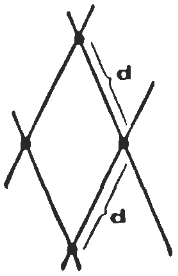
6. GEAR SELECTIVITY

In several methods discussed in Chapter 4 it appeared that the complete length ranges (or age ranges) of fish or shellfish are not always under full exploitation. Most fishing gears, for example trawl gears, are selective for the larger sizes, while some gears (gill nets) are selective for a certain length range only, thus excluding the capture of very small and very large fish. This property of fishing gear is called "*gear selectivity*". It needs to be taken into account when we want to estimate the real size (or age) composition of the fish in the fishing area. At the same time, it is an important tool for fisheries managers who, by regulating the minimum mesh sizes of a fishing fleet, can more or less determine the minimum sizes of the target species of certain fisheries. Gear selectivity is strongly related to the estimation of the total mortality, Z, the analysis of trawl survey data vis-à-vis commercial fisheries and predictions of future yields (Thompson and Bell, see Chapter 8). A recent special issue of Fisheries Research provides a useful overview of fishing gear selectivity (MacLennan, 1992).

Since it is conceptually easier, we will first discuss the selectivity of trawl gear and then that of gill nets and similar gears.

6.1 ESTIMATION OF TRAWL NET SELECTION

A full description of a bottom trawl net is given in Section 13.1. The fine- meshed end of the net where the catch is collected is called the codend. It appears that the "*mesh size*" of the codend determines, to a large extent, the selectivity of trawl gear.



The "*mesh size*" is usually defined as the length of the "stretched" whole mesh. The mesh size of the netting shown here is 2*d, where d is the length between two knots.

For a detailed discussion of definitions of mesh size and mesh measuring techniques, see FAO (1978b).

It is possible to determine the amount and sizes of fish that escape through the meshes of the codend by covering the codend with a much larger bag with much finer meshes. The idea behind the experiment is illustrated in Fig. 6.1.1. The selectivity of the gear can then be determined by comparing the sizes of the fish in the codend with those of the fish in the cover. The "*covered codend method*" has been described, among others, by Pope *et al.*, 1975, and Jones, 1976.

Example 21: Covered codend experiment, *Nemipterus japonicus*, South China Sea

The experiment deals with the threadfin bream, *Nemipterus japonicus*, which is caught with a trawl net with a codend mesh size of 4 cm and a cover of much smaller meshes. The typical catch of one trawl haul is given in Table 6.1.1 in the form of two length-frequency tables for the codend and the cover respectively (columns B and C). The fraction of the total catch which was retained in the codend can then be calculated. It is presented as the fraction (e.g. 1/7 = 0.14) retained of each length group. When the fraction retained is plotted against the mid-length of the corresponding length group, it appears that the points are following a sigmoid curve, which reaches 1.00 (100% retention) at a certain length and which approaches 0.00 (0% retention) at a certain small length. This sigmoid curve is called the "*gear selection ogive*". It resembles a cumulative normal distribution.

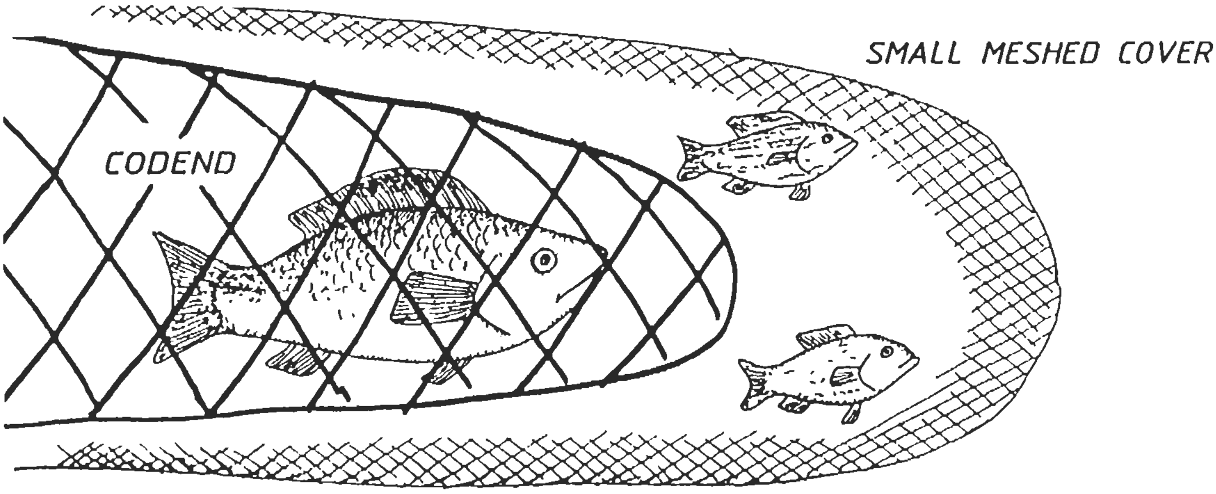


Fig. 6.1.1 Covered codend experiment

The easiest mathematical expression to describe the gear selection ogive is the so-called "*logistic curve*":

$$S_L = \frac{1}{1 + \exp(S1 - S2*L)} \qquad (6.1.1)$$

where $S_L = \frac{\text{number of fish of length L in the codend}}{\text{number of fish of length L in the codend and in the cover}}$

and L is the length interval midpoint (mid-length). S1 and S2 are constants (Paloheimo and Cadima, 1964; Kimura, 1977, and Hoydal *et al.*, 1982).

Eq. 6.1.1 can be rewritten as

$$\ln(1/S_L - 1) = S1 - S2*L \qquad (6.1.2)$$

which represents a straight line, where S1 = a and S2 = b. So the observations of the fractions retained (column E) can be used to determine the logistic curve that fits to the observations. The estimated logistic curve ($S_L$est) can then be used to calculate the fractions that correspond to the curve (column H in Table 6.1.1).

It is seen that if $S_L = 0$ or if $S_L = 1$ the expression in Eq. 6.1.2 is not defined.

By applying a few algebraic manipulations it follows that there is a one-to-one correspondence between S1 and S2 and L25%, L50% and L75%, the lengths at which respectively 25%, 50% and 75% of the fish are retained in the codend. The length range from L25% to L75%, which is symmetrical around L50%, is called the "*selection range*" (see Fig. 6.4.3.1). The formulas for calculating L25%, L50% and L75% are

$$L25\% = (S1 - \ln 3)/S2 \qquad (6.1.3)$$

$$L50\% = S1/S2 \qquad (6.1.4)$$

$$L75\% = (S1 + \ln 3)/S2 \qquad (6.1.5)$$

S1 and S2 can be derived from L75% and L50% using the following formulas:

$$S1 = L50\%*\ln(3)/(L75\%-L50\%) \tag{6.1.6}$$

$$S2 = \ln(3)/(L75\%-L50\%) = S1/L50\% \tag{6.1.7}$$

The regression analysis is done over a length range between zero (0) and full (1) retention, thus excluding those length intervals where no or full retention was obtained and all values beyond those points, even if they are between 0 and 1.

For *Nemipterus japonicus* the regression gives the following results, as presented in Table 6.1.1 and Fig. 6.1.2:

$$a = S1 = 9.4875 \quad \text{and} \quad -b = S2 = 0.7193$$

which gives

$$S_Lest = 1/(1 + \exp(9.4875 - 0.7193*L))$$

$$L25\% = (9.4875 - \ln 3)/0.7193 = 11.7 \text{ cm}$$
$$L50\% = 9.4875/0.7193 = 13.2 \text{ cm}$$
$$L75\% = (9.4875 + \ln 3)/0.7193 = 14.7 \text{ cm}$$

As the probability that a fish will escape through a mesh depends on its shape, and in particular on its body depth compared to the mesh size, it is natural to assume proportionality between d50% (the body depth at which 50% of the fish are retained) and the mesh size:

$$d50\% = A*(\text{mesh size}) \tag{6.1.8}$$

where A is a constant. As body depth is approximately proportional to body length (cf. Section 2.4) Eq. 6.1.8 implies that a similar expression holds for the length of a fish:

$$L50\% = SF*(\text{mesh size}) \tag{6.1.9}$$

where SF is called the "*selection factor*".

Table 6.1.1 **Estimation of gear selection ogive for *Nemipterus japonicus* from a covered codend experiment (from Jones, 1976, cf. Fig. 6.1.2)**

A	B	C	D	E	F	G	H
length interval L1-L2	number in codend	number in cover	total number	fraction retained S_Lobs	$\ln(1/S_L-1)$ (y)	midlength (L1+L2)/2 (x)	fraction retained S_Lest
9-10	0	1	1	0	-	-	-
10-11	1	6	7	0.14	1.82	10.5	0.13
11-12	2	7	9	0.22	1.27	11.5	0.23
12-13	2	4	6	0.33	0.71	12.5	0.38
13-14	7	5	12	0.58	-0.32	13.5	0.56
14-15	30	13	43	0.70	-0.85	14.5	0.72
15-16	61	8	69	0.88	-1.99	15.4	0.84
16-17	27	3	30	0.90	-2.20	16.5	0.91
17-18	7	0	7	1.00	-	17.5	0.96
18-19	4	1	5	0.80	-	18.5	0.98

intercept = a = S1 = 9.4875 -slope = -b = S2 = 0.7193
L50% = S1/S2 = 13.2 cm L75% = (S1 + ln 3)/S2 = 14.7 cm
$S_Lest = 1/(1 + \exp(9.4875 - 0.7193*L))$
(used to calculate the curve in Fig. 6.1.2)

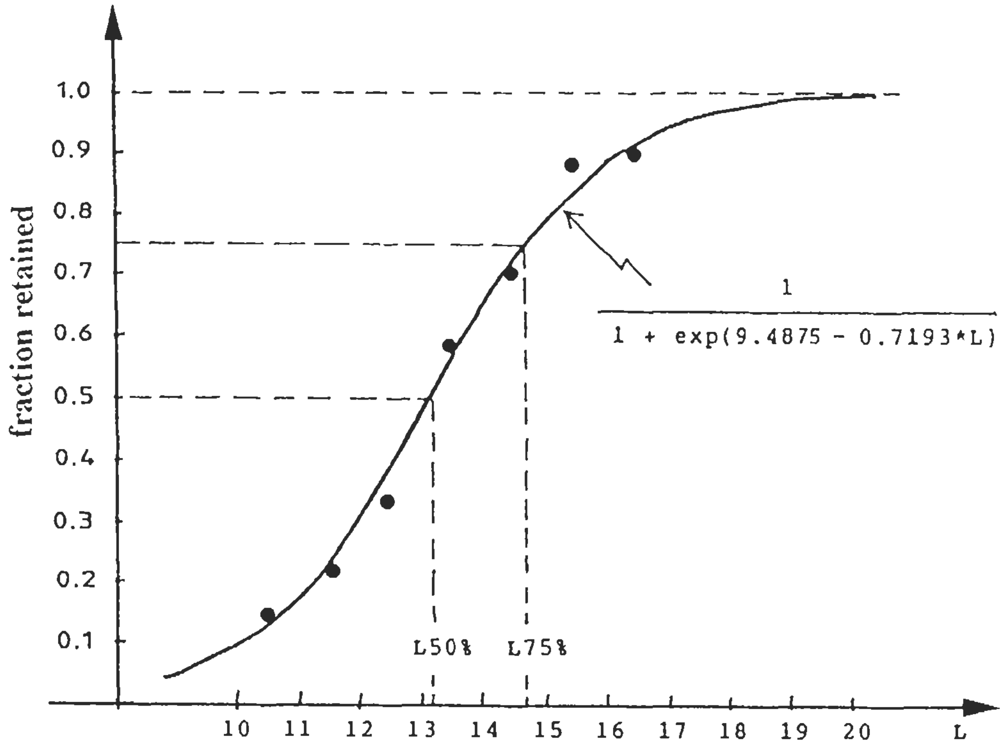


Fig. 6.1.2 **Gear selection ogive for *Nemipterus japonicus* caught by a trawl with a codend mesh size of 4 cm (from Jones, 1976)**

In the case of our example (Table 6.1.1) we found L50% = 13.2 cm for a mesh size of 4 cm. Thus, the selection factor is

```
SF = 13.2/4 = 3.3
```

This selection factor can now be used to determine L50% for different mesh sizes, for instance, L50% of *Nemipterus japonicus* when using meshes of 3 cm would be:

```
L50% = 3.3*3 = 9.9 cm.
```

Further applications of L50% and SF will be discussed in Chapter 8.

6.2 ESTIMATION OF GILL NET SELECTION

6.2.1 Symmetrical selection curves

Gill nets are usually long rectangular nets where the upper edge, the head rope has floats while the foot rope has sinkers. Often gill nets (drifting and set nets) are in the form of gangs of nets with different mesh sizes. For further descriptions of gill nets, see FAO (1978b), Nédélec (1982) or Karlsen and Bjarnason (1986).

The selection properties of gill nets are reviewed in Hamley (1975). Discussions on gill net selectivity can be found in, for example, Baranov (1948); McCombie and Fry (1960), Gulland and Harding (1961), Regier and Robson (1966), Hamley and Regier (1973) and Jensen (1986).

Gill nets are *"passive gears"*, i.e. the fish have to swim into the net to get caught. Theoretically, this implies that fish which move fast, have a larger probability of encounter with the gear than slow moving fish. Further it is known that large fish move faster than small fish of the same species. The swimming speed can be approximated by a constant times a power function of length:

$A*L^B$ where A and B are constants (Yates, 1983).

Rudstam, Magnuson and Tonn (1984) included swimming speed (with $B = 0.8$ for the cisco, *Coregonus artedii*, from Wisconsin, USA) into a model for gill net selection. They considered the selection as the product of two probabilities:

(selection) = (probability of encounter)*(probability of being caught given encounter)

We shall, however, only deal with the last factor, the probability of being caught given encounter.

For simple gill nets the selection curve has (unlike trawl selection) a descending slope on the right-hand side. Small fish can pass through the meshes as was the case for trawl nets, but large fish may also avoid being caught in a gill net, because their heads are so large that they cannot be "gilled". This is the simple theory behind gill net selection. The picture becomes somewhat more complicated when other ways by which the fish can get stuck in a gill net are also considered. Karlsen and Bjarnason (1986) distinguished four ways of getting caught as illustrated in Fig. 6.2.1.1:

a. Snagged, where the mesh is around the fish just behind the eye

b. Gilled, where the mesh is around the fish just behind the gill cover

c. Wedged, where the mesh is around the body as far as the dorsal fin

d. Entangled, where the fish is held in the net by teeth, maxillaries, fins or other projections, without necessarily penetrating the mesh.

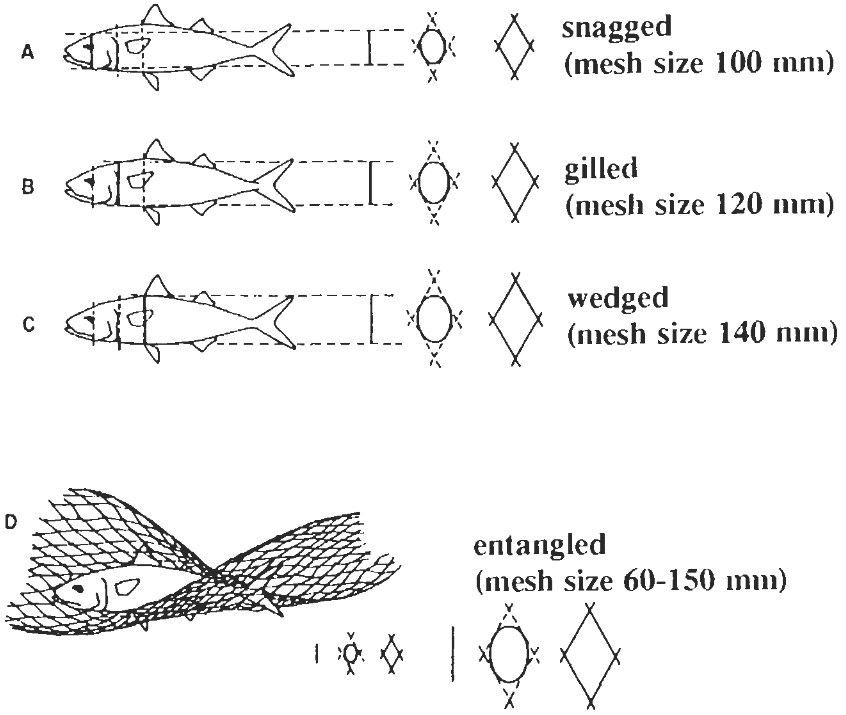


Fig. 6.2.1.1 Gill net selection (from Karlsen and Bjarnason, 1986)

Holt's model for two mesh sizes

For gilling and wedging Holt (1963) suggested a bell-shaped selection curve similar to the normal distribution (cf. Section 2.2 and Fig. 6.2.2.2). For these two types of getting stuck in a gill net we use the model:

$$S_L = \exp\left[-\frac{(L-Lm)^2}{2*s^2}\right] \qquad (6.2.1.1)$$

where Lm is the "*optimum length for being caught*" and s is the standard deviation of the normal distribution. The factor "n*dL/(s*√(2π)" which appears in the expression for a normal distribution (Eq. 2.2.1) is not used here. Omitting this factor, S_L becomes a fraction, i.e. $0 < S_L < = 1$.

Holt (1963) suggested an experiment to estimate Lm and s by using two gill nets with different mesh sizes, ma and mb. The two mesh sizes must be such that their selection curves overlap. The two nets are set to fish in the same area at the same time and the observations are numbers caught by length group. The assumptions behind this method are:

1. The optimum length Lm (the top of the bell-shaped selection curve) is proportional to the mesh size (Lm = SF*m, where SF is the selection factor, cf. Section 6.1)

2. The two selection curves have the same standard deviation

3. The two gill nets have the same fishing power. This includes that when set, they must have the same length and height and be made of the same material.

Example 22: Selection curves for tilapia in Lake Victoria

Table 6.2.1.2 shows an example of an experiment with two mesh sizes on *Tilapia esculenta* from Lake Victoria. The numbers caught, Ca, by length group for the smaller meshed gear (ma = 8.1 cm) and the corresponding numbers, Cb, for the larger meshed net (mb = 9.1 cm) are given. The parameters to be estimated by means of Holt's model (Eq. 6.2.1.1) are:

Lma: Optimum length for the smaller meshed net

Lmb: Optimum length for the larger meshed net

s: The common standard deviation

Input data for the analysis are the numbers caught by length group for each gear, Ca and Cb, and the two mesh sizes ma and mb. The mathematical derivations are lengthy and are bypassed here.

Step 1: Calculate the log ratios y = ln(Cb/Ca) for each length group (see Table 6.2.1.2). Only the lengths where the frequencies overlap can be used.

Step 2: Do a regression analysis of the log ratios (y = ln(Cb/Ca)) against the interval midpoint for fish length (x = L), and determine a and b:

$$\ln(Cb/Ca) = a + b*L \qquad (6.2.1.2)$$

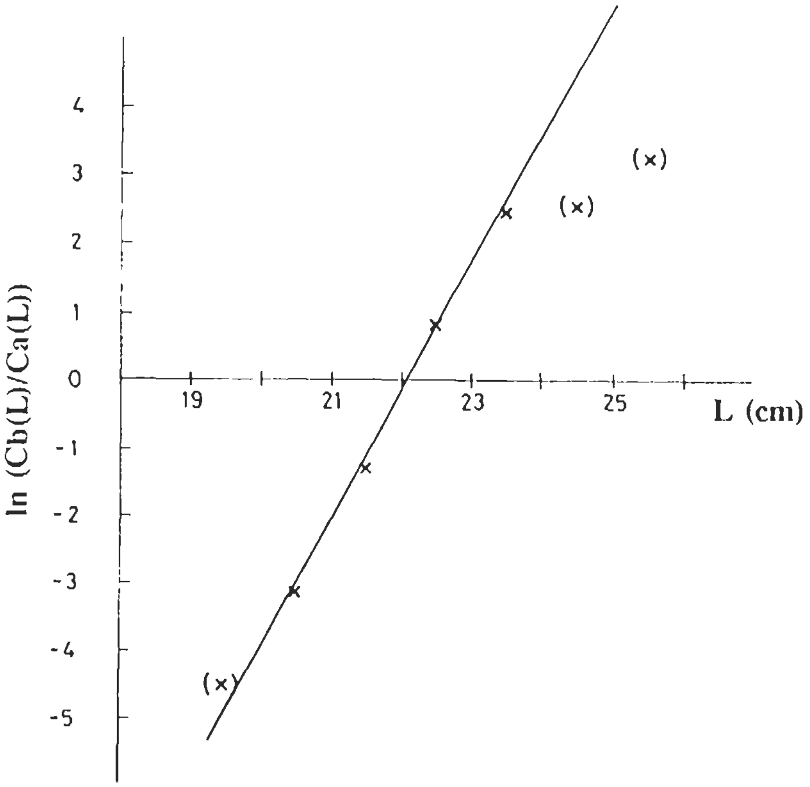


Fig. 6.2.1.1a ***Tilapia esculenta*. The regression of ln(Cb(L)/Ca(L)) on fish length (Eq. 6.2.1.2)**

Step 3: The results are finally obtained by inserting the values of a, b, ma and mb in the following expressions.

The selection factor is estimated from

$$SF = \frac{-2*a}{b*(ma+mb)} \qquad (6.2.1.6)$$

The optimum fish lengths for the small and large mesh size are respectively Lma = SF*ma and Lmb = SF*mb.

The common standard deviation s is determined by the variance

$$s^2 = \frac{-2*a*(mb-ma)}{b^2*(ma+mb)} = SF*\frac{mb-ma}{b} \qquad (6.2.1.6a)$$

Step 4: Points on the selection curves are found by inserting values of L into Eq. 6.2.1.1:

$$Sa(L) = \exp\left[-\frac{(L-Lma)^2}{2*s^2}\right]$$

$$Sb(L) = \exp\left[-\frac{(L-Lmb)^2}{2*s^2}\right]$$

Step 5: From these and the catches Ca(L) and Cb(L) an index of the numbers in the population is estimated for each mesh size:

$$Na(L) = Ca(L)/Sa(L) \qquad (6.2.1.6b)$$
$$Nb(L) = Cb(L)/Sb(L)$$

Table 6.2.1.2 **Estimation of gill net selection curves for *Tilapia esculenta*, Lake Victoria (data from Garrod, 1961)**

length interval midpoint L	number caught		$\ln \frac{Cb_L}{Ca_L}$	selection		population estimates	
(x)	ma = 8.1 Ca_L	mb = 9.1 Cb_L	(y)	Sa_L	Sb_L	Na_L	Nb_L
18.5	7	0	-	0.1333	0.0001	52	-
19.5	90	1	-4.500	0.5164	0.0036	174	(282)
20.5	199	9	-3.096	0.9583	0.0443	208	203
21.5	182	53	-1.234	0.8519	0.2611	214	203
22.5	119	290	0.891	0.3627	0.7373	328	393
23.5	29	357	2.510	0.0739	0.9970	392	358
24.5	17	225	2.583	0.0072	0.6458	(2492)	348
25.5	3	82	3.308	0.0003	0.2003	(8881)	409
26.5	0	19	-	0.0000	0.0304		(638)
27.5	0	10	-	0.0000	0.0021		(4721)

$\ln (Cb_L/Ca_L) = a + b*L;\ a = -41.907;\ b = 1.894$

$$SF = \frac{-2*a}{b*(ma+mb)} = \frac{-2*(-41.907)}{1.894*(8.1+9.1)} = 2.573$$

$Lma = SF*ma = 20.84$ cm
$Lmb = SF*mb = 23.41$ cm

$$s^2 = SF*\frac{mb-ma}{b} = 2.573*\frac{9.1-8.1}{1.894} = 1.3584$$

$s = 1.1655$

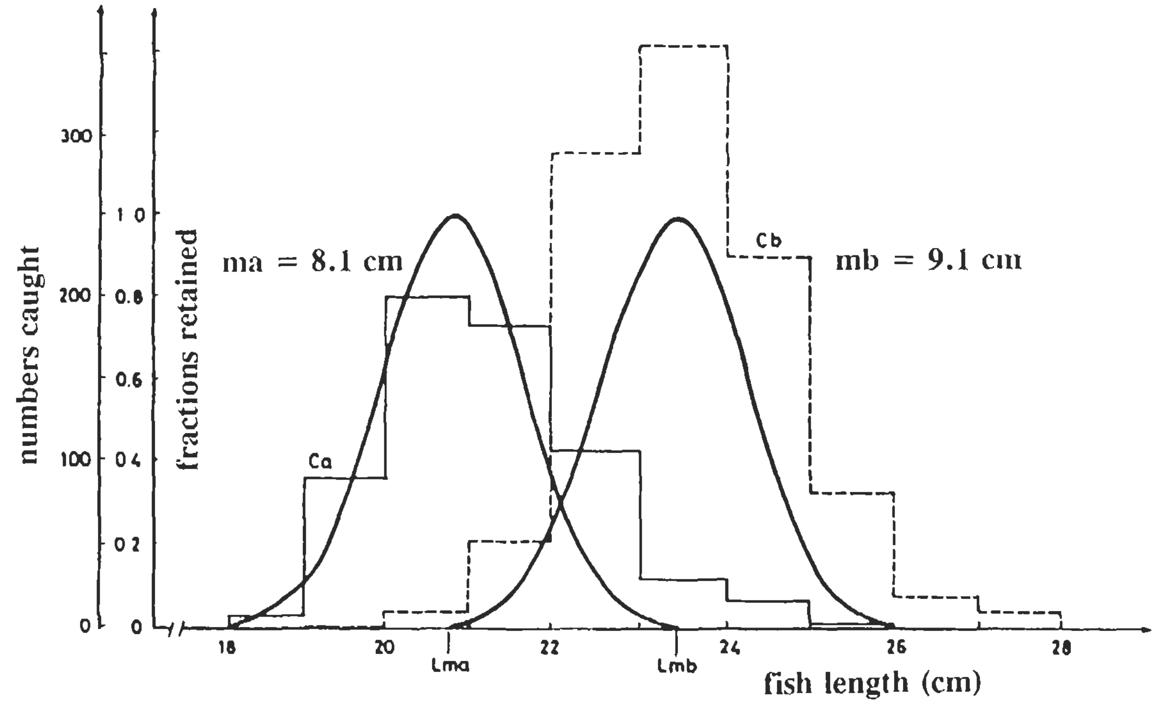


Fig. 6.2.1.2 **Selection curves for *Tilapia esculenta* for gill nets of 8.1 and 9.1 cm mesh size from Lake Victoria (from Garrod, 1961)**

The indices Na and Nb are in principle the same for given L except for accidents of sampling. They should be calculated only for length groups for which there is a fair number of fish in the catch of the mesh size in question. If the basic assumption that the selection curves are shaped like normal distributions is not fulfilled the estimation of the numbers in the population must be restricted to the part of the curve for which the assumption is approximately fulfilled.

The results are presented in Table 6.2.1.2 and Figs. 6.2.1.1a and 6.2.1.2. The catch curves are skew, probably an effect of entanglement: the big fish are over-represented in both. This is seen when plotting data for the regression analysis, Fig. 6.2.1.1a. The estimation is restricted to four points which are almost on a straight line and not based on very small numbers of fish. Na(L) and Nb(L) are in fair agreement for the four points used in the regression analysis. For the big fish they are unreliable because the catch curves are skew. A larger number of mesh sizes is required to cover a wider range of the population size structure.

Model for various mesh sizes

When there are n mesh sizes, all used together in nets of the same size, there will be n-1 estimates of the intercept, a, and the slope, b, of Eq. 6.2.1.2. Thus we have the results

$$[a(1),b(1)],[a(2),b(2)],\ldots,[a(n-1),b(n-1)]$$

corresponding to the mesh sizes:

$$[m(1),m(2)],[m(2),m(3)],\ldots,[m(n-1),m(n)]$$

Each data set (each mesh size) was used twice to produce these estimates: set no. 2 was used first with set no. 1 to estimate a(1) and b(1) and again with set no. 3 to estimate a(2), b(2) and so on. This introduces a correlation between consecutive pairs a(i), b(i) whose effect is difficult to ascertain, but may be important when data for only a few mesh sizes are available. Bearing this in mind we continue by rearranging Eq. 6.2.1.6 to give a straight line through the origin:

$$-2*a(i)/b(i) = SF*[m(i)+m(i+1)], \quad i = 1,2,\ldots,n-1 \qquad (6.2.1.7)$$

from which the common selection factor, SF, is estimated as the slope, b.

With $y(i) = -2*a(i)/b(i)$ and $x(i) = m(i)+m(i+1)$ we have from Eq. 2.4.15:

$$SF = \Sigma[x(i)*y(i)]/\Sigma x(i)^2$$

The common variance is estimated as the mean of the individual estimates for each consecutive pair of mesh sizes:

$$s^2 = \frac{1}{n-1} * \sum_{i=1}^{n-1} \left[SF(i)*\frac{m(i+1)-m(i)}{b(i)} \right] \qquad (6.2.1.9a)$$

The optimum length for each mesh size i is obtained by

$$Lm(i) = SF*m(i) \qquad (6.2.1.10)$$

Subsequently, points on the selection curves Si_L are calculated for each length group. Then these values are summed for each length group and normalized to a maximum of one, in order to get a composite selection curve. This is done by dividing the values of the sums by the highest value amongst the sums.

A flat curve over a wide range of lengths indicates that all length groups within this range were sampled evenly such that the sum of the catches for each length group Ci_L can be used directly as an index of population numbers. If the composite selection curve has conspicuous summits and valleys the population numbers must be estimated by dividing the catch of each length class by the value (≤ 1) on the composite selection curve (Eq. 6.2.1.6b). There may be length groups for which the population index cannot be calculated.

Example 22a: Estimation of combined selection of several gillnets for a cichlid in Lake Kariba

Figs. 6.2.1.2a and 6.2.1.2b show selection curves for a cichlid in Lake Kariba. In an experiment 21000 specimens of *Serranochromis codringtoni* were caught in a gang of 12 mesh sizes of gill nets ranging from 38-178 mm stretched mesh. The curves were estimated as described above. After summation and normalisation to one it is seen that the resultant composite selection curve is flat-topped for fish lengths of 11 to 31 cm. Thus, the total catch in the nets of 12 mesh sizes gave an almost true index of the size composition in the population for which was estimated $L_\infty = 27$ cm. The increase in the left-hand side of the broad selection curve resembles a trawl selection curve such as Fig. 6.1.2. The decrease to the right will not be observed because there was no fish that big. It should be remembered that the data was from experimental fishery. The commercial fishery in the lake is mainly with gill nets of one mesh size. The fishing mortality is therefore not expected to be the same from a certain size and up, as in a commercial trawl fishery.

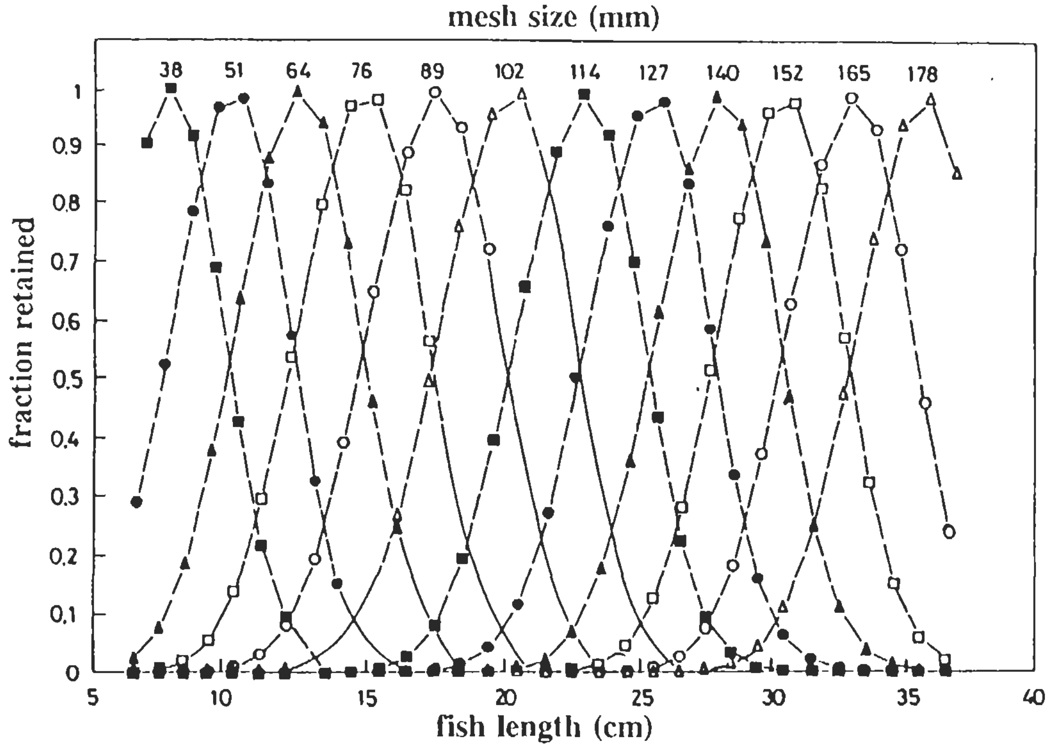


Fig. 6.2.1.2a Selection curves for the cichlid *Serranochromis codringtoni* in Lake Kariba, southeast Africa. Gill nets of 12 mesh sizes. Redrawn from Zambia/Zimbabwe/SADC Fisheries Project, Project Report No 26, 1993

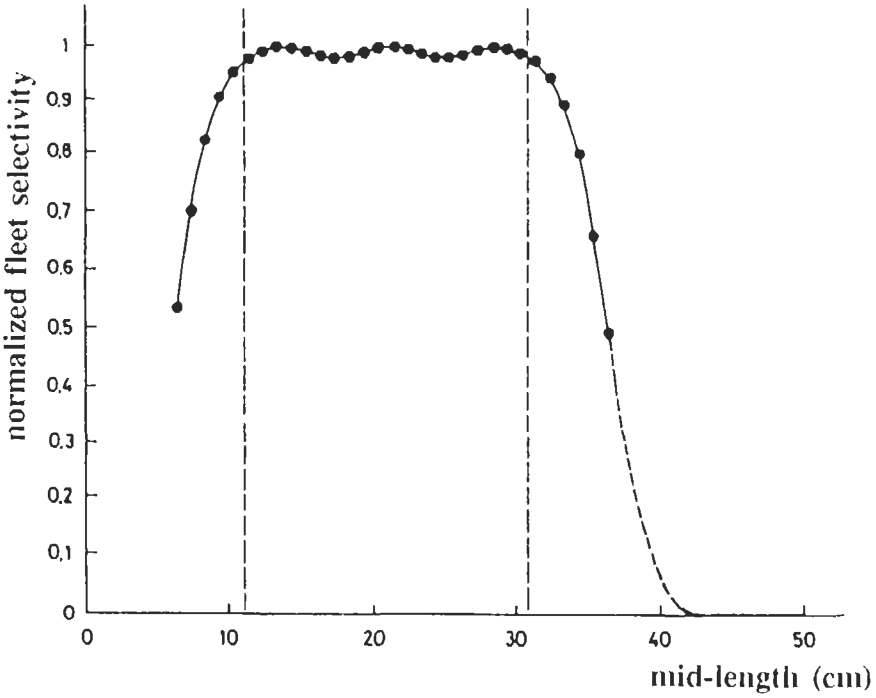
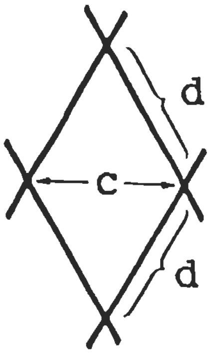


Fig. 6.2.1.2b **The selection curves of Fig. 6.2.1.2a summed and adjusted to a maximum value of one. Redrawn from the above mentioned report**

Hanging ratio

Gill net selection is known to depend on a variety of factors besides mesh size: net construction, visibility and stretchability of the net, net material and the shape and behaviour of the fish (Hamley, 1975). Entangling more than wedging and gilling (cf. Fig. 6.2.1.1) is affected by net construction. The probability of a fish being entangled is believed to depend on the so-called "hanging ratio" or "hanging coefficient" which is defined (FAO, 1978b) as:



$$\frac{\text{length of the head rope}}{\text{(number of meshes)*(mesh size)}}$$

or (see figure):

$$\text{hanging ratio} = \frac{c}{2*d} \qquad (6.2.1.11)$$

Thus, for a square mesh ($d = c/\sqrt{2}$) we have the hanging ratio $\sqrt{2}/2 = 0.707$ which represents the maximum opening. Hanging ratios are usually in the range of 0.2 to 0.7 (see Fig. 6.2.1.3). The smaller the hanging ratio the larger the probability of entangling. This is demonstrated by Riedel (1963), who reported catches of *Tilapia mossambica* with 10 cm mesh gill nets with three different hanging ratios:

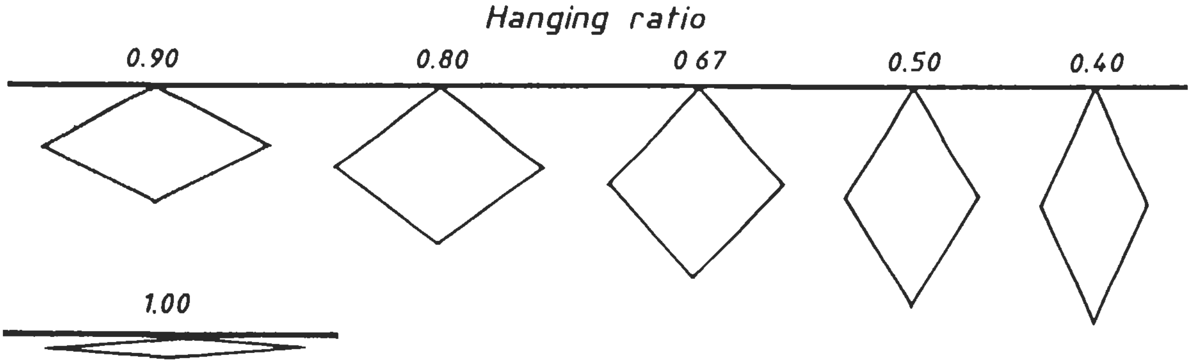


Fig. 6.2.1.3 Mesh shapes with various hanging ratios for gill nets (from FAO, 1978b)

hanging ratio	average number caught per day	percent entangled	size range of 95% of catch
0.707	9.3	0	18-23 cm
0.36	29.5	24	13-23 cm
0.24	81.0	80	8-22 cm

6.2.2 The product of two logistic curves

If entangling is an important factor, the normal distribution method described above is not suitable. One way of estimating the selection curve would be to compare the catches of the gill net to a non-selective gear, e.g. to trawl catches. The catches from the non-selective gear would then play the same role as the total combined catch in the cover and the codend of a trawl when operated as described in Section 6.1. The same procedure as used in Table 6.1.1 can be applied. In this case we need a non-symmetrical selection curve of the type shown in Fig. 6.2.2.1. A mathematical expression for this type of curve can be obtained by multiplying two logistic curves (Hoydal *et al.*, 1982). The ascending part of the curve is given by the usual logistic curve (cf. Eq. 6.1.1), it reflects the probability of being gilled or wedged. We call it "SL" where "L" stands for "left-hand side of the selection curve":

$$SL_L = 1/(1 + \exp(S1 - S2*L)) \qquad (6.2.2.1)$$

This type of selection is the dominating one up to length A (see Fig. 6.2.2.1). For lengths larger than B the selection is the combined effect of gilling, wedging and entangling. This part of the curve is modelled by a "*reversed logistic curve*". We call it "SR" where "R" stands for "right-hand side of the selection curve":

$$SR_L = 1/(1 + \exp(D1 - D2*L)) \qquad (6.2.2.2)$$

The parameters in the SR-function, D1 and D2, are negative numbers, whereas the parameters in the SL-function, S1 and S2, are positive numbers. The lengths corresponding to the 50% and 75% de-selection, D50% and D75%, are related to D1 and D2 by the same mathematical expressions as those used for S1, S2, L50% and L75% (cf. Eqs. 6.1.4 to 6.1.7):

$$D50\% = D1/D2 \quad \text{and} \quad D75\% = (D1 + \ln 3)/D2$$

$$D1 = D50\%*\ln(3)/(D75\%-D50\%) \quad \text{and} \quad D2 = D1/D50\%$$

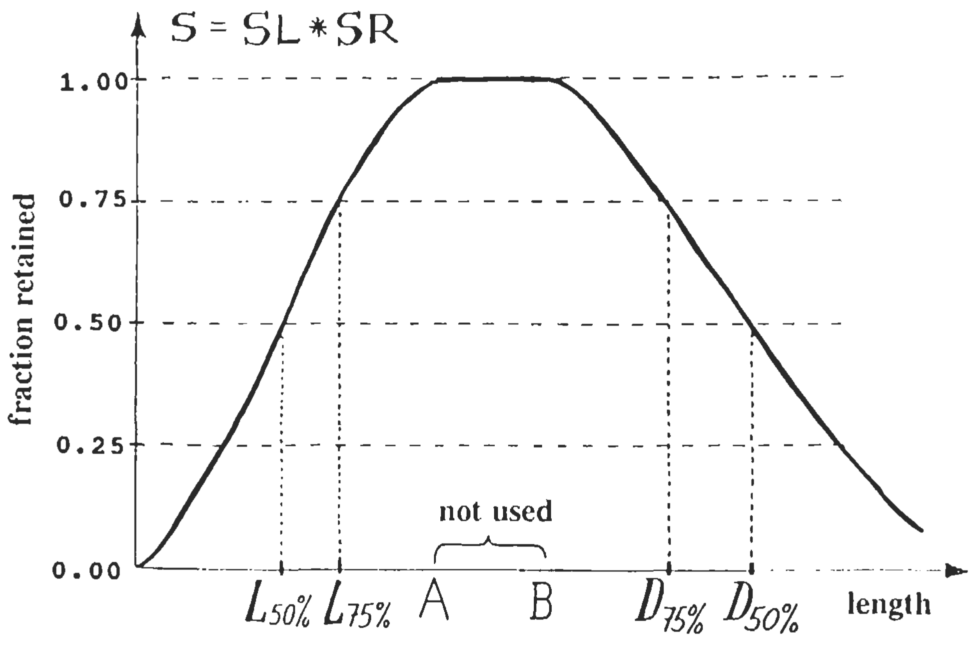


Fig. 6.2.2.1 Asymmetric selection curve

By multiplying the ascending curve, SL, and the descending curve, SR, we obtain the desired type of curve, S. When SL is ascending SR is "neutral" (i.e. approximately equal to 1.0), and when SR is descending SL is "neutral":

$$S_L = SL_L * SR_L = \frac{1}{1 + \exp(S1 - S2*L)} * \frac{1}{1 + \exp(D1 - D2*L)} \tag{6.2.2.3}$$

The expression for S_L is supposed to take the maximum value, 1.0, for at least one L-value. Therefore, the expression Eq. 6.2.2.3 (as well as the normal distribution in Eq. 6.2.1.1) should be normalized so that the maximum value equals 1.

In practice this is obtained in the following way. Let S(i) be the point on the selection curve representing length class no. i (estimated by Eq. 6.2.1.1 or Eq. 6.2.2.3) and let MAX {S(j)} designate the maximum value of S(j) among all length classes. We normalize by replacing the value of S(i) by the value:

$$\frac{S(i)}{\underset{j}{MAX}\{S(j)\}}$$

The parameters can be estimated in the same way as the parameters of the trawl selection ogive (cf. Section 6.1). To estimate S1 and S2 we use only the length classes below A (see Fig. 6.2.2.1) and perform the regression analysis:

$$\ln(1/S - 1) = S1 - S2*L \tag{6.2.2.4}$$

where the dependent variable, y = ln(1/S - 1), is derived from the comparison with the non-selective gear:

$$S(i) = \frac{Cg(i)/Cn(i)}{\underset{j}{MAX}\{Cg(j)/Cn(j)\}} \tag{6.2.2.5}$$

where

$$\frac{Cg(i)}{Cn(i)} = \frac{\text{no. of length class i fish caught in gill net}}{\text{no. of length class i fish caught in non-selective gear}}$$

The denominator in Eq. 6.2.2.5, "MAX {Cg(j)/Cn(j)}", is the maximum value of the ratio Cg/Cn among all length groups with non-zero values of Cg and Cn. Thus, S(i) as defined by Eq. 6.2.2.5 takes values between 0 and 1 (including 1).

Eq. 6.2.2.5 is based on the assumption that the numbers Cn are caught by a gear which is non-selective for all those length classes which are caught by the gill net. If this is not the case Eq. 6.2.2.5 should be replaced by:

$$S(i) = \frac{[Cg(i)/Cn(i)]*Sn(i)}{\underset{j}{MAX}\{(Cg(j)/Cn(j))*Sn(j)\}} \qquad (6.2.2.6)$$

where Sn(i) is the selection curve for the "other gear".

The descending (right-hand side) of the selection curve is estimated using the same calculation procedure and the corresponding observations as those used for the left-hand side. Thus we use the data for the length classes above point B (see Fig. 6.2.2.1) and perform the linear regression analysis:

$$\ln(1/S - 1) = D1 - D2*L \qquad (6.2.2.7)$$

The method based on the product of two logistic curves is a generalization which includes the trawl selection ogive (Eq. 6.1.1) and the symmetric curve (Eq. 6.2.1.1) as special cases. Assigning the values $D1 = -\infty$ and $D2 = 0$ makes the factor $1/(1 + \exp(D1 - D2*L))$ in Eq. 6.2.2.3 take the value 1 for all values of L and then Eq. 6.2.2.3 equals Eq. 6.2.1.1. If the curve is symmetrical we estimate parameters so that:

$$L50\% + D50\% = L75\% + D75\%$$

but we do not have to make assumptions beforehand.

The symmetrical curve created by the product of two logistic curves may not be the same as the normal distribution curve. The product of two logistic curves may take the maximum value (1) for a range of values (in Fig. 6.2.2.1 A to B). It may also, however, come very close to the normal distribution as shown by an example in Fig. 6.2.2.2.

Thus, if data for a non-selective gear (or a gear with a known selection curve) are available, there is really no need to use the traditional model, the normal distribution, since the same curve can be obtained as a special case of the logistic product function (Eq. 6.2.2.3). Moreover, the latter is versatile and easy to handle from a computation point of view. Using the product of two logistic curves we are not forced to make the questionable assumption that the selection curves are normally distributed with a common standard deviation.

Finally, it should be mentioned that data collected from gill net catches are difficult to use for the estimation of growth parameters or mortality rates. This is illustrated in Fig. 6.2.2.3 as a hypothetical example. We consider a length-frequency sample representing the population (double line) i.e. a sample from a non-selective gear and a sample representing the gill net catch (shaded line). The population contains four components or cohorts (normal distributions), whereas the gill net sample appears to contain only one component with mean value Lm, which does not coincide with any of the four cohort mean lengths (L0,L1,L2 and L3).

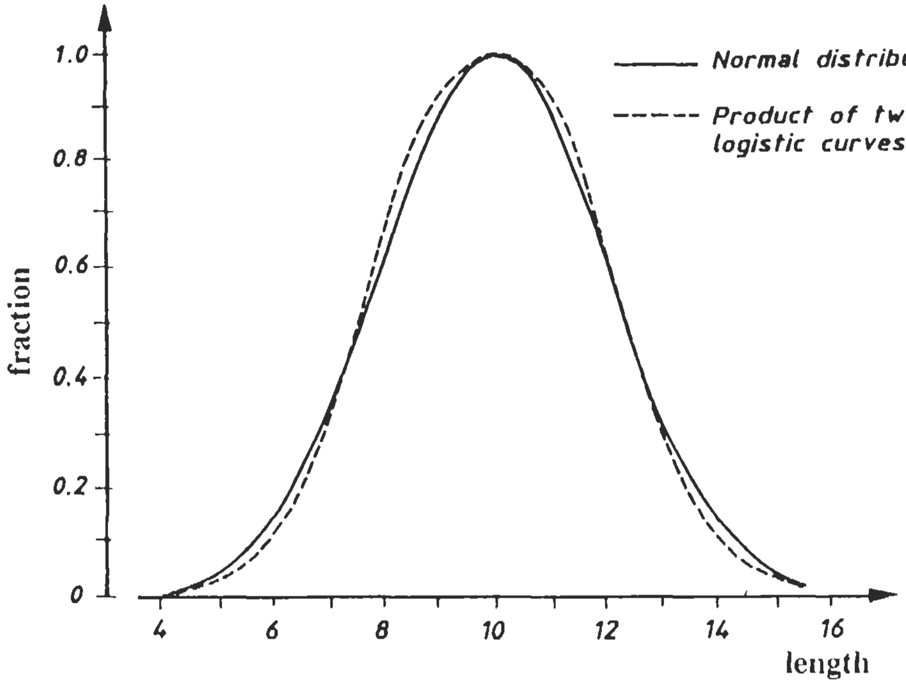


Fig. 6.2.2.2 **A product of two logistic curves which is nearly identical to a normal distribution. The parameters are:**
Normal distribution: Lm = 10 and s = 2
Product of two logistic curves:
L50% = 7.645 L75% = 8.483
D50% = 2*Lm - L50% D75% = 2*Lm - L75%

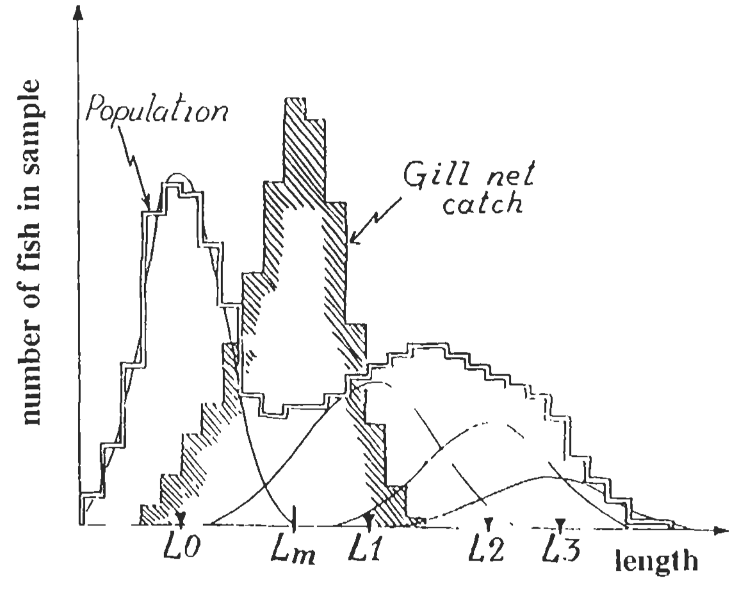


Fig. 6.2.2.3 **Hypothetical example to illustrate bias problems when using gill net data for estimation of growth parameters and mortality rates**

Thus, the gill net sample does not give any information which can be used for the separation of cohorts and the estimation of length-at-age.

Also samples collected during a whole year would all give more or less the same picture. Summing a time series over a year would therefore give a curve not very different from the curve for the gill net catch in Fig. 6.2.2.3. Using the descending slope of this curve to estimate total mortality from the length-based catch curve analysis would lead to an overestimate of Z. Before using any gill net data for estimation of growth parameters or mortality rates, they should be critically examined. The result of such an examination may be either that the data cannot be used at all or that they can be used only after having been adjusted for gear selection as described in Section 6.7.

6.3 DISCUSSION OF SELECTION BY OTHER GEARS

The previous two sections dealt with the selectivity of trawl nets (active gears) and gill nets (passive gears). The scientific literature on selectivity has been mainly concerned with these gears, partly because it is relatively easy to conduct experiments for the estimation of their selection curves. Other types of gear are also more or less selective and the pattern of selection can usually be changed by suitable adjustments of the gear. The gear selection model based on the logistic curve (Eq. 6.1.1) or the model based on the product of two logistic curves (Eq. 6.2.2.3) are believed versatile enough to describe the selection curve of any gear.

Below is a brief discussion of the selection properties of two passive gear types: hooks and traps, and of an active gear type: seine nets.

Much more appears to be known about trawl and gill net selection than about hook fisheries. For hook-and-line fisheries some authors report that the selection curve is bell-shaped, of the gill net type, dependent on hook size, whereas others find a trawl type selection. The idea behind the use of the bell-shaped selection curve is that small fish cannot take a large hook in their mouth and that large fish are not held securely by small hooks.

A discussion of hook selection can be found in Ralston (1982), who observed the trawl type of selection for the Hawaiian deep-sea hand line fishery. From an experiment where four hook sizes were used for catching snappers and groupers he found that small hooks were nearly as efficient as large hooks at catching large fish. For the ascending left-hand selection curve (the small fish) he found a sigmoid curve. Pope *et al.* (1975) suggested using the gill net type of selection for hook fisheries, although they quote a number of works which show the trawl type of selection.

Pope *et al.* (1975) suggested the trawl type of selection for traps arguing that traps behave like codends in retaining fish. Munro (1974, 1983) discusses selectivity and other aspects of the operation of portable Antillean fish traps. These 3 m long traps are made of chicken wire-netting with two funnels whose bottoms are the entrance openings. They are used for catching coral reef fish. Munro (1974) developed a model for the catchability of traps as a function of the soak time (the time the trap is left on the fishing ground).

Trap selectivity is complicated because it relies on the fish to move actively into the trap. For small traps (as the Antillean trap mentioned) only one specimen of a territorial fish species can be expected to be caught, but the trapped fish may have been replaced by another before the trap is pulled. As the other extreme we have the hunters, like the jacks (Carangidae) in a coral reef fishery which cover a lot of ground in a short time and therefore become over-represented in trap catches. If a large predator is caught in the trap it may keep potential prey fish from entering the trap. If prey species are already in the trap they may act as live-bait and attract the large predators, which in turn may eat the prey before the trap is pulled.

Trap catches depend on the duration of the soak (Munro, 1974). There is always a chance that a trapped fish finds the entrance opening and leaves through it. There are considerable differences between species. Some species leave the trap with great ease (Munro, 1983). Thus, trap selectivity may not only be a function of the mesh size used in the trap. For example, the size of the entrance opening and the soak time may be of importance. The species composition on the ground where the trap is placed also may influence the selectivity. For the escapement through the meshes, however, it appears reasonable to assume the trawl selection type of ogive. When considering the average of a large number of trap catches some of the above mentioned complications may disappear, i.e. they may turn out to be "random noise" around the selection curve.

In principle a seine net should work like a trawl as far as selection is concerned. However, it is more difficult to deal with the seines because this type of gear is usually used to catch schooling species, such as sardines, mackerels and tunas. These species have a tendency to form schools consisting of fish of the same size. Thus, we should consider a school to be a sampling unit (instead of an individual fish).

6.4 OTHER ASPECTS OF GEAR SELECTIVITY

6.4.1 Knife-edge selection

Fig. 6.4.1.1 shows two selection curves. Curve A has a selection range of 3 cm and curve B, the fat vertical line, has a selection range of 0 cm. Curve B is a so-called *"knife-edge selection curve"* (Beverton and Holt, 1957). Knife-edge selection should be considered a hypothetical model since it will never describe a real situation. However, knife-edge selection is often used as an approximation to the selection ogive. For lengths below L50% the numbers selected are under-estimated and for lengths above L50% the numbers are over-estimated. These two sources of bias have opposite signs and as the two areas "a" and "b" (see Fig. 6.4.1.1) are the same size they balance out. However, the fish of area "a" will weigh more than those of area "b", since the weight of a fish corresponds to the cube of the length.

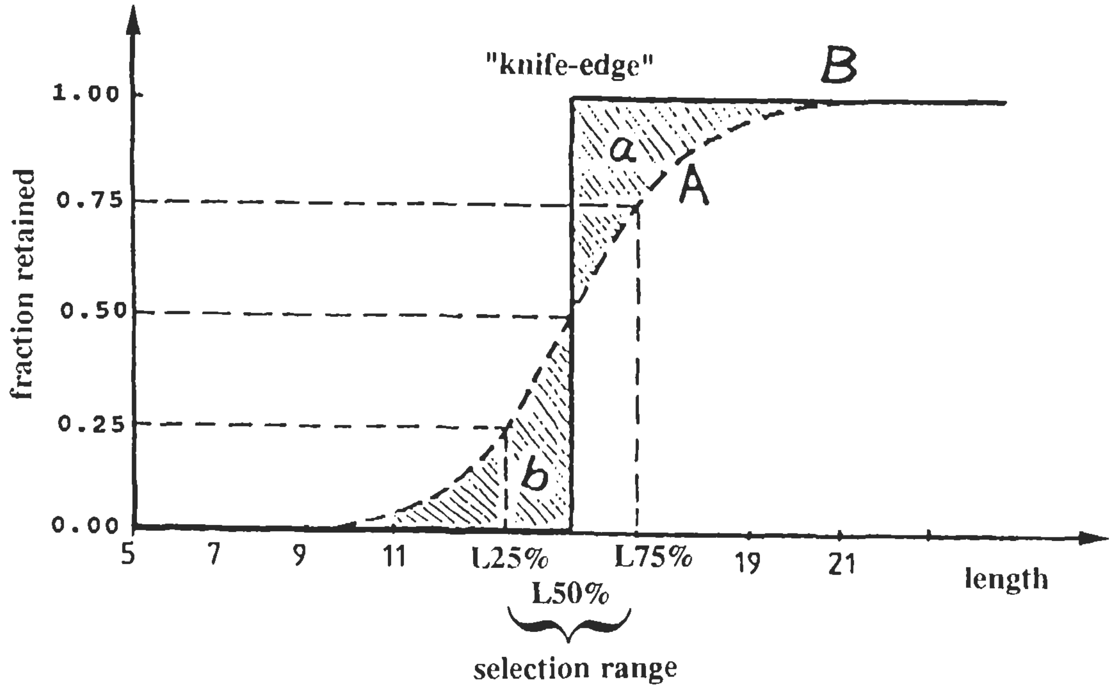


Fig. 6.4.1.1 **Trawl selection curve as a function of body length. An illustration of the concepts of knife-edge selection and selection range**

6.4.2 Recruitment and selectivity

The recruitment of fish to the fishing area, that is when they move away from the nursery or spawning areas to the fishing grounds, is also size dependent, in the same way as a trawl selection ogive. This means that every size of fish will not be fully represented at the fishing grounds and, thus, when there is a fishery for the size ranges which are not yet fully recruited the probability that a fish is retained by the fishing gear is in fact the product of two probabilities:

1. The probability that the fish is present on (has recruited to) the fishing ground.

2. The probability that the fish is retained by the meshes once it has entered the gear.

Fig. 6.4.2.1 illustrates these points. Curve R is the "*recruitment curve*", curve G is the "*gear selection curve*",and curve S is the "*resultant curve*".

The probability that a certain size of fish will be caught is the product of the probabilities of recruitment and selection. The probability can therefore be described by a "*resultant curve*", S, where S = R*G (see Fig. 6.4.2.1).

The L50% for the three curves, R, G and S, are different as indicated in Fig. 6.4.2.1. The probability of capture of a fish of length Q is the product of probability A, related to the recruitment curve, and probability B related to the gear selection curve, and the result is probability C.

In this example A*B = C or R(Q)*G(Q) = S(Q) or 0.62*0.42 = 0.26. At length X practically all fish have recruited to the fishing grounds while some are still small enough to escape through the meshes. At length Y mesh retention is complete and no fish escape.

When the meshes are so large that there is no overlap of the recruitment curve with the selection curve we can ignore recruitment. The resultant curve is then determined by selection only, see Fig. 6.4.2.2.

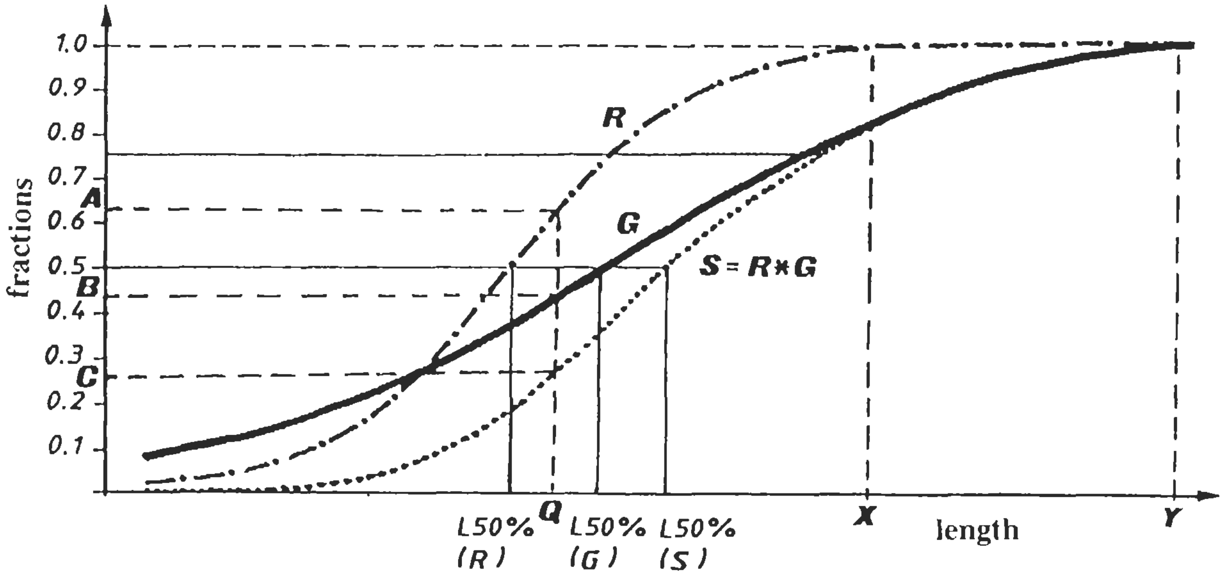


Fig. 6.4.2.1 **Curves representing: recruitment to the fishing grounds (R), gear selection (G), and the resultant (S = R*G) (see also text)**

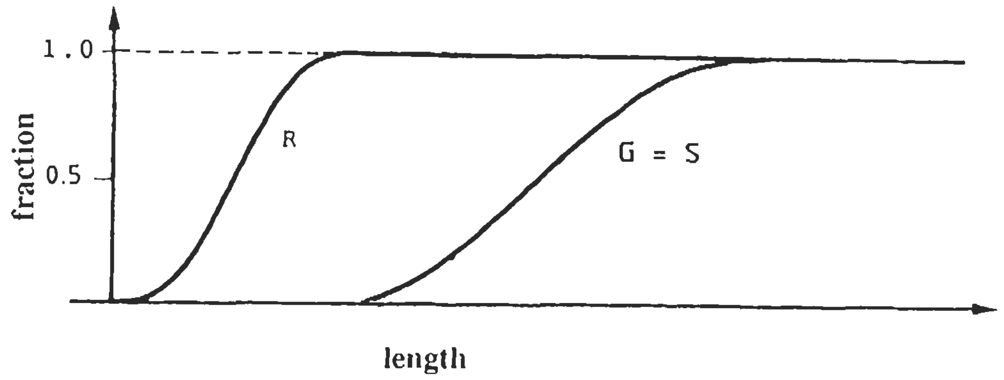


Fig. 6.4.2.2 Example of equality (overlap) between the gear selection curve (G) and the resultant curve (S)

6.4.3 Selectivity as a function of age

So far, selectivity has been considered a function of length. Another example of a selection curve S_L is given in Fig. 6.4.3.1. The values of S1, S2, L50% and L75% corresponding to this curve are as follows:

$$S1 = 15*\ln(3)/(18-15) = 5.4930 \quad \text{and} \quad S2 = \ln(3)/(18-15) = 0.3662$$

$$L50\% = 5.4930/0.3662 = 15 \text{ cm} \quad \text{and}$$

$$L75\% = (5.4930+\ln 3)/0.3662 = 18 \text{ cm}$$

The selection range is 2*(18-15) = 6 cm

Using the von Bertalanffy growth equation we can express length as a function of age, and express S as a function of age, t:

$$S_t = \frac{1}{1 + \exp[S1 - S2*L_\infty*(1 - \exp(-K*(t-t_o)))]} \qquad (6.4.3.1)$$

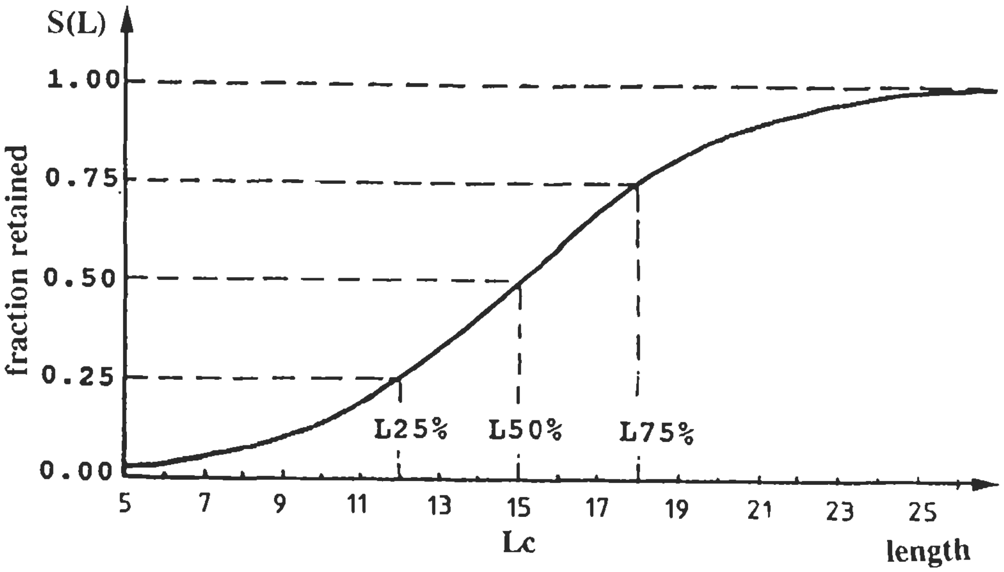


Fig. 6.4.3.1 The selection curve referred to in the text

The next, age-based expression is equivalent to Eq. 6.1.1 which is length-based.

$$S_t = \frac{1}{1 + \exp(T1 - T2*t)} \tag{6.4.3.2}$$

and which can be rewritten in linear form as:

$$\ln(1/S_t - 1) = T1 - T2*t \tag{6.4.3.3}$$

where:

$$T1 = t50\%*\ln(3)/(t75\%-t50\%) \tag{6.4.3.4}$$

$$T2 = \ln(3)/(t75\%-t50\%) = T1/t50\% \tag{6.4.3.5}$$

(cf. Eqs. 6.1.6 and 6.1.7)

The formulas for t50% and t75% are:

$$t50\% = T1/T2 \tag{6.4.3.6}$$

$$t75\% = (T1 + \ln 3)/T2 \tag{6.4.3.7}$$

(cf. Eqs. 6.1.4 and 6.1.5)

Fig. 6.4.3.2 shows the two age-based selection ogives. Curve A is based on the exact transformation according to Eq. 6.4.3.1, while curve B is the approximate selection ogive based on Eq. 6.4.3.2 and the related equations 6.4.3.4 to 6.4.3.7. It can be observed that both curves are almost identical.

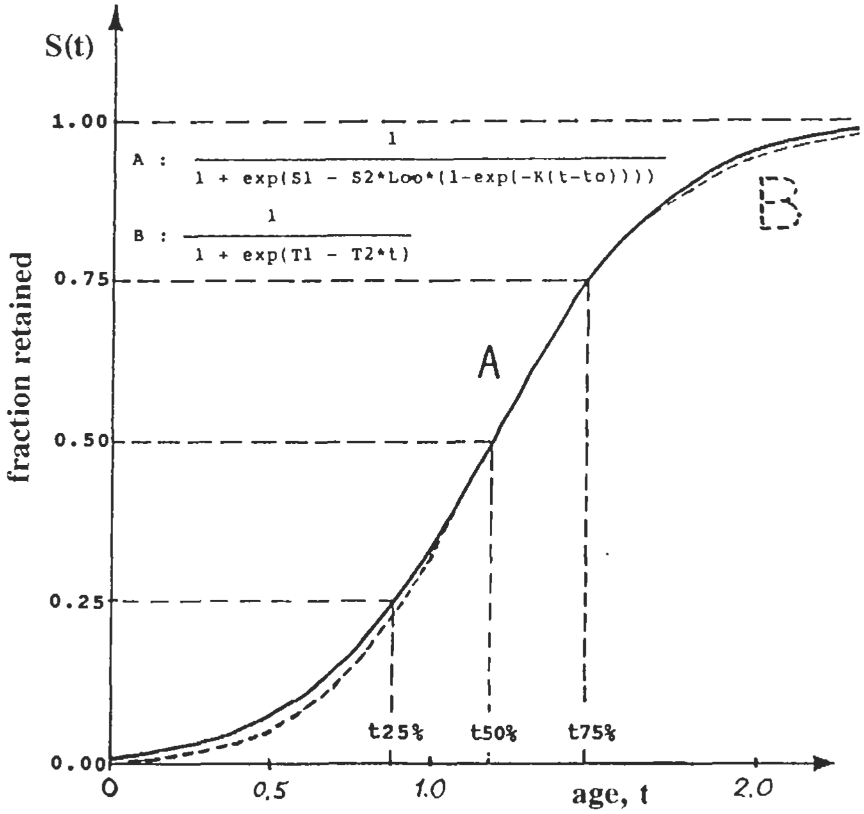


Fig. 6.4.3.2 **A: Exact age-transformed selection ogive (Eq. 6.4.3.1)**
B: Approximated selection ogive (Eq. 6.4.3.2)

It is also possible to express t50% and t75% in lengths and vice versa to express L50% and L75% in ages, using the following formulas:

$$t50\% = t_0 - (1/K)*\ln(1 - L50\%/L_\infty) \qquad (6.4.3.8)$$

$$t75\% = t_0 - (1/K)*\ln(1 - L75\%/L_\infty) \qquad (6.4.3.9)$$

and

$$L50\% = L_\infty*[1 - \exp(K*(t_0-t50\%))] \qquad (6.4.3.10)$$

$$L75\% = L_\infty*[1 - \exp(K*(t_0-t75\%))] \qquad (6.4.3.11)$$

Assume that $L_\infty = 50$ cm, $t_0 = 0$ years and $K = 0.3$ per year for the fish stock associated with the length-based selection ogive in Fig. 6.4.3.1, then:

$$t50\% = 0 - (1/0.3)*\ln(1 - 15/50) = 1.1889$$

$$t75\% = 0 - (1/0.3)*\ln(1 - 18/50) = 1.4876$$

$$T1 = 4.3727 \quad \text{and} \quad T2 = 3.6779$$

The corresponding L50% and L75% are:

$$L50\% = 50*[1 - \exp(0.3*(0 - 1.1889))] = 15.0 \text{ cm}$$

$$L75\% = 50*[1 - \exp(0.3*(0 - 1.4876))] = 18.0 \text{ cm}$$

which are the same as the results obtained for the length-based selection ogive.

6.5 ESTIMATION OF THE RESULTANT OGIVE FROM A CATCH CURVE

When using a linearized catch curve to estimate mortality (e.g. Fig. 4.4.5.1) it is usually necessary to discard the left-hand side of the curve because the juvenile fish are not fully exploited or not fully recruited. A conceptually simple way to estimate how many fish are missing at each age is to extrapolate on the straight line from which the total mortality coefficient Z is estimated, in order to find the number of juveniles there "ought to be", (see Fig. 6.5.1). The differences between the "expected" numbers and the actual numbers should give the ogive resulting from the combined effect of recruitment and mesh selection. As shown below, the calculations are easily performed. The problem is that an important and probably unrealistic assumption is made, namely that the total mortality rate, Z = F+M, is the same for all ages. F alone is not constant because it must be smaller in the mesh selection phase. M, on the other hand, is likely to be higher for small fish than for the adults. It is therefore possible that Z remains approximately constant although so far, nobody has shown it to be. Nevertheless, the method has achieved considerable popularity and is therefore mentioned here.

Example 23: Estimation of the resultant selection ogive from a catch curve, hypothetical data

To explain this method (Pauly, 1984a) the example of Table 6.5.1 is used. Columns A-E contain the input data and calculations for a length-converted catch curve analysis (cf. Section 4.4.5). In this case we calculate the total mortality Z = 1.0 per year from the growth parameters, $L_\infty = 50$ cm, K = 0.3 per year (see Fig. 6.5.1). The result of the regression analysis is:

$$\ln \frac{C}{\Delta t} = 9.208 - 1.0*t$$

In contrast to the example discussed in Section 4.4.5 we now have a use for the intercept (a = 9.208).

Under the assumption of constant mortality we expect the values of ln(C/Δt) to be on the regression line, ln(C/Δt) = a-Z*t. Thus, the hypothetical true frequency the total population numbers in the sea, CT, is expected to fulfill the equation:

$$\ln(CT/\Delta t) = a - Z*t \qquad (6.5.1)$$

The idea behind this method is that the number in the sea is proportional to the number caught, i.e.

$$\frac{C}{CT} = \frac{\text{the number in the catch}}{\text{total population number in the sea}}$$

Let t1 be the age corresponding to the first length group which is supposed to be fully represented in the catch and therefore used in the catch curve regression (in the case of Table 6.5.1, we have t1 = 2.180, see Fig. 6.5.1). For ages above t1, CT_t should be approximately equal to the observed frequencies, since the probability of capture is 1, because selection and recruitment are supposed to have finished before that age. For the ages below t1 we expect that the population in the sea is higher than that represented in the catch, i.e:

$$\ln(CT_t/\Delta t) > \ln(C_t/\Delta t)$$

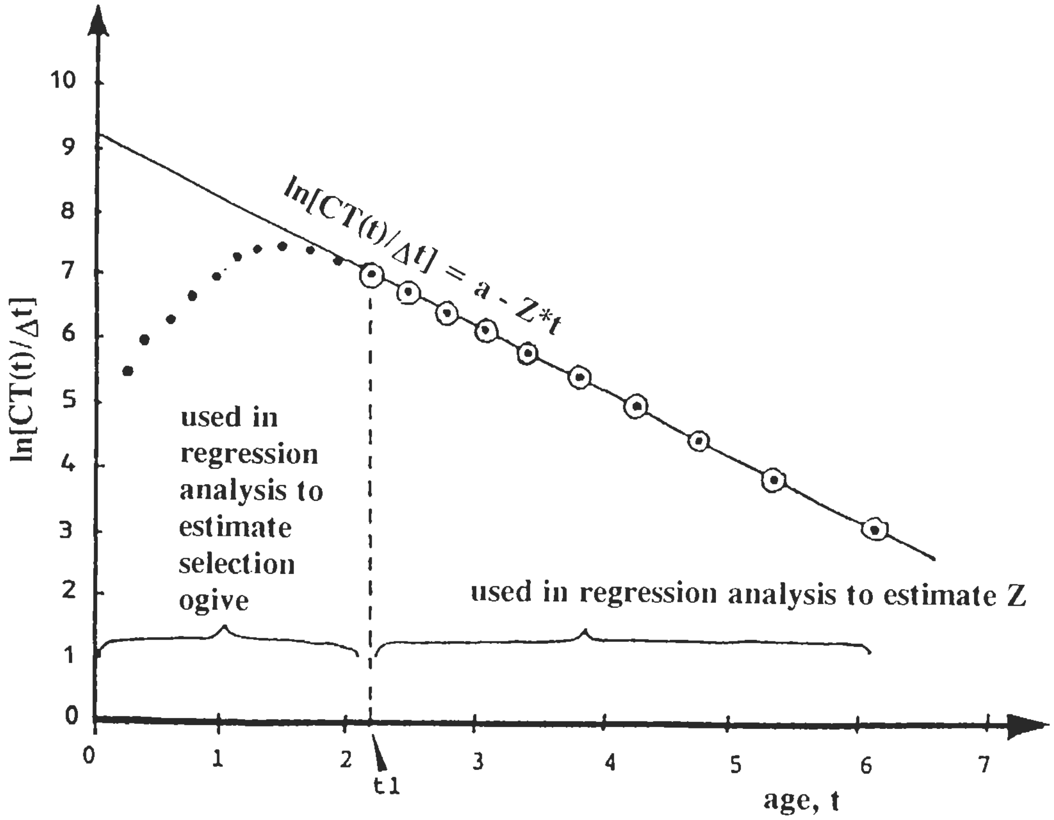


Fig. 6.5.1 **Estimation of the resultant ogive from a length-converted catch curve analysis based on Table 6.5.1**

Table 6.5.1 Example to illustrate estimation of the selection ogive from a catch curve (cf. Fig. 6.5.1). L_∞ = 50 cm, K = 0.3 per year, t_0 = 0. (The same data were used in Table 4.5.4.1.)

A	B	C	D	E	F	G	H
length interval L1-L2	t (x)	Δt (L1,L2)	C(L1,L2)	ln (C/Δt) (y')	S_t obs.	ln (1/S-1) (y)	S_t est.
3-5	0.278	0.145	37	5.54	0.034	3.35	0.03
5-7	0.426	0.151	56	5.92	0.057	2.81	0.06
7-9	0.581	0.159	86	6.29	0.097	2.23	0.10
9-11	0.744	0.167	129	6.65	0.163	1.64	0.16
11-13	0.915	0.176	188	6.97	0.267	1.01	0.27
13-15	1.095	0.186	258	7.23	0.416	0.42	0.42
15-17	1.286	0.196	319	7.39	0.590	-0.37	0.59
17-19	1.487	0.208	352	7.43	0.750	-1.10	0.75
19-21	1.703	0.222	351	7.37	0.870	-1.90	0.87
21-23	1.933	0.238	324	7.22	0.943	-2.80	0.94
23-25	2.180	0.257	283	7.00	(0.976)	-	0.98
25-27	2.447	0.278	239	6.76	-	-	0.99
27-29	2.734	0.303	196	6.47	-	-	1.00
29-31	3.054	0.334	158	6.16	-	-	1.00
31-33	3.406	0.371	123	5.80	-	-	1.00
33-35	3.798	0.417	93	5.41	-	-	1.00
35-37	4.243	0.477	69	4.97	-	-	1.00
37-39	4.757	0.557	48	4.46	-	-	1.00
39-41	5.365	0.669	31	3.84	-	-	1.00
41-43	6.109	0.838	18	3.04	-	-	1.00
43-45	7.068	1.122	10	2.19	-	-	1.00
45-47	8.419	1.702	3	0.57	-	-	1.00

column	contents
A	length group in cm
B	t(L1+L2)/2, age corresponding to interval midlength (cf. Eq. 3.3.3.2), (x) in both regressions
C	Δt(L1,L2) = t(L2)-t(L1) = $\frac{1}{K}*\ln\frac{L\infty-L1}{L\infty-L2}$ (Eq. 4.4.5.1)
D	C(L1,L2) = catch in numbers per length group
E	ln(C/Δt), dependent variable in catch curve regression analysis (y')
F	$S_t$obs. = C/[Δt*exp(a - Z*t)], **observed** selection ogive (a = 9.208, Z = 1.0, obtained from the linearized length-converted catch curve (Eq. 4.4.5.3), by linear regression of columns B(x) and E(y'), for the length ranges 23 to 43 cm
G	ln(1/S - 1), dependent variable in regression analysis for (the estimated) selection ogive (y). The linear regression of x = t and y = ln(1/S - 1) gives T1 = a and T2 = b (Eq. 6.4.3.3.)
H	$S_t$est. = 1/[1 + exp(T1 - T2*t)], estimated (theoretical) selection ogive

As CT_t is supposed to be proportional to the population number the ratio C_t/CT_t is an estimate of the probability that a fish of age t will be on the fishing ground and be retained if it encounters the gear, i.e. C_t/CT_t can be used as an estimate of the resultant ogive S_t.

CT can be predicted by Eq. 6.5.1, modified into:

$$CT_t = \Delta t*\exp(a - Z*t) \tag{6.5.2}$$

Thus, the ogive can be estimated by:

$$S_t = \frac{C_t}{CT_t} = \frac{C_t}{\Delta t*\exp(a - Z*t)} \tag{6.5.3}$$

The fractions retained of the **observed** selection ogive are presented in column F of Table 6.5.1. In order to obtain the theoretical (estimated) selection ogive the expression for S_t is used in linear form (Eq. 6.4.3.3):

$$\ln(1/S_t - 1) = T1 - T2*t$$

Eq. 6.4.3.3 enables us to estimate the parameters T1 and T2 by linear regres-sion. Columns B (x) and G (y) of Table 6.5.1 contain the inputs for this regression. (Columns C, D and E contain the results of the catch curve analysis used to calculate the dependent variable, y, column G.) Column H contains the estimated selection ogive. Only values of S_t less than 1 (column F) can be used in the expression ln(1/S-1) (column G). Carrying out the regression analysis we find:

$$a = T1 = 4.396 \quad \text{and} \quad -b = T2 = 3.701$$

which gives, using Eqs. 6.4.3.6, 6.4.3.7, 6.4.3.10 and 6.4.3.11:

$$t50\% = T1/T2 = 1.1877 \text{ years}$$
$$t75\% = (T1 + \ln 3)/T2 = 1.4846 \text{ years}$$
$$L50\% = 50*(1 - \exp(-0.3*(1.1877 - 0))) = 15.0 \text{ cm}$$
$$L75\% = 50*(1 - \exp(-0.3*(1.4846 - 0))) = 18.0 \text{ cm}$$

The example of Table 6.5.1 is a hypothetical one constructed to give the results of Figs. 6.4.3.1 and 6.4.3.2. Because the data are ideal hypothetical data there is a perfect agreement between the observed fractions retained (column F of Table 6.5.1) and the theoretical fractions retained (column H).

The exercise provides a check on the adequacy of the choice of points used in the regression analysis for the estimation of Z. The conclusion to be drawn from Table 6.5.1 is that the first length group to be used in the estimation of Z should have been 27-29 cm, as this group is the first one under full exploitation. However, because the logistic curve never attains the value 1 the concept of "full exploitation" is determined by the number of decimals in the table. Taking into account that the logistic curve is an approximation to the real selection curve one cannot expect to get a precise estimate for the first length under full exploitation. If we are somewhere in the "near neighbourhood" of 1 the choice of first length group in the catch curve regression is likely to be good enough.

As emphasized in the introduction to this section, the results of the method described should be treated with a certain reservation.

(See **Exercise(s)** in Part 2.)

6.6 GEAR SELECTIVITY AND VPA METHODS

6.6.1 Gear selectivity and fishing mortality

Fishing mortality, F, is clearly related to the selection ogive. When $S_L = 0$ fishing mortality must be zero and when $S_L = 1$ fishing mortality is at its highest level. The obvious relationship between fishing mortality and selection is:

$$F_L = Fm*S_L \tag{6.6.1.1}$$

where Fm is the "*maximum fishing mortality*". Thus, F, as a function of length has the same shape as S, but it has a different level (see Fig. 6.6.1.1A).

In Eq. 6.6.1.1 we consider F a continuous function of length, L. In practice, however, it is often convenient to replace the continuous function by a step function as shown in Fig. 6.6.1.1B, where F is assumed to remain constant within each length group.

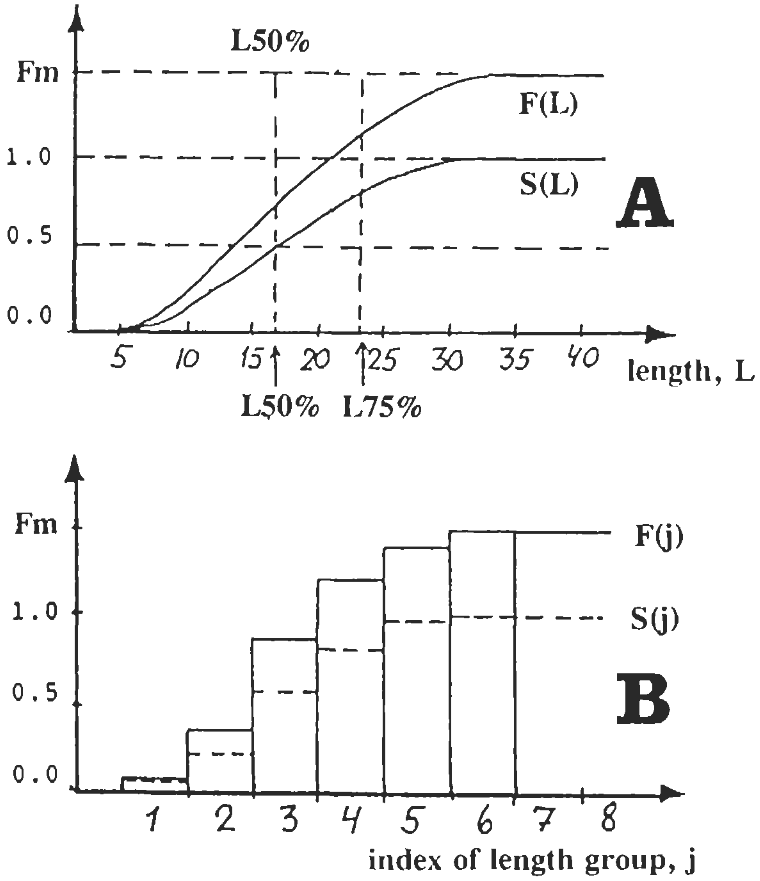


Fig. 6.6.1.1 **Relationship between selection ogive and fishing mortality**
A: Continuous functions
B: The step-functions corresponding to A

The continuous selection curve S_L may also be approximated by a step function, S(j), in which the value for length group no. j is S((L1+L2)/2), where L1 and L2 are the lower and upper limits of length group no. j. When we use the length group index, j, as argument rather than the length L, we may write a step-function model for total mortality, Z;

$$Z(j) = M + Fm*S(j) \tag{6.6.1.2}$$

where M is the natural mortality coefficient (here assumed to remain con-stant for all length groups), S(j) is the step function of the selection ogive and Fm the maximum fishing

mortality. If Z, M and Fm are known the selection can be estimated by (Pope *et al.*, 1975 and Hoydal *et al.*, 1982):

$$S(j) = F(j)/Fm \qquad (6.6.1.3)$$

where

$$F(j) = Z(j) - M$$

Fig. 6.6.1.2 shows F(j), Z(j) and S(j) as functions of length. When we work with a step function rather than with a continuous logistic curve the selec-tion is given as an array of S-values and this array can replace the mathematical expression (Eq. 6.6.1.1) or the array may be applied to estimate the parameters of the logistic curve. Actually, an array of S-values is a more versatile way of presenting selection ogives as no assumptions have to be made about the underlying mathematical expression. (cf. the discussion of age/length keys versus growth equations in Section 3.2.1).

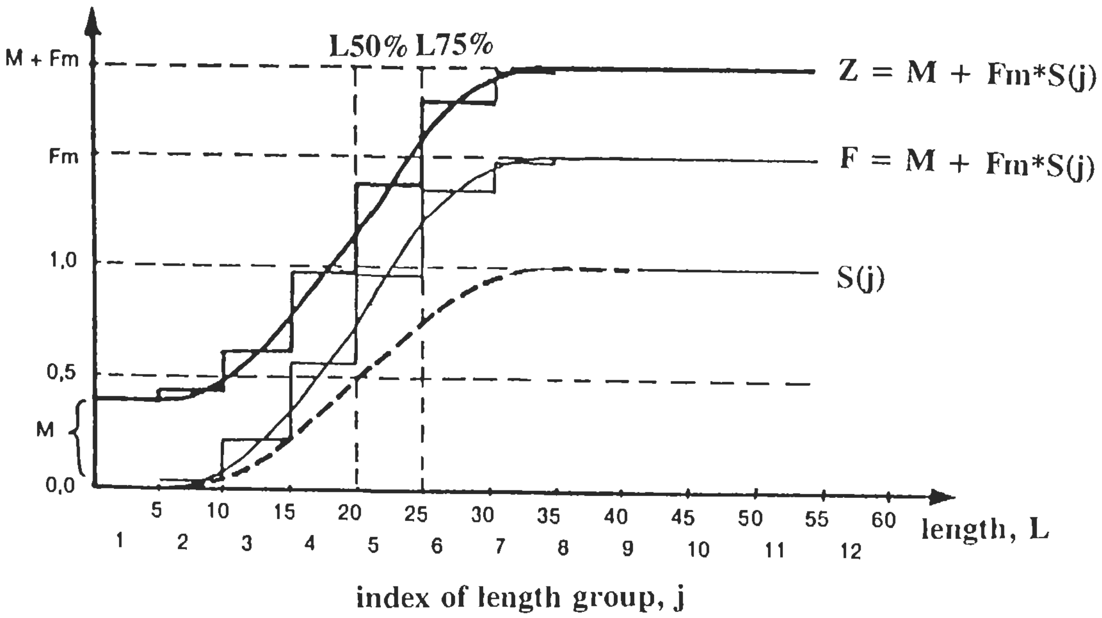


Fig. 6.6.1.2 **The relationship between mortality and the selection ogive for further explanation, see text)**

6.6.2 Estimation of selection curves from cohort analysis

The various kinds of cohort analyses (cf. Chapter 5) produce an array of estimates of F-values (the so-called "*fishing pattern*"), by age group or by length group. These F-values supply data for a gear selectivity/recruitment curve which is obtained by:

$$S(i) = \frac{F(i)}{\underset{j}{MAX}\{F(j)\}} \qquad (6.6.2.1)$$

where F(i) is the fishing mortality for age or size group i and MAX{F(j)} is the maximum value of the fishing mortality among all age or size groups (cf. Eq. 6.6.1.3). Eq. 6.6.2.1 applies to any gear or any combination of gears combined with any recruitment curve (Hoydal *et al.*, 1980 and 1982). The method makes no assumptions on the type of gear or on how the fish are caught. Thus, the selection curve of a gear can be estimated from catch data only. Eq. 6.6.2.1 gives the actual results of fishing operations and is therefore called the "*effective mesh size*", i.e. the observed selection/recruitment parameters. The concept of "effective mesh size" also applies to gear without meshes, such as hook and lines.

This approach has a number of advantages over methods where selection curves are derived from measurements of gear characteristics, e.g. mesh size. Let us, for example, consider the trawl. If we assume (as is often done) that the gear selection curve is determined by the mesh size in the codend only, then two fishing boats using gears with the same mesh size should have the same gear selection ogive. However, this is likely to be the case only if the two boats operate the gear in exactly the same way. For example, if one boat takes hauls of 5 hours duration and the other boat only uses one hour for a haul the selective properties may be different because of clogging of the net by the catch. Also the towing speed may influence the selectivity. Higher speed may make the meshes more elongated and cause a lower selection factor.

6.7 USING A SELECTION CURVE TO ADJUST LENGTH-FREQUENCY SAMPLES

When analysing a length-frequency sample, (e.g. when doing the Bhattacharya analysis, Section 3.4.1) selection may create biased results. As an example we look at the first part of Table 3.2.1.1. The sample is shown in column B of Table 6.7.1. Actually column B is the first component estimated by the Bhattacharya analysis as can be seen from column H of Table 3.4.1.1, which was based on the same data. These hypothetical data were supposed to represent a random sample of the population. Thus, in the case of Table 3.2.2.1 we assumed a non-selective gear. If the sample had been taken with a selective gear it would have been different.

Now, suppose that a gear with a trawl type selection curve with L50% = 15 cm and L75% = 18 cm had been used. In that case we would have observed the frequencies shown in column C of Table 6.7.1 and not those of column B. (Figures in column C are hypothetical ones and are calculated as the product of columns B and D.) The frequencies of column C yield a biased estimate of the mean length and the standard deviation as can be seen from the last two rows of Table 6.7.1. However, if the selection ogive is known it is possible to estimate the unbiased sample, i.e. to estimate column B. This is done by dividing the observed frequencies (column C) by the fractions retained. This raising procedure gives column E. As could be expected there are problems with small frequencies (lengths 12-14 cm). The method cannot be used to raise a zero frequency and is not dependable for small frequencies.

In general, the effect of trawl selection is:

1. Over-estimation of mean length
2. Under-estimation of standard deviation
3. Under-estimation of cohort size

The bias caused by selection is illustrated by Fig. 6.7.1.

Table 6.7.1 Example to illustrate the estimation of a random sample from a sample biased by selection (cf. Fig. 6.7.1)

A	B	C	D	E
length interval cm	observed unbiased sample (Table 3.2.1.1)	sample biased by selection	estimated ogive S_L	estimated unbiased sample C/D
12-13	1	0	0.30	0
13-14	4	1	0.37	3
14-15	11	5	0.45	11
15-16	24	13	0.55	24
16-17	38	24	0.63	38
17-18	42	30	0.71	42
18-19	33	26	0.78	33
19-20	20	17	0.84	20
20-21	7	6	0.88	7
21-22	2	2	0.92	2
total	182	124		180
mean L	17.3	17.6		17.3
s	1.69	1.60		1.64

Column	contents
A	length interval in cm
B	unbiased random sample of the population (from Table 3.2.1.1)
C	sample as it would have been obtained with a trawl net with a selection curve with L50% = 15 cm and L75% = 18 cm
D	estimated selection ogive (fraction retained) S_L = 1/(1 + exp(S1 - S2*L) Eq. 6.1.1 where S1 = L50%*ln(3)/(L75%-L50%) (Eq. 6.1.6) and S2 = S1/L50% (Eq. 6.1.7)
E	estimated unbiased samples corrected for selection, frequency of biased sample divided by fraction retained (C/D) (compare with column B)

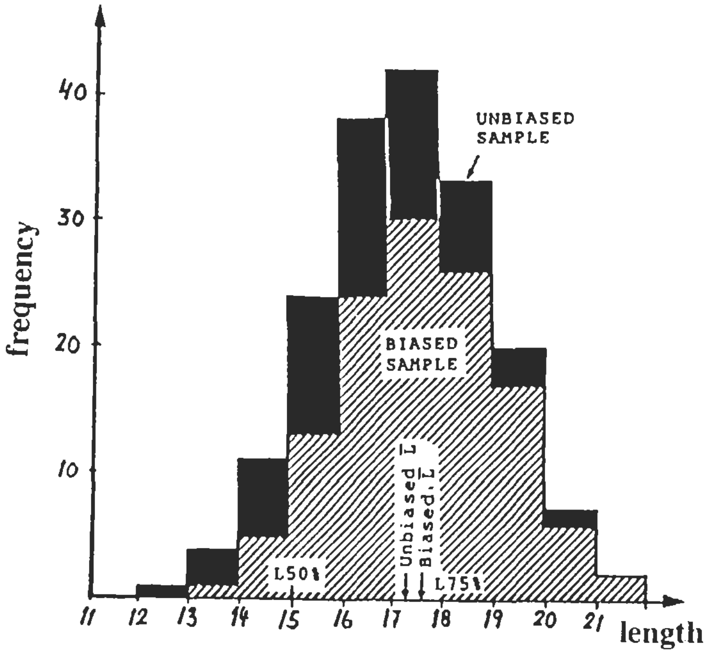


Fig. 6.7.1 Bias created by selection

Correction for mesh selection should preferably be made by means of selection curves determined by experiments like trawling with a covered codend (Section 6.1) or by analysis of fishing mortality arrays from cohort analysis (Section 6.6). Sometimes, selection curves for similarly shaped, closely related species can be used.

When no such data are available a selection curve may perhaps be estimated from a linearized catch curve (Section 6.5). Doing this, however, we encounter a logical problem because the estimation of selection is the last part of the catch curve analysis and therefore based on parameter estimates which are biased by the effects of selection. We want to start with the correction and fortunately, it is possible to do so. The sequence of analyses can be as follows:

Estimate L_∞ by the Powell-Wetherall method

Correct length-frequencies for selection using the value 1.0 for the curvature parameter, K, and the estimate of L_∞ obtained by Stage 1

Separate normally-distributed components by the Bhattacharya method (Section 3.4.1) from the corrected length-frequency distribution

Use the estimated mean lengths of the components in modal progression analysis to estimate the growth parameters K and L_∞ (Section 3.4.2)

Estimate Z using length-converted catch curve analysis with the newly-estimated growth parameters (Section 4.4.5).

This procedure is applicable because the estimation of a selection ogive is not very sensitive to the choice of the curvature parameter, K.

Example 24: Using a selection curve to adjust the length-frequency sample of Table 6.5.1

We apply the Powell-Wetherall method to the data in Table 6.5.1 column D (the numbers caught) and find $L_\infty = 49.7$ cm (cf. Table 4.5.4.1 which uses the same input data to estimate L_∞ by the Powell-Wetherall method). Redoing the calculations of Table 6.5.1 with $K = 1.0$ gives the results presented in Table 6.7.2.

The estimated selection ogive $S_t$est in Table 6.7.2 calculated with $K = 1.0$ per year and $L_\infty = 49.7$ cm is almost identical to the one presented in Table 6.5.1, calculated with $K = 0.3$ per year and $L_\infty = 50$ cm. The values of L50% and L75% are 14.8 cm and 17.8 cm respectively with $K = 1.0$, while they were 15.0 and 18.0 cm respectively with $K = 0.3$.

The last column of Table 6.7.2 contains the results of Step 2 of the process, *viz.* the length-frequencies corrected for selectivity. A comparison with the observed data (column D) shows immediately that large numbers of fish were not accounted for in the sample. The next step (3), the Bhattacharya method will therefore be very different from the one on the original data.

In principle, the above-mentioned method can be applied to any type of gear selection curve, but the narrower the selection range the more difficult it is to estimate the length-frequency you would have got with a non-selective gear.

Table 6.7.2 **Example to illustrate the use of a selection curve to adjust a length-frequency sample for selectivity, using the same length-frequency data as presented in Table 6.5.1, with L_∞ = 49.7 cm (estimated by the Powell-Wetherall method), K = 1.0 per year and t_0 = 0**

A	B	C	D	E	F	G	H	I
L1-L2	t $\frac{(L1+L2)}{2}$ (x)	Δt (L1,L2)	C (L1,L2) obs.	ln (C/Δt) (y')	S_t obs.	ln (1/S-1) (y)	S_t est.	C (L1,L2) est.
3-5	0.084	0.044	37	6.74	0.03	3.35	0.03	1121
5-7	0.129	0.046	56	7.11	0.06	2.81	0.06	1000
7-9	0.176	0.048	86	7.49	0.10	2.22	0.10	887
9-11	0.225	0.050	129	7.85	0.17	1.61	0.17	777
11-13	0.276	0.053	188	8.17	0.27	0.99	0.27	689
13-15	0.331	0.056	258	8.44	0.42	0.32	0.43	604
15-17	0.389	0.059	319	8.59	0.60	-0.40	0.61	526
17-19	0.450	0.063	352	8.63	0.76	-1.14	0.77	459
19-21	0.515	0.067	351	8.56	0.88	-1.98	0.88	398
21-23	0.585	0.072	324	8.41	0.95	-2.97	0.95	342
23-25	0.660	0.078	283	8.20	0.98	-3.94	0.98	289
25-27	0.741	0.084	239	7.95	1.00		0.99	241
27-29	0.829	0.092	196	7.66			1.00	197
29-31	0.925	0.102	158	7.35			1.00	158
31-33	1.032	0.113	123	6.99			1.00	123
33-35	1.152	0.128	93	6.59			1.00	93
35-37	1.289	0.146	69	6.16			1.00	69
37-39	1.446	0.171	48	5.64			1.00	48
39-41	1.934	0.207	31	5.01			1.00	31
41-43	1.865	0.261	18	4.23			1.00	18
43-45	2.166	0.355	10	3.34			1.00	10
45-47	2.598	0.554	3	1.69			1.00	3

T1 = 4.428   T2 = 12.492
t50% = T1/T2 = 0.3545 years   t75% = (T1 + ln 3)/T2 = 0.4424 years
L50% = 49.7*(1 - exp(-1*(0.3545 - 0))) = 14.8 cm
L75% = 49.7*(1 - exp(-1*(0.4424 - 0))) = 17.8 cm

For gill nets or any other gear with a bell-shaped selection curve one has to be careful in the interpretation of length-frequency samples. The mode observed (usually there is only one mode for this type of gear) may have little to do with a cohort, but it may primarily reflect the selection curve of the gear (cf. Section 6.2).

(See **Exercise(s)** in Part 2.)