INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES

Serial No. 725
(D.c.3)

Document No. 8

ANNUAL MEETING - MAY/JUNE 1960

Methods for Estimating Fish Discarded at Sea

by R.S. Keir

1. Introduction

1.1. Value of the data:

Data on the sizes and quantities of fish discarded at sea have three immediate applications:

1) In the assessment of the "initial loss" upon introduction of a mesh regulation.

2) In establishing ages at which fishing mortality begins, and, for "waste species" (which includes redfish and halibut for the salt-cod fleet), in estimation of the total catch of commercial-sized fish.

3) In forecasting the size of incoming year-classes.

1.2. Several basic methods are available to estimate the sizes and quantities of fish discarded at sea by the commercial fishery:

1) Using data reported by ships' officers.

2) Using data collected by scientific observers at sea.

3) Using data on research vessel catches.

4) Miscellaneous methods.

These are described in the second section of this paper. Each of them may have many variants generated by the characteristics of the particular fishery being investigated and the ingenuity of the scientist. Several of them may be used simultaneously in the study of a fishery. Estimates obtained by different methods will complement each other and provide both a check on, and a measure of, the accuracy of the final estimate.

1.3. As was pointed out in Annex VI of the Report of the Expert Meeting on Fisheries Statistics in the North Atlantic Area (1959), it is possible that not all of the discards are dead or dying. An estimate of the percentage expected to live is therefore a desirable observation.

1.4. Fillets and Fish Meal:

The filleting at sea of the marketable (food) catch and the use of by-catch and small fish, not wanted by the market, for the manufacture of fish meal at sea is increasing rapidly. The sampling of these fish raises very similar difficulties to the sampling of the discarded fish. However, in the fish used for fillets, the total weight by species can be estimated from the landings (a conversion factor of about 3.3 is commonly used) and the total weight (not be species) can be estimated from the fish meal (conversion factor of the order of 5X.)

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1.5. In the third section of the paper the manner in which all those data should be reported to ICNAF is discussed.

1.6. The co-operation of experts from Canada, Germany, Portugal, and the United Kingdom in describing the methods used in their countries is gratefully acknowledged.

2. Methods

2.1. Using data reported by ships' officers:

Description:

Logbooks or printed forms are placed on board fishing vessels. On them estimates of the fish caught, retained and discarded may be recorded for each operation of the gear or daily or even at longer intervals. The smaller the intervals, the better will be the resulting total estimates. A variant of this method is to have the reports completed by a port interviewer at the end of each trip.

Data collected:

1) Quantities and species discarded by place and time.

2) Samples of the discards or total catch may also be preserved and brought ashore for scientific study. A variant of this, successfully used by A.D. McIntyre was to have the heads and stomachs (of halibut) only preserved. This reduced the bulk of the sample enormously. Still further reduction would be possible by preserving some small part of the fish only, e.g. pectoral fins. The great difficulty here is ensuring the randomness of the sample.

Compilation of data:

The various estimates made on one trip are allocated to month/subdivisions. If two or more trips are reported from the same month/subdivision, the data are added. An estimate of the total discards of the fleet being studied is made by multiplying the total discarded by the sampled trips by a factor

$$\frac{\text{Total landings all trips}}{\text{Total landings sampled trips}}$$

Coverage:

For fleets of relatively few large vessels almost complete coverage may be practicable, as the data can be recorded at the same time as the retained catch and effort is recorded. The practical coverage is limited mainly by the willingness of ships' officers to keep the necessary records. This is probably the only method which can approach the nature of a complete census and may therefore be used as a base for other methods of sampling.

Source of errors:

Serious errors will be biasses arising from:

1) Consistent under- or over-estimating through lack of possibility of checking by weighing.

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2) Incomplete records - especially non-recording of species other than those sought by the fishery.

3) The discarding practices of vessels reporting data may not be typical. The method is self-checking to the extent that reports of different vessels from the same area may be compared.

Practical Experience:

This method has been used quite extensively in recent years. Portugal has reported the results of such observations made on otter trawlers for the years 1955-1959 (cod only). Specimen forms used by Portugal, Newfoundland and the United Kingdom are attached as examples in Appendix I. An even more detailed form requiring records to be made at each set has been kept by a few selected Newfoundland trawlers for several years. The interview system has also been used by a number of countries, including the United States, which has reported estimates of haddock discarding since 1956. The interview system is now being used by Canada as part of a study on halibut. A special questionnaire completed by the port interviewers is illustrated below.

HALIBUT CATCH AND DISCARD QUESTIONNAIRE

Port ____________________ Vessel Name ____________________

Date ____________________ Gear: Type ____________________

Mesh or hook size ____________________

Main species fished ____________________

Amount of halibut caught ____________________ lbs.

Where caught (general region ____________________

Halibut discarded __________ lbs. or __________ Nos.

Sizes discarded __________ lbs. or __________ inches

Halibut for crew's personal use __________ lbs. or __________ Nos.

Sizes for personal use __________ lbs. or __________ inches

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Technician

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2.2. By reports of observers at sea:

Description of method:

Scientifically trained observers are sent on board commercial vessels during normal fishing trips. These observers keep records of the fish caught, retained and discarded, including length frequencies, species composition, etc. Gulland has described the United Kingdom use of this method in Appendix II.

Data collected:

1) Estimates of quantities caught, retained and discarded, etc. by ships' officers.

2) Estimates of quantities caught, retained and discarded, etc. by observer himself.

Possibly these estimates can be checked against actual weighings.

3) Length frequencies and species composition of catches, discards and retained catch.

4) Length frequencies of the landings.

A principal variant of this method is used when it is difficult, even at sea, to obtain samples of the discards. The discards are then estimated as the difference between total catch and landings (see below, where this method is described by W.R. Martin).

Observations are frequently attempted at each operation of the gear, i.e. each set, or by a definite system of sampling; e.g. sets to be studied may be selected randomly or the sets might be divided into day operations and night operations, and each of these groups sampled randomly and the total number of sets in each group counted.

Photographic records could be collected to supplement other records.

Samples may be brought back to the labratory.

Costs:

The cost is usually only the cost of the time of the observer but may include a fee payable to the vessel owner or skipper, etc.

Compilation of data:

The data are first used to calculate total catches, discards and landings by month/subdivisions for the trip. Such estimates for all trips with observers are then added. The total estimates for the whole fleet are then estimated as for method 1. The details of computation would vary depending on the observations made.

Coverage:

Because of the relatively great expense involved and the shortage of suitably trained observers, this method will usually be used either as a supplement to method 1 or in special cases where the value of obtaining the data on discards is especially high.

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However, a relatively few observers could contribute greatly to an overall data collection, as an observer could also make many other observations besides those on discards. Seasonal coverage is most important. Wide spot coverage combined with ships' officers reports should be the usual aim.

Some time ago ICNAF proposed that each country should have two sea-observers working in the ICNAF area. This would be something of the order of 20 observers and might give about 400 "observer weeks" on the fishing grounds or about one "observer week" per 3,500 tons of groundfish landed. If this amount of observer time could be distributed "ideally" over the fishing fleet, it would be sufficient to give very good estimates of the data required (not only on discarding).

Source and magnitude of errors:

1) Non-random sampling. This error is especially important if the estimates of discards is given by the difference of the total catch and the landings.

2) Observer on board atypical vessel - best reduced by observer moving from vessel to vessel.

3) Shrinkage of fish between time of capture and time of landing - same comment as for error 1.

If each of the discards, retained catch, total catch, and landings are estimated separately, then the data themselves provide a check, thus eliminating gross errors.

Value of Data:

Especially valuable as a supplement to ships' officers reports.

Practical Experience:

Many countries have from time to time used this method.

Canada has reported such observations to ICNAF for the years 1956-1959, and an analysis of some of the data has been made by W.R. Martin and Y. Jean (1958). Dr. Martin describes their method as follows:

"During recent years we have been employing summer students to make sea trips on commercial otter trawlers in order to measure quantities and sizes of groundfish discarded at sea. During 1959, for example, two summer students made 14 sea trips. The results of their work will be provided in our research report for 1959.

"Some of the details of the program of our observers may be of interest: samples of 1,000 to 2,000 fish are measured at sea on each trip, and shore samples of 300 to 700 fish are measured at the wharf at the time of landing. In the case of cod, the numbers of fish 51 cm and above are equalized. The difference between numbers caught and numbers landed represents the numbers discarded. Discards are then expressed as a percentage of numbers caught. The total weight of discards is obtained from a length-weight curve. Discards by weight are expressed in per cent of total weight caught.

"Although our observers have been concentrating on the species in which we are most interested, cod, haddock and

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plaice, we do obtain information on other species. Estimates of discards by weight (and by numbers when the catch is small) of all species caught during a trip are entered in a log book at the end of each tow. Two copies of a sample sheet are attached."

The United Kingdom has also reported data collected by this means ° John Gulland has descarded other method in Appendix 11.

In Newfoundland the method is very simular and is discarded briefly by A.M. Fleming-----"

"In addition we obtain information on sizes and amounts of discards at sea (especially of haddock where the discard problem is the only serious one in our area) by sending observers to sea on commercial trawlers for a series of trips during the peak haddock fishery in the winter-spring season. We are just now completing a series of six trips on commercial trawlers for this purpose.

"Our method on commercial trawlers is to obtain representative measurements of the sizes of fish caught before discard and from time to time, where possible, to obtain sizes of the fish which are to be discarded. When the vessel returns to port measurements are obtained of the sizes of fish as landed."

2.3 Comparison with Research Vessel Catches:

Description of Method:

The difference between the length of the landings of the commercial fleet and the catches of research vessels fishing in the same area, after adjustment has been made for gear selectivity, is attributed to discarding.

Data Collected:

1. Length ° species composition of research vessel catches by time ° area.
2. Length ° species composition of commercial landings by time ° area of capture.
3. Data necessary to establish selectivity of commercial gear.
4. Data necessary to establish selectivity of research vessel gear.
5. Observations necessary to confirm that both research vessel ° Commercial fleet are fishing on the same stock.

Costs: Either very expensive owing to research vessel time involved, if the survey is made primarily for this If however advantage is made of a research vessel in the area for another purpose, its cost may be quite small only measuring ° computation time.

Compilation of data: Probably the research vessel will fish partly in ° partly out of the area being exploited by the commercial fleet ° this will necessitate a certain selection of the research vessel data or alternatively each research vessel catch can be weighted in proportion to the amount of commercial landings which it "represents". Then the research catches are adjusted to the selectivity of the commercial gear. It will generally be necessary to assume so size, say L, above which the commercial fishery retains all fish. The difference between the two length compositions is then attributed to discards.

The weighted ° selectivity adjusted research vessel length frequency is finally multiplied by a factor *

Number of fish greater than size L in the commercial landings
Number of fish greater than size L in the weighted ° selectivity adjusted research vessel catch.

The difference between the two length compositions is then attributed to discards.

Coverage:

It will only be on exceptional occasions that a research vessel will be made available primarily for this work. Hense coverage is likely to be spotty ° not necessary over the most important fisheries. However it will serve as a very useful method from time to time.

Source ° Magnitude of error:

1) The major error will come from the fact that the research vessel may not be fishing exactly the same concentrations of fish as the commercial fishery.

2) The catches of the research vessel will be measured fresh, usually whole while the landings may be measured after gutting and several days of storage on ice. Any shrinkage etc. will effect the results.

Compensation can be made for both types of error but neither can be eliminated entirely.

Comparison of the length frequency distributions above the size L will give some measure of the reliability (or lack of reliaiblity) of the method in paticular cases.

Value of Method: Especially valuable in studies of past years (when by chance necessary data have been collected for other purposes) where no other means are available to assess discarding.

Practical Experience: Sahrhage (1958, 1959) has carried out extensive work using this method to measure the discards of whiting and haddock by the German North Sea Herring Fishery.

The method is also used by Newfoundland to study haddock discards in Subarea 3.

2.4 Other Methods:

Calculation from theoretical model of the fishery:

1) Hempel and Sahrhage (1959) have described a procedure by which the quantity of fish discarded can be estimated, as a first approximation, by use of the Beverton and Holt yeild equations. The estimate given by this method is an average value for a series of years and requires for its application estimates of the total mortality and growth coefficiants, an estimate of the 50% discard size and statistics of the landings over a series of years. A translation of this paper is given in appendix 111.

2) From time to time reports have reached fishery offices of large quantities of dead fish floating on the surface or caught in trawls, apparantly discards. Some estimate of the quantities discarded and the length and species composition could be obtained by compiling such reports, especially if samples of the jetsam could be obtained.

Similar methods have been used in studies of the mortality caused by very cold water or by "red tide".

The landings of fish meal by vessels processing it at sea may give estimates of the total discards by vessels not processing fish meal at sea.

3. Reporting to ICNAF:

3.1 How should all these data be reported to ICNAF. Within the extremes of reporting raw data on the one hand and gross totals on the other there are many possible positions to take. It is however strongly desirable that ICNAF should propose some standard, for else very similar original observations will be reported in very different ways.

It is probably most reasonable that data on discards be reported by the same units as the data on landings, ie. by gear, species, tonnage class of vessel, month, subdivision. A proposed form is attached in Appendix 4.

However whether estimates made by different methods should be reported separately or grouped together might best be left to the discretion of the scientists reporting.

Unlike statistics on landings a complete census will rarely be available. Thus the total quantities discarded will have to be calculated. For any fleet, this is best done by scientists of the country operating the fleet. Length or size composition of the discards (and of total catch and landings if obtained at the same time) should be reported in a similar manner to other sampling data.

3.2 Where the study of discarding is more in the nature of an isolated experiment reporting could be made in a different way. It is important to recognize that spotty or thin coverage by any one country may, when added to the information from the other fifteen countries fishing in the convention Area give quite adequate information on discards for first approximation. This will also make it much easier to determine the fisheries on which effort spent in the measurement of discards, would be most profitable. ICNAF might therefore encourage scientists to write up reports of experiments carried out to measure discarding including a summary of the results obtained. The following information should be included if available.

1) 50% Selection size for the gear.
2) 50% discard size.
3) Total quantity discarded and landed by species.
4) Length frequency of discards, landings, total catch.

Estana (1958): Report of the Expert Meeting on Fishery Statistics in the North Atlantic Area. Joint FAO/ICES/ICNAF meeting.
Hempel, G. and Sahrhage D. (1959): Arch. Fischereiwess. X ½, p.58-67.

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Martin, W.R. and Jean Y. (1958) F.R.B. of C. Progress Reports of the Atlantic Coast Stations. No. 69.
" First-Year effects of mesh regulation on northern New-Brunswick dragger fishery."

Sahrhage D. (1958): Ber. Dtsch. Wiss. Komm. Meeresforsch. XV, 2, pp. 105-131.
"Untersuchungen uber die Vernichtung untermafiger Schellfische durch die deutsche Heringsschleppnetzfischerei in der Nordsee".

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Newfoundland APPENDIX 1 (1)

YEAR__________ SHIP__________ CAPTAIN__________ TRIP NUMBER__________

PORT__________ SAILED__________ RETURNED__________ RECORDED BY__________

DATE	POSITION LAT.	POSITION LONG.	DEPTH IN FATHOMS	NUMBER OF DRAGS	HOURS DRAGGING NET ON BOTTOM	ESTIMATE OF AMOUNTS OF FISH CAUGHT (LB.)							REMARKS
						KEPT							
						DISCARDED							
						KEPT							
						DISCARDED							
						KEPT							
						DISCARDED							
						KEPT							
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						DISCARDED							

FISHERIES RESEARCH BOARD OF CANADA
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Portugal APPENDIX 1 (2)

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GRÉMIO DOS ARMADORES DE NAVIOS DA PESCA DO BACALHAU

(Delegação do Governo)

Campanha de ....

BOLETIM DE ELEMENTOS PARA A ESTATÍSTICA DA PESCA DO BACALHAU

Arrastões

Tripulantes .... Nome do navio ....
Companha .... Tonelagem bruta ....
Total .... Tonelagem de registo ....
Porto de descarga ....

Mês .... Data da largada do porto de armamento .... Data da chegada ao porto de armamento ....

Área do Atlântico Noroeste

	GROENLÂNDIA						LABRADOR			TERRA NOVA							NOVA SCOTIA						
	Sub-Area I						Sub-Area II			Sub-Area III							Sub-Area IV						
	1 A	1 B	1 C	1 D	1 E	1 F	2 G	2 H	2 J	3 K	3 L	3 M	3 N	3 O	3 P Norte	3 P Sul	4 R	4 S	4 T	4 V Norte	4 V Sul	4 W	4 X
Dias de permanência nos bancos																							
Horas de arrasto — entre 3' e 6'																							
Horas de arrasto — » 6' e 12'																							
Horas de arrasto — além de 12'																							
Números de lanços																							
Bacalhau — Quintais																							
Arinca — »																							
Outras espécies - Quintais																							
Bacalhau inutilizado - Quint.																							
Outras espécies inutilizadas — Quintais																							

Observações: ....

O CAPITÃO

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United Kingdom **APPENDIX 1 (3)**

DATE	POSITION	DEPTH (fms.)	QUANTITY KEPT					QUANTITY REJECTED					REMARKS
			COD	HADDOCK			TOTAL	COD	HADDOCK			TOTAL	

NOTE: (1) Please record each haul separately (2) Use symbol 'B' for recording number of baskets or 'F' for number of fish.

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APPENDIX II

ESTIMATION OF DISCARDS
ENGLAND

1. Log-books.

These are supplied to certain skippers (copies attached). They are filled up according to the instructions on the back, usually very completely. The proportion discarded by reporting ships is then obtained at once by adding the relevant columns of "total kept" and "total discarded" for species concerned. The ratio kept discarded may then be applied to the total landings to give the estimated discards by weight. The average weight of individual fish discarded may be roughly estimated from the measurements of fish landed, as being about the same as the smallest fish kept. Thus the number discarded (but not their precise size-composition) may be estimated.

2. Observers

On occasion scientists may go on commercial vessels to obtain more detailed information. The basic observations made are:-

(a) Every haul (or whenever possible), estimate (i) total catch - this can be done remarkably accurately by eye, at least by the skipper, as the net comes on board; (ii) weight discarded, this may be measured directly if the crew can be persuaded to put these on one side, and the actual discarding over the side is done by the observer; (iii) weight kept, which can usually be estimated fairly well by the mate or other man responsible for stowing the catch. (These quantities should check, (ii) + (iii) = (i), and any gross error detected).

(b) When possible, and at least once for each separate group of hauls, where rejection may be different, e.g. different grounds, measure samples of known size:

e.g. 2 baskets from:-

(i) fish as caught
(ii) fish discarded
(iii) fish kept

In practice, only one of samples (i) and (iii) need be taken, the other size distribution, e.g. of total catch, being obtained by addition from the sizes of fish rejected. It is possible to estimate discards as the difference between landings and total catch, but not very efficient statistically because of the sampling errors involved, particularly when rejection is not great, or extends over a range of sizes.

Having obtained the size-distribution of the sample of each group of fish these can be multiplied by the ratio total weight : weight sampled to give the total numbers in each size-group caught, discarded or landed. The percentage described in each size-group can also be estimated at once.

(c) Collection of otoliths and examination of maturity, feeding etc., can also be carried out. This is best done by stratified sampling, i.e. fixed quantities from each length-group, rather than by random sampling from the catch as a whole.

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APPENDIX III

The following translation of a paper by G. Hempel and D. Sahrhage published in Arch. Fischereiwiss., X, 1/2, Braunschweig, October 1959, has been prepared in the Secretariat following recommendation 3.3 of the *ad hoc* Committee on Statistics (1959).

On Estimation of the Proportion of Discarded and Undersized Fish in the Total Catch

by Gotthilf Hempel and Dietrich Sahrhage
Biologische Anstalt, Helgoland

A. Introduction

The landings from a commercial fishery are frequently smaller than the total catch because of the selection of fish for the market which takes place on board the vessels. This selection is determined by (1) the demand of the market, (2) the keeping qualities of the fish, and (3) the quantity and composition of the catches. Small fish are in varying numbers, thrown back dead, as a rule, into the sea, and the same is the case with the less valuable species. The international agreements concerning the minimum landing size of some commercial fish species may force the fishery to discard undersized fish. This discard of unmarketable or undersized fish has biological and commercial disadvantages. However, it cannot be avoided, especially in mixed fisheries. It is the aim of international agreements to avoid, by regulation of the mesh sizes, unnecessarily many fish being caught only to be discarded. In most cases, the basis for a combined yield-and-stock calculation is the landings, for which in general good statistical data are available. For the study of the dynamics of the stock, however, the amount taken from the sea by the fishery, i.e. the total catch, and not the landings, is the deciding factor. Therefore, in population dynamic studies the landings should be converted to total catch, where selection for the market has taken place. The estimation of the size of the total stock from the landings also requires that the landings be converted to total catch to ensure useful results.

In practice, it is hardly possible to determine directly at sea the total catch of the commercial fisheries. Bowman (3), Russell (6) and others have made extensive observations at sea of the total catch from fishing vessels, and have estimated the ratio between total catch and landings. Conversion factors calculated in this way were used when considering the statistical data from the fish markets. Such extensive investigations at sea can, however, rarely be carried out. An indirect method to determine the conversion factor for single species is to compare the length composition of the landings of the commercial fishery with the length composition of the total catch from a research vessel working under comparable conditions. Sahrhage (7 and 8) used this method to calculate the discarded portion, especially of undersized haddock and whiting, in the catches of the German herring trawl fishery in the North Sea.

B. Calculation of Total Catch from the Landings Statistics

In the following a procedure is described to calculate the mean size of the total catch relative to the landings. The procedure is based on the equations published by Beverton and Holt (2) on yield in weight and number from a fish stock dependent upon recruitment, growth and natural and fishing mortality. From these calculated relative values of the total catch and landings the conversion factors are calculated, by means of which the average total catch C (in number or weight) can be

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estimated from the average landings, determined by the statistics (as a rule expressed as the mean annual yield of the fishery). These calculations cannot completely replace the earlier mentioned methods, but they give an indication of the proportion of fish discarded, and thus destroyed, by the fishery.

1. <u>The Conversion Factor T_N</u>

As a relative measure of the number in the total catch we select:

$$\frac{Y_N}{R'} = \frac{F}{M+F} (1-e^{-(M+F)(t_\infty - t_c)}). \qquad (1)$$

Y_N is the mean theoretical total catch (in numbers) taken by the fishery in the time interval chosen (usually a year); R' is the number of recruits. From this formula, after Beverton and Holt (2), the yield is calculated from the coefficients for the natural and fishing mortalities M and F. The minimum age of catchable fishes (t_c), which is also included in the calculation, depends, as a rule, on the mesh size. For many fish species this is calculated from the mean length (l_c) at the 50 percent selection value[1]. In other cases t_c can be calculated directly from selection experiments. If the fishery is carried out with small mesh nets, it may happen that t_c is not dependent on the mesh size but on the development of the young of the fish, for instance by the termination of the pelagic phase.

The corresponding relative yield for the landings is

$$\frac{Y_{N''}}{R'} = \frac{F.e^{-(M+F)(t_{c''}-t_c)}}{M+F} (1-e^{-(M+F)(t_\infty - t_{c''})}). \qquad (3)$$

From the length composition of the landings we can estimate the length group for which about half of the fish are considered as marketable and the other half as discardable (i.e. the 50 percent discard size). To conform with the net selection this mean minimum length is written as $l_{c''}$ and the corresponding age as $t_{c''}$. An estimate of $l_{c''}$ is possible when the selection curve of the landings is steep and includes few centimetre groups. With the section $e^{-(M+F)(t_{c''}-t_c)}$ in (3) those natural and fishing mortalities are considered which occur during the time between the minimum catchable and the minimum market sizes. Further, (3) is distinguished from (1) by the terms $(t_\infty - t_{c''})$ instead of $(t_\infty - t_c)$. For most groundfishes in our seas, the time between reaching the minimum catchable age or the minimum market age, and the mean theoretical final age t_∞ is so large that the term

$$e^{-(M+F)(t_\infty - t_c)} \text{ or } e^{-(M+F)(t_\infty - t_{c''})}$$

comes close to 0 and that hence the section

$$(1-e^{-(M+F)(t_\infty - t_c)}) \text{ or } (1-e^{-(M+F)(t_\infty - t_{c''})})$$

---

1) $t_c = -\frac{1}{K} \log_e \left(1 - \frac{l_c}{L_\infty}\right) + t_o \qquad (2)$

K, L_∞ and t_o are the coefficients of the v. Bertalanffy growth equation.

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can be disregarded[1]. For calculation of T_N it is not necessary to calculate completely the equations (1) and (3), but

$$T_N = \frac{Y_N}{Y_{N''}} \approx \frac{1}{e^{-(M+F)(t_{c''}-t_c)}} \tag{4}$$

Following (4) the term T_N (theoretical catch in numbers divided by the theoretical landing) depends upon the age difference ($t_{c''}-t_c$), which can be calculated accurately and in a rather simple way, and upon the exponential coefficient for the total mortality (M + F). Estimates of (M + F) are not difficult to obtain when the age composition of the fish stocks is available. A brief summary of the procedure for calculating (M + F) is given by Beverton and Holt (1). In recent years values for M and F have been published for a series of fish species; from this it appears that for strongly fished species (M + F) is close to 1. When the mean number of the landings (A_N) is multiplied by T_N, one gets an estimate of the mean number of fish in the total catch (C_N). The estimated mean number of the fish discarded into the sea under the existing stock and fishery conditions is $C_N - A_N$.

Since no data on numbers are usually given in the landing statistics, it is necessary to convert the landings weight into the separate length groups (Lundbeck (4)) on the basis of the length composition of the landings and the mean weight of the fish in each length group.

In Fig. 1 is shown for various time intervals ($t_{c''}-t_c$) the way in which the conversion factor T_N depends upon the coefficient of total mortality (M + F). The section

$$(1-e^{-(M+F)(t_\infty-t_c)}) \text{ or } (1-e^{-(M+F)(t_\infty-t_c)})$$

was not considered in doing so.

2. The Conversion Factor T_W

When considering the population dynamics of the stocks fished, estimates of the number of fish in the total catch are of the greatest importance. The commercial fishery, however, is mainly interested in the weight differences between total catch and landings. To determine the conversion factor T_W, that is the ratio of the weight of the mean theoretical total catch Y_W to the mean theoretical landing $Y_{W''}$, we have to use basically the same procedure as for calculating T_N. However, for calculation of the weight of the total catch it is necessary to have data on the growth of the species in question. Therefore we cannot calculate for T_W as we could for T_N, a conversion factor based on the

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1) If the phase of life in which the fish is fished is short, or if the total mortality is extremely small, it is possible to calculate t_∞ from the growth of the species in question (Beverton and Holt (2)). It is so calculated that (M + F) ($t_\infty-t_c$) or (M + F) ($t_\infty-t_{c''}$) is smaller than about 3. If this is so, it is better not to calculate in conformity with (4) but to determine $\frac{Y_N}{R'} / \frac{Y_{N''}}{R'}$ from (1) and (3)

.../4

total mortality (M + F) and ($t_{c''}-t_c$) which will be applicable for most fish stocks.

The total catch in grams per recruit is[1]

$$\frac{Y_W}{R'} = F.W_\infty \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c-t_0)}}{(M+F)+nK} \left(1-e^{-(M+F+nK)(t_\infty-t_c)}\right) \qquad (5)$$

The mean relative yield for the total weight of marketable fish in the total catch, i.e. a measure for the landing, is

$$\frac{Y_{W''}}{R'} = F.e^{-(M+F)(t_{c''}-t_c)}.W_\infty \sum_{n=0}^{3} \frac{U_n . e^{-nK(t_{c''}-t_c)}}{(M+F)+nK} \left(1-e^{-(M+F+nK)(t_\infty-t_{c''})}\right). \qquad (6)$$

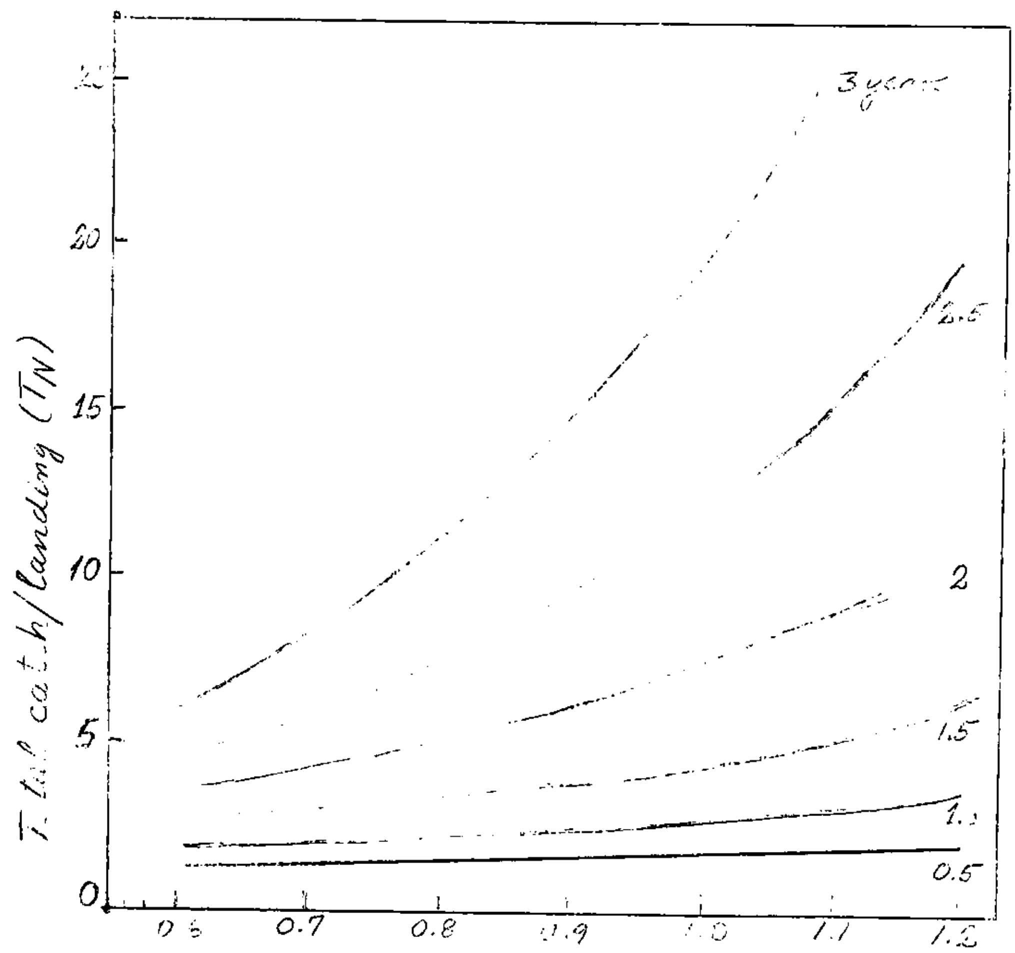

Fig. 1. Relation between Total Mortality (M + F) and conversion factor T_N (see text) for various values of ($t_{c''}-t_c$). Valid for all fisheries on long-lived species.

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1) In formulas (5) to (7) U_n means:

n = 0	U_0 = +1	n = 2	U_2 = +3
n = 1	U_1 = -3	n = 3	U_3 = -1

.../5

In the calculation of T_W it is not necessary to evaluate all the sections in formulas (5) and (6), as several of the sections can be cancelled. Also it is possible in most cases to delete the last section of the two equations, that is

$$(1-e^{-(M+F+nK)(t_\infty-t_c)} \text{ or } (1-e^{-(M+F+nK)(t_\infty-t_c'')})$$

which very rarely differ appreciably from 1. Sometimes values for t_o and for K are needed from the growth equation. Also necessary is an estimate of (M + F). Separate figures for M and F are, however, not necessary. From formulas (5) and (6) the conversion factor T_W is calculated:

$$T_W = \frac{Y_W}{Y_{W''}} \approx \frac{\sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c-t_o)}}{(M+F)+nK}}{e^{-(M+F)(t_c''-t_c)} \sum_{n=0}^{3} \frac{U_n \cdot e^{-nK(t_c''-t_o)}}{(M+F)+nK}} \quad (7)$$

Fig. 2 shows for the haddock stock in the North Sea and its fishery between the two world wars, the changes in T_N and T_W in relation to the fishing intensity (here expressed as total mortality (M + F), as M can be considered as constant). For the pre-war period Beverton and Holt have calculated for the North Sea haddock the following parameters $t_o = -1.07$ years, $t_\infty = 10$ years, $K = 0.2$. The curves shown in Fig. 2 are based upon $t_c = 1.83$ years, which would correspond to the 50 percent selection of 70 mm meshes. $t_c'' = 3.1$ years; this is the mean age of the haddock with 50 percent selection for the market ($l_c'' = 30$ cm).

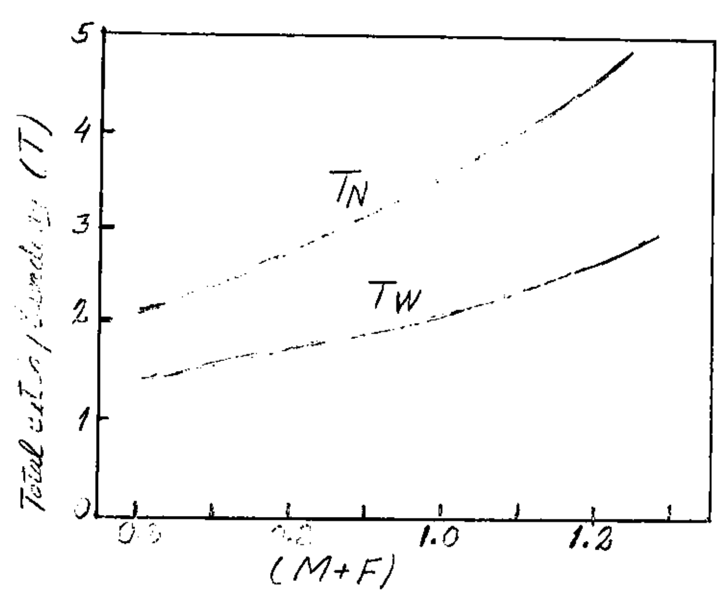

Fig. 2

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The mean weight of the total catch is estimated by multiplying the mean weight of the landings (A_W) by the factor T_W. The mean number and weight of the discarded fish are given by

$$V_N = (A_N \cdot T_N) - A_N \qquad (7a)$$

$$V_W = (A_W \cdot T_W) - A_W \qquad (7b)$$

C. Total Number and Total Weight of the Destroyed Legal-Size and Undersized Fishes Calculated from the Landings

When the 50 percent selection point of the market selection corresponds with the legal minimum size so that all legal-size fish are landed, one can estimate directly from the landings (after 7a and b) the number of destroyed undersized fishes. If the market selection is stronger than demanded by the minimum legal size, then the total catch (C_N; C_W) falls in three groups:

1. The undersized fish, which are all to be discarded ($_{un}V_N$; $_{un}V_W$)
2. The unmarketable fish of legal size, also discarded ($_{leg}V_N$; $_{leg}V_W$)
3. The marketable, landed fish (A_N; A_W)

When considering the regulation of mesh sizes, it is desirable to separate the discarded fish into the two first-mentioned groups $_{un}V$ and $_{leg}V$. Hence we arrive at the following:

$$_{un}V = (A \cdot T) - \frac{A \cdot T}{T'} = C - \frac{C}{T'} \qquad (8)$$

$$_{leg}V = \frac{A \cdot T}{T'} - A = \frac{C}{T'} - A \qquad (9)$$

To calculate the desired values for $_{un}V$ and $_{leg}V$, it is necessary to determine T', i.e. the ratio between the number in the theoretical total catch Y and the number of legal-size fish in the total catch Y'. Therefore, we substitute in formulas (4) and (7) for $t_{c''}$ (mean age upon reaching marketable size) $t_{c'}$ (mean age upon reaching the minimum size). From (8) and (9) the weight, as well as the number, of the marketable legal-size and undersized fish can be calculated by using corresponding values[1].

[1] In many cases estimates of the following relations can be described easily through different combinations of T and T':

a) Ratio of undersized fish to total catch: $\frac{Y - Y'}{Y} = 1 - \frac{1}{T'}$

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To conclude, we note that T_N and T_W are average values; when calculating them one works from the mean figure for recruitment and the average growth and mortality parameters. The values calculated for the total catch and the proportion of undersized fish in the catch are therefore also mean values. As a result of fluctuations in the number of recruits and variations in growth and mortality, the actual total catch in any year can vary very much from these means. The fact that T_N and T_W, as estimated by the method described above, are long-term means is, in certain cases, a disadvantage compared with the formerly used procedures based on short-term observations.

D. Example of the Use of the Methods of Calculation

The haddock landings in the North Sea by the herring trawl fishery from Germany provide a suitable example for the procedures described above. The results of the calculations can then be compared with estimates of the total catch and of the proportion of not landed and undersized haddock which have been made by Sahrhage (7) for this fishery using a completely different procedure. The fishery of the German trawlers in the North Sea is in the main concerned with the catch of herring. All other fish species are considered as by-catch. For the herring fishery a small-mesh herring trawl with a codend mesh size of about 45 mm is necessary. This trawl also catches haddock of small size. For this mesh size the 50 percent selection point length for haddock (l_c) can be estimated from the mesh size and the selection factor as follows:

$$\text{Mesh Size} \times \text{Selection Factor} = l_c$$

$$4.5 \text{ cm} \times 3.2 = 14.4 \text{ cm}$$

The mean age of the fish upon reaching the catchable size of 14.4 cm, t_c, can be calculated by using formula (2). This gives $t_c = 1$ year. The market selection of haddock is carried out very strictly because the holds of the vessels as far as possible should be used for herring. Only the larger haddock, from a minimum of about 30 cm are considered as marketable. Hence the mean length of the haddock when reaching marketable size (50 percent discard size) is rather high: $l_c'' = 35$ cm. According to formula (2), this length corresponds to a mean age of $t_c'' = 3.12$ years. To estimate the proportion of undersized haddock it is necessary to know the mean age of the fish when reaching the minimum legal size, t_c'. According to the International Fishery Convention of 1946, the minimum legal size of haddock is 27 cm; corresponding to an age of 2.14 years = t_c'.

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b) Ratio of undersized fish to legal-size fish in the total catch:

$$\frac{Y - Y'}{Y'} = T' - 1$$

c) Ratio of undersized fish to marketable fish (landing) in total catch:

$$\frac{Y - Y'}{Y''} = T - \frac{T}{T'}$$

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The estimates of the mortality and growth of haddock for the pre-war period given in Section B are unsuitable for this study as the haddock, as with many other fish species, show an increased growth rate during recent years. Mortality and growth of haddock in the North Sea have been analyzed for the years 1946-50 by Parrish and Jones (5), and these investigations permit an estimate of the coefficient of total mortality (M + F) to be made at around 1.0. From the mean length of the haddock of the various age groups, we can get the necessary figures for the growth by using the Bertalanffy equation as $L_\infty = 49.4$ cm; $K = 0.38$ and $t_o = 0.06$ years.

From this growth equation the lengths l_c, $l_{c'}$ and $l_{c''}$ can be converted into the corresponding mean ages t_c, $t_{c'}$ and $t_{c''}$. Using these data in formulas (4) and (7), the conversion factors T_N and T_W, and $T_{N'}$ and $T_{W'}$, can be calculated This gives

$$T_N = 8.33 \qquad T_W = 2.70$$
$$T_{N'} = 3.13 \qquad T_{W'} = 1.49$$

The factors T_N and T_W have now to be multiplied by the mean annual haddock landings during the herring fishery of the German trawlers (number or weight). Sahrhage (7) gives these landings for the years 1954-56 as a yearly mean of 942 tons, which corresponds to about 2.2 million marketable haddock. The conversion of these landings gives the following estimates for the total catch:

2.2 million X 8.33 = 18.3 million specimens
942 tons X 2.70 = 2543.4 tons

The total number and weight of the discarded fish are now calculated as the difference between the estimated total catch and the landings:

18.3 million - 2.2 million = 16.1 million specimens
2543.4 tons - 942 tons = 1601.4 tons

From the conversion factors $T_{N'}$ and $T_{W'}$, the number and weight of under-legal-sized haddock discarded from the total catch can be calculated by use of formula (8):

$$18.3 \text{ million} - \frac{18.3 \text{ million}}{3.13} = 12.5 \text{ million specimens}$$

$$2543.4 \text{ tons} - \frac{2543.4 \text{ tons}}{1.49} = 836.4 \text{ tons}$$

The quantity of legal-sized haddock discarded can be calculated from Formula (9), or by deducting the quantity of under-legal-sized fish from the total discarded fish:

.../9

16.1 million - 12.5 million = 3.6 million specimens

1601.4 tons - 836.4 tons = 765 tons

From the formulas given in the footnote on pages 6 and 7, the proportion of under-legal-sized haddock in the total catch was calculated as 0.68 by number and 0.33 by weight. The ratio of under-legal-sized to legal-sized haddock in the total catch is 2.13:1 by number and 0.49:1 by weight. The quantity of under-legal-sized haddock in the total catch in proportion to the quantity of marketable landed individuals is 5.67:1 by number and 0.89:1 by weight.

When comparing the calculated values obtained by this procedure with the estimates published by Sahrhage (7, Table 6), a fairly good agreement in the weight estimates can be seen (see Table 1). Greater variation occurs in the estimates of the numbers of the undersized and legal-sized haddock discarded. This is understandable, as the estimate by Sahrhage of the number of fish is based on the length composition of haddock catches from only the autumn of 1957 in the area Fladengrund and Dogger Bank. More adequate would be a mean length composition from a series of years, as in that case the influence of fluctuations would tend to cancel.

Table 1. Weight and number of haddock (estimated) caught by German trawlers in the North Sea during the herring fishing season.

	Weight (in tons)		Number (in million specimens)	
	From Landing and T or T'	After Sahrhage (7)	From Landing and T or T'	After Sahrhage (7)
Total catch	2543.4	2944	18.3	13.7
Thereof landed	942	942	2.2	2.2
Thereof not landed	1601.4	2002	16.1	11.5
Discarded:				
Undersized	836.4	736	12.5	5.9
Legal-sized	765	1266	3.6	5.6

A comparison of the estimates shows, on the one hand, that the figures given by Sahrhage on the catch of haddock during the herring trawl fishery of the German trawlers are expected to approach rather closely the actual situation. On the other hand, the methods described here yield usable estimates only when based on the mean quantity and size composition of the landings and average mortality and growth figures obtained from the biological stock analyses. This procedure can be used in all cases where the stock composition and the growth of the fish has been established from research vessel catches, and when it is not possible to estimate the quantity of the discarded fish.

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Serial No. 725 Document No. 8 Appendix IV

COUNTRY	VESSEL TYPE	AUXILIARY	TONN. CLASS		MAIN SPECIES	SUBDIVISION	YEAR

ICNAF STATISTICS
DISCARDS

Metric tons

	1A	1B	1C	1D	LE	1F	2G	2H	2J	3K	3L	3M	3N	3O	3Pn	3Ps	4R	4S	4T	4Vn	4Vs	4W	4X	5Y	5Z
JAN																									
FEB																									
MAR																									
APR																									
MAY																									
JUN																									
JUL																									
AUG																									
SEP																									
OCT																									
NOV																									
DEC																									
TOT																									