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Gillnet Selectivity and a Re-analysis of Case Studies of Several Species of Marine and Anadromous Fish

by

D. Clay
Department of Fisheries and Oceans, Bedford Institute of Oceanography
Dartmouth, Nova Scotia, Canada B2Y 4A2

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I. Introduction

Gillnets are one of the oldest, simplest, and easiest forms of passive fish harvesting. In order to utilize gillnet catch data for quantitive 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. The first detailed description of gillnet fishing and selectivity was carried out prior to 1920 by Baranov (Baranov, 1933). Since then, and especially in the last 20 years, many scientists (Holt, 1963; McCombie, 1961; Hamley and Regier, 1973; Regier and Robson, 1966;) have attempted to utilize mathematical techniques to describe the selectivity pattern of gillnets. This paper reviews previous theories of gillnet operation and attempts to show how gillnet catches can be used as random sampling tools. Regier and Robson (1966) provide a detailed review of the many mathematical models used in attempting to calculate selectivity and therefore this aspect will not be repeated here.

In order to make the terminology of this paper clear the following definitions are proposed:- (Much of this terminology has been adopted from otter trawl selectivity studies (Pope _et al._, 1975)).

1. Selectivity - the relative likelihood that a fish of any given size encountering a unit of gear will be retained by it. This value is relative and therefore normalized to some standard, generally 100%.

2. Availability - the likelihood that a fish of any given size will encounter the fishing gear. This is controlled by distribution and behaviour of gear, fish, and fishermen.

3. Partial recruitment - the absolute probability of capture of any member of the population whether or not that fish encounters the gear. Partial recruitment can be expressed as:

   Partial Recruitment = Selectivity x Availability

4. Efficiency - the selectivity of one gillnet relative to another. The nets will require an overlapping range of selectivities to permit the calculation of relative fishing efficiency and the series of nets are generally normalized to the highest single value.

5. Selection curve is a model or mathematical expression of gillnet selection with the highest point (modal) usually normalized to 100%. This curve is often represented by a normal or Gausian distribution and will have the same 4 moments as the efficiency curve.

6. Modal point or length - the length of fish at the highest point of the selection curve (also the mean length when selection is normal).

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

8. Selection factor - the fish length at the modal point divided by the stretched mesh size, both being measured in the same units.

II. Background to theory of gillnet selectivity

a) Gillnet fishing (principle)

Fish are caught in gillnets by two methods, gilling or wedging and tangling. The latter method is of negligible importance with smooth bodied fish, such as cod and herring; however, for fish with spines, such as the African catfish (Clarias gariepinus) (Gulland and Harding, 1961) and fish with teeth, such as walleye (Stizostedion vitreum vitreum) (Hamley and Regier, 1973), tangling can result in a significant portion of the catch.

A gillnet will catch fish of varying lengths with unequal success. Baranov (1948) showed how the size of meshes and the body form of the fish are most important in controlling the ability of an individual net to retain any particular fish. There is an optimum length of each fish species retained by each net. Above and below this length, the ability of the net to retain fish decreases. Smaller fish, in the extreme, pass freely through the meshes and as fish increase in size they are able to squeeze through the meshes with differing degrees of success. This is due to twine elongation and body compression. Large fish meet resistance and are often able to back away before becoming entangled.

A basic assumption has long been made that selection of a gillnet approximates a normal or Gaussian curve (Baranov, 1948; Holt, 1963; McCombie, 1961). Baranov pointed out that the relationship between the bar measure of the mesh ($\emptyset$) and the modal group (Lm) is:- $\emptyset = K \times Lm$. He found the constant (K) to be equal to 0.125 for herring (Clupea sp.) and 0.150 for roach (Rutilis sp.). After further work he found the relationship $\emptyset = k \times Gm$ to be a superior form, the constant being equal for different species; in this latter case Gm is the girth of the modal group and k is a constant (proportional to K). This, in principle, indicates that fish of the same girth are caught equally well in the same net irrespective of species. This premise, that girth is the controlling factor of selectivity (at least for the wedging portion of the catch) leads to the conclusion that the girth/selectivity relationship must be normal. Baranov found the modal girth to be approximately 1.25 times the mesh size. As the pattern of girth distribution for any fish length is normal the assumption that the selection of fish about the modal length of a gillnet catch approximates a normal curve is sound.

Since the time of Baranov the results of two further studies, Rollefsen (1953) and Richardson (1956) have given further indication that selectivity follows a normal pattern. Both of these studies used a presumed unselective gear to fish the same areas as gillnets. The comparison between catch and presumed populations indicated a normal type curve.

b) Factors affecting the efficiency of gillnets

Four major factors affect the fishing behavior of gillnets. These are:

1. twine size and elasticity,
2. twine colour,
3. mode of hanging the net, and,
4. duration of set.

The first of these has been studied by many authors since the first theoretical analysis by Baranov (1948). Hansen (1974) found a significant increase in the size of fish caught by a thinner diameter monofilament twine when compared to the same mesh size with thicker monofilament twine. He postulated that this was due to the greater elasticity of the thinner twine. He did not see any trend in efficiency (i.e., increase in the catch per unit effort) with gillnets of thinner twine; Baranov, however, in his study did find the catch decreased five fold with thicker twine. This difference could be due to the fact that the thickest twine used by Hansen was less than one-half of the diameter of the thinnest twine used by Baranov. It is probable that as twine diameter decreases the efficiency does improve to a maximum, at which point only an increase in numbers 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 strength of the net. Different fisheries require different compromises to design the most suitable gear.

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

Colour is the second factor affecting the fishing behaviour of gillnets. Visibility of nets in the water is a function of water clarity, illumination, and wave length of the light reflected by the twine. Hunter and Wisby (1964) found that fish could 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 (i.e. are most effective) from dusk until dawn. Many studies such as Libosvansky (1970) have investigated colour and arrived at confusing results due to the alteration of more than one parameter at a time. Baranov (1948) observed that often the most efficient colour of a net was similar to the colour of the dorsal region of the fish. Protective colouration of fish conceals them in their local environment, and therefore the same (dorsal) colour is most efficient for concealing the net.

Fish catches have been found to be related to lunar phases (Collins, 1979; Quartier, 1975). This relationship is attributed to increased illumination making nets more visible and thus increasing avoidance (Blaxter and Parrish, 1965). Molin (1953) suggested the invisible nature of monofilament twine was the major factor in its improved fishing efficiency compared to multifilament nylon; however, Collins (1979) did not note any difference in relative efficiency between monofilament and multifilament twine during various lunar phases. He did note a drop in catch during the full moon with both twine types. This implies that in some cases, changes in catch may be more attributable to changes in fish activity (Lawler, 1969; Ryder, 1977) than in increased avoidance of the net.

The third factor affecting the fishing behaviour of gillnets is the method of "hanging". The hanging of gillnets is the attachment of the webbing to the mainline 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 fishery practice, a value is given to hanging such as 1/2 or 1/3 and this is calculated by the formula:

$$P = \frac{2\varnothing - A}{2\varnothing}$$

where P is the hanging coefficient, $\varnothing$ is the bar mesh length and A is the horizontal distance between two opposite knots of a mesh. A net "hung" by the half has a final length equal to 0.5 the length of the sum of the stretched meshes. A net "hung" by the 1/3 has a final length equal to 0.667 the length of the stretched webbing.

Although hanging will affect the fishing characteristics of a gillnet, little work has been done to study the degree of this effect (Mohr, 1965). Jackson et al. (1963) in a brief analysis concluded one measureable advantage was that of area. The maximum area occurs by hanging by the 0.707. These authors felt the most efficient mounting might be dependent on the cross-sectional shape of the major species in the catch, i.e., by the 1/2 for salmon (Peterson, 1954) and by the 0.7 for catfish (Bagrus sp.) (Jackson et al., 1963).

The last factor affecting fishing behaviour, duration of the set, has been studied by several authors (Baranov, 1948; Kennedy, 1951; Pycha, 1962). Kennedy (1951) found that high levels of fish present in gillnets reduced the fishing efficiency of these nets over time. Baranov (1948) also commented on this saturation level of the catch and both Kennedy (1951) and Pycha (1962) showed the necessity of calculating effective effort by assessing duration of the set and estimating saturation limits. Kennedy (1951) noted that many fishermen felt rotting fish reduced the catch efficiency.

c) Selectivity

There are three curves to be considered in any work involving gillnets. The first and easiest to measure is the catch - those fish actually retained by the net (Figure 1). The other two curves are both unknown, at least initially, although once one has been estimated, the other can be calculated. These latter two curves are selectivity and population[1] (Figure 1). The selectivity, or "the relative fishing efficiency" (Baranov, 1948), is the unknown we try to estimate.

Since it is virtually impossible to directly calculate either selectivity or population, therefore, indirect means are generally employed. Most authors (Baranov, 1948; Holt, 1963; McCombie and Fry, 1960) have suggested two or more nets be fished concurrently. Baranov outlines some of the basic assumptions needed for indirect techniques to work. The shape of selection curve of nets hung in the same manner, made of the same material, and catching fish of the same species should be the same (in the case of this paper, assumed normal). Two selection curves S_1 and S_2, have mean or modal values X_1 and X_2 and mesh sizes a_1 and a_2 (Figure 2). If the difference in mesh size is not great (15-20%) and adjacent limbs overlap, the common point of the selection curves will have the same selectivity for both nets. If these nets are fished identically, they will have the same catch at this common point; thus, this position can be identified from the catch curves. If our catch of fish is sampled in 1 cm intervals, then the variation in any one interval could cause difficulties in identifying this common point. The relative inaccuracies due to random causes are inversely proportional to the square roots of the size of the sample at each interval, therefore at least 500 fish should be sampled by each net (Baranov, 1969). As he pointed out, the simplest approach is to plot the data points and draw a smooth curve through them. The cross-over point of these two smoothed curves is a good approximation to the common point.

d) Indirect mortality caused by gillnets

An extensive review of noncatch mortality due to Pacific coast gillnets was completed by Ricker (1976) and Atlantic coast gillnets by Ritter *et al*. (1979), therefore only a brief comment will be made here. Although some direct evidence of escapees (fallouts and dropouts) from gillnets is available (Ishida *et al*., 1969; French and Dunn, 1973) little

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1. The term population is used throughout this paper to denote the population structure by size groups over the range of fish available to the gillnet.

direct observation of the mortality is available. Petrova (1964) observed a higher percentage of net marked salmon dying in fresh water than unmarked salmon. Although many estimates (quoted by Ricker (1976)) indicate losses due to noncatch mortality at 50% or more of the catch, such losses appear to be restricted to salmonids. There is no reason to believe the number of escapees for herring and cod would be equal to these levels or that such escapees would die as a result of their wounds.

Several authors (Jewel, 1970; French and Dunn, 1973) have found noncatch mortality to be extremely low - in the order of 1-2% - for inshore coastal areas. This implies the possibility of increasing total catches from gillnets by restricting their use to sheltered inshore areas.

III. Methods

All data used in this analysis have been adjusted to metric form and all mesh sizes where necessary changed to stretched mesh.

Data for the case studies were gathered from several sources. Data for Arctic char (Salvelinus alpinus) were taken from Hunter (1972) for Pacific salmon (Salmo gorbuscha) from Ishida (1962a), for sockeye salmon (Oncorhynchus nerka) from Peterson (1954), for herring (Clupea harengus) from both the Department of Fisheries and Oceans archives at St. Andrews Biological Station and from Olsen (1959), and for cod (Gadus morhua) from both the Department of Fisheries and Oceans archives at the St. John's Biological Station and the author's own groundfish gillnet study in the summer of 1978. The data used from each of the above sources are presented in Appendix I.

The technique chosen in this study for analysis of selectivity was developed from some of the general principles proposed by Baranov (1948). The gillnet catch curve was smoothed by the Graham Charlier Series (Kendall and Stuart, 1969) and this smoothed approximation of the curve was used in estimating the common point between two overlapping curves. Two additional points can be calculated for each pair of curves by dividing the catch at the chosen mean of each curve by the catch of the other curve at the same length interval. Normal selection 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 derived, the populations calculated from the selectivity and corresponding catch were compared. This final test determined if the selectivity curves were reasonable.

If a series of catch curves for increasing mesh sizes are available then successive pairs can be investigated. Except for the smallest and largest mesh sizes at least two estimates of selectivity will be available for each gillnet. After "best fits" have been achieved for several pairs of catch curves the resulting selectivity pairs, for each catch curve, can be averaged and used to calculate an estimate of the population. These populations, one from each curve, can then be averaged and the result divided by each catch curve in turn to give the final selectivities for each net. For this technique to give valid results nets must be fished with equal effort and on the same population. The results achieved by this technique are not unique and must be judged on experience and supporting data.

Although Baranov (1948) showed the common point of two smoothed catch curves would be the common point of the selectivities - he did not suggest any means of using this information to calculate the unknown selection curves. The iterative technique used in this paper is the first step towards a gillnet selectivity model.

IV. Results and discussion of case studies

a) Sample data

Sample data were generated to test the computer programming and general selectivity hypothesis (Table 1). Selection curves (1 and 2) were calculated with means of 18.0 cm and 22.0 cm and standard deviations of 1.5 and 2.0 respectively. Catch curves generated by multiplying these selection curves for the population of Table 1 have means of 18.20 and 21.75 cm and standard deviations of 1.51 and 1.86. Unless the population follows a very unusual configuration the first two moments of the catch curve approximate those of the selection curve. A noteable exception to this are those fish caught by more than one method (i.e. by gilling and tangling) - in such cases catch curves would have to be divided into appropriate sections.

After eleven minor adjustments to the mean and standard deviation a "best fit" was achieved. This fit is subjective and decided upon by the proximity to the three estimable points. The two resulting populations were similar to one another (and approximated the starting population although this normally would not be known). The two estimated normal selection curves were then adjusted by averaging the two estimated populations and dividing the mean population by the appropriate catch (see Fig. 3 for the flowchart of the process).

b) Pacific salmon data (Peterson, 1954)

The above technique is simple and allows an estimation of a normal selectivity curve when data are adequate. Peterson (1954) documented data that can be assumed to be from the same population. The 1947 and 1948 data from the 140 mm (5.5 in.), 152 mm (6.0 in.), and 165 mm (6.5 in.) nets were used (sexes combined, years separate). These nets have sufficient overlap and numbers to make reasonable samples. Each annual combination of net pairs was fitted with normal selection curves as described. The final result of the 1947 data indicates a large difference in relative efficiences (Figure 4). When individual curves are normalized to 100% (i.e. assuming equal efficiencies) all three curves are similiar in shape (Figure 5). The modal points for the 3 nets are 58.8, 61, and 63.8 respectively. The selection range and selection factors are 10.6, 9.4, and 10.0 cm and 4.2, 4.0, and 3.9 respectively. Although the unexplained difference in efficiency is difficult to accept, no plausible alternatives are presently available.

Holt (1963) also analysed Peterson's data. He combined the catches of 1947 and 1948 - i.e. the catches of two different years or populations (total of 1947 and 1948 catches in Appendix I:1). Between the two years the mean size of fish caught for the three nets discussed above changed by -2.4 cm, -1.5 cm, and -1.1 cm respectively. An initial investigation of the three selection curves proposed by Holt and their corresponding catches show the common selectivity points do not occur at the expected lengths (Figure 6) or at the same lengths found above. However there is serious difficulty with this set of selection curves, given his hypothesis that the efficiency is the same for all curves. If these curves are correct then the catch for the 140 mm net implies all fish in the population must disappear below 52 cm - a length where the net is supposed to be catching 70% of encountered fish (Figure 6). Similar difficulties occur if ratio's of catches of a pair of gillnets at one length are compared to ratio's of the selectivities at the same length. The selection curves presented previously (Figure 5) do not suffer this problem to the same extent.

The selection curves for the 1948 data (Peterson, 1954) were calculated as for the 1947 data. The catch between these two years was very different for each net (Figure 7). The selection curves, however, are very close, especially those of the 140 mm and 152 mm nets (Figure 8). The relative fishing efficiency does not have the same range as was found for the 1947 data (Figure 9).

The efficiency of one net compared to another should not change greatly between years or populations of the same species. The difference in relative "efficiency" between nets between years therefore cannot be explained solely as difference in efficiency of the gear. A partial explanation for this difference may be the positioning of the gear. The position of a net in a fleet of nets tied end to end will affect it's ability to catch fish (von Brandt (1955). During the two years of fishing by Peterson (1954), 10 sizes of net were fished by several boats each weekend between July and October. The positioning of the different sizes of net in the fleet was different each weekend, however the catch rate was not equal on all weekends and over 70% of the total catch was caught in 3 and 4 consecutive weekends of 1948 and 1947 respectively. If position of a net does affect the catch then this situation could produce an anomaly that would appear to be efficiency. Therefore it is necessary to add one additional definition to those of the introduction.

9. Relative fishery efficiency - the difference in catch between two or more units of gear that cannot solely be attributed to efficiency. This value could be affected by fishing environment and the advantage any one unit of gear is given by fishermen.

c) Pacific salmon data (Ishida, 1962a)

A second attempt was made to measure selectivity of Pacific salmon (although a different species) using data from Ishida (1962a). Several of the basic assumptions necessary for any calculation of gillnet selectivity were violated is his study - primarily that of fishing identically on the same population. The effort expended by the 96 mm, 106 mm and the 121 mm nets ranged over a factor of five. For these analyses, catches from the 96 mm and 106 mm nets were adjusted to make the effort for each equal to the effort of the 121 mm nets. Using these adjusted data no two normal curves could be found that would give approximately the same population (even within the same order of magnitude) for any of the pairs of nets. A close inspection of the data in Appendix I:2 shows the smallest mesh net caught greater numbers of large fish than either of the larger nets. These two factors indicate a strong probability that the different nets were not only used with differing frequency but were also used on different populations (possibly schools). The data therefore are not suitable for analysis by this technique.

d) Arctic char data (Hunter, 1970)

The catch length frequencies of Arctic char caught in 1963 (Hunter, 1970) have two modes. These modes represent fish caught by gilling or wedging and by tangling with their head, teeth and mouth parts (Beck, pers. comm.). In order to separate these two superimposed curves into their components a computer program (NORMSEP) was used to conduct a modal analysis (Abramson, 1971). The 38 mm (1.5 in.) net has modes at 20 and 30 cm, the 51 mm (2.0 in.) net at 25 cm and 30 cm, and the 64 mm (2.5 in.) net at 30 cm and 31 cm. The length frequency mode of two different sized gillnets would be expected to shift while the length frequency caught by tangling of their mouth parts (relatively independent of size) should remain the same. The 38 and 51 mm nets have common modes at 30 cm and modes at 20 and 25 cm respectively. These latter two modes are considered to be the gilled portion of the catch and have wider standard deviations than the frequencies caught by tangling. Using this information the two frequencies from the 64 mm net with means of 31.0 and 31.1 cm and standard deviations of 2.36 and 1.44 respectively were alloted to the gilled portion of the catch and that portion caught tangling respectively (Figure 10). The total catch broken into two portions is:

Net Size (mm)	Total Catch	Gilled Catch	Tangled Catch
		Numbers of Fish	
38	1309	434	875
51	1286	442	844
64	1415	562	853

The actual length frequencies are listed in Appendix I:3. The selectivities were then estimated for the gilled portion of the catch for each net. However those portions caught by the head and mouth parts are so similar (means 30.5, 30.9, and 31.9 cm; standard deviations 2.1, 1.9, and 1.5 for nets 38, 51, and 64 mm respectively) that any estimate is extremely difficult to calculate (Figure 10). The only part of the tangled portion of the catch curve that is changing is the ascending (left-hand) limb. This probably indicates that over the range of nets used each has the same selectivity for tangling fish over 25 cm. There is a slight drop in tangled catch of the smaller fish (25-29 cm) in the 64 mm net however this is not believed by the author to be important and an estimate of the selectivity could be made by averaging the three catches (tangled portions) and dividing by the mean population calculated from the selectivities of the three gilled portions of the catches. The relative fishery efficiency for these net sizes is relatively equal in 1963, as expected for long-term random catches from a stable population (Figure 11).

In this case the char population was relatively small in Keyhole Lake and the gillnet fishery of 1963 removed over 50% of the total population (Hunter, 1970). This sudden reduction of a stable Arctic population greatly altered food availability and therefore subsequent growth. In 1965 when a second gillnet survey was conducted the resulting catch was different from 1963 (Appendix I:3). The 1965 catch data show a general shift to larger fish when compared to the catch of 1963.

Similar analyses were carried out on 1965 data (Hunter, 1970) and satisfactory results achieved - however the numbers of fish sampled were low and therefore greater variability was found - especially for the larger mesh net (64 mm) where only 188 fish were caught.

The relative fishery efficiency shows similar variation in 1965 to that in 1963 (Figure 12). The modes are displaced by about 2 cm (except the poorly sampled 64 mm net, the mode of fish from this net is displaced 5 cm). The selectivity curves of 1963 and 1965 are similar in shape despite the displacement of the modes (Figure 13). This shift in mode is likely due to either the actual changes in the shape of the fish caused by increased food supply after the 1963 population reduction or possibly due to changes in true mesh size (as opposed to the manufacturers stated size) of the gillnets between the two periods of fishing (Hunter, pers. comm.).

e) Herring data (Olsen, 1959)

The herring data presented by Olsen (1959) were collected from at least two locations over a period of at least six months (data in Appendix I:4). Herring, being pelagic schooling fish, complicate any selection study as individual schools may vary in age, ripeness as well as state of feeding. Such variability makes it unlikely that each unit of gear has fished the same population throughout the entire study period. In spite of this difficulty, selection curves were estimated using these data. Although the "best fit" for each of the pairs of nets was not good - it was considered adequate. Olsen (1959) calculated the population from each gillnet catch, and found the relative difference between the populations estimated from each of the three nets. His estimates were similar to those obtained by the present technique. The selection curves (Figure 14) have a similar shape to those of Olsen (1959); however, the mean length is increased by over 2 cm for each net.

The modal size for herring caught in these gillnets with mesh sizes of 59.7, 65.1, and 72.5 mm is 31, 34, and 35.5 cm respectively. This does not follow the expected linear relationship, and this coupled with the poor relationship between population estimates from the different pairs of nets makes the data suspect. It is quite possible that the only "good" estimates of gillnet selectivity for such pelagic schooling fish as herring will be to use a single night's catch to ensure only one school is sampled equally by each net.

f) Cod data

The cod and herring gillnet data from the archives of St. John's Biological Station and St. Andrews Biological Station respectively are both made up of large samples of fish from many net sizes. However the data from any one year cover a wide range of locations and therefore populations. Catches from various populations can result in a very wide distribution if the populations are different. The cod data when analysed resulted in selectivites with standard deviations in the order of 11.0 for nets with mesh sizes of 152 mm, 165 mm, and 178 mm. Although the data for the 3 net pairs gave satisfactory values - the final result was poor (Figure 15). Similiar difficulties were encountered with these data as with Holt's (1962) combined data (section b above). The same cod data when separated by location and year resulted in selectivities having standard deviations of 6 to 8 (Figure 16). When separated by location there were only 2 net sizes available at any one site (data, Appendix I:5), thus the proposed method was not used. Instead a "best fit" for each pair of nets at each location was estimated and the selectivity curves for each size of net were combined to provide a composite (Figure 16). The variation between estimates of selectivities by this method is not great - especially considering the variation in catches (Figure 17). The one major limitation, when only two net sizes are available, is the shape of the selection curve - the normal model results in normal output. When three or more nets are available the combination of different estimates allows some skewness, if present, to enter the selection pattern.

V. Use and significance of gillnet selectivity

Knowing the selectivity of any gear, especially gillnets, allows better management of a commercial stock through choice of net 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. If a series of gillnets has infinitely small differences between their mesh sizes then they will provide an unbiased sample of fish between the modal length of the first and last nets. As the difference between mesh sizes increases more and more "noise" will enter the catch length distribution. To remove this "noise" the summed catches must be divided by the summed selectivities whose resulting distribution has been normalized to 1.00. Such a technique would allow gillnet catches to be used in ageing studies and as sources of catch curves for mortality estimates.

The optimum size and number of nets for any fishery cannot be calculated before hand. Initial fishing with a fleet of gillnets gives an estimate of the population structure and the selectivity of the different nets. From these initial data an estimate can be made (by summing normalized selectivities) of the optimum fishery selectivity to remove the desired number and size of fish.

Clay (1979) showed the variation in trawl codend selectivity to be extremely great. Gulland (1964) found most of the variation in selection studies due to real differences in the fish, gear or fishing technique. There is no reason to believe selection by gillnets will be any less variable than that by codends. Because of this variability, the technique of making a composite selection curve (Figure 8, 13, and 16) of available data is the only way to achieve a mean estimate of the selectivity. This should be attempted over a period of several years using the same gear, on the same or different populations in the same locality. Such a series of estimates should approximate the true selectivity and give an indication of the variation or confidence limits for the species in question.

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VI. Bibliography and reference list*

**Abramson, N.J. (1971). Computer programs for fish stock assessment: NORMSEP. FAO/UN Fish. Tech. Pap. No. 101. (pag. var.).

Andreev, N.N. (1946). [Effect of colour on the catching power of gillnets.] Rybno. Khoz. No. 12 (In Russian). Not seen in original.

Andreev, N.N. (1955). [Some problems in the theory of the capture of fish by gillnets.] Proc. All-Union Sci. Res. Inst. Sea Fish. Ocean. Vol. XXX:109-127. (In Russian). Translation available from Fish. Lab., Lowestoft, U.K. (Mimeo).

Andreev, N.N. (1967). [Influence of the ratio of twine diameter and mesh size on the catching capacity of gill nets.] Rybno. Choz'ajstvo. 43(5): 39-41. (In Russian). Not seen in original.

Anon. (1962). The gillnet fishery for the Nile perch Lates mariae. In: Annual Report No. 10 of Joint Fish. Res. Organ. (Northern Rhodesia): 27-30.

Anon. (1962). Further notes on gillnet experiment on Labeo mesops (Gunther). In: Annual Report No. 10 of Joint Fish. Res. Organ. (Northern Rhodesia): 48-56.

* Papers referenced in this study are marked with "**"

Anon. (1969). A summary of information of the "shaker" catch by Washington's ocean salmon fisheries. Wash. Dept. Fish. 13 p. (Mimeo).

Anon. (1978). [The draggers and gillnetters of Quebec 1977.] Bur. Statis. Quebec. Quebec City, Quebec, Canada. (In French).

**Atton, F.M. (1955). The relative effectiveness of nylon and cotton gillnets Can. Fish. Cult. 17: 18-26.

**Baranov, F.I. (1933). [Commercial Fishing Technique.] (In Russian). Not seen in original.

**Baranov, F.I. (1948). [Theory and estimation of fish gear]. Fish Industry Press, Moscow. (In Russian). Chap. 7: [Theory of fishing with gillnets.] Translated by Department of Lands and Forests, Maple, Ontario, Canada. (Mimeo).

**Baranov, F.I. (1969). [Selected works on fishing gear. Vol. I Commercial fishing techniques.] Pischevaya Promyshlennost. Moscow, 1969. (In Russian). (Three volume treatise translated by Israel Program for Scientific Translations, Jerusalem, 1976.

Berst, A.H. (1961). Selectivity and efficiency of experimental gillnets in South Bay and Georgian Bay of Lake Huron. Trans. Amer. Fish. Soc. 90 (4): 413-418.

Berst, A.H. and H.R. McCrimmon. (1961). An apparatus for measuring the girth of fish. Prog. Fish-Cult 23(1): 42.

**Blaxter, J.H.S. and B.B. Parrish. (1965). The importance of light in shoaling, avoidance of nets and vertical migration by herring. J. du Conseil. (ICES). 30:40-57.

Broadhead, G.C. (1953). Investigations of the black mullet, *Mugil cephalus* L., in northwest Florida. Tech. Ser. Fla. Bd. Conserv. 7.

Burd, A.C. (1959). An analysis of the method of sampling the East Anglian herring catches. J. du Conseil. (ICES). 24(1) 80-94.

Burd, A.C. (1963). On selection by the drifter fleets in the East Anglian herring fishery. J. du Conseil. (ICES) 28 (1): 91-120.

Carlander, K.D. (1953). Use of gillnets in studying fish populations of Clear Lake, Iowa. Iowa Academy of Science. 60: 621-625.

Chapman, D.G. (1955). Population estimation based on change of composition caused by selective removal. Biometrika. 42: 279-290.

Christensen, O. (1971). Observations on selectivity and relative efficiency of salmon drift nets in connection with population studies on salmon at west Greenland. ICNAF Res. Doc. 71/65. Serial No. 2535. pp 8. (Mimeo).

Christensen, O. and W.H. Lear. (1974). By-catches in salmon drift nets at West Greenland in 1972. ICNAF Res. Doc. 74/44. Serial No. 3230. pp 27. (Mimeo).

**Clay, D. (1979). Current mesh selection studies on the Scotian Shelf in relation to historical selectivity data. ICNAF Sel. Pap. 5: 49-60.

**Collins, J.J. (1979). Relative efficiency of multifilament and monofilament nylon gillnet towards lake whitefish (Coregonus clupeaformis) in Lake Huron. J. Fish. Res. Bd. Can. 36: 1180-1185.

Cucin, D. and H.A. Regier. (1966). Dynamics and exploitation of lake whitefish in southern Georgian Bay. J. Fish. Res. Bd. Canada. 23(2): 221-274.

Doi, T. (1962a) [Theoretical considerations on rationality of offshore salmon fisheries from the standpoint of effectual utilization of the population.] Bull. Tokai Fish. Res. lab. 34: 1-11. (In Japanese). Not seen in original.

Doi, T. (1962b). [Approach from population dynamics ratio of salmon falling off gillnets.] Bull. Tokai Reg. Lab. 34: 13-18. (In Japanese) (Translation: US Nat'l. Mar. Fish. Serv.).

Doi, T. (1962c) [On the problems of population dynamics relevant to immature salmons caught offshore in the North Pacific.] Bull. Tokai Fish. Res. Lab. 35: 1-8. (In Japanese). Not seen in original.

Farran, G.P. (1936). On the mesh of herring drift-nets in relation to the condition factor of the fish. J. du Conseil. (ICES) 11(1): 43-52.

**French, R.R., and J.R. Dunn. (1973). Loss of salmon from high-seas gillnetting with reference to the Japanese salmon mothership fishery. Fish. Bull. 81: 845-875.

Garrod, D.J. (1961). The selection characteristics of nylon gillnets for Tilapia esculenta Graham. J. du Conseil. (ICES). 26(2): 191-204.

Gulland, J.A. (1961). The estimation of the effect on catches of changes in gear selectivity. J. du Conseil. (ICES) 26(2): 204-214.

**Gulland, J.A. (1964). Variations in selection factors and mesh differentials. J. du Conseil. (ICES). 29(2): 158-165.

**Gulland, J.A. and D. Harding. (1961). The selection of Clarias gariepinus (Peters) by nylon gillnets. J. du Conseil. (ICES). 26(2): 215-222.

Hamley, J.M. (1972). Use of the DeLury method to estimate gillnet selectivity. J. Fish. Res. Bd. Canada. 29(11): 1636-1638.

**Hamley, J.M. and H.A. Regier. (1973). Direct estimates of gillnet selectivity to walleye (Stizostedion vitreum vitreum). J. Fish. Res. Bd. Canada. 30(6): 817-830.

**Hansen, R.G. (1974). Effect of different filament diameters on the selective action of monofilament gillnets. Trans. Amer. Fish. Soc. 103(2): 386-387.

Havinga, B. and C.L. Deelder. (1948). The relation between the sizes of mesh of gillnets and size of Lucioperca sandra in the catches. Rapp. et Proc. Verb. (ICES). 125 (II): 59-62.

**Hewson, L.G. (1951). A comparison of nylon and cotton gillnets used in the Lake Winnipeg winter fishery. Can. Fish. Cult. 11: 7-9.

Hewson, L.G. (1952). study of nylon and cotton gillnets. Dept. of Fisheries (Canada) Trade News 1952: 3-4.

Hickling, C.F. (1939). The selective action of the drift-net on the cornish pilchard. J. du Conseil. (ICES). 11(1): 67-80.

Hodgson, W.C. (1933). Further experiments on the selective action of commercial drift nets. J. du Conseil. (ICES). 8(3): 344-354.

Holt, S.J. (1957). A mathematical model for line and gillnet fisheries. Contrib. P. 19 to joint meeting of ICNAF, ICES, and FAO, Lisbon, on selectivity of fishing gear (Mimeo).

**Holt, S.J. (1963). A method for determining gear selectivity and its application. ICNAF Spec. Pub. 5: 106-115.

Hunter, C.J., B.G. Patten and R.B. Thompson. (1972). Viability of mature sockey salmon that disentangle from gillnets. Int. North Pac. Fish. Comm. Ann. Rept. 1970, pp 90.

**Hunter, J.G. (1970). Production of Arctic char (Salvelinus alpinus Linnaeus) in a small Arctic lake. FRB Can. Tech. Rept. 231. pp 190.

**Hunter, J.R. and W.J. Wisby. (1974). Net avoidance behavior of carp and other species of fish. J. Fish. Res. Bd. Can. 21: 613-633.

Ishida, T. (1961a). [On the mesh selectivity of salmon gillnet.] J. Hokkaido Fish. Exp. Sta. 18(3): 12-13 (In Japanese). Not seen in original.

Ishida, T. (1961b). [Theory on the mesh selectivity curve of gillnet and its method of presumption.] J. Fish. 915: 48-50. (In Japanese). Not seen in original.

**Ishida, T. (1962a). [On the gillnet mesh selectivity curve.] Bull. Hokkaido Reg. Fish. Res. Lab. 25: 20-25. (In Japanese). (Translated by FRB Can. Trans. Ser. No. 1338).

Ishida, T. (1962b). [Gillnet selectivity curve for pink salmon and its application to analysis for catch data.] J. Hokkaido Fish. Exp. Sta. 19(3): 85-90. (In Japanese). Not seen in original.

Ishida, T. (1963). [Mesh selectivity biases on the gillnet caught sockeye and chum salmon.] Bull. Hokkaido reg. Fish. Res. Lab. 25: 20-25. (In Japanese). Not seen in original.

Ishida, T. (1964). [Gillnet mesh selectivity for sardine and herring. Bull. Hokkaido Reg. Fish. Res. Lab. 28: 56-60. (In Japanese). Not seen in original.

Ishida, T. (1969). The salmon gillnet mesh selectivity curve. Bull. INPFC. 26:1-11.

Ishida, T., J. Ito, and M. Osako. (1966). [Design of the non-mesh-selective salmon gillnets for research use and results of the experimental operations.] Bull. Hokkaido Reg. Fish. Res. Lab. 31: 1-10. (In Japanese). Not seen in original.

**Ishida, M., N. Sano, S. Mishima, and S. Saito. (1969). On measuring the dropping rate of salmon gillnets by means of underwater television techniques Bull. Jap. Soc. Sci. Fish. 35: 1157-1166.

**Jackson, P.B.N., T.D. Iles, D. Harding, and G. Fryor. (1963). Gillnet fishery in the northern lake. In: Report on the survey of northern Lake Nyasa 1954-55. Government Printer, Zomba, Nyasaland (Malawi). pp 118-145.

**Jewel, E.D. (1970). Gillnet dropout study. Wash. Dept. Fish., Prog. AFC-14:5 p.

Kawamura, G. (1972). Gillnet mesh selectivity curve developed from length-girth relationship. Bull. Jap. Soc. Sci. Fish. 38(10): 1119-1127.

**Kendall, M.G. and A. Stuart. (1969). The advanced theory of statistics. Vol. I. Distribution theory. Charles Griffin and Co. Ltd., London, U.K.

**Kennedy, W.A. (1951). The relationship of fishing effort by gillnets to the interval between lifts. J. Fish. Res. Bd. Canada. 8(4): 264-274.

Kipling, C. (1957). The effect of gillnet selection on the estimation of weight-length relationships. J. du Conseil. (ICES). 23(1): 51-63.

Kipling, C. (1963). Some estimates of theoretical minimum expected sizes of perch in gillnets. ICNAF Spec. Pub. 5: 128-130.

Kitahara, T. (1971). On selectivity curve of gillnet. Bull. Jap. Soc. Sci. Fish. 37(4): 289-296.

Kondo, M. (1952). [Relationship between mesh size and age of fish in herring gillnet.] J. Hokkaido Fish. Exp. St. 9(3): 31-34. (In Japanese). Not seen in original.

Kondo, M. (1962). [The relation between the size of mesh of salmon gillnet and the length of salmon in the catch.] Bull. Hokkaido Reg. Fish. Res. Lab. 24: 139-147. (In Japanese). Not seen in original.

Kondo, M. (1964). [Difference of catching power between Amiran twisted thread net and Amilan gut net.] Jap. Fish. Agency (mimeo). pp 51. (In Japanese). Not seen in original.

Kondo, M. (1966). Studies on optimum mesh of salmon gillnet. Mem. Fac. Fish., Hokkaido Univ. 14(1/2): 1-88.

Lander, R.H. (1963). Girth-length relationships in sockeye and chum salmon. Trans. Amer. Fish. Soc. 92: 305-307.

Lander, R.H. (1969). Swimming thrust of sockeye salmon (<u>Oncorhynchus nerka</u>) in relation to selectivity of gillnets. J. Fish. Res. Bd. Can. 26(5): 1383-1385.

**Larkins, H.A. (1963). Comparison of salmon catches in monofilament and multifilament gillnets. Commer. Fish. Rev. 25(5): 1-11.

**Larkins, H.A. (1964). Comparison of salmon catches in monofilament and multifilament gillnets. - Part II. Commer. Fish. Rev. 26(10): 1-7.

Larkin, P.A. and J.G. McDonald. (1968). Factors in the population biology of the sockeye salmon of the Skenna River. J. Anim. Ecol. 37: 229-258.

**Lawler, G.H. (1950). The use of nylon netting in the gillnet fishery of Lake Erie white fish. Can. Fish. Cult. 7: 22-24.

**Lawler, G.H. (1969). Activity periods of some fishes in Heming Lake, Canada. J. Fish. Res. Bd. Can. 26: 3266-3267.

Lear, W.H. and O. Christensen (1974) Selectivity and relative efficiency of salmon drift nets. ICNAF Res. Doc. 74/41. Serial No. 3227. pp 9. (Mimeo).

Leim, A.H., S.N. Tibbo, and L.R. Day. (1957). Explorations for herring in Canadian Atlantic waters, 1945-1950. Bull. Fish. Res. Bd. Canada. No. 111: 35-83.

**Libosvarsky, J. (1970). The entangling capacity of gillnets of different twine color and age when fishing for white fish and lake trout. FRB Can. Tech. Rept. No. 180: 25-35.

Marcotte, A. (1962). The gillnet, its use for catching groundfish. Cashiers d'Information No. 12., Stat. Biol. Mar. Grande-Rivere, Quebec, Canada. pp 38.

Marcotte, A. (1970). [Gillnet experimental fishing.] Rap. Ann. (1960). Station de Biol. Mar. de Grande Riviere, Min. d I'Ind. et du Comm., Quebec, Canada. pp 116-118. (In French).

Marcotte, A. (1972). [Cod in gillnets.] Rap. Ann. (1961), Station de Biol. Mar. de Grande riviere, Min. de I'Ind. et du comm., Quebec, Canada. 4 p. (In French).

May, A.W. (1970). Relative catching efficiency of salmon drift nets and relative viability of salmon caught. ICNAF Res. Doc. 70/9. Serial No. 2330. pp 8. (Mimeo).

**McCombie, A.M. (1961). Gillnet selectivity of lake white fish from Goderick-Bayfield area, Lake Huron. Trans. Amer. Fish. Soc. 90 (2): 337-340.

McCombie, A.M. and A.H. Berst. (1969). Some effects of shape and structure of fish on selectivity of gillnets. J. Fish. Res. Bd. Can. 26(10): 2681-2689.

**McCombie, A.M. and F.E.J. Fry. (1960). Selectivity of gillnets for lake white fish, Coregenus clupeaformis. Trans. Amer. Fish. Soc., 89: 176-184.

Miller, R.J. (1976). Trap mesh selection and catches of the spider crab, Chionecetes opilio. Fish. Mar. Serv. Res. Dev. Tech. Rept. Canada. 598: 15 p.

**Mohr, H. (1965). [Effect of hanging of gillnets on catches of perch and roach.] Arch. Fischereiwiss., 16(1): 108-115. (In German).

**Molin, G. (1953). Test fishing with nets made of monofilament nylon thread. Ann. Rep. Inst. Freshwater Res. Drottningholm. 34: 73-77.

Mongean, J.R. (1976). [Methods of experimental fishing in freshwater, for use of biologists and technicians of wildlife.] Rapp. Tech., Wildlife Service, Min. of Tourism, Wildlife, and Fisheries, Quebec, Canada pp 83. (In French).

Moshenko, R.W. and G. Low. (1978). An experimental gillnetting program on Great Slave Lake, Northwest Territories, 1977. Fish. Res. Res. Bd. Can. Data Report 102. pp51.

Moyle, J.B. (1949). Gillnets for sampling fish populations in Minnesota waters. Trans. Amer. Fish. Soc. 79: 195-204.

Moyle, J.B., J.H. Kuehn, and C.R. Burrows. (1950). Fish population and catch data from Minnesota Lakes. Trans. Amer. Fish Soc. 78: 163-175.

Moyle, J.B. and R. Lound. (1960). Confidence limits associated with means and medians of series of net catches. Trans. Amer. Fish. Soc. 89(1): 53-58.

Naumov, V.M. and A.N. Smirnov. (1969). [Influence of the selectivity of gillnets on quantitative and qualitative composition of the commercial fish populations of the Sea of Azov.] Pischevaya Promyshlennost, Moscow. 67: 269-299. (In Russian). (Translated by FRB Can. Trans. Ser. No. 1593. (Mimeo).

**Olsen, S. (1959). Mesh selection in herring gillnets. J. Fish. Res. Bd. Can. 16: 339-349.

Olsen, S. and J. Tjemsland. (1963). A method of finding an empirical total selection curve for gillnets, describing all means of attachment. Fisheridir. Skr. (Havunders), 13(6): 88-94.

Parrish, B.B. and G. MacPherson. (1956). Sampling problems in fish population studies, with special reference to North Sea herring investigations. Rapp. et Proc.-Verb. (ICES). 140(1): 48-57.

Parrish, B.B. (1969). A review of some experimental studies of fish reactions to stationary and moving objects of relevance to fish capture processes. FAO/UN Fish. Rep. (62). 2: 233-245.

**Peterson, A.E. (1954). The selective action of gillnets on Fraser River sockeye salmon. Int. Pac. Salmon Fish. Comm. Bull. 5: pp 101.

Petrova, Z.I. (1964). [On the condition of the salmon stocks of the Balshaya River.] In: Lososevoe khozyaistvo dalnego vostoka. E.N. Pavlovsky (Ed.). Nauka Press, Moscow. (In Russian). Not seen in original.

**Pitre, K.R. (1970). Summary of "shaker" investigations on the west coast of Vancouver Island troll fishery. Can. Dep. Fish. For. Pac. Reg. Tech. Rep. 1970-1: 10p.

**Pope, J.A., A.R. Margetts, J.M. Hamley, and E.F. Akyuz. (1975). Manual of methods for fish stock assessments. Part III. Selectivity of fish gear. FAO/UN Fish. Tech. Pap. 41.65p.

**Pristas, P.J. and L. Trent. (1977). Comparisons of catches of fishes by gillnets in relation to webbing material, time of day, and water depth in St. Andrew Bay, Flordia. Fish. Bull. U.S. 75: 103-108.

**Pycha, R.L. (1962). The relative efficiency of nylon and cotton gillnets for taking lake trout in Lake Superior. J. Fish Res. Bd. Can. 19(6): 1085-1094.

**Quartier, A.A. (1975). [Influence of the moon on fishing with gillnets in Neuchatal Lake.] Schweiz. A. Hydrol 37: 220-224. (In French).

Rawson, D.S. (1947). Lake Athabaska. Bull. Fish. Res. Bd. Canada. No. 72: 69-85.

**Regier, H.A. (1969). Fish size parameters useful in estimating gillnet selectivity. Prog. Fish. Cult. 31: 54-57.

**Regier, H.A. and D.S. Robson. (1966). Selectivity of gillnets, especially to lake white fish. J. Fish. Res. Bd. Can. 23: 423-454.

**Richardson, I.D. (1956). Selection of drift nets. ICES. C.M. Doc. (Comp. Fish. Comm.) No. 57. pp 14. (Mimeo).

Ricker, W.E. (1976). Review of the rate of growth and mortality of Pacific salmon in salt water, and non-catch mortality caused by fishing. J. Fish. Res. Bd. Can. 33: 1483-1524.

Ridenhour, R.L. and C.J. DiCostanzo. (1956). Nylon vs linen gillnets at Clear Lake, Iowa. Proc. Iowa Acad. Sci., 63: 700-704.

**Ritter, J.A., T.L. Marshall, and D.G. Reddin. (1979). A review of non-catch mortality as it relates to Atlantic salmon (Salmo solar L.) fisheries. ICES c/m 1979/M:25. pp.9.

Robson, D.S. and D.G. Chapman. (1961). Catch curves and mortality rates. Trans. Amer. Fish. Soc. 90(2): 181-187.

**Rollefsen, G. (1953). The selectivity of different fishing gear used in Lofoten. J. du Conseil. (ICES). 19(2): 191-194.

**Ryder, R.A. (1977). Effects of ambient light variations on behavior of yearling, sub-adult and adult walleyes. (Stizostedion vitreum vitreum). J. Fish. Res. Bd. Can. 34: 1481-1491.

Scidmore, W.J. and Z. Scheftel. (1958). Relative efficiency and selectivity of experimental nets of line and nylon. Minn. Fish. and Game Invest. Fish. Ser. 1: 46-53.

Saetersdal, G. (1957). On the fishing power of nylon gillnets. Contrib. E. 7. to joint meeting of ICNAF, ICES, and FAO, Lisbon, on selectivity of fishing gear (Mimeo).

Sechin, Yu. T. (1969a). [A mathematical model for the selectivity curve of a gillnet.] Rybn. Khoz. 45(a): 56-58. (In Russian). Translation: International Pacific Halibut Commission, Seattle, Washington, U.S.A.

Sechin, Yu. T. (1969b). [Experimental basis for the relative catch efficiency of gillnets.] Rybn. Khoz. 45(1): 48-49. (In Russian). Translation: US Dept. Comm., NTIS, Springfield, Va. No. TT-69.590000.

**Steinberg, R. (1964). Monofilament gillnets in freshwater experiment and practice. In: Modern fishing gear of the world. 2. Fishing News (Books) Ltd., London. p. 111-115.

Taguchi, K. (1961a). [On the suitable mesh size on salmon gillnets inferred from the relationship between body weight of salmon caught by gillnets and its mesh size.] Bull. Japan Soc. Sci. Fish. 27: 645-649. (In Japanese).

Taguchi, K. (1961b). [A trial to estimate the instantaneous rate of natural mortality of adult salmon (Oncorhynchus sp.) and the consideration of rationality of offshore fishing. I. For chum salmon (Oncorhynchus keta).] Bull. Jap. Soc. Sci. Fish. 27: 963-971. (In Japanese). (Translation: U.S. Bur. Comm. Fish. Biol. Lab., Seattle, Wash.).

Taguchi, K. (1961c). [A trial to estimate the instantaneous rate of natural mortality of adult salmon (Oncorhyrchus sp.) and the consideration of rationality of offshore fishing. II. For red salmon (Oncorhynchus nerka).] Bull. Jap. Soc. Sci. Fish. 27: 972-978. (In Japanese). (Translation: U.S. Bur. Comm. Fish. Biol. Lab., Seattle, Wash.)

Thompson, J.M. (1957). Biological studies of economic significance of the yellow-eye mullet, Aldmichetta forsteri (Cuvier and Valenciennes) (Mugilidae). Austr. J. Mar. Freshwater Res. 8(1): 1-13.

Thompson, W.F. (1945). Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. Int. Pac. Salmon Fish. Comm. Bull. 1: 1-175.

Thompson, R.B., C.J. Hunter and B.G. Patten. (1971). Studies of live and dead salmon that unmesh from gillnets. Int. North Pac. Fish. Comm. Ann. Rept. 1969: 108-112.

Todd, I.S. and P.A. Larkin. (1971). Gillnet selectivity on sockeye (Oncorhynchus nerka) and pink salmon (O. gorbuscha) of the Skeena River system, British Columbia. J. Fish. Res. Bd. Can. 28: 821-842.

Trent, L., and W.W. Hassler. (1968). Gillnet selection, migration size and age composition, sex ratio, harvest efficiency, and management of striped bass in the Roanoke River, North Carolina. Chesapeake Sci. 4: 217-232.

Treschev, A. (1963). On the selectivity of trawls and drift nets. ICNAF Spec. Pub. 5: 218-221.

**von Brandt, A. (1955). The efficiency of drift nets. J. du Conseil. (ICES). 22(1): 8-16.

von Olsten, J. (1935). Logically justified deductions concerning the Great Lakes fishery exploded by scientific research. Trans. Amer. Fish. Soc., 65: 71-75.

Ueno, M., S. Mishima, and K. Shimakazi. (1965). [On the falling and escapting of the salmon from the gillnet.] Bull. Fac. Fish. Hokkaido Univ. 40: 71-77. (In Japanese). Not seen in original.

**Washington, P. (1973). Comparison of salmon catches in mono- and multi-filament gillnets. Mar. Fish. Res. 35: 13-17.

Wydoski, R.S. and D.R. Wolfert. (1968). An improved girthometer for studies of gillnet selectivity. Prog. Fish Cult. 30(1): 62-64.

Yamamoto, S. and S. Mishima. (1962). [Study on the suitable mesh size for salmon gillnet with results of measurement of netted fish.] Bull. Fac. Fish. Hokkaido Univ. 13(2): 82-97 (In Japanese). Not seen in original.

Table 1. Data generated to test the selectivity analysis technique. Numbers under generated catch are calculated from the starting selectivities and population, the numbers in brackets are the Gram-Charlier smoothed series

Total Length (cm)	Starting Population Distribution	Starting Selectivity 1 %	Starting Selectivity 2 %	Generated Catch 1	Generated Catch 2
10	1,000				
11	2,000				
12	4,000			(2)	
13	6,000	0.4		23(22)	
14	6,075	2.9		174(175)	
15	6,125	13.5		829(833)	(2)
16	6,250	41	0.8	2563(2540)	52(30)
17	6,500	80	3	5206(5160)	214(194)
18	7,000	*100*	10	7000(7101)	711(783)
19	8,000	80	24	6408(6514)	1948(2150)
20	10,000	41	46	4100(3818)	4549(4183)
21	8,948	13.5	66	1211(1342)	5922(5900)
22	8,007	2.9	*75*	229(251)	6005(6146)
23	7,165	0.4	66	28(15)	4742(4818)
24	6,411		46		2916(2899)
25	5,737		24		1397(1363)
26	5,133		10		521(506)
27	4,593		3		151(148)
28	4,110		0.8		34(34)
29	3,678				(6)
30	3,291				
31	2,945				
32	2,635				
33	2,235				
34	2,110				
35	1,888				
36	1,689	u = 18.0	22.0	18.20	21.75
37	1,512	SD = 1.5	2.0	1.51	1.86
38	1,353	common length		common length	
39	1,210	20.2		19.9	
40	1,083				

Table 2. The selection ogives estimated from the generated catch curves of Table 1. The technique used was that described in the text.

Total Length (cm)	Starting Population (Table 1)	Selection Curve 1 Starting Generated	Selection Curve 1 Estimated	Selection Curve 2 Starting Generated	Selection Curve 2 Estimated	Estimated Mean Population
13	6,000	0.4	0.4			
14	6,075	2.9	2.9			
15	6,125	13.5	13.5			6,126†
16	6,250	41	41	0.8	0.8	6,234†
17	6,500	80	80	3	3.3	6,502†
18	7,000	100	100	10	10.4	6,915
19	8,000	80	80	24	26	7,828
20	10,000	41	41	45.5	48	9,740
21	8,948	13.5	13.5	66	69	8,756
22	8,007	2.9	2.9	75	77	7,817†
23	7,165	0.4	0.4	66	66	7,228†
24	6,411			45.5	43	6,770†
25	5,737			24	22	6,426†
26	5,133			10	8.4	6,426†
27	4,593			3	2.5	
28	4,110			0.8	0.6	

Starting population
Rate of Decline* 20+cm = 0.099

Estimated population
Rate of Decline* 20+cm= 0.098

* Rate of decline (mortality) in this case assumes a contant decline or mortality by size.

† These values are calculated from only one net as population estimates calculated from selectivities of less than 10% are not included.

Table 3. Four moments of the catch curves (smoothed by Graham-Charlier series) for Pacific salmon (Peterson, 1954).

Net (mm)	Catch (date)	Total Number	Mean (cm)	Standard Deviation	Skewness	Kurtosis
140	1947	318	59.5	3.1	0.44	2.7
140	1948	654	58.1	2.5	0.93	6.9
140	combined*	989	58.4	3.0	0.91	4.6
152	1947	626	61.5	2.9	0.49	3.2
152	1948	497	60.5	2.6	0.97	5.4
152	combined*	1123	60.8	2.9	0.69	3.7
165	1947	446	64.0	2.8	0.05	3.1
165	1948	279	63.2	3.0	0.23	3.5
165	combined*	725	63.3	2.9	0.03	3.2

* data for combined years taken from Holt (1963)

Table 4. Four moments of the salmon selection curves for Pacific salmon

Net (mm)	Analysis & Date	Mean (cm)	Standard Deviation	Skewness	Kurtosis
140	1947 - this study	59.2	3.2	0.47	3.0
140	1948 - this study	58.2	3.2	0.20	2.5
140	combined - Holt	56.8	5.7	0.00	3.0
152	1947 - this study	61.3	2.9	0.47	3.2
152	1948 - this study	62.1	3.4	0.54	2.4
152	combined - Holt	62.5	6.6	0.00	3.0
165	1947 - this study	63.9	2.9	0.05	2.9
165	1948 - this study	64.4	2.6	-0.37	3.4
165	combined - Holt	67.4	5.4	0.00	3.0

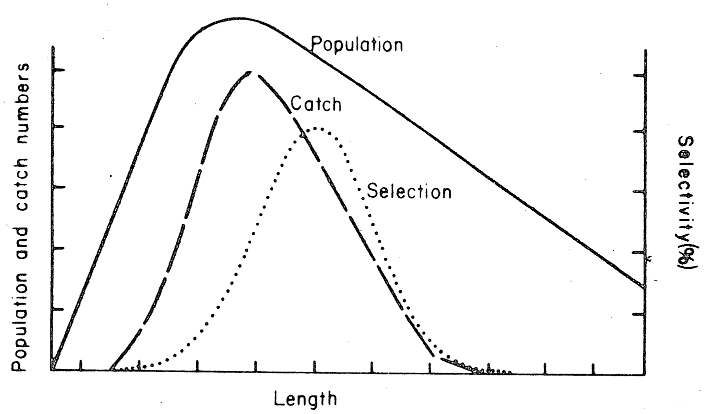

Figure 1. The three curves involved in any gillnet selectivity study. The catch is known and the selectivity and population are both unknowns to be calculated.

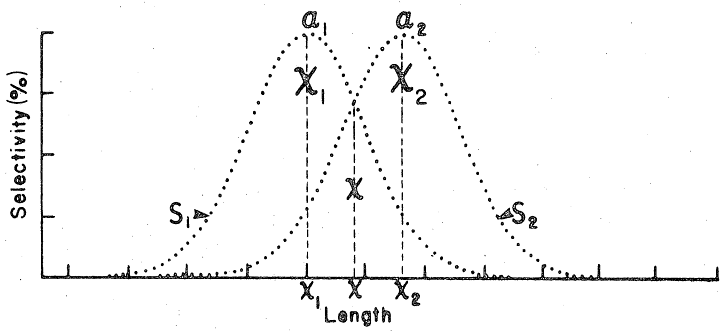

Figure 2. Hypothetical selection ogives S_1 and S_2 with modal values X_1 and X_2 and mesh sizes a_1 and a_2 having a common point X.

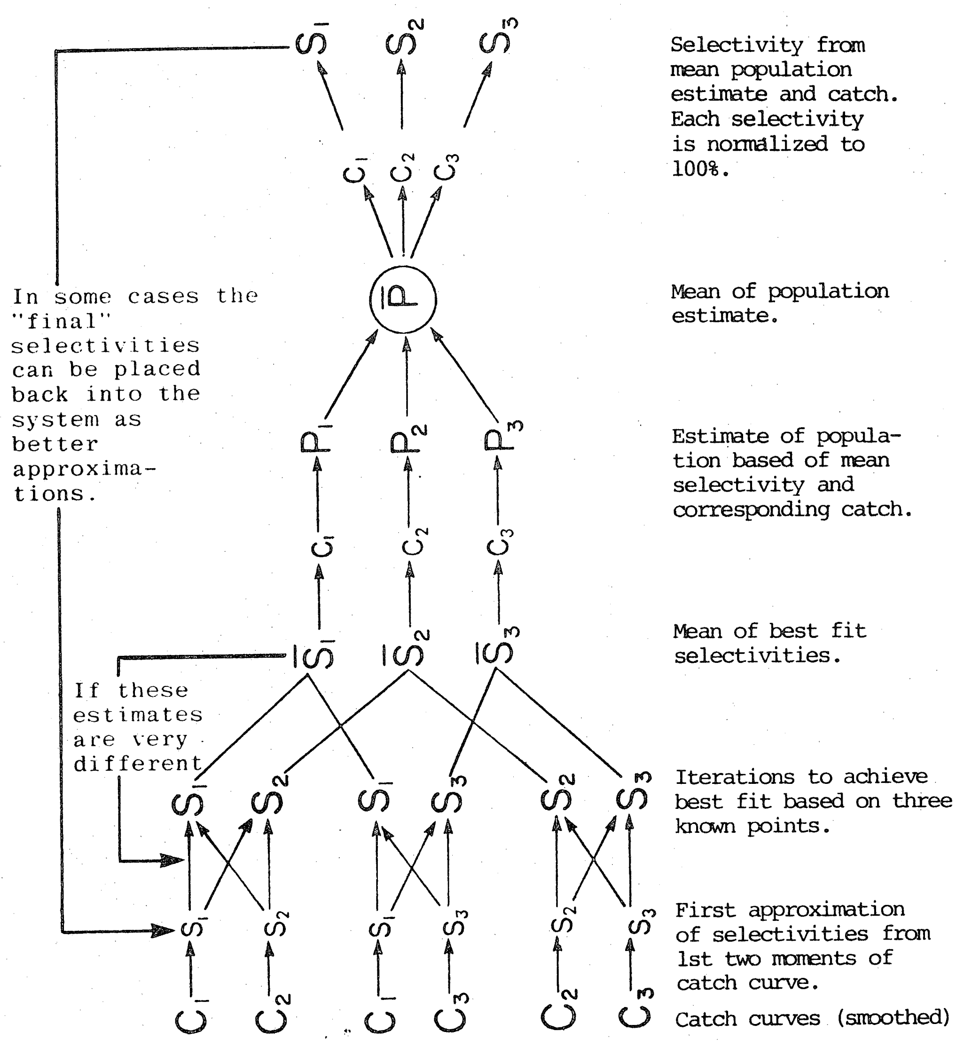

Figure 3. Flowchart of process used in calculating selectivities of three or more gillnets with overlapping catch curves.

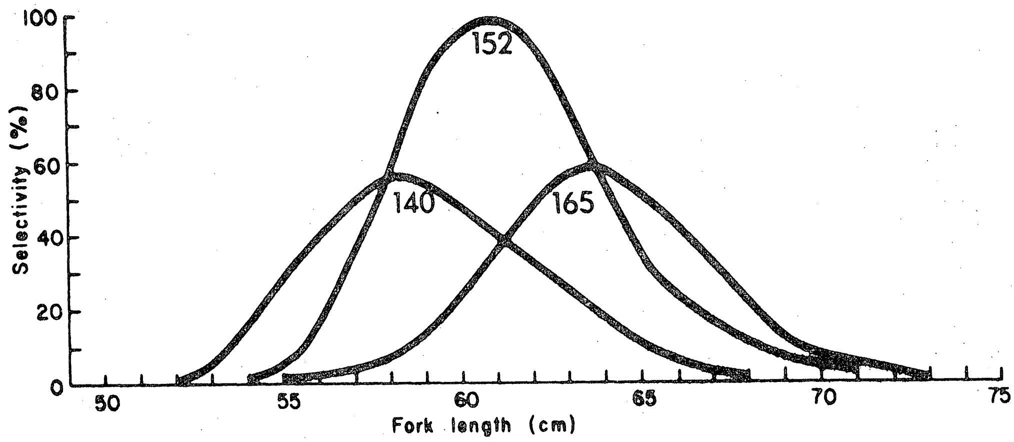

Figure 4. The relative fishery efficiency of the 140, 152, and 165 mm gillnets from the 1947 catch of Pacific salmon (Peterson, 1954).

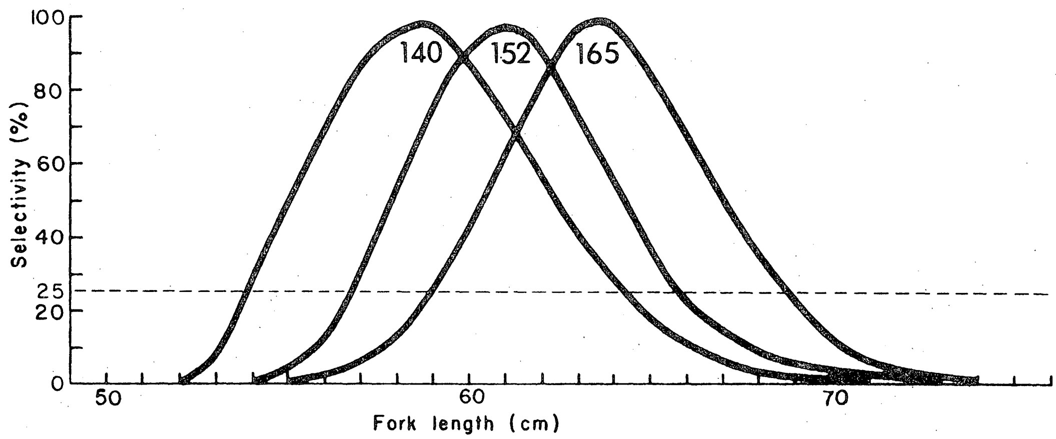

Figure 5. The selectivity of the 140, 152, and 165 mm gillnets from the 1947 catch of Pacific salmon (Peterson, 1954). The modal points are 58.8, 61, 63.8 cm respectively and the selection ranges are 10.6, 9.4, and 10.0 respectively.

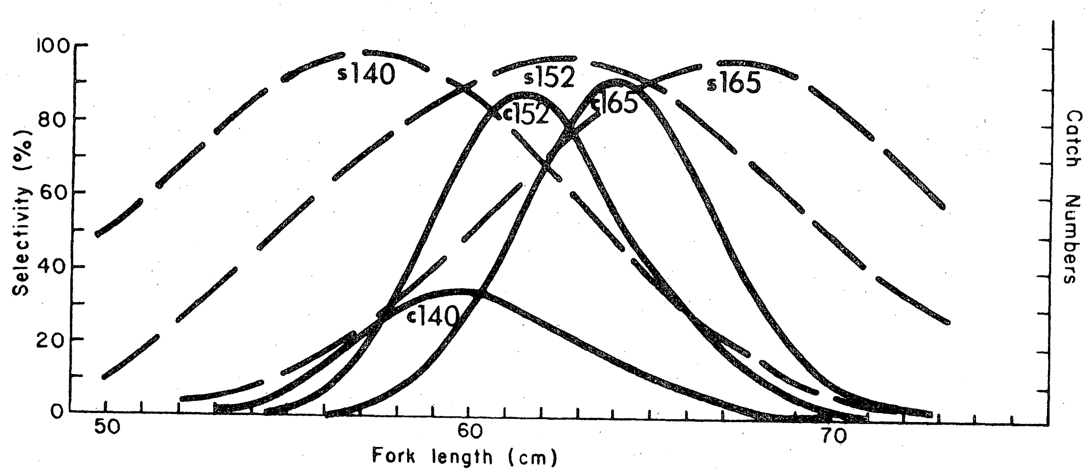

Figure 6. Selecton curves (S) proposed by Holt (1963) for the 1947 and 1948 catches (C) combined of Pacific salmon (Peterson, 1954).

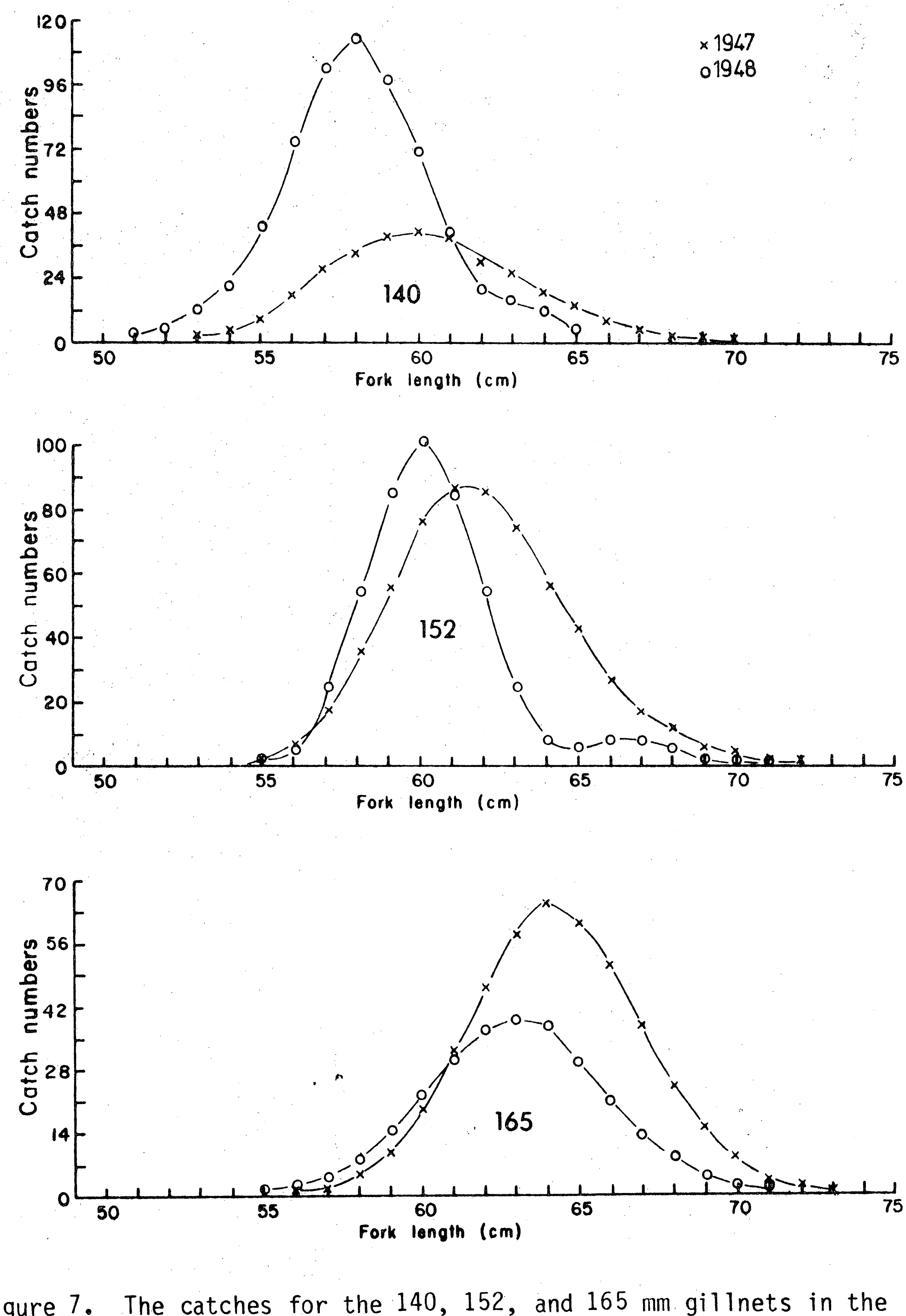

Figure 7. The catches for the 140, 152, and 165 mm gillnets in the years 1947 and 1948 for Pacific salmon (Peterson, 1954).

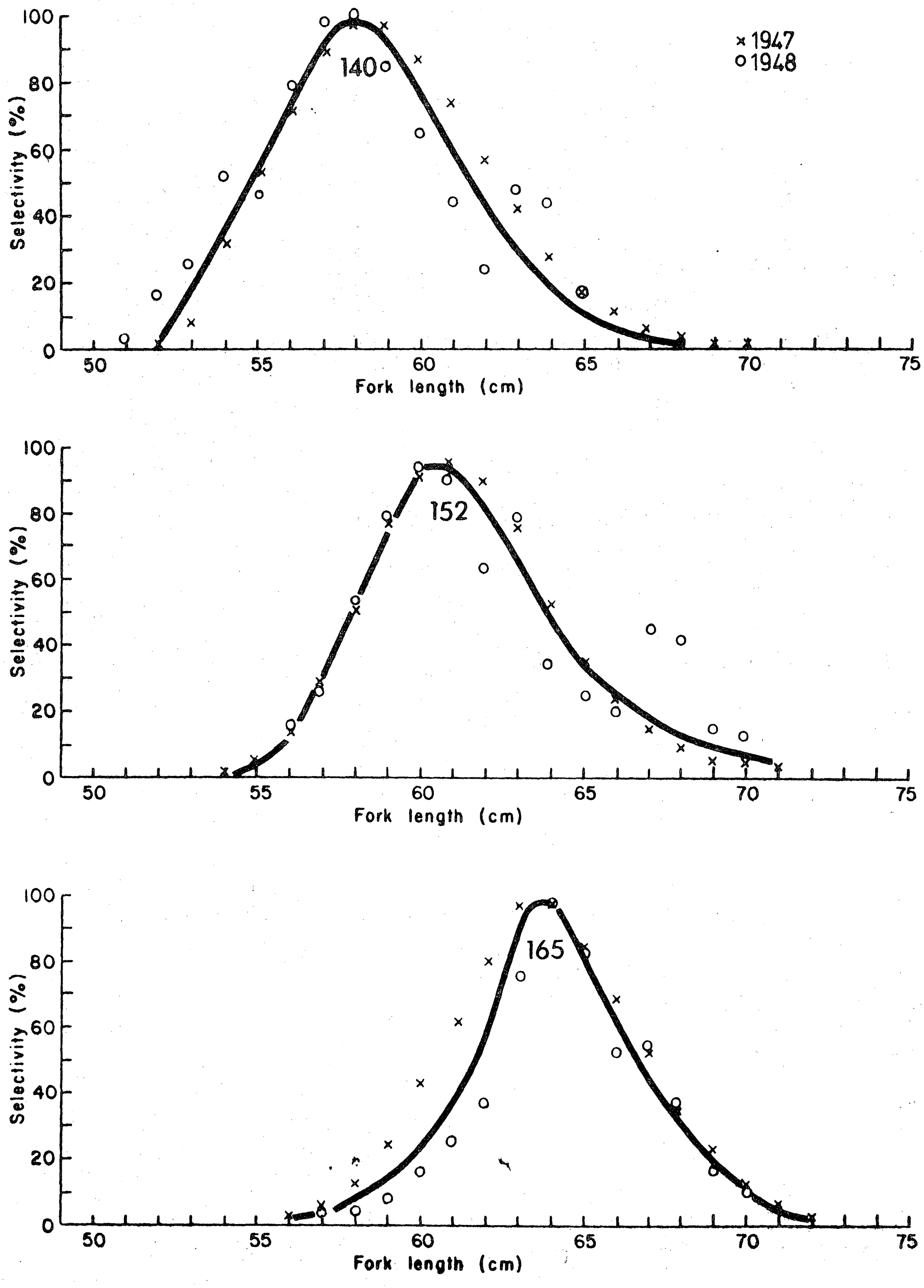

Figure 8. The composite selectivities for Pacific salmon in 140, 152, and 165 mm gillnets estimated from 1947 (x) and 1948 (o) data (Peterson, 1954).

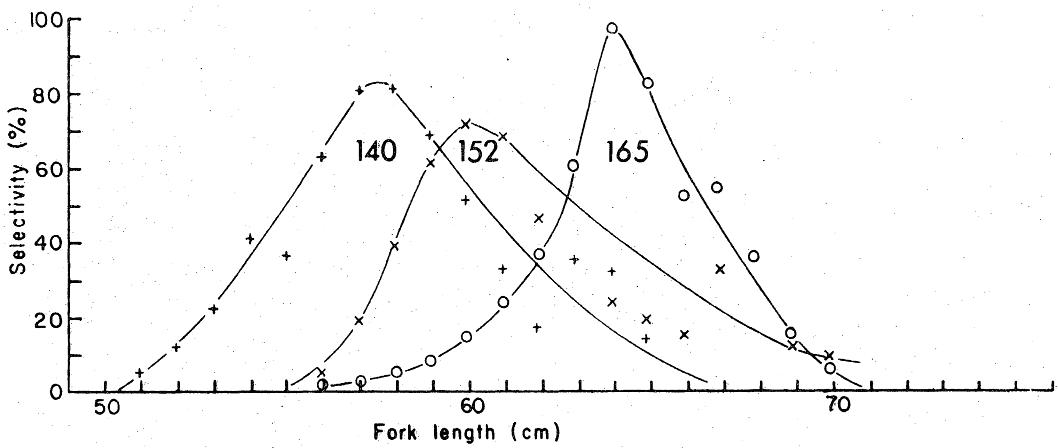

Figure 9. The relative fishery efficiency of the 140, 152, and 165 mm gillnets from the 1948 catch of Pacific salmon (Peterson, 1954).

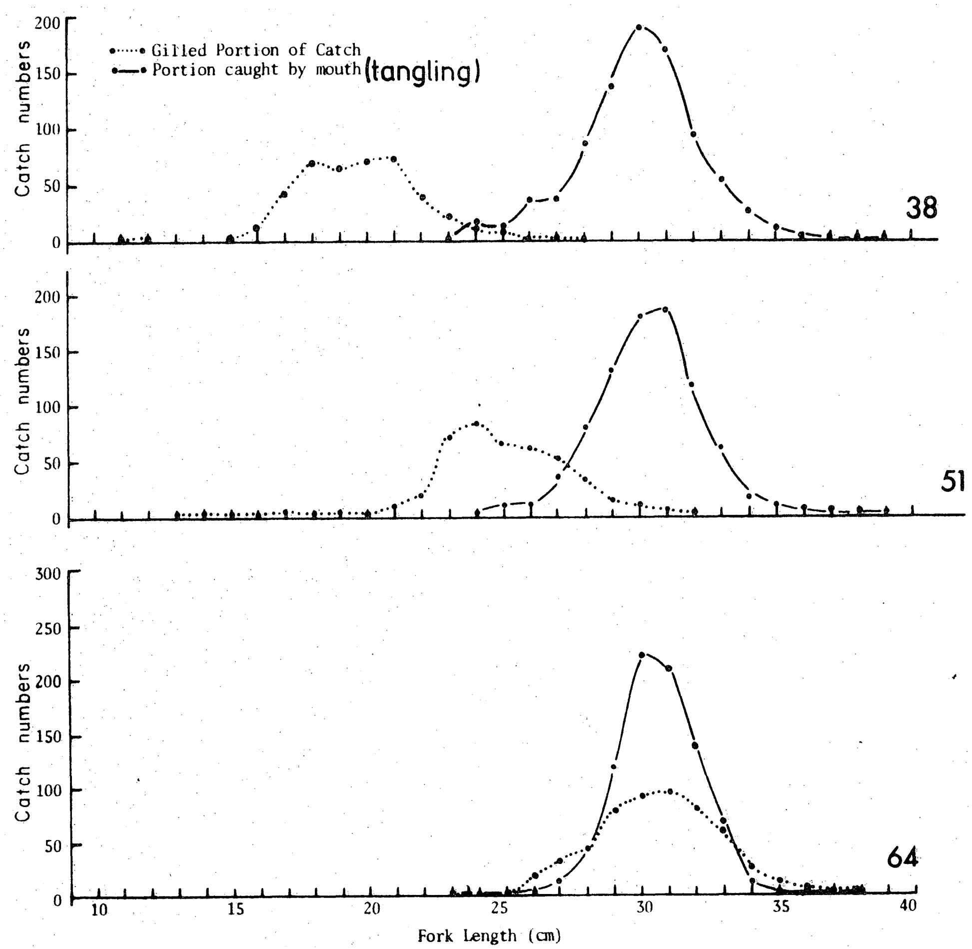

Figure 10. The 1963 catch of Arctic char (Hunter, 1970) for the 38, 51, and 64 mm gillnets. Each biomodal catch has been separated by the computer program (NORMSEP) into its component distributions - assumed to represent the gilled and tangled portions of the catch.

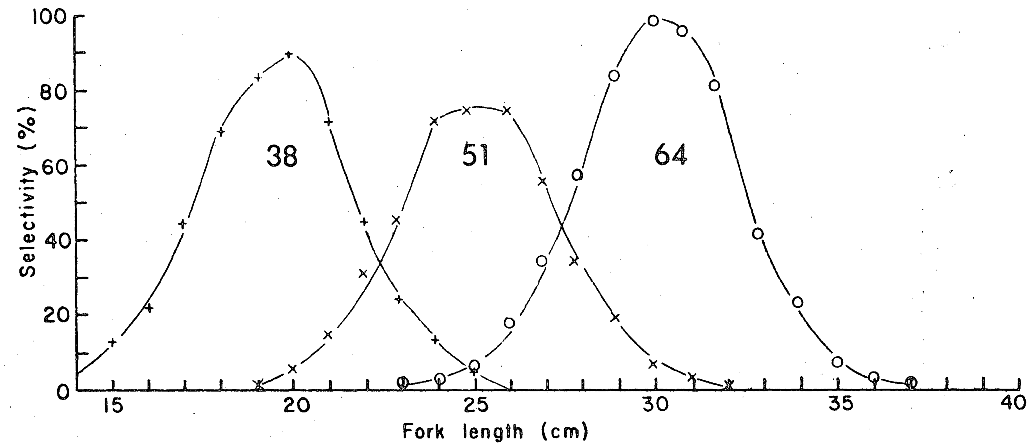

Figure 11. The relative fishery efficiency for the 1963 catch of Arctic char (Hunter, 1970) for 38, 51 and 64 mm gillnets.

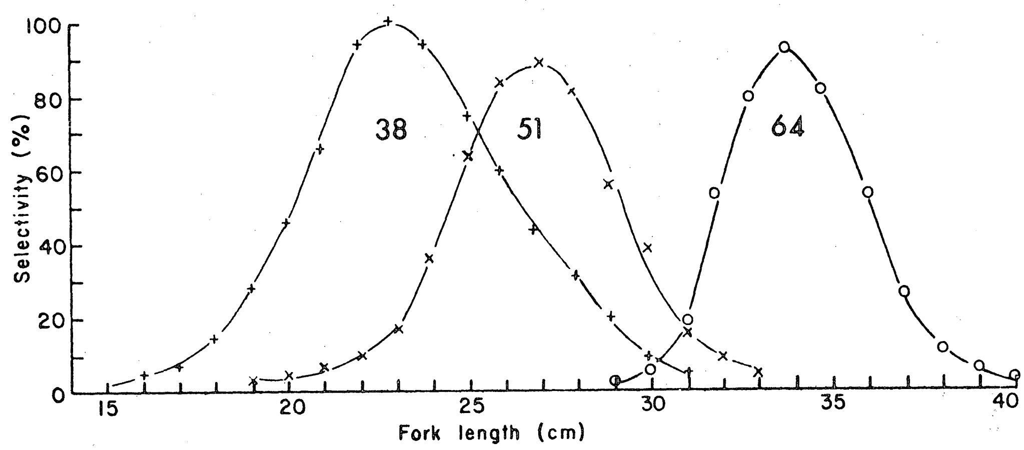

Figure 12. The relative fishery efficiency for the 1964 catch of Arctic char (Hunter, 1970) for 38, 51 and 64 mm gillnets.

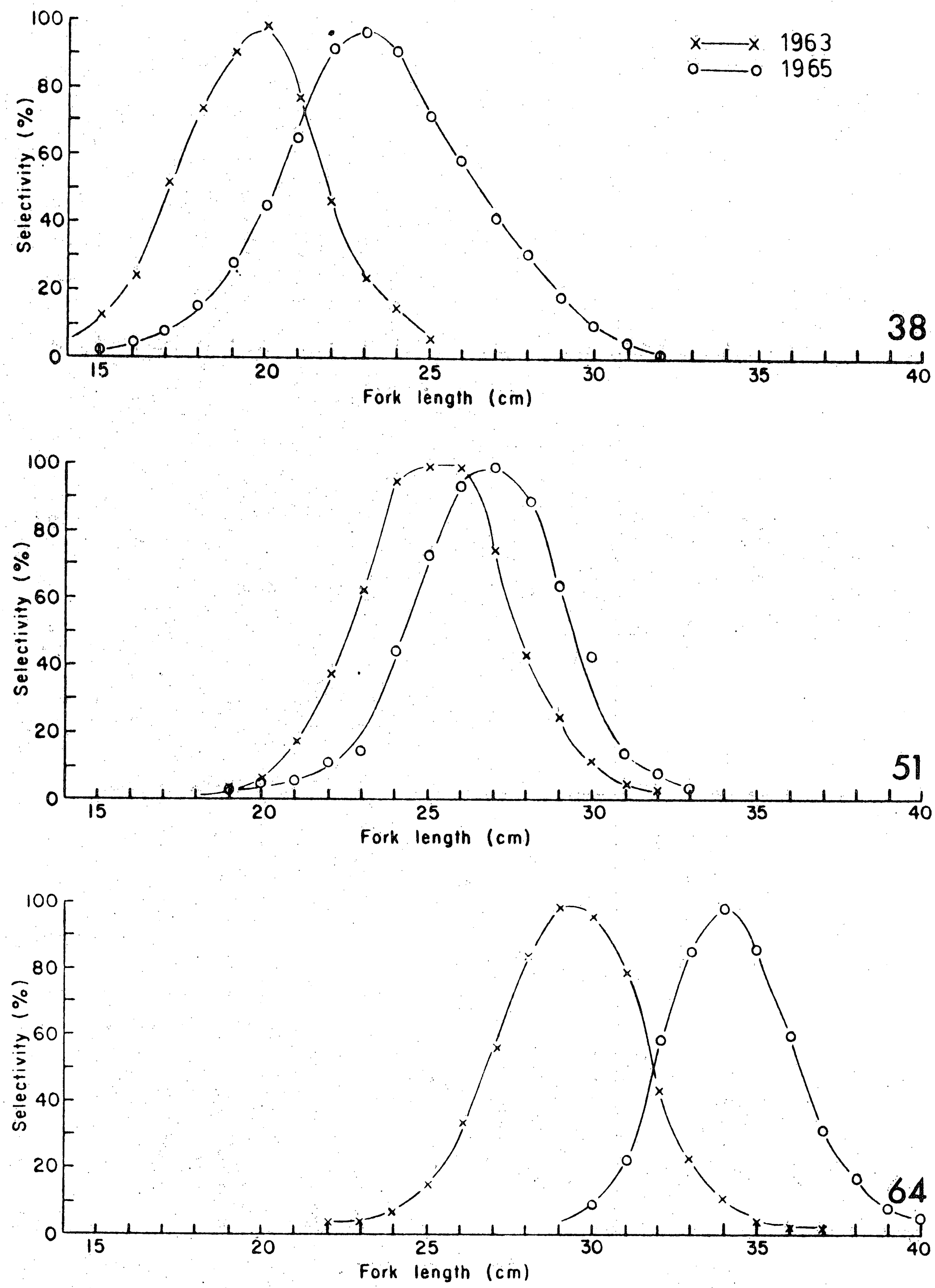

Figure 13. The selectivity of Arctic char from 38, 51, and 64 mm gillnets in 1963 and 1965.

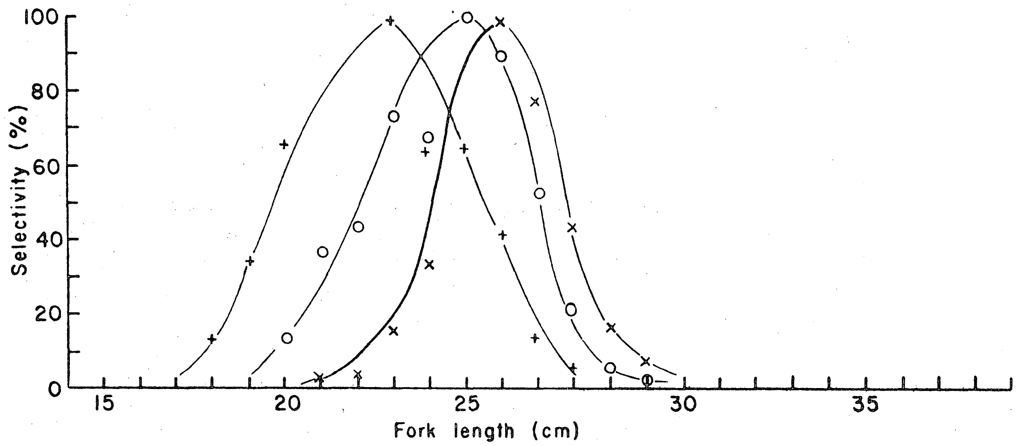

Figure 14. Selectivity of herring (Olsen, 1959) from 59.7(+), 65.1(o), and 72.5(x) mm gillnets.

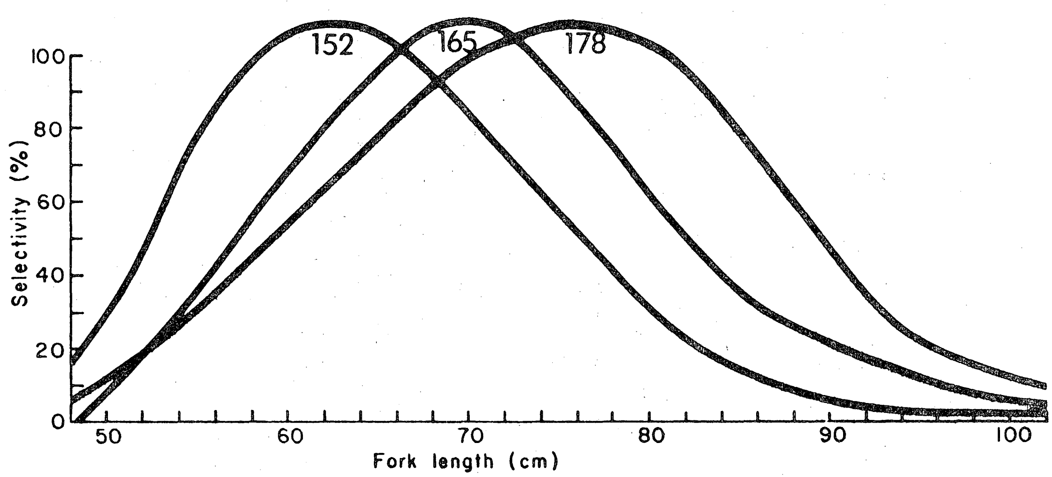

Figure 15. Selection curves for Atlantic cod (Gadus morhua) for 3 locations and 2 years data combined from 152, 165, and 178 mm gillnets.

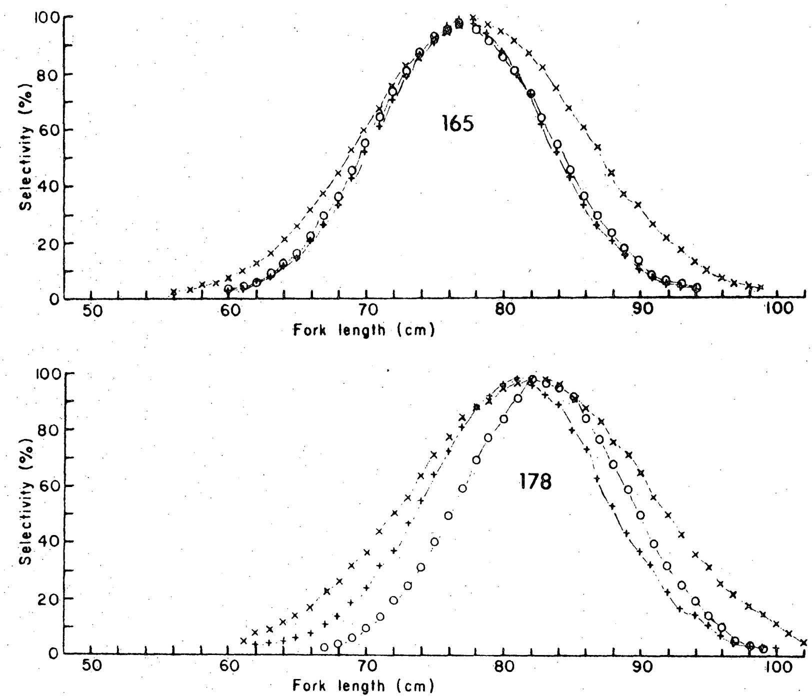

Figure 16. Selectivity of Atlantic cod (Gadus morhua). Normal estimates for data from St. Mary's Bay, 1964-(x), 1965-(o), Placentia Bay, 1965-(+). All three samples composed of fifteen 50 fathom sets during a 1 week period.

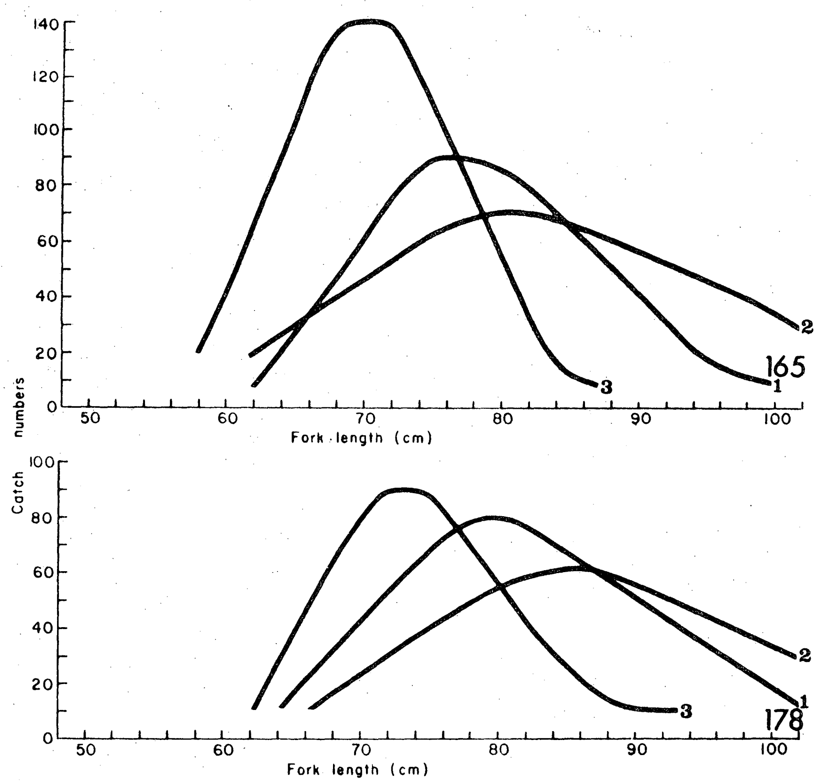

Figure 17. Atlantic cod (Gadus morhua) catch data smoothed by Graham Charlier-series St. Mary's Bay, 1964-(1), 1965-(2): Placentia Bay, 1965-(3). All three samples composed of fifteen 50 fathom sets during a one week period.

APPENDIX I. CATCH DATA FROM VARIOUS SOURCES USED IN THIS PAPER

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

Fork Length (cm)	Mesh Size (mm) 140		152		165	
Year	1947	1948	1947	1948	1947	1948
50						
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

App. Table 2. Pacific salmon (*Salmo gorbuscha*) (Ishida, 1962a). Unadjusted samples with correction figures below.

Fork Length (cm)	Mesh Size (mm) 96	106	121
35			
36			
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*	4.168	3.152	1.215

(multiply each of the length frequencies by its correction factor to make each equal with respect effort).

* the correction factor includes a correction for both effort and the percent of fish sampled from the true catch.

App. Table 3. Arctic char (Salvelinus alpinus) (Hunter, 1970). Raw data, the numbers in brackets after each length frequency indicates those fish caught by gilling.

Fork Length (cm)	Mesh Size (mm) 38		51		64	
	Year 1963	1965	1963	1965	1963	1965
10					1	
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	1(2)	10(6)
38	1	7	1	5	2(1)	7(4)
39	1	1	1	1		4(3)
40	1					1
41		1		2		
42						
43						
44		1				
45		1				

App. Table 4. Herring (Clupea harengus) (Olsen, 1959). Raw data.

Total Length (cm)	Mesh Size (mm) 59.7	65.1	72.5
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
35.3	29	167	305
37.0	11	93	230
38.5	2	20	82
40.0		1	20
41.5			2

App. Table 5. Atlantic cod (Gadus morhua). The combined data (smoothed by Gram-Charlier Series) includes all locations combined (Placenta Bay, Conception Bay, and St. Mary's Bay) for 1964 and 1965 data. The two separate raw data series provided (14 sets each) are St. Mary's Bay (1964) and Placentia Bay (1965).

Fork Length (cm)	Mesh Size (mm) 152 Combined	165 Combined	165 S.M.B.	165 P.B.	178 Combined	178 S.M.B.	178 P.B.
46	1						
47	2						
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		5	7		
61	14	16		4	9		
62	15	19		11	11		
63	17	22	1	15	13		1
64	19	26	1	10	15		3
65	20	29	2	6	17	1	6
66	21	32	5	6	19	0	5
67	23	36	2	11	22	5	4
68	24	39	4	14	24	6	9
69	24	41	9	16	27	3	7
70	25	44	8	16	30	3	6
71	25	46	8	18	32	4	15
72	24	48	9	12	35	10	10
73	24	49	6	10	37	8	10
74	23	50	12	13	39	9	8
75	22	50	6	7	41	3	9
76	21	49	9	14	43	9	4
77	19	48	5	12	44	8	7
78	18	47	8	4	45	5	7
79	16	45	14	46	46	7	5
80	15	43	12	7	46	12	8
81	13	41	10	3	46	10	7
82	12	38	4	3	46	7	2
83	10	36	10	4	45	8	2
84	9	33	7	3	44	6	2
85	8	30	7	1	43	6	3
86	7	28	6	1	41	7	2
87	6	25	3		39	6	3
88	5	23	3		37	5	1
89	4	21	2		35	5	2
90	4	19	0		33	5	2
91	3	17	2		31	4	1
92	3	16	3		28	2	2
93	2	15	6		26	1	1
94	2	13	6		24	2	
95	2	12	4		22	2	
96	2	11	3		20	5	
97	2	10	2		18	3	
98	1	10	2		16	5	
99	1	9	1		14	4	
100	1	8			13	2	
101		7			11	5	
102		7			10	2	
103		6			9	0	
104		5			7	2	
105		5			7	2	