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Estimation of effective mesh sizes and their utilization in assessment

Kjartan Hoydal
Fiskirannsoknarstovan, Debessartrød, 3800 Torshavn, Faroe Islands
Carl Jakob Rørvik
Institute of Marine Research, Bergen, 1870-5011 Nordnes, Norway
Per Sparre
The Danish Institute for Fisheries and Marine Research, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark

Abstract

A method to estimate the effective mesh sizes used by different fleets fishing on the same stock is described. The model of the fisheries makes use of the von Bertalanffy and the traditional Beverton & Holt equations to describe the dynamics of the stock. Logistic curves are used to describe the recruitment of the fish to grounds, the selective properties of the gears and the discard practice. The effective mesh sizes are estimated by minimizing the sum of squares between the estimated and observed relative length or age composition of the landings. The model can be used to estimate the effects on the different fleet's fishing mortalities and catches of changes in the mesh sizes and effort in one or more fleets etc.

Contents

1. Introduction

An important part of the work of the fisheries research has been to estimate the short-term effects on catches and stock caused by changes of the selectivity of the gears being used, in particular of changes in the mesh size of trawls. Models for such assessments have been studied by several authors (Gulland 1961, 1964; Jones 1961, 1974 and K.P. Andersen, pers. comm.).

Besides assumptions inherent in the models these methods assume that the present mesh size is known. However, as Gulland (1961) points out it is often a practical problem to determine precisely the average effective mesh size in use. He mentions two factors that may contribute to make the effective mesh size of a trawl different from the minimum legal size:

1. Shrinkage of new nets and subsequent stretching.
2. Chafing gear.

We will add some other factors to the list:

3. Lining inside the codend by small mesh netting.
4. Clogging of the net by fishes, especially when large catches are taken. This might be a significant factor even for small (by-)catches of fishes like redfish or flatfish.
5. The selective properties might change as the towing speed is changed. Higher speed may make the meshes more elongated and cause a lower selection factor.
6. The (direct measurable) mesh size in the codend may be different from the minimum legal one.

To elaborate the second factor somewhat: A covernet if allowed might be of too small mesh size. For example, a covernet of the same mesh size as used in the codend (a double codend) is found to reduce the effective mesh size by about 20-30 % (Sætersdal 1960). Tight ropes around the codend might reduce the effective mesh size (Beltestad 1977).

To make the sixth factor more clear; the codend may have been made of a slightly larger mesh size than the minimum legal size in order to make sure to be on the 'legal' side. Alternatively a codend with too small mesh sizes may be used illegally.

The present paper describes a method that on the basis of the length composition, or age composition of the catches from fleets that exploit the same stock, gives an estimate of the *effective mesh sizes* in use by the fleets.

The basic idea (K.P. Andersen, pers. comm.) is to estimate for a given set of mesh sizes, the expected length distributions, and then to compare the estimated with the respective observed distributions. An optimization routine changes the calculated (effective) mesh size in order to minimize the sum of the squared distances between the estimated and the observed relative length- (or age) distributions.

When this sum of squares is at some defined minimum, the optimization is terminated. Within the realism of the model and the quality of the fixed input parameters, we then have estimates of the effective mesh sizes used for the period from which the observed length- (or age) distributions are taken.

In addition to the catch-composition data, information about how the availability of the fish to the different fleets changes as the fish grow is needed. Information on discard practice of small fish is essential, as this practice, if used, makes the composition of the landed fish different from the actual catch composition.

The method further requires information about the total fishing mortality and how it is distributed on the different fleets. The model uses the von Bertalanffy growth equation, to correct the length with age.

For fleets that do not use trawl the gears are regarded as if they were trawls.

The result from this model may be of interest itself, not only because it gives estimates of the effective mesh sizes, but also because one might do some extent test the consistency of the basic input data versus independent information.

In the present paper the assessment of mesh size is done within the scope of a single species assessment method, but it may also be carried out in more complicated models. In Sparre (1980), a detailed description of mesh assessment in the commonly used time discrete model was given. This work also describes how mesh assessment can be incorporated into a species interaction and technical interaction model.

This model for mesh assessment is called STEP 1 in the present paper. The results from STEP 1 may be used in another model, STEP 2, which gives assessments of the effect on catches after a change in mesh sizes. These effects are estimated on yearly basis until the new stability is achieved.

STEP 2 requires that the results are given in terms of catch and discards per age-group rather than per length group. Assessments done on the basis of length-distributions may easily be recalculated in terms of age groups for the same estimated effective mesh sizes.

2. Estimation of gear parameters (STEP 1)

To aid memory, a list of all symbols used is given in Section 6.

2.1 *Fishing mortality at length and age*

In the present context the population to be considered is a yearclass during its lifespan.

Let

$N(TI)$ = the initial number of fish of the youngest age (TI years) considered.
$N(T)$ = the number of survivors at age T.

As Beverton & Holt (1957) we shall assume a constant recruitment, and constant mortality on each age- or length group, from year to year.

A corrollary of this assumption is that the characteristics of a yearclass during its lifespan equal the characteristics of all age groups of one particular year.

Consider one stock exploited by E fishing fleets. Within each fishing fleet all vessels are assumed to use the same type of gear.

A fleet is characterized by:

1. Selection curve: $SL(e,L)$
2. Recruitment curve: $RL(e,L)$
3. Discard curve: $DL(e,L)$

$SL(e,L)$ is the fraction retained of the fish of length L entering the gear of fishing fleet no. e ($e = 1, 2, \ldots, E$).

SL is composed of an ascending and a descending part. For example the larger fish might not so easily get entangled in a gill net as the medium sized ones.

All fish that enter the gear, without being retained, are assumed to survive.

$RL(e,L)$ is the recruitment of fish of length L.

The recruitment is composed of an ascending and a descending part (derecruitment) describing the migration of the fish into and out of the area exploited by fleet e.

$DL(e,L)$ the fraction of the number caught of length L which is not discarded. None of the discarded fish are assumed to survive.

Fishing mortality exerted by fishing fleet e on the fish of length L, $FL(e,L)$ is the sum of the mortalities:

$$FL(e,L) = FLLAND(e,L) + FLDISC(e,L)$$

where $FLDISC$ is the mortality caused by discarding and $FLLAND$ is the remaining fishing mortality, the 'landing mortality'.

Fishing mortality is assumed to be the product of three factors:

$$FL(e,L) = SL(e,L) \cdot RL(e,L) \cdot EF(e) \qquad (1)$$

where $EF(e)$ is the maximum fishing mortality on length groups exerted by fleet e. Discard and landing mortalities are:

$$\begin{aligned} FLLAND(e,L) &= DL(e,L) \cdot FL(e,L) \\ FLDISC(e,L) &= (1 - DL(e,L)) \cdot FL(e,L) \end{aligned} \qquad (2)$$

Total fishing mortality is the sum of the mortalities caused by the individual fleets.

$$FL(L) = \sum_{e=1}^{E} FL(e,L) = FLLAND(L) + FLDISC(L)$$

$$FLLAND(L) = \sum_{e=1}^{E} FLLAND(e,L)$$

$$FLDISC(L) = \sum_{e=1}^{E} FLDISC(e,L)$$

The relationship between age T and length L is described by the usual von Bertalanffy equation:

$$L(T) = L8(1 - \exp(-K(T - T0))) \text{ or}$$
$$T(L) = T0 - \log(1 - L/L8)/K$$

SL, RL, DL and FL can be considered as functions of age by:

$$\begin{aligned} S(e,T) &= SL(e,L(T)) \\ R(e,T) &= RL(e,L(T)) \\ D(e,T) &= DL(e,L(T)) \\ F(e,T) &= FL(e,L(T)) \\ FLAND(e,T) &= FLLAND(e,L(T)) \\ FDISC(e,T) &= FLDISC(e,L(T)) \\ F(T) &= \sum_{e=1}^{E} F(e,T) = FLAND(T) + FDISC(T) \end{aligned}$$

2.2. Population dynamics

The dynamics of the yearclass and the catches are described by the usual equations as given by Beverton & Holt (1957).

The number of survivors of the yearclass is determined from:

$$\frac{dN(T)}{dT} = -(F(T) + M(T))N(T)$$

where $M(T)$ is the natural mortality at age T.

The number caught is given by:

$$\frac{dC(T)}{dT} = F(T) \cdot N(T)$$

where $C(T)$ is the total number caught in the time period from TI to T.

The number caught by fleet e is given by:

$$\frac{dC(e,T)}{dT} = F(e,T) \cdot N(T)$$

where $C(e,T)$ is the number caught by fishing fleet e in the time period from TI to T:

$$C(e,T) = \int_{TI}^{T} F(e,t) \cdot N(t)dt$$

The number landed by fleet e is:

$$LAND(e,T) = \int_{TI}^{T} D(e,t) \cdot F(e,t) \cdot N(t)dt$$

and the number discarded is:

$$DISC(e,T) = \int_{TI}^{T} (1 - D(e,t)) \cdot F(e,t) \cdot N(t)dt$$

Total number caught, landed and discarded by all fleets are $\sum C(e,T)$, $\sum LAND(e,T)$ and $\sum DISC(e,T)$ respectively.

The number caught in time period from $T1$ to $T2$ is:

$$C(T2) - C(T1) = \int_{TI}^{T2} F(t) \cdot N(t)dt$$

The number caught of lengths between $L1$ and $L2$ is:

$$C(T(L2)) - C(T(L1)) = \int_{T(L1)}^{T(L2)} F(t) \cdot N(t)dt$$

The number caught by fleet e of lengths between $L1$ and $L2$ is:

$$C(e,T(L2)) - C(e,T(L1)) = \int_{T(L1)}^{T(L2)} F(e,t) \cdot N(t)dt$$

2.3. *Number caught per length group*

Let the catch be divided into length groups by

$LG(1), LG(2), \ldots\ldots, LG(\mathrm{I})$.

A fish belongs to length-group i, if

$LG(i) \leqq$ length of the fish $< LG(i+1)$

Let

$TG(i) = T(LG(i))$

Then the number caught in length group i becomes:

$C(TG(i+1)) - C(TG(i))$

and the number caught in length group i by fishing fleet e is:

$C(e,TG(i+1)) - C(e,TG(i))$

The number landed from length group i by fishing fleet e is:

$$CL(e,i) = LAND(e,TG(i+1)) - LAND(e,TG(i)) \tag{3}$$

and the number discarded is:

$$CD(e,i) = DISC(e,TG(i+1)) - DISC(e,TG(i)) \tag{4}$$

The total catch per length group is designated:

$CT(e,i) = CL(e,i) + CD(e,i)$

CT and CL are the basic observations of this analysis.

The number caught per age group is calculated by defining the limits of the length groups so that each length group corresponds to one whole agegroup.

The isometric relationship between length and weight is given by:

$w(T) = Q \cdot L(T)^3$

where Q is the condition factor. The yield per length group (or age group) can be calculated by inserting this relationship under the integrals above, for example

$$CW(e,T) = \int_{TI}^{T} Q \cdot L(t)^3 F(e,t) N(t) dt \tag{5}$$

where $CW(e,T)$ is the catch in weight by fleet e in the time period from TI to T.

2.4. *Parameters of the selection curves*

The gear-selection curve $SL(e,L)$ is defined by:

$$SL(e,L) = \frac{1}{1 + GSEL(e,L)} \cdot \frac{1}{1 + DGSEL(e,L)} \tag{6}$$

where:

$$GSEL(e,L) = \exp\left\{-\frac{(L - L50\%(e))\log 3}{L75\%(e) - L50\%(e)}\right\} \tag{7}$$

and

$$DGSEL(e,L) = \exp\left\{-\frac{(L - DL50\%(e))\log 3}{DL75\%(e) - DL50\%(e)}\right\} \tag{8}$$

Thus, the gear-selection curve is a product of two logistic curves. The logistic equation rather than the normal model has also been used by Kimura (1977).

L50%(e) and *L75%(e)* are the lengths at which 50% and 75% resp. of the fish entering the gear of fleet *e* are retained by the gear (see Fig. 1).

L50% and *L75%* describe the left hand side of the gear-selection curve (the ascending part). *DL50%* and *DL75%* are the equivalent parameters for the right hand side of the curve (the descending part), as illustrated in Fig. 1.

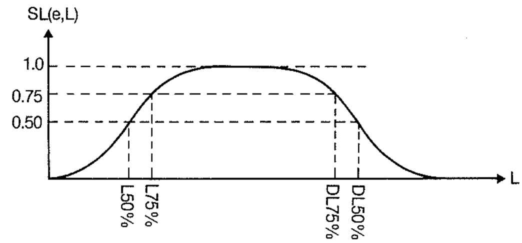

Fig. 1. Gear selection curve.

The expression of the recruitment curve is mathematically equivalent to that of the gear-selection curve:

$$RL(e,L) = \frac{1}{1 + RSEL(e,L)} \cdot \frac{1}{1 + DRSEL(e,L)}$$

where

$$RSEL(e,L) = \exp\left\{-\frac{(L - RL50\%(e))\log 3}{RL75\%(e) - RL50\%(e)}\right\}$$

$$DRSEL(e,L) = \exp\left\{-\frac{(L - DRL50\%(e))\log 3}{DRL75\%(e) - DRL50\%(e)}\right\}$$

The discard curve, *DL(e,L)* (= the fraction not discarded) does not have a descending part as only small fish are assumed to be discarded. For the ascending part of the curve the expression is equivalent to those of gear selection and recruitment:

$$DL(e,L) = \frac{1}{1 + DISEL(e,L)}$$

where

$$DISEL(e,L) = \exp\left\{-\frac{(L - DIL50\%(e))\log 3}{DIL75\%(e) - DIL50\%(e)}\right\}$$

Thus, landing and discard mortalities (Eqs. (1) and (2)) are determined by the set of parameters (one set for each fishery):

EF:	total fishing mortality on age- or length-groups subject to maximum exploitation.
L50%, *L75%*:	ascending gear-selection curve.
DL50%, *DL75%*:	descending gear-selection curve.
RL50%, *RL75%*:	ascending recruitment curve.
DRL50%, *DRL75%*:	descending recruitment curve.
DIL50%, *DIL75%*:	discard curve.

The parameter to be estimated is $MESH(e)$, the effective mesh size of fishing fleet e.

$MESH(e)$ is determined by $L50\%$ and the selection factor $SEL(e)$

$$L50\%(e) = MESH(e) \cdot SEL(e) \tag{9}$$

In the present analysis all parameters, except for $MESH(e)$ (and consequently $L50\%(e)$) are assumed to be known from independent investigations. Instead of assuming $L75\%(e)$ to be known, the ratio

$$FAC(e) = \frac{L75\%(e)}{L50\%(e)} \tag{10}$$

is assumed to be known, so that the estimation of $L75\%$ follows immediately from the estimate of $MESH$ (or $L50\%$).

That $FAC(e)$ is taken to be constant implies that the slope of the selection curve decreases as the mesh size increases. At least for haddock there are experimental evidence that this is the case (Jones 1963, Fig. 4).

For some fisheries derecruitment does not occur, or fishes are not discarded whatever the size of the fishes. In the case of no derecruitment this is simulated in the program by setting the lengths defining the derecruitment $DRL50\%$ and $DRL75\%$ to some suitable values well above the length range simulated. If fishes are not discarded at all, this is simulated by setting $DIL50\%$ and $DIL75\%$ to some suitable values well below the length range simulated.

2.5. *Observed and theoretical length distribution of the catches*

Eqs. (3) and (4) define the theoretical length distributions of catches as predicted by the model.

Let us rewrite the expressions by inserting the symbols for selection curves.

$$CL(e,i) = \int_{TG(i)}^{TG(i+1)} FLLAND(e,L(t)) \cdot N(t)dt =$$
$$\int_{TG(i)}^{TG(i+1)} DL(e,L(t)) \cdot SL(e,L(t)) \cdot RL(e,L(t)) \cdot EF(e) \cdot N(t)dt \tag{11}$$

and

$$CD(e,i) = \int_{TG(i)}^{TG(i+1)} FLDISC(e,L(t)) \cdot N(t)dt =$$
$$\int_{TG(i)}^{TG(i+1)} (1 - DL(e,L(t))) \cdot SL(e,L(t)) \cdot RL(e,L(t)) \cdot EF(e) \cdot N(t)dt$$

The estimates of numbers landed by length are based on samples from commercial landings. The standard is that the observed length distribution of landings is taken as the average of a number of years in which the gears are assumed to have remained unchanged.

The observations are designated:

$OBSCL(e,i)$ = observed number of fish landed in length group i by fishing fleet e.

The estimation problem is to find values of $MESH(e)$, $e = 1, 2, \ldots, E$ so that

$$\sum_{e=1}^{E} \sum_{i=1}^{I} (CL(e,i) - OBSCL(e,i))^2 \tag{12}$$

is minimized.

To spell out the relations between the various parameters and variables the expression (12) may be rewritten by using the expression for CL defined by Eq. (11). The term SL, the gear-selection curve, was defined by Eqs. (6), (7) and (8) and these expressions are inserted into Eq. (11). The last thing to do for converting Eq. (12) into Eq. (13) is to insert Eqs. (9) and (10) into the expression for SL.

$$\sum_{e=1}^{E} \sum_{i=1}^{I} \left\{ \int_{TG(i)}^{TG(i+1)} DL(e,L(t)) \cdot RL(e,L(t)) \cdot EF(e) \cdot \frac{1}{1 + DGSEL(e,L(t))} \cdot \frac{1}{1 + \exp\left(- \frac{(L(t) - MESH(e) \cdot SEL(e))\log(3)}{(FAC(e) - 1)MESH(e) \cdot SEL(e)}\right)} N(t)dt - OBSCL(e,i) \right\}^2 \tag{13}$$

Thus, the problem is to determine $MESH(e)$ so that the sum (13) is minimized, when all other terms of (13) are known parameters or observations.

The values of $MESH(e)$, $e = 1, 2, \ldots, E$ which minimizes the sum of squares of deviations (13) are the *effective mesh sizes.*

With some appropriate changes in integration limits in (13) and by substituting the observed length distribution with an observed age distribution, age distributions can be used in the same way. The summation in (13) is then done over age groups rather than length groups.

2.6. *Estimation procedure*

To determine the value of the sums of squares (13) requires the solution of a set of simultaneous differential equations. The differential equations are those which describe the dynamics of the population and landings.

$$\begin{aligned}
\frac{dN(t)}{dt} &= -(M(t) + F(t))N(t) \\
\frac{dLAND(1,t)}{dt} &= D(1,t)F(1,T)N(t) \\
\frac{dLAND(2,t)}{dt} &= D(2,t)F(2,t)N(t) \\
&\vdots \\
\frac{dLAND(E,t)}{dt} &= D(E,t)F(E,t)N(t)
\end{aligned} \tag{14}$$

To determine a unique solution of Eqs. (14) initial values of the variables N and $LAND$ are required.

The initial value of $LAND$ is obviously zero.

$$LAND(e,TI) = 0 \text{ for all } e.$$

The initial value of N is arbitrarily assigned the value 1000 ($N(TI) = 1000$) which means that all calculations are made on a relative basis.

To make the observations comparable to the theoretical catches, $OBSCL$ should be expressed in relative terms. This could be done as follows:

The observed relative length distribution of catches is defined

$$\frac{OBSCL(e,i)}{\sum_e \sum_i OBSCL(e,i)} = ROBSCL(e,i)$$

The estimated (theoretical) distribution is defined

$$\frac{CL(e,i)}{\sum_e \sum_i CL(e,i)} = RCL(e,i)$$

The sum of squares to be minimized (12) becomes

$$\sum_e \sum_i [RCL(e,i) - ROBSCL(e,i)]^2 \quad (15)$$

This object function considers the observations relative to the total catch.

Another possibility is to consider the catches of each fleet relative to the catch of the fleet, i.e. to define relative observations as

$$\frac{OBSCL(e,i)}{\sum_i OBSCL(e,i)} = ROBSCL(e,i) \quad (16)$$

and relative estimates as

$$\frac{CL(e,i)}{\sum_i CL(e,i)} = RCL(e,i) \quad (17)$$

The latter approach considers each fleet as being of equal importance, whereas the first approach considers those fleets with the largest catch as the most important ones.

The differential equations can be solved by some numerical method (e.g. Runge-Kutta, see e.g. Ralston, 1956).

In the Appendix a numerical example of Eqs. (14) is discussed. To minimize the sum of squares of deviations (15) some numerical optimization method must be applied.

Several optimization methods were tested (cf. App.). However, from a biological point of view these technical details are of a limited interest, and only a brief description of the procedure is given here. The optimization algorithm works as an iterative process. That is, the algorithm should be provided with an initial guess on the unknown variables (the *MESHs*), and based on that the algorithm calculates an improved estimate. This process continues until the estimates in the current and in the foregoing iteration are approximately equal.

3. Assessing the effect of changing gear parameters (STEP 2)

The time continuous single species model has been used in some assessments of mesh changes (Anon. 1974, 1977, 1979 and 1980) and a formal description of the method is given in this section.

The time table of a mesh change is illustrated by Fig. 2.

In this approach, it is assumed that the population is in a steady state situation before time $T1$. After the change of mesh sizes the parameters of the system are assumed to remain constant, which implies that the system ends up in a new steady state after a certain transient period.

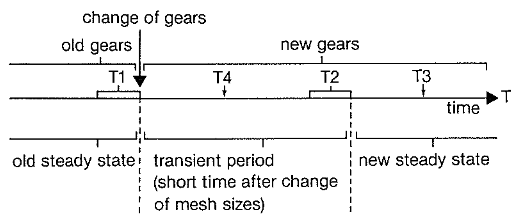

Fig. 2. Time table of mesh change assessment.

The model could be applied as a strategic model, i.e. to assess the long term effect of a mesh change. A drawback of the model, which it shares with the usual yield per recruit models, is that density dependent growth and recruitment is not accounted for.

The output of the model contains a description of the transient period between the old steady state and the new steady state (see Fig. 2), but these results should be treated with reservation, as the assumptions of an initial stable situation and a constant recruitment may not be fulfilled. However, the simulated age compositions of the stock and the catches give estimates of the fishing mortalities for each fleet. The changes in these fishing mortalities may be used to calculate the actual short term changes in the catches, when the mesh sizes are changed in a nonequilibrium situation of the stock.

In the following it should be assumed that we are in a constant parameter system.

Let $OMESH(e)$ designate the set of old parameters and mesh sizes and $NMESH(e)$ the new set of parameters and mesh sizes. Let the change of mesh sizes occur at the end of year $T1$. Let $T2$ designate the time at which the transient period is over (see Fig. 2). In the present context we consider all year classes during one year, and not as in the foregoing sections, a year class during its life span.

To describe such a system the notation must be modified. Let $N(y,t)$ designate the number of survivors in year y at age t from a year class. Thus at the beginning of year $T1$ the stock is composed of the following year-classes.

$$N(T1,0),\ N(T1,1),\ N(T1,2),\ \ldots$$

(Due to notational convenience, fish are assumed to be 'born' on January 1, in the following derivations.)

At time u in year $T1$ $(0 \leqq u \leqq 1)$ the stock is composed of

$$N(T1,u),\ N(T1,1+u),\ N(T1,2+u),\ \ldots\ldots$$

Let $T3$ be some year after the end of the transient period.

The number landed in age groups a before change of mesh size (e.g. in year $T1$) by fleet e is:

$$LANDY(e,T1,a) = \int_0^1 OFLAND(e,a+u)N(T1,a+u)du$$

where $OFLAND$ is the landing mortality defined by the old gear-selection curve (and discard and recruitment curve).

i.e.

$$OFLAND(e,a+u) = D(e,a+u)R(e,a+u)EF(e) \cdot$$

$$\left(1 + \exp\left\{-\frac{L(a+u) - OMESH(e)SEL(e))\log 3}{(FAC(e)-1)OMESH(e)SEL(e)}\right\}\right)^{-1}$$

After the transient period the landings in, say, year $T3$ become

$$LANDY(e,T3,a) = \int_0^1 NFLAND(e,a+u)N(T3,a+u)du$$

where $NFLAND$ is defined by the new gear-selection curve.

The landings are determined by solving the system of differential equations (Eqs. (14)) for both the new and the old parameters.

Discards are given by:

$$DISCY(e,T1,a) = \int_0^1 OFDISC(e,a+u)N(T1,a+u)du$$

and

$$DISCY(e,T3,a) = \int_0^1 NFDISC(e,a+u)N(T3,a+u)du$$

and as the landings they are found by solving a system of differential equations:

$$\frac{dDISC(e,t)}{dt} = (1 - D(e,t)) \cdot F(e,t) \cdot N(t,a)$$

$$e = 1,2,\ \ldots,E$$

By the above described procedure the landings and discards before and after the transient period are determined.

The yield of fleet e before and after the transient period is calculated by using Eq. (5) or by the approximation:

$$\sum_a LANDY(e,T1,a)W(a) = YIELD(e,T1)$$

and

$$\sum_a LANDY(e,T3,a)W(a) = YIELD(e,T3)$$

where $W(a)$ is the average body weight of an a year old fish.

Discards are found by similar expressions.

The yields in the transient period may be assessed in the following way:
Let $T4$ be some year in the transient period ($T1 < T4 < T2$).
Let $A4 = T4 - T1$. The yield in year $T4$ by fleet e is then

$$YIELD(e,T4) =$$
$$\sum_{a=0}^{A4-1} LANDY(e,T3,a)W(a) + \sum_{a=A4} \frac{N(T1,a)}{N(T3,a)} LANDY(e,T3,a)W(a)$$

4. Choosing the input parameters

Observed length- (or age) distributions: These observed values should be averaged for several years, so that the assumption of constant recruitment applies reasonably well. The number of years should be at least the same as the number of recruited age groups.

The von Bertalanffy parameters: These include the assymptotic length as the age increases ($L8$), the growth rate (K) and the age at zero length ($T0$).

Keeping all the other parameters constant, the higher the K (or $L8$) the lower becomes the effective mesh size when estimated from the length distributions. This is intuitively reasonable. The shorter time a year class spends in a length group, in particular the smallest length groups, the lower must the effective mesh size be, in order to 'explain' the observed frequency of the smaller fishes in the catch. The effective mesh sizes are independent of the value of $T0$ when using the length distributions.

Simulations on the basis of the age distributions show rather contrary effects. The estimates of the effective mesh size increase as $L8$ or K increase. This is reasonable as the average length of any age-group then increases. Thus higher effective mesh sizes are required, otherwise the youngest age groups will be over-represented in the simulated age distributions. If $T0$ increases the average length of any age group decreases, and by similar reasoning – a lower effective mesh size is required when using the observed age distributions.

Selection factor ($SEL(e)$) and steepness of selection curve ($FAC(e)$)
These parameters are determined in mesh selection experiments.

Recruitment function
A fleet might not cover the whole area of distribution for any size of the fish from the stock concerned. Therefore a proper interpretation of the recruitment function that varies between 0 and 1.0 is not the proportion of all the fishes of length L that are available to the fleet concerned, but rather the availability at length L compared with the maximum availability to the fleet of fishes of any length.

The parameters needed in the recruitment function are not as easily determined from experiments as the selection factor and the $L75\,\%/L50\,\%$ ratio. However, general knowledge about the distribution of the stock and its migration may help. The general fit between the observed and the estimated length- (or age) distributions may also give clues to whether the input parameter values are reasonable.

For example, if the estimated frequencies drop much faster than the observed frequencies as the length (or age) increases above that value giving the peak of the frequencies, it may mean that the de-recruitment function applied is too steep, or biased towards the lower length groups. However, the discrepancies may also be caused by a too high total mortality assumed, which leaves fewer fish to survive to the higher length- (or age) groups.

The recruitment function used affects the estimation of the effective mesh sizes in the following way: The more the ascending part is shifted to the right that is towards higher values of *RL50%* and *RL75%*, the lower becomes the estimated effective mesh size. The less the smaller fish are assumed to be available, the higher selectivity of the gear for smaller fish is needed in order to explain the observed occurrence of these sizes in the catch.

Discard parameters: Discarding of small fishes at sea cuts off the lower tail of the length- (and age) distributions, and it is essential to have reliable observations about this practice. In the model only discarding of small fish is assumed.

The discard parameters affect the outcome of the simulation in the same general way as the recruitment parameters. The larger the length of discarded fish, the lower become the estimates of the effective mesh sizes.

Fishing mortalities: The first problem is to choose the fishing mortality coefficient on the age-groups subject to maximum exploitation to put into the simulations.

This corresponds to the summed fishing mortality by all fleets on the same age-groups. One way to do this is to choose the corresponding values from VPA (Virtual Population Analysis, Gulland, 1965) averaged for the same years which the basic data in the mesh estimation procedure cover.

Assuming a constant natural mortality coefficient, increases in the fishing mortalities, assumed in the simulations, will give higher estimates of effective mesh size, or to put it another way, to get correspondence between observed and simulated distributions, there has to be assumed a higher effective mesh size if the fishing mortality is increased. If this is not done the simulated distributions will have too large numbers of small fishes.

The second problem is to split the fishing mortality between fleets. If there are age- or length-groups, where all fleets exploit the stock at maximum, the splitting is done according to the proportion of catches in numbers by each fleet in these groups.

There is another iterative way to estimate the split of *F* on fleets by which 'educated guesses' is made until the estimate of the total catch, by number or weight, is distributed between the different fisheries in the same proportions as the observed catches. This alternative requires, however, several optimizations, especially if other input parameters, which affect the estimated catch distribution, are changed concurrently.

A third method is to change the estimated proportions *F* until the estimated fishing mortality on age groups subject to maximum exploitation becomes equal to the observed fishing mortality in each fleet. The observed fishing mortalities generated by each fleet might be calculated from VPA. However, this requires that the basic age compositions of the catch for each fleet are available for the years concerned.

Natural mortality M: In all applications of the model, the natural mortality coefficient, M, was assumed to be constant for all length groups. This has been done since it has been the usual practice in stock assessments. However, a length dependent natural mortality curve could easily be included. If M is changed, it should be recognized that the input fishing mortality on maximum exploited age groups probably also should be changed, since it is often derived from methods (VPA or catch curves) where the calculated fishing mortalities depend on the assumed natural mortality.

5. Use of the method for other purposes

The use of these methods is not restricted to estimating effective mesh sizes and the yearly effects of a change in gear parameters or fleet parameters, although the present description of the methods are focused on these possibilities. Effects of a change in the discard practice, or a shift of a fishery to an area where the recruitment is different etc. may be estimated. The effects on the other fisheries of reducing or excluding one fishery may be estimated by reducing F or by setting F to zero for this particular fishery. Thus prognosis on the separate fleets as well as for the total fisheries may be given. This has been done by Sparre (1980), and Hoydal (1977, 1980).

In the model the catch is calculated for a particular fleet, by using the product of the discard curve, the selction curve, and the recruitment curve. Except for the discard curve, the curves consists of an ascending and a descending part. As described above all parts of the curves are fixed by the input parameters, except for the ascending part of the selection curve which depends on the effective mesh size which is to be determined.

However, any other parts of curves may be estimated. If, for example, the effective mesh size is determined by an independent method, the recruitment to the fisheries may be determined by an appropriate rearrangement of the input parameters. Or for example, the derecruitment could be estimated by fixing the selection curve and let the guesses length at 50% derecruitment replace the initial guess of the downward slope of the effective mesh size. If several of these different curves are simulated, one should be aware of the possibility of circular arguments.

There are obviously possibilities to manipulate the input parameters in order to get low estimates of effective mesh, especially by shifting the parameters for the ascending recruitment curves or the discard curves towards higher length values. However, accepting the observed length- (or age) distributions there are upper limits to what the effective mesh sizes could be. Estimates of these maximum possible effective mesh sizes are achieved by using the most 'conservative' input parameters. This is examplified in the Arctic Fisheries Working Group (Anon. 1979) where the maximum effective mesh sizes for North-East Arctic cod and haddock are given.

Questions may be raised about the validity of the exact estimates of the effective mesh size. However, if one wants to investigate the effects of raising the legal mesh size by, say, 35 mm, and one assumes this to correspond to an increase of the effective mesh size by the same amount (35 mm), then it has been our experience that these effects (in % change) are not very sensitive to the initial mesh sizes chosen, that is if one choose the old legal mesh size or the estimated effective mesh size. This means that STEP 2 used in the connection with STEP 1 may be useful even when the results from STEP 1 are questionable, because the relative effects will be less questionable.

6. List of symbols

a	Index of age group.
$C(e,T)$	The number caught in the time period TI to T by fleet e.
$C(T)$	$\sum_e C(e,T)$ total number caught in the time period from TI to T by all fleets.
$CD(e,i)$	The number from length group i discarded by fleet e.
$CL(e,i)$	The number landed of length group i by fleet e, theoretical value.
$CT(e,i)$	Total number caught (landings + discards) of length group i by fleet e.
$D(e,T)$	Discard curve (the fraction not discarded) as a function of age, for fleet e.
$DL(e,L)$	Discard curve (the fraction not discarded) as a function of length, for fleet e.
$DL50\%(e)$	50 percent gear-selection length of fleet e, for the descending part of the curve.
$DL75\%(e)$	75 percent gear-selection length of fleet e, for the descending part of the curve.
$DRL50\%(e)$	50 percent recruitment length of fleet e, for the descending part of the curve.
$DRL75\%(e)$	75 percent recruitment length of fleet e, for the descending part of the curve.
$DIL50\%(e)$	50 percent discard length of fleet e.
$DIL75\%(e)$	75 percent discard length of fleet e.
$DGSEL(e,L)$	Term in the descending factor of the gear-selection curve of fleet e.
$DISEL(e,L)$	Term in the discard curve of fleet e(the fraction not discarded).
$DRSEL(e,L)$	Term in the descending factor of the recruitment curve of fleet e.
$DISC(e,T)$	The number discarded in the time period from TI to T by fleet e.
$DISCY(e,T,a)$	Discards of age group a in year T by fleet e (only used in the prognosis part of the model.
E	Number of fleets.
e	Index of fleet.

$EF(e)$	Fishing mortality exerted by fleet e, on age groups subject to maximum exploitation.
$F(e,T)$	Fishing mortality at age T exerted by fleet e.
$F(T)$	$\sum_e F(e,T)$: total fishing mortality at age T.
$FL(e,L)$	Fishing mortality at length L exerted by fleet e.
$FL(L)$	$\sum_e FL(e,L)$: total fishing mortality at length L.
$FLAND(e,T)$	Landing mortality at age T exerted by fleet e.
$FDISC(e,T)$	Discard mortality at age T exerted by fleet e.
$FLAND(T)$	$\sum_e FLAND(e,T)$: total landing mortality at age T.
$FDISC(T)$	$\sum_e FDISC(e,T)$: total discard mortality at age T.
$FLLAND(e,L)$	Landing mortality at length L, exerted by fleet e.
$FLDISC(e,L)$	Discard mortality at length L, exerted by fleet e.
$FLLAND(L)$	$\sum_e FLLAND(e,L)$: total landing mortality at length L.
$FLDISC(L)$	$\sum_e FLDISC(e,L)$: total discard mortality at length L.
$FAC(e)$	$L75\%(e)/L50\%(e)$.
$GSEL(e,L)$	Term in the ascending factor of the gear-selection curve of fleet e.
i	Index of length group.
I	Number of length groups.
K	von Bertalanffy growth parameter.
L	Length.
$L(t)$	Length at age t (the von Bertalanffy growth equation: $L8(1 - \exp(-K(t - T0)))$.).
$L8$	Assymptotic length in the von Bertalanffy equation.
$LG(i)$	Length group i. Length group i is defined as the interval between $LG(i)$ and $LG(i + 1)$.
$LAND(e,T)$	Number landed in the time period from TI to T by fleet e.
$L50\%(e)$	50 percent gear-selection length of fleet e for the ascending part of the curve.
$L75\%(e)$	75 percent gear-selection length of fleet e, for the ascending part of the curve.
$LANDY(e,T,a)$	Landings of age group a in year T by fleet e (only used in the prognosis part of the model).
$M(T)$	Natural mortality at age T.
$N(T)$	Stock number at age T.
$N(T,a)$	The stock number at age a in year T(only used in the prognosis part of the model).
$NMESH(e)$	'New mesh size', mesh size after change of gear of fleet e.
$NFLAND(e,a)$	'New' landing mortality (after change of gear) of fleet e, on age-group a.
$NFDISC(e,a)$	'New' discard mortality (after change of gear) of fleet e, on age-group a.

OBSCL(e,i)	Observed number landed of length group *i* fish by fleet *e*.
OMESH(e)	'Old mesh size' before change of gear of fleet *e*.
OFLAND(e,T)	'Old' landing mortality (before change of gear) of fleet *e*, on fish of age *T*.
OFDISC(e,T)	'Old' discard mortality (before change of gear) of fleet *e*, on fish of age *T*.
Q	Condition factor.
R(e,T)	Recruitment curve for fleet *e*, as a function of age.
RL(e,L)	Recruitment curve for fleet *e*, as a function of length.
RCL(e,i)	Relative number of length group *i* landed by fleet *e*. Estimated (theoretical) value.
ROBSCL(e,i)	Relative number of length group *i* landed by fleet *e*, observed value.
RSEL(e,L)	Term in the ascending factor of the recruitment curve.
RL50%(e)	50% recruitment length of fleet *e*, for the ascending part of the curve.
RL75%(e)	75% recruitment length of fleet *e*, for the ascending part of the curve.
S(e,T)	Gear-selection curve as a function of age, for fleet *e*.
SL(e,L)	Gear-selection curve as a function of length, for fleet *e*.
SEL(e)	Selection factor of fleet *e*.
T	Time (year), or age.
TI	Youngest age considered.
T0	The theoretical age of length 0 on the von Bertalanffy equation.
T(L)	The inverse von Bertalanffy function.
TG(i)	Age corresponding to length *LG(i)*.
T1	Year when gears are changed.
T2	Last year of transient period.
T3	Some year after the transient period.
T4	Some year in the transient period.
W(a)	Average body weight of age group *a*.
YIELD(e,T)	Yield of fleet *e* in year *T*.

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Appendix

An example

The present (hypothetical) example deals with three fleets ($E = 3$) and 15 five-cm length groups ($I = 15$). The lengths are all in cm units and the time is in years.

The parameters in the von Bertalanffy growth equation are

$L8 = 131.0$, $K = 0.13$, $T0 = 0.0$

Natural mortality is assumed constant for all age-groups

$M = 0.2$

Condition factor Q is given the value 0.01.

The observed length distributions are shown in Table A1. Gear and recruitment parameters are given in Table A2. Tables A1 and A2 are the input for the computer program. In this example the relative length distributions are relative to the catch of each fleet (i.e. Eqs. (16) and (17) are used).

For the sake of simplicity we have chosen $RL50\%(e) = 0$, $RL75\%(e) = 1.0$, $DRL50\%(e) = 150$ and $DRL75\%(e) = 149$ which means that recruitment to fishing grounds is assumed to be finished before fishing starts at a length of 10 cm

Table A1. Observed numbers caught (arbitrary unit).

i	Length-groups, cm $LG(i) - LG(i+1)$	Total catch per length group (numbers) Fleet 1 $OBSCL(1,i)$	Fleet 2 $OBSCL(2,i)$	Fleet 3 $OBSCL(3,i)$	$\sum_{e=1}^{3} OBSCL(e,i)$
1	10-15	110	11	19	140
2	15-20	648	25	42	715
3	20-25	3946	128	96	4170
4	25-30	16829	413	229	17471
5	30-35	32280	1344	627	34251
6	35-40	44682	3353	1163	49198
7	40-45	40688	7163	2420	50271
8	45-50	33015	10515	4562	48092
9	50-55	24782	10517	7349	42648
10	55-60	16243	8183	9747	34173
11	60-65	10162	4491	8926	23579
12	65-70	3714	1841	3839	9394
13	70-75	1761	1178	1235	4174
14	75-80	267	983	128	1378
15	80-85	6	8	5	19
Total		229133	50153	40387	319673

Table A2. Gear parameters.

		Fleet, e 1	2	3
Selection factor:	$SEL(e)$	3.00	3.60	3.60
$L75\%/L50\%$:	$FAC(e)$	1.10	1.10	1.08
Descending part of the gear selection curve:	$DL50\%(e)$	150.0	150.0	150.0
	$DL75\%(e)$	149.0	149.0	149.0
Recruitment curve:	$RL50\%(e)$	0	0	0
	$RL75\%(e)$	1.0	1.0	1.0
	$DRL50\%(e)$	150.0	150.0	150.0
	$DRL75\%(e)$	149.0	149.0	149.0
Discard curve:	$DIL50\%(e)$	0	0	0
	$DIL75\%(e)$	1.0	1.0	1.0
Fishing mortality subject to maximum exploitation:	$EF(e)$	0.450	0.225	0.225
Initial guess on mesh sizes, cm		10.0	12.0	12.0

and no derecruitment is assumed. Thus, $RL(e,L(t)) = 1.0$ for all t in the simulated length range. $DIL50\%(e) = 0$ and $DIL75\%(e) = 1.0$ implies that $DL(e,L(t)) = 1.0$ for all t, i.e. no fish are discarded in this example, which simplifies the subsequent equations.

In the present example $LAND = C$. If the parameter values in Table A2 are inserted into Eqs. (14) with the expression for SL (Eqs. (7) and (8)) the system of differential equations, (14), becomes:

$$
\begin{aligned}
&\text{I: } \frac{dN(t)}{dt} = -\Bigg\{ 0.2 + 0.450\left[1 + \exp\left(-\frac{(L(t) - MESH(1)3.0)\log 3}{0.3MESH(1)}\right)\right]^{-1} \\
&\quad +0.225\left[1 + \exp\left(-\frac{(L(t) - MESH(2)3.6)\log 3}{0.36MESH(2)}\right)\right]^{-1} \\
&\quad +0.225\left[1 + \exp\left(-\frac{(L(t) - MESH(3)3.6)\log 3}{0.288MESH(3)}\right)\right]^{-1}\Bigg\} N(t) \\
&\text{II: } \frac{dLAND(1,t)}{dt} = 0.450\left[1 + \exp\left(-\frac{(L(t) - MESH(1)3.0)\log 3}{0.3MESH(1)}\right)\right]^{-1} N(t) \\
&\text{III: } \frac{dLAND(2,t)}{dt} = 0.225\left[1 + \exp\left(-\frac{(L(t) - MESH(2)3.6)\log 3}{0.36MESH(2)}\right)\right]^{-1} N(t) \\
&\text{IV: } \frac{dLAND(3,t)}{dt} = 0.225\left[1 + \exp\left(-\frac{(L(t) - MESH(3)3.6)\log 3}{0.288MESH(3)}\right)\right]^{-1} N(t) \\
&\quad \text{where } L(t) = 131.0(1 - \exp(-0.13t))
\end{aligned}
\tag{A1}
$$

To solve the system the values of N and $LAND$ at time $t = 0$ must be given. The values of $LAND$ at time 0 should be 0, and N is given the value 1000. Since in the last end everything is expressed in relative terms the initial value of N can be given an arbitrary value.

The iteration procedure of optimization, i.e. the minimization of the sum of squares (15), involves that the systems of equations A1 are solved several times for various choices of mesh sizes.

For the first iteration a guess of $MESH(1)$, $MESH(2)$ and $MESH(3)$ must be made by the user.

We shall not go into details about the Runge-Kutta-Merson method for numerical solutions of differential equations which was used (for a detailed description see e.g. Ralston 1956). Having solved the system, the functions $N(t)$ and $LAND(e,t)$ become known and CL can be calculated from Eq. (3).

The next step is to calculate the estimated relative distribution $RCL(e,i)$ (cf. Eq. (17)) and to compare RCL with the observed relative distribution by the sum of squares of differences (Eq. (15)).

If the sum of squares (15) is considered too large a new iteration is performed, i.e. $MESH(e)$ is assigned a new value and the process is repeated.

How the new mesh sizes for the next iteration are generated will not be explained here, since the methods applied are explained elsewhere. Actually, several methods were tested, i.e. the Nelder & Mead Algorithm (see e.g. Nash, 1979), the Peckham's Mimization Method (Peckham, 1970), Newton-Raphson & Marquardt-method (see e.g. Dixon, 1972).

Table A3 shows the estimates of effective mesh sizes, i.e. the values of *MESH* used in the last iteration, and their contribution to the sum of squares.

Table A3. Estimates of effective mesh sizes. 'Sum of squares of deviations' means the sum $SSD = \sum [RCL(e,i) - ROBSCL(e,i)]^2$ defined by (17).

	Fleet, *e*		
	1	2	3
Initial guess on mesh size, cm	10.0	12.0	12.0
Estimate of effective mesh size, cm	10.66	12.76	15.09
Sum of squares of deviations, SSD	0.000686	0.000947	0.005165

The observed and the theoretical relative distributions for the three fleets are shown in Figs A1-3. Table A4 shows the gear-selection curve *SL* (cf. Eq. (6)), the relative calculated (theoretical) length distribution of catch, *RCL*, and the observed relative length distribution, *ROBSCL* (cf. Eqs. (16) and (17)).

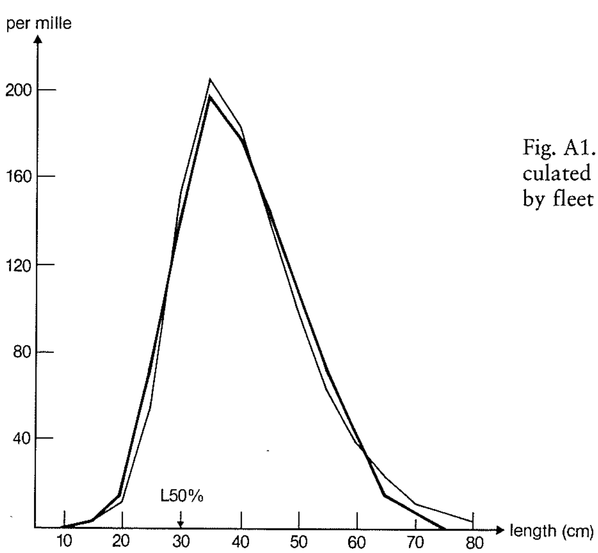

Fig. A1. Heavy line observed and thin line calculated relative length distribution of catches by fleet no. 1.

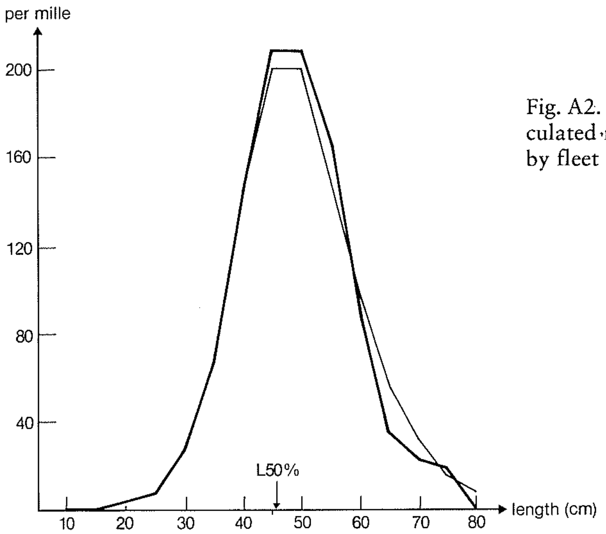

Fig. A2. Heavy line observed and thin line calculated relative length distribution of catches by fleet no. 2.

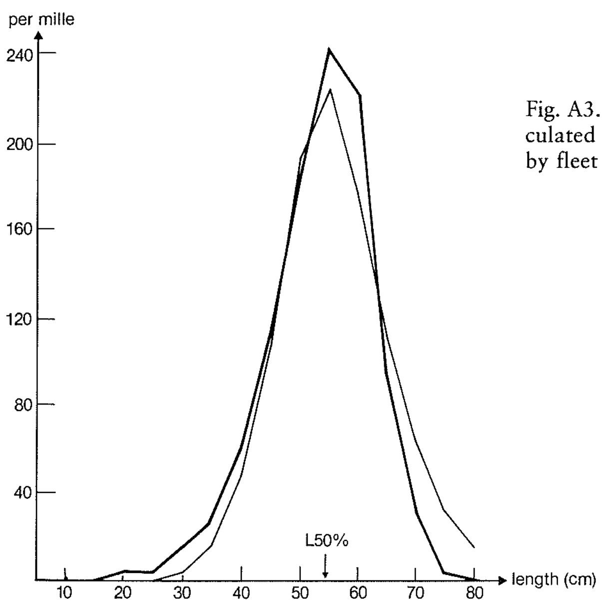

Fig. A3. Heavy line observed and thin line calculated relative length distribution of catches by fleet no. 3.

Table A4. Selection curves (*SL*), relative calculated (theoretical) length distribution of catch (*RCL*) and observed relative catch (*ROBSCL*)

				Fleet 1			Fleet 2			Fleet 3		
i	Length-group, cm	Age,* years	Weight,* kg	*SL**	$10^4 \times$ *ROBSCL*	$10^4 \times$ *RCL*	*SL**	$10^4 \times$ *ROBSCL*	$10^4 \times$ *RCL*	*SL**	$10^4 \times$ *ROBSCL*	$10^4 \times$ *RCL*
1	10-15	0.77	0.020	0.00	5	5	0.00	2	3	0.00	5	0
2	15-20	1.10	0.054	0.00	28	25	0.00	5	9	0.00	10	2
3	20-25	1.45	0.114	0.02	172	131	0.00	26	30	0.00	24	5
4	25-30	1.81	0.208	0.08	734	570	0.01	82	94	0.00	57	19
5	30-35	2.19	0.348	0.34	1409	1501	0.02	268	272	0.00	155	59
6	35-40	2.59	0.527	0.74	1950	2026	0.07	669	688	0.01	288	175
7	40-45	3.02	0.768	0.94	1776	1827	0.19	1429	1392	0.03	599	471
8	45-50	3.46	1.072	0.90	1441	1411	0.44	2097	2004	0.09	1130	1097
9	50-55	3.94	1.447	1.00	1082	999	0.73	2097	1982	0.25	1820	1927
10	55-60	4.45	1.901	1.00	709	655	0.90	1632	1486	0.54	2413	2238
11	60-65	4.99	2.441	1.00	443	400	0.97	895	950	0.81	2210	1774
12	65-70	5.57	3.076	1.00	162	230	0.99	367	554	0.94	951	1119
13	70-75	6.20	3.811	1.00	77	125	1.00	235	304	0.98	306	628
14	75-80	6.89	4.656	1.00	12	65	1.00	196	157	0.99	32	326
15	80-85	7.64	5.615	1.00	0	31	1.00	2	76	1.00	1	158
			Total	–	10000	10000	–	10000	10000	–	10000	10000
			SEL		3.00			3.60			3.60	
			FAC		1.10			1.10			1.08	
			L50%		30.2			45.9			54.3	
			L75%		33.2			50.5			58.7	
			MESH		10.06			12.76			15.09	

* In the middle of the time interval.

Assessing the effect of a mesh change

A change of gear parameters is examplified in Table A5.

Table A5. 'Old' and 'new' mesh sizes.

	Fleet, e		
	1	2	3
Old mesh size (effective mesh size), cm	10.66	12.76	15.09
New mesh size, cm	12.0	15.0	15.0

Thus, in this example we consider an increase of mesh sizes of fleets 1 and 2, and slight reduction for fleet no. 3.

Before the change of gears the stock is assumed in a steady state situation.

The stock number and the number caught are now recalculated to be given by age group (cf. section 3).

The numbers caught before the change is *not* the average number caught during the last years, but given by the solution to the system of differential equations (14).

As we now know the mesh sizes there is no need to run any iterational procedure. The system (14) can be expressed in a somewhat simpler form by inserting into it:

	Fleet, e		
	1	2	3
$L50\%$	32.3	45.2	50.1
$\dfrac{\log 3}{L75\% - L50\%}$	0.333	0.244	0.275

$$
\begin{aligned}
\text{I:}\quad & \frac{dN(t)}{dt} = -\{0.2 + 0.450[1 + \exp(-(L(t) - 32.3)0.333)]^{-1} \\
& \quad +0.225[1 + \exp(-(L(t) - 45.2)0.244)]^{-1} \\
& \quad +0.225[1 + \exp(-(L(t) - 50.1)0.275)]^{-1}\} \cdot N(t) \\
\text{II:}\quad & \frac{dLAND(1,t)}{dt} = 0.450[1 + \exp(-(L(t) - 32.3)0.333)]^{-1} \cdot N(t) \\
\text{III:}\quad & \frac{dLAND(2,t)}{dt} = 0.225[1 + \exp(-(L(t) - 45.2)0.244)]^{-1} \cdot N(t) \\
\text{IV:}\quad & \frac{dLAND(3,t)}{dt} = 0.225[1 + \exp(-(L(t) - 50.1)0.275)]^{-1} \cdot N(t) \\
& \text{where } L(t) = 131.0\,(1 - \exp(-0.13t))
\end{aligned}
\tag{A2}
$$

The number caught in age-group a thus becomes

$$LANDY(e,T1,a) = LAND(e,a+1) - LAND(e,a)$$

The numbers caught and the number in sea long time after change of gear is obtained by solving a system similar to A2, but with the new mesh sizes, and thus, new values of $L50\%$ and $L75\%$.

The results are given in Tables A6 & A7.

Table A6. Numbers landed, yield and stock numbers before change of gears.

Age, a	$LANDY(1,T1,a)$	$LANDY(2,T1,a)$	$LANDY(3,T1,a)$	$N(T1,a)$
0	3	0	0	10000
1	270	10	1	8184
2	1650	116	15	6432
3	1127	318	93	3641
4	456	211	150	1597
5	159	79	75	577
6	53	27	26	195
7	18	9	9	65
8	6	3	3	22
9	2	1	1	7
10	1	0	0	3
$YIELD(T1,e)$, tonnes	37.7	12.4	8.1	–

$\sum_e YIELD(T1,e) = 58.2$ tonnes

Table A7. Numbers landed, yield and stock numbers long time after change of gears.

Age, a	$LANDY(1,T3,a)$	$LANDY(2,T3,a)$	$LANDY(3,T3,a)$	$N(T3,a)$
0	2	0	0	10000
1	111	4	1	8185
2	1208	38	17	6591
3	1312	150	121	4228
4	596	194	202	2034
5	215	98	102	777
6	72	36	36	266
7	24	12	12	89
8	8	4	4	30
9	3	1	1	10
10	1	0	0	3
$YIELD(T3,e)$, tonnes	43.4	11.1	11.0	–

$\sum_e YIELD(T3,e) = 65.5$ tonnes

Table A8. Yields in the transient period. The rightmost column contains the percentage gain or loss from the gear change, i.e. $\frac{\sum YIELD(e,T) - \sum YIELD(e,T1)}{\sum YIELD(e,T1)}$ 100%

Years after change	$YIELD(1,T)$	$YIELD(2,T)$	$YIELD(3,T)$	$\sum_e YIELD(e,T)$	Percentage gain or loss
0	37.7	12.4	8.1	58.2	0
1	35.9	8.6	8.4	53.0	−9
2	38.8	9.3	9.1	57.2	−2
3	41.1	10.0	9.9	61.0	5
4	42.3	10.6	10.5	63.4	9
5	42.9	10.9	10.8	64.6	11
6	43.2	11.0	10.9	65.1	12
7	43.3	11.1	11.0	65.3	12
8	43.4	11.1	11.0	65.4	12
9	43.4	11.1	11.0	65.5	12
10	43.4	11.1	11.0	65.5	12
% change after 10 years	15	−10	36	–	12

Only 10 age groups are considered, as only very small fractions are made up by the older age groups.

The main conclusion of the present exercise is that fleet 1 and 3 would benefit (in the long term) from an increase in mesh sizes of fleets 1 and 2. In the short term, of course, the effect of a mesh size increment would be a reduction of yields.

The development of catches during the transient period is summarized in Table A8.