves represents a good approximation to the common point.

Non-catch mortality caused by gillnets

Non-catch mortality in gillnets was extensively reviewed by Ricker (1976) for Pacific coast fisheries and by Ritter *et al.* (MS 1979) for Atlantic coast fisheries, and this aspect is considered only briefly here. Although some observations on escapees (fallouts) from gillnets have been reported (Ishida *et al.*, 1969; French and Dunn, 1973), little direct evidence of the mortality is available. Petrova (1964) observed a higher proportion of net-marked salmon dying in fresh water than unmarked salmon. Although many estimates, quoted by Ricker (1976), indicate that losses due to non-catch mortality exceed 50% of the catches, such losses appear to be restricted to salmonids. There is no reason to believe that the number of cod or herring escapees would be as high as these levels or that such escapees would die as a result of their wounds. Jewel (1970) and French and Dunn (1973) reported that non-catch mortality in gillnets was very low (1-2%) for inshore coastal areas. This implies that the catch per unit effort could possibly be increased if gillnet fishing is restricted to sheltered coastal waters.

Materials and Methods

Data for the case studies outlined in this paper were obtained from several sources: sockeye salmon, *Oncorhynchus nerka*, data from Peterson (1954); pink salmon, *Oncorhynchus gorbuscha*, data from Ishida (1962); Arctic char, *Salvelinus alpinus*, data from Hunter (1970); Atlantic herring, *Clupea harengus*, data from Olsen (1959); and Atlantic cod, *Gadus morhua*, data from the archives of the Biological Station, St. John's, Newfoundland (Appendix Tables 1 to 5). Atlantic herring data from the archives of the Biological Station, St. Andrews, New Brunswick, and Atlantic cod data from the author's study of gillnet

selectivity in the summer of 1978 were used to develop some of the basic concepts utilized in this paper although the results have not been presented. All data use in these case studies have been adjusted to metric measurements, and mesh sizes have, where necessary, been adjusted to stretched mesh equivalents.

The technique developed for the analysis of gillnet selectivity was derived from some of the general principles proposed by Baranov (1914). For each pair of gillnets with different mesh sizes, the catch curves were smoothed by the Graham Charlier Series (Kendall and Stuart, 1969) and the point of intersection of the overlapping limbs was estimated. Two additional points were calculated for each curve by dividing the catch at the calculated mean length of one curve by the catch at the same length interval of the other. Initially, normal curves were fitted arbitrarily and the common point and the two relative values at the modal points were used as indicators of the goodness of fit. When a satisfactory fit (or the best that could be found) was achieved, the population curves calculated from the selectivity and corresponding catch curves were compared. This final test determined if the selectivity curves were reasonable.

If a series of catch curves are available for gillnets of increasing mesh size, successive pairs can be analyzed and at least two estimates of selectivity will be available for each net except those with smallest and largest mesh sizes. After 'best fits' have been achieved for several pairs of catch curves, the resulting selectivity estimates for each curve can be used to estimate the population. The population estimates, one for each catch curve, can then be averaged and the result divided by each catch curve in turn to provide a final selectivity estimate for each net (Fig. 3). For this technique to give valid results, the gillnets must be fished with equal effort on the same population. The results achieved by this technique are not unique and must be judged from experience and supporting data.

Although Baranov (1948) indicated that the common point of two smoothed catch curves was also the common point of the selection curves for the two gillnets, he did not suggest a way of using this information to calculate the unknown selection curves. The iterative technique used in this paper is a first step toward a gillnet selectivity model. It is possible that future improved techniques may reduce the subjectivity of the estimates.

Results and Discussion

Test data

Sample data were generated to test the computer programming and the general selectivity hypothesis
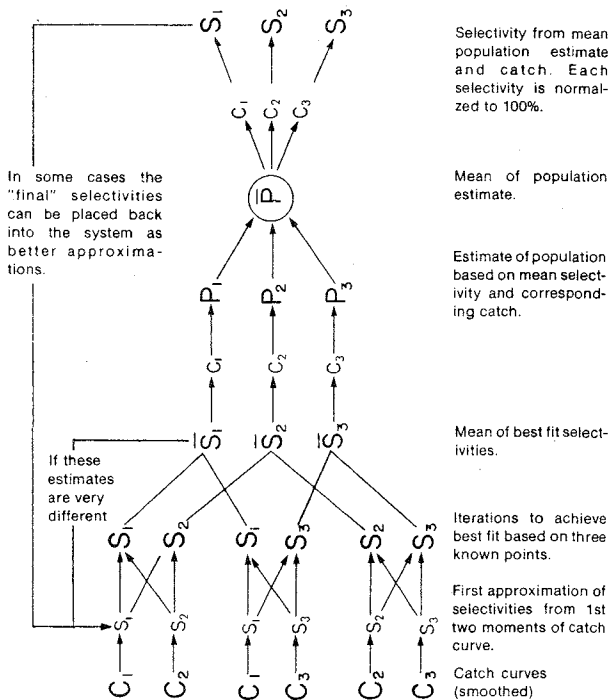
Fig. 3. Flowchart of procedures used in calculating selectivities of three or more gillnets with overlapping catch curves.

(Table 1). Starting selection curves 1 and 2, with means of 18.0 and 22.0 cm and standard deviations of 1.5 and 2.0 respectively were applied to the 'starting' population frequency to generate catch curves 1 and 2, with resultant means of 18.20 and 21.75 cm and

standard deviations of 1.51 and 1.86 cm respectively. Unless the population structure has a very unusual configuration, the first two moments of the catch curve will approximate those of the selection curve. Minor adjustments to the mean and standard deviation of the initial selection curves altered the difference between the actual values of the common and other two relative points estimated from the catch curves and the corresponding three points calculated from the selection curves. The 'best fit' was taken to be that step in the procedure where the difference between the two sets of points did not reduce appreciably with further adjustments to the selection curves. After the 'best fit' was decided upon and the two resultant population frequencies found to be similar (and approximated the 'starting' population, although this would not normally be known), the average of these population frequencies was divided by the catch frequencies to provide adjusted selection curves for each net (Fig. 3). This technique is simple and allows the estimation of normalized selection curves when data are adequate.

Sockeye salmon data (Peterson, 1954)

The 1947 and 1948 data (sexes combined) for 140, 152 and 165 mm mesh gillnets, documented by Peterson (1954) (Appendix Table 1), were used in an attempt to estimate gillnet selectivity by the above technique. The numbers of fish caught and the overlaps of the catch curves were considered adequate for analysis, assuming that the data for both years pertained to the same population. The smoothed catch

TABLE 1. Sample data used to test the selectivity analysis technique and estimated selection curves from the generated catch curves. (Numbers in parentheses are generated catches smoothed by the Graham-Charlier series; population estimates based on selectivities of less than 10% are not included.)

Length (cm)	Starting population	Starting selection		Generated catch data				Estimated selection		Estimated population
		Curve 1	Curve 2	Catch 1		Catch 2		Curve 1	Curve 2	
11	2,000	—	—	—		—		—	—	...
12	4,000	—	—	—	(2)	—		—	—	...
13	6,000	0.4	—	23	(22)	—		0.4	—	...
14	6,075	2.9	—	174	(175)	—		2.9	—	...
15	6,125	13.5	—	829	(833)	—	(2)	13.5	—	6,126[a]
16	6,250	41.0	0.8	2,563	(2,540)	52	(30)	41.0	0.8	6,234[a]
17	6,500	80.0	3.0	5,206	(5,160)	214	(194)	80.0	3.3	6,502[a]
18	7,000	100.0	10.0	7,000	(7,101)	711	(783)	100.0	10.4	6,915
19	8,000	80.0	24.0	6,408	(6,514)	1,948	(2,150)	80.0	26.0	7,828
20	10,000	41.0	45.5	4,100	(3,818)	4,549	(4,183)	41.0	48.0	9,740
21	8,948	13.5	66.0	1,211	(1,342)	5,922	(5,900)	13.5	69.0	8,756
22	8,007	2.9	75.0	229	(251)	6,005	(6,146)	2.9	77.0	7,817[b]
23	7,165	0.4	66.0	28	(15)	4,742	(4,818)	0.4	66.0	7,228[b]
24	6,411	—	45.5	—		2,916	(2,899)	—	43.0	6,770[b]
25	5,737	—	24.0	—		1,397	(1,363)	—	22.0	6,426[b]
26	5,133	—	10.0	—		521	(506)	—	8.4	...
27	4,593	—	3.0	—		151	(148)	—	2.5	...
28	4,110	—	0.8	—		34	(34)	—	0.6	...
29	3,678	—	—	—		—	(6)	—	—	...
30	3,291	—	—	—		—		—	—	...
Mean		18.0	22.0	18.20		21.75				
Standard deviation		1.5	2.0	1.51		1.86				
Common length		(20.2)		(19.9)						

[a] These estimates based on selection curve 1 only as values for curve 2 less than 10%.
[b] These estimates based on selection curve 2 only as values for curve 1 less than 10%.

frequencies for each mesh size differed considerably between years (Fig. 4). Normalized selection curves were fitted to the catch frequencies and the results indicate large differences in the relative fishing efficiency of the 140, 152 and 165 mm mesh gillnets in both years (Fig. 5). When the individual selection curves for 1947 are normalized to 100% (i.e. assuming equal efficiency), the modal lengths occur at 58.8, 61.0 and 63.8 for the 140, 152 and 165 mm mesh nets respectively (Fig. 6). However, all three curves are similar in shape with selection ranges of 10.6, 9.4 and 10.0 cm and selection factors of 4.2, 4.0 and 3.9 respectively. Similar results were obtained from the 1948 data although the catch frequencies differed somewhat from those for 1947. The composite selection curves estimated from the 1947 and 1948 data for 140, 152 and 165 mm mesh gillnets are shown in Fig. 7, with modal lengths of 58.0, 60.5 and 63.5 cm, selection ranges of 9.8, 9.4 and 8.2 cm, and selection factors of 4.1, 4.0 and 3.9.

The efficiency of gillnets of similar size should not differ greatly between years or when used to fish the same population. The differences in 'relative efficiency' between nets, therefore, cannot be explained solely as differences in the efficiency of the gear. A partial explanation of this may be the

Fig. 5.   Relative fishery efficiencies of the 140, 152 and 165 mm mesh gillnets for sockeye salmon in 1947 and 1948, derived from data reported by Peterson (1954).

Fig. 6.   Calculated selection curves for sockeye salmon in the 140, 152 and 165 mm mesh gillnets, derived from the 1947 data reported by Peterson (1954).

positioning of the gear. Von Brandt (1955) noted that the position of a net in a fleet of nets attached end to end will affect its ability to catch fish. During the 2 years of fishing activity, reported by Peterson (1954), nets of 10 mesh sizes were fished by several boats during each weekend between July and October, the positioning of the different nets being varied from one fishing period to the next. However, since more than 70% of the total catch was taken in 3 and 4 consecutive weekends of 1947 and 1948 respectively, the catch rate was not equal for all fishing periods. If the position of a net in the fleet affects its catch rate, this introduces an anomoly which may be termed 'relative fishery efficiency', a definition of which has been included in the terminology listed in the 'Introduction'.

Holt (1963) also analyzed Peterson's (1954) data for sockeye salmon, with the catches of both years combined (Appendix Table 1). Between 1947 and 1948, the mean size of fish caught in the 140, 152 and 165 mm
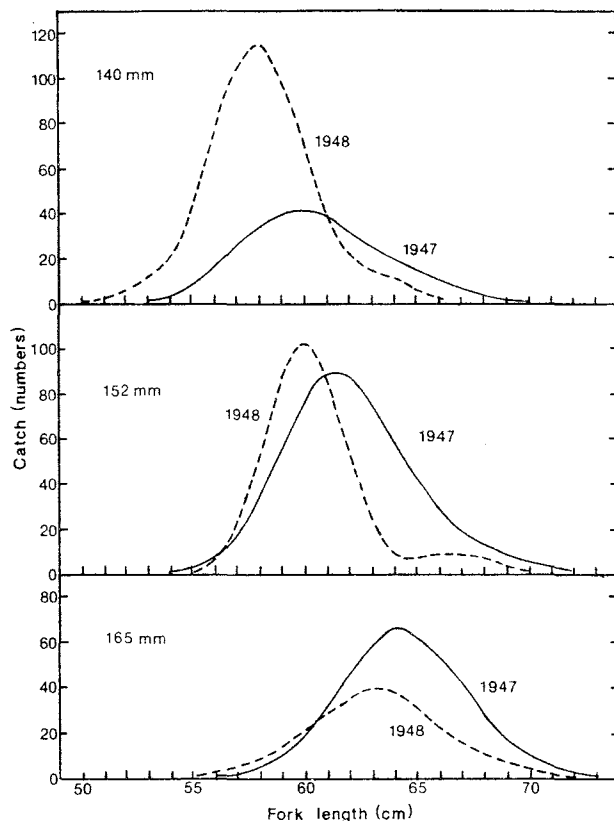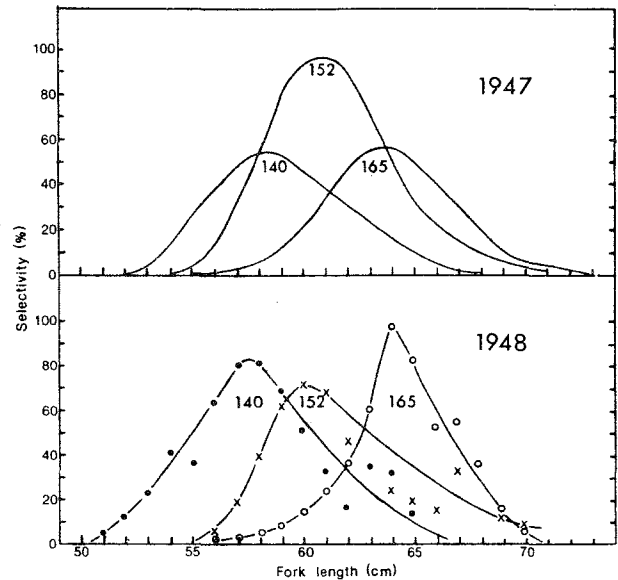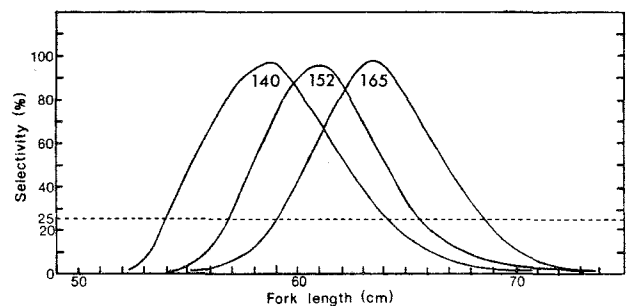

Fig. 4.   Smoothed catch curves for sockeye salmon in 140, 152 and 165 mm mesh gillnets in 1947 and 1948, derived from data reported by Peterson (1954).
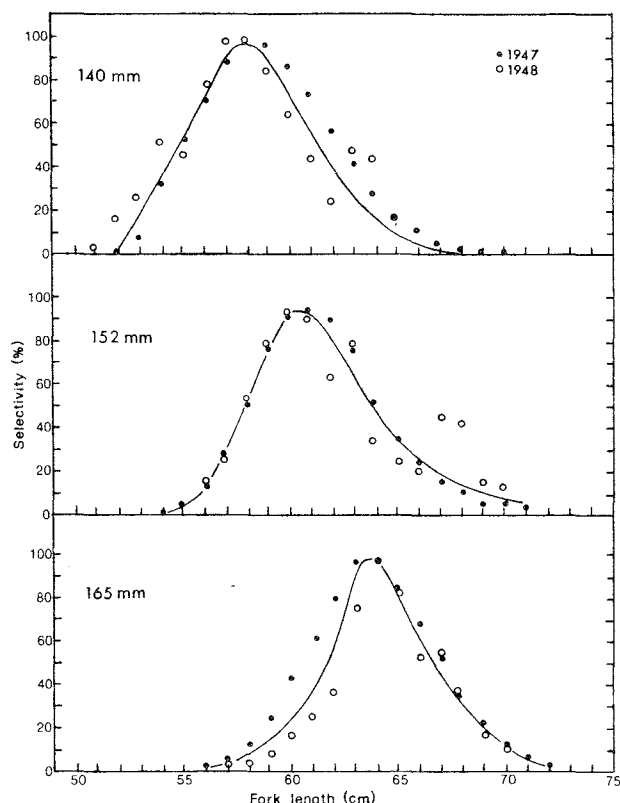
Fig. 7. Composite selection curves for sockeye salmon in 140, 152 and 165 mm mesh gillnets in 1947 and 1948, estimated from data reported by Peterson (1954).
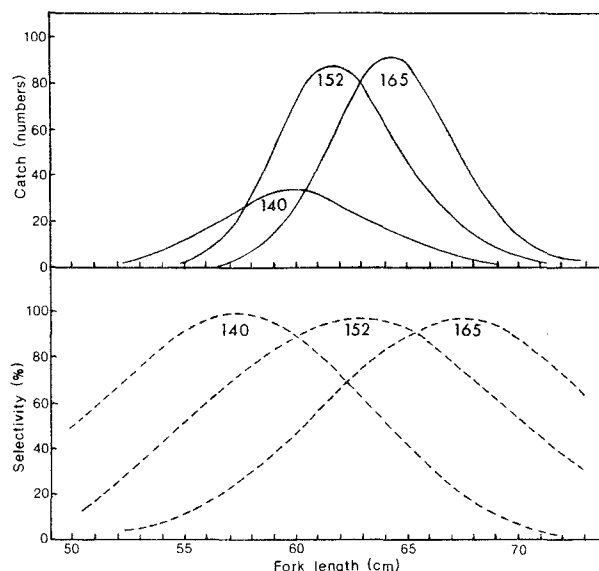

Fig. 8. Selection curves (lower) proposed by Holt (1963) for the combined 1947 and 1948 catches (upper) of sockeye salmon, based on data reported by Peterson (1954).

mesh nets decreased by 1.4, 1.0 and 0.8 cm respectively (Table 2). Examination of the catches and the three corresponding selection curves proposed by Holt (1963) shows that the common selectivity points do not occur at the expected lengths (Fig. 8) or at the lengths estimated by the present technique when the 1947 and 1948 data are treated separately (Table 2). There is serious difficulty in interpreting Holt's (1963) proposed selection curves, given his hypothesis that

the efficiency is the same for all curves. The catch in the 140 mm mesh net is negligible at sizes below 52 cm, but the selection curve for this mesh size indicates that more than 60% of the available population of 52-cm fish should be caught. Similar difficulties occur if the ratios of catches of a pair of nets at one fish length are compared with the ratios of the selectivities for the same length. The selection curves estimated by the present technique (Fig. 6) do not suffer from these problems to the same extent.

Pink salmon data (Ishida, 1962)

Several of the basic assumptions necessary for the calculation of gillnet selectivity were violated in Ishida's (1962) study (Appendix Table 2), primarily that of fishing identically on the same population.

TABLE 2. Characteristics of the catch and selection curves for sockeye salmon, based on data reported by Peterson (1954).

Mesh size (mm)	Year	Number of fish	Catch curves		Selection curves			
			Mean (cm)	Standard deviation	Mean (cm)	Standard deviation	Skewness	Kurtosis
140	1947	318	59.5	3.1	59.2	3.2	0.47	3.0
	1948	654	58.1	2.5	58.2	3.2	0.20	2.5
	1947–48[a]	989	58.4	3.0	56.8	5.7	0.00	3.0
152	1947	626	61.5	2.9	61.3	2.9	0.47	3.2
	1948	497	60.5	2.6	62.1	3.4	0.54	2.4
	1947–48[a]	1,235	60.8	2.9	62.5	6.6	0.00	3.0
165	1947	446	64.0	2.8	63.9	2.9	0.05	2.9
	1948	279	63.2	3.0	64.4	2.6	−0.37	3.4
	1947–48[a]	725	63.3	2.9	67.4	5.4	0.00	3.0

[a] Combined data for 1947–48 from Holt (1963); other values based on the present analysis.

Correction factors to account for variation in fishing effort and the proportion of fish sampled from the catch varied by a factor of four. Consequently, the catch frequencies for the different nets were adjusted so that the fishing effort for all three nets was the same. Even after this adjustment, no two normal curves could be found that would give approximately the same population structure for any of the pairs of nets. A close inspection of the data in Appendix Table 2 shows that the smallest mesh size caught greater numbers of large fish than either of the larger-meshed nets. It is probable that the different nets were not only used with differing frequency but also on different populations (or schools). The data, therefore, are not suitable for analysis by the technique described in this paper.

Arctic char data (Hunter, 1970)

The catch length frequencies for 1963 and 1965, reported by Hunter (1970) are bimodal, at least for the 38 and 51 mm mesh gillnets (Appendix Table 3), with one modal group representing fish caught by gilling or wedging and the other by tangling, especially by their head, teeth and mouth parts. The computer program NORMSEP (Abramson, 1971) was used to do a modal analysis of the catch frequencies in order to separate the two superimposed frequencies for each mesh into their components. The resultant length compositions for the 1963 data are shown in Fig. 9. Satisfactory

results were also achieved for the 1965 data, but there was greater variability due to lower catches, especially in the 64 mm mesh net where only 188 fish were caught.

In the length frequency data for 1963, the modes for the 38 mm net are at 21 and 30 cm, for the 51 mm net at 24 and 31 cm, and for the 64 mm net at 30 and 31 cm (Fig. 9). The modes of the length frequencies for gilled fish increased with mesh size, as expected, whereas the length compositions of the tangled portion of the catches were essentially the same, with modes at 30 or 31 cm. However, for the 64 mm mesh net, although the means of the superimposed length frequencies are essentially the same (31.0 and 31.1 cm), the standard deviations are quite different (2.36 and 1.44 cm). Since the standard deviations of the gilled portion of the catches in the 38 and 51 mm mesh nets are higher than those of the tangled portion of the catches, the frequency with the higher standard deviation was taken as representing the gilled portion of the catch in the 64 mm mesh net. The gilled and tangled components of the 1963 gillnet catches (numbers) were estimated as follows:

Mesh size (mm)	Gilled catch	Tangled catch	Total catch
38	434	875	1309
51	442	844	1286
64	562	853	1415

The length frequencies of the tangled portion of the catches in the three nets (mean lengths of 30.5, 30.9 and 31.9 cm with standard deviations of 2.1, 1.9 and 1.5 respectively) were similar (Fig. 9) and it was not possible to calculate selection curves. The only noticeable difference in the catch curves for the tangled fish is the ascending left limb where fewer small fish (25-29 cm in length) were caught in the 64 mm mesh net. It is probable that, over the range of mesh size used, each net has the same selectivity for tangling fish greater than 25 cm in length. Thus, an estimate of the selectivity for tangled fish could be made by averaging the three catch frequencies and dividing the results by the mean population calculated from the selection curves of the three gilled portions of the catches.

The relative fishery efficiency of the three sizes of gillnets was approximately the same in 1963, (Fig. 10), and a similar pattern is evident for the 1965 data although the modes are displaced by 2-4 cm, the greatest displacement of the mode being related to the poorly sampled catch in the 64 mm mesh net. The selection curves for the 1963 and 1965 data are very similar in shape despite the displacement of the modes (Fig. 11). The Arctic char population in the lake surveyed by Hunter (1970) in 1963 was quite small and
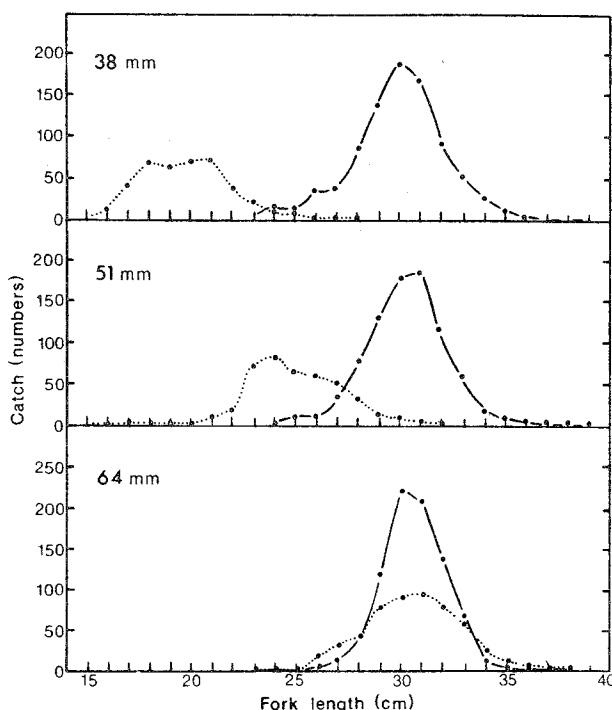

Fig. 9.   Length composition of Arctic char in 38, 51 and 64 mm mesh gillnet catches in 1963, based on data reported by Hunter (1970). The gilled (dotted line) and tangled (solid line) components of the catches were estimated by the computer program NORMSEP (Abramson, 1971).
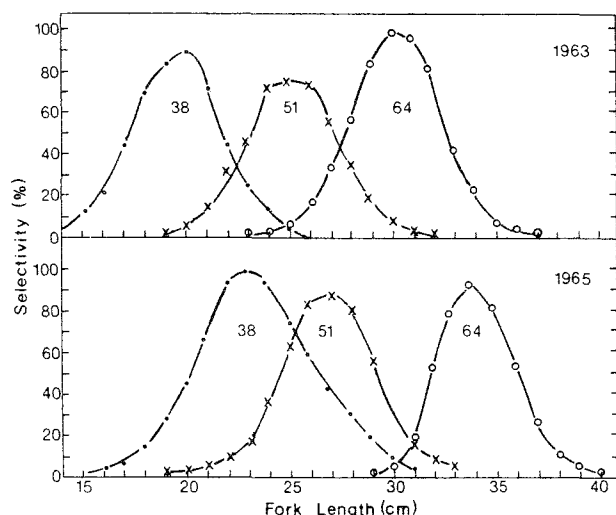
Fig. 10. Relative fishery efficiencies of the 38, 51 and 64 mm mesh gillnets for Arctic char in 1963 and 1965, based on data reported by Hunter (1970).
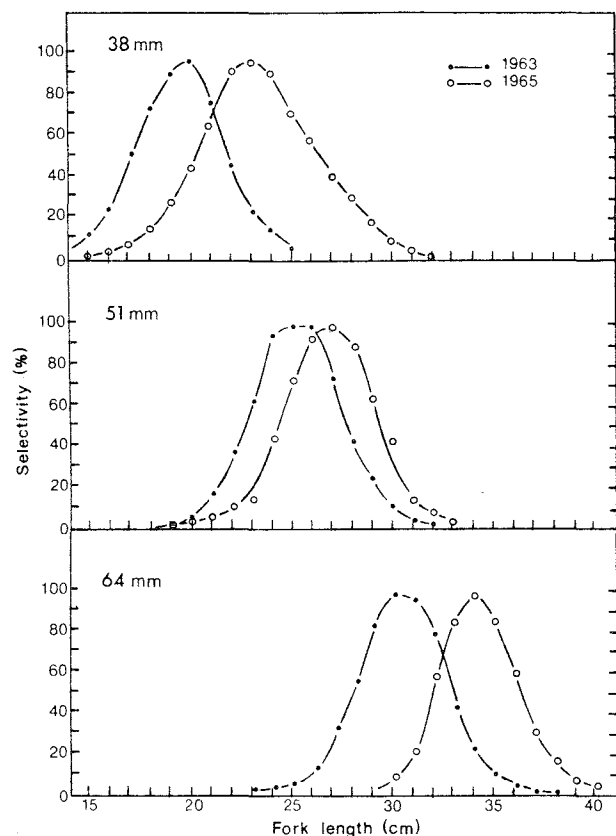

Fig. 11. Selection curves for Arctic char in 38, 51 and 64 mm mesh gillnets in 1963 and 1965, based on data reported by Hunter (1970).

the gillnet catch is believed to have removed over 50% of the population. This sudden reduction of a stable Arctic char population greatly altered food availability for the remaining fish with a probable consequent effect on growth, so that there was a general shift to

larger fish in the catches when the second survey was conducted in 1965, thus accounting for the large displacement of the modes in the catch curves between 1963 and 1965. However, this should not affect the selection curves which also show a displacement of modes between 1963 and 1965. This shift in mode may be due to either actual changes in the shape of the fish or changes in the true mesh size of the gillnets used. The former cause is unlikely, as the increase in food supply would tend to decrease the modal length of retained fish, the reverse of what actually occurred. The latter is more probable as all mesh sizes noted by Hunter (1970) are manufacturers' stated sizes, and, since the gillnets were used only as a sampling tool, no routine mesh measurements were taken. It is possible, therefore that the actual mesh sizes (as opposed to manufacturers' size) of the gillnets used in 1965 were larger than those used in 1963 (Hunter, pers. comm.)

Atlantic herring data (Olsen, 1959)

The herring data reported by Olsen (1959) were collected from at least two locations over a period of 6 months (Appendix Table 4). The pelagic, schooling behavior of herring complicates any study of gillnet selectivity, as individual schools may vary in age composition, maturity condition and state of feeding. Such variability makes it unlikely that each unit of gear had fished the same population throughout the study period. Despite this problem, selection curves were estimated from the length frequencies of catches in gillnets of three different mesh sizes (Fig. 12). The modal sizes of herring selected by these gillnets with mesh sizes of 59.7, 65.1 and 72.5 mm were found to be 31, 34 and 35.5 cm respectively, which do not follow the expected linear relationship. This together with the great variation in the population estimates derived for the three sizes of gillnets make these data unsuitable for analysis by the technique described in this paper. Olsen's (1959) population estimates were similar to those obtained by the present technique, and his selection curves were also similar in shape to those in
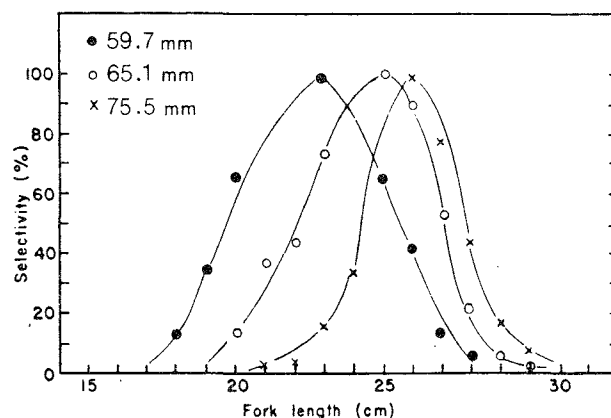

Fig. 12. Gillnet selection curves for Atlantic herring estimated from data reported by Olsen (1959).

Fig. 12, except that the modal lengths for his curves were slightly more than 2 cm lower. It is quite possible that the only 'good' estimates of gillnet selectivity for such pelagic schooling fish as herring will come from analysis of individual (single night) catches to ensure that only one school is sampled equally by nets of different mesh sizes in the fleet.

Atlantic cod data

The gillnet data for cod from the archives of the Biological Station, St. John's, Newfoundland, consist of samples taken in gillnets of various mesh sizes during several years at different locations. Such catch length frequencies from different locations may vary greatly if the populations are different. Analysis of combined catch frequencies from three locations in 2 years (Appendix Table 5) resulted in selection curves with standard deviations in the order of 11.0 for nets with mesh sizes of 152, 165 and 178 mm (Fig. 13). With corresponding modal lengths of 62.1, 69.8 and 76.4 cm, the selection factors were quite similar (4.1, 4.2 and 4.3) but the selection ranges were quite large (32.1, 35.4 and 40.2 cm). Although the combined data appeared satisfactory during initial analysis, the final result was rather poor. The difficulties encountered were similar to those found upon examination of Holt's (1963) analysis of sockeye salmon data.

Some of the Newfoundland cod data could be separated by location and year for two mesh sizes of gillnet (Appendix Table 5). The catch frequencies, smoothed by the Graham Charlier Series, for three samples (each composed of 15 sets made during a 1-week period) are shown in Fig. 14. Because data for only two mesh sizes were available, all of the steps in the procedure (Fig. 3) could not be used. It was therefore considered appropriate to use a composite of the selectivity estimates for each of the mesh sizes (Fig. 15). The variation in selectivity estimates is not large, despite the considerable variation in the catch frequencies (Fig. 14). The composite selection curves of the 165 and 178 mm mesh gillnets had modal lengths

Fig. 14. Smoothed catch curves for Atlantic cod in 165 and 178 mm mesh gillnets from St. Mary's Bay in 1964 (1) and 1965 (2), and Placentia Bay in 1965 (3). Each set of data was derived from 15 gillnet sets during a 1-week period.
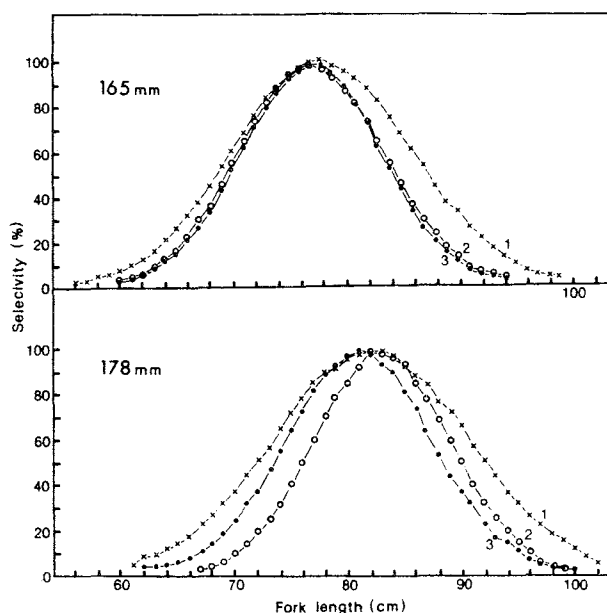
Fig. 15 Selectivities of Atlantic cod in 165 and 178 mm mesh gillnets, estimated from the catch curves of Fig. 14. St. Mary's Bay in 1964 (1) and 1965 (2), and Placentia Bay in 1965 (3).

Fig. 13. Selection curves for Atlantic cod in 152, 165 and 178 mm mesh gillnets, based on catches combined for 2 years and three locations in southeastern Newfoundland (unpublished data of St John's Biological Station).

at 76.2 and 82.0 cm respectively, values very different from the combined data above. The selection factor is 4.6 for each mesh size and the selection ranges were 25 and 24 cm respectively. The one major limitation, when only data for two mesh sizes are available, is the shape of the selection curve, which is represented by a normal distribution. When data for three or more mesh sizes are available, the combination of different

population estimates allows for some skewness, if present, to enter the selection pattern.

Use and Significance of Gillnet Selectivity

Knowledge of the selectivity of any gear, especially gillnets, allows better management of a commercial fish stock through the choice of mesh size to suit the available population. It also permits an independent estimate of the population structure from the commercial catch data, something not possible with uncorrected gillnet catch data.

To allow unbiased sampling of a population for research purposes, unselective gear must be used or the catch must be adjusted to compensate for selection. Fishing with a series of gillnets with very small differences in their mesh sizes will provide an unbiased sample of the population over the size range between the modal lengths of the fish caught by the smallest and largest meshed nets. As the difference between mesh sizes increases, the catch length distributions become more variable. To remove or reduce this variability, the summed catch frequencies must be divided by the summed selectivities whose resulting distribution has been normalized to 1.0. Such a procedure allows gillnet catch data to be used in ageing studies and as sources of catch curves for mortality estimates.

The optimum mesh size and the number of nets for any fishery cannot be estimated in advance without a knowledge of the population structure and the selectivity of the nets to be used. Experimental fishing with a fleet of gillnets of different mesh sizes will provide the data for estimating optimum fishery selectivity to remove the desired number and size of fish.

Clay (1979) showed that variation in trawl codend selectivity was quite large. Gulland (1964) found that most of the variation in sleectivity was due to real differences in the fish, gear or fishing technique. It is not likely that selection by gillnets is less variable than that by otter trawl codends. Therefore the technique of constructing composite selection curves (Fig. 7, 11 and 15) from available catch frequencies may be the only way to achieve mean estimates of selectivity. Experiments undertaken over several years with the same or different populations in the same locality should provide the data necessary to approximate the true selectivity of the gear for a particular species with an indication of the variation or confidence limits. However, it is important not to combine data from different populations (i.e. schools, locations, years, etc.) for analysis.

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APPENDIX

Appendix Table 1. Sockeye salmon, *Oncorhynchus nerka* (Peterson, 1954).

Length (cm)	Catch frequencies by mesh size and year					
	140 mm		152 mm		165 mm	
	1947	1948	1947	1948	1947	1948
51	1	3	—	—	—	—
52	—	1	—	—	—	—
53	—	10	—	1	—	—
54	1	26	—	3	—	—
55	9	35	—	1	—	2
56	17	81	11	13	2	2
57	31	102	12	25	2	7
58	36	133	43	49	5	4
59	41	108	61	90	8	9
60	41	77	81	99	19	23
61	26	29	86	76	29	29
62	30	20	82	56	57	44
63	29	8	70	31	57	43
64	21	11	68	22	63	33
65	13	3	46	7	58	28
66	9	2	25	9	61	21
67	5	1	12	5	32	8
68	3	1	9	3	18	12
69	2	—	10	1	23	6
70	1	1	8	3	6	4
71	—	1	1	2	4	2
72	2	—	1	1	1	1
73	—	1	—	—	1	1

Appendix Table 2. Pink salmon, *Oncorhynchus gorbuscha* (Ishida, 1962).

Length (cm)	Unadjusted catch frequencies by mesh size		
	96 mm	106 mm	121 mm
37	1	—	—
38	4	1	—
39	3	8	—
40	28	26	5
41	60	57	18
42	103	160	42
43	100	190	72
44	84	198	135
45	40	137	138
46	29	98	133
47	18	56	109
48	17	24	62
49	19	11	28
50	16	6	23
51	11	3	13
52	4	—	6
53	4	—	—
54	—	—	—
55	1	—	—
56	1	—	—
Correction factor[a]	4.168	3.152	1.215

[a] Each factor, which includes a correction for both fishing effort and percent of fish sampled from the true catch, must be multiplied by the length frequency to make each equal with respect to effort.

Appendix Table 3. Arctic char, *Salvelinus alpinus* (Hunter, 1970). (Numbers in parentheses indicate fish caught by gilling.)

Length	Unadjusted catch frequencies by mesh size and year											
	38 mm				51 mm				64 mm			
(cm)	1963		1965		1963		1965		1963		1965	
11	1	(1)	—		—		—		—		—	
12	2	(2)	—		—		—		—		—	
13	—		—		1	(1)	—		—		—	
14	—		—		2	(2)	—		—		—	
15	1	(1)	—		1	(1)	—		—		—	
16	14	(14)	1	(1)	1	(1)	—		—		—	
17	40	(40)	9	(9)	3	(3)	2	(2)	—		—	
18	71	(71)	24	(24)	2	(2)	3	(3)	—		—	
19	68	(68)	33	(33)	2	(2)	2	(2)	1	(1)	—	
20	72	(72)	58	(58)	1	(1)	2	(2)	1	(1)	1	
21	74	(74)	55	(55)	6	(6)	1	(1)	—		1	
22	38	(38)	69	(69)	21	(21)	6	(6)	—		—	
23	25	(24)	47	(47)	74	(74)	15	(15)	2	(1)	—	
24	29	(10)	33	(33)	82	(80)	24	(24)	1	(1)	—	
25	21	(10)	29	(29)	79	(70)	18	(18)	2	(2)	—	
26	37	(2)	22	(22)	75	(68)	41	(39)	21	(20)	—	
27	35	(1)	25	(25)	88	(53)	30	(30)	48	(32)	—	
28	86	(1)	15	(13)	112	(33)	33	(30)	87	(48)	1	
29	144		6	(3)	146	(17)	13	(10)	204	(78)	1	
30	191		17	(2)	189	(10)	22	(7)	317	(93)	11	(2)
31	173		20	(1)	185	(3)	25	(3)	310	(94)	11	(3)
32	97		30		122	(1)	32	(1)	222	(79)	13	(4)
33	51		61		63		39		131	(61)	33	(13)
34	26		64		20		65		40	(26)	42	(19)
35	11		48		7		34		18	(16)	29	(15)
36	4		19		5		24		9	(6)	23	(13)
37	1		12		2		13		2	(1)	10	(6)
38	1		7		1		5		2	(1)	7	(4)
39	1		1		1		1		—		4	(3)
40	1		—		—		—		—		1	
41	—		1		—		2		—		—	

Appendix Table 4. Atlantic herring, *Clupea harengus* (Olsen, 1959).

Length	Unadjusted catch frequencies by mesh size		
(cm)	59.7 mm	65.1 mm	72.5 mm
23.5	1	—	—
25.0	12	2	—
26.5	51	15	1
28.0	47	29	2
29.5	68	91	21
31.0	85	126	75
32.5	153	239	245
34.0	86	239	292
35.5	29	167	305
37.0	11	93	230
38.5	2	20	82
40.0	—	1	20
41.5	—	—	2

Appendix Table 5. Atlantic cod, *Gadus morhua*, smoothed catch frequencies. Combined data for 152, 165 and 178 mm mesh nets from Conception Bay, Placentia Bay and St. Mary's Bay, Newfoundland, in 1964 and 1965. Data are listed separately for Placentia Bay in 1965 and St. Mary's Bay in 1964.

| Length (cm) | Catch frequencies by area and mesh size (mm) | | | | | | |
| | Combined data | | | Plac. Bay | | St. M. Bay | |
	152	165	178	165	178	165	178
46	1	—	—	—	—	—	—
47	—	—	—	—	—	—	—
48	2	—	—	—	—	—	—
49	2	—	—	—	—	—	—
50	2	—	—	—	—	—	—
51	3	—	1	—	—	—	—
52	3	1	1	—	—	—	—
53	4	2	1	—	—	—	—
54	5	2	2	—	—	—	—
55	6	4	2	—	—	—	—
56	7	5	3	—	—	—	—
57	8	7	4	—	—	—	—
58	9	9	5	—	—	—	—
59	11	11	6	—	—	6	—
60	12	13	7	—	—	5	—
61	14	16	9	—	—	4	—
62	15	19	11	—	—	11	—
63	17	22	13	1	—	15	1
64	19	26	15	1	—	10	3
65	20	29	17	2	1	6	6
66	21	32	19	5	—	6	5
67	23	36	22	2	5	11	4
68	24	39	24	4	6	14	9
69	24	41	27	9	3	16	7
70	25	44	30	8	3	16	6
71	25	46	32	8	4	18	15
72	24	48	35	9	10	12	10
73	24	49	37	6	8	10	10
74	23	50	39	12	9	13	8
75	22	50	41	6	3	7	9
76	21	49	43	9	9	14	4
77	19	48	44	5	8	12	7
78	18	47	45	8	5	4	7
79	16	45	46	14	7	6	5
80	15	43	46	12	12	7	8
81	13	41	46	10	10	3	7
82	12	38	46	4	7	3	2
83	10	36	45	10	8	4	2
84	9	33	44	7	6	3	2
85	8	30	43	7	6	1	3
86	7	28	41	6	7	1	2
87	6	25	39	3	6	—	3
88	5	23	37	3	5	—	1
89	4	21	35	2	5	—	2
90	4	19	33	—	5	—	2
91	3	17	31	2	4	—	1
92	3	16	28	3	2	—	2
93	2	15	26	6	1	—	1
94	2	13	24	6	2	—	—
95	2	12	22	4	2	—	—
96	2	11	20	3	5	—	—
97	2	10	18	2	3	—	—
98	1	10	16	2	5	—	—
99	1	9	14	1	4	—	—
100	1	8	13	—	2	—	—
101	—	7	11	—	5	—	—
102	—	7	10	—	2	—	—
103	—	6	9	—	—	—	—
104	—	5	7	—	2	—	—
105	—	5	7	—	2	—	—