The Estimation of the Effect on Catches of Changes in Gear Selectivity

By

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An important part of the present work of fisheries research workers is to estimate the effects on catches both immediate and long-term, of changes in selectivity of the gear being used, in particular of changes in the mesh size of trawls. Such effects can of course be estimated by the use of any of the general population models (cf. BEVERTON and HOLT, 1957). However, application of minimum trawl mesh sizes should, for both practical and administrative needs, be as uniform as possible; that is, if a fleet of trawlers is fishing several species or in several areas, the minimum mesh size should, for ease of administration, be the same for all species or all areas. This means that a minimum mesh size will often at least be considered as a possibility even when the scientific data are far too scanty to provide adequate estimates of all the parameters required in the general population models. Further, these parameters, as generally estimated, refer to the main bulk of the fished population, while the effects of changes in selection are determined by the values for the smallest fish caught, which may well be different. In particular the values of fishing mortality, and possibly also natural mortality, are likely to be different for different sizes of fish. This paper will be concerned with methods of assessing the effect of mesh changes with limited data, but data which will not be unduly biassed if the fishing or natural mortalities in the selection range are different from those in the main fished stock. Such methods will of course not be directly applicable in assessing changes resulting from alteration in fishing effort.

ALLEN (1953) has shown that if the size of first capture (i. e. the smallest size at which the fish are retained by the gear in use) has been properly chosen so as to give the greatest catch with the existing fishing mortality, then the condition satisfied is that, (with some changes from his notation)

$$W_c = E\bar{W}$$

where W_c = weight at size of first capture

$\bar{W}$ = mean weight of fish in the catch greater than W_c

E = proportion of fish of size W_c which are ultimately caught.

In the simple constant parameter case $E = {}^{F}/_{F+M}$. The equation shows

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that the weight of fish released is equal to the "expected" weight when caught later in life. In this equation $\bar{W}$ and W_c can be readily determined from observations of the present catches, but the value of E is not so easy to determine with any precision. The equation may then be re-written in a form which may be more useful,

$$E = W_c/\bar{W}$$

or, in terms of length, assuming $W \times l^3$

$$E = l_c^3/\bar{l^3}$$

when $\bar{l^3}$ denotes the mean value of l^3, which will be rather greater than $(\bar{l})^3$, the cube of the mean value of l.

This can also be re-written as an inequality, giving the condition that E has to satisfy for an increase in size of first capture to give an increase in catch, viz.

$$E > W_c/\bar{W} = l_c/\bar{l^3}$$

In those fisheries for which no good estimate of E can be obtained — and these are very numerous — the right hand side of this inequality can still be readily calculated, giving a limiting value of E $(= E_L)$. A range of likely values of E may be judged by comparison with similar but better studied fish stocks, or by the degree of development of the fishing on the stock, etc., and it may often happen that the limiting value, E_L, lies outside this range. For example if E_L is greater than any likely value of E, increasing the size of first capture is most unlikely to increase the catch. Thus reasonably reliable statements about the desirability or otherwise of an increase in size of first capture can not infrequently be made.

When recruitment to the exploited stock takes place over a range of sizes rather than abruptly at one size — e. g., mesh selection by trawls — then the values used for $\bar{W}$ and W_c have to be slightly modified, so that, following ALLEN's original development,

W_c = average weight of fish released following a small increase in mesh size and as before

$\bar{W}$ = average weight of fish in the catch.

The value of W_c corresponding to the mesh size, m_1, in use (say ${}_1W_c$) can be determined at once from the present catch and the difference in selection between meshes m_1 and $m_1 + dm$; it is the average size of fish caught by mesh m_1 but released by mesh $m_1 + dm$. For any larger mesh m_2, the catches with it, and hence ${}_2\bar{W}$, must first be determined from the difference in selectivity of meshes m_1 and m_2, and then ${}_2W_c$ determined as the average size of fish caught by m_2 but released by $m_2 + dm_2$.

While a qualitative statement as to whether or not an increase in size of first capture will give an increased catch is useful, a quantitative assessment of the size of such increase following any given increase in size of first capture is usually needed. Such a quantitative assessment can be considered in two stages: the assessment of the immediate effect of a change in selectivity, and that of the long-term effect, after the population has settled into the new steady state. For the former the essential information is the size distribution of the present catches (the problem of discards, and the distinction between catch and landings, is ignored here, but will be dealt with later in this paper),

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and the selectivity of the present and proposed new gears. Then for any size group we may write

$_tC_1$ = numbers caught with the present gear
$_tC_K$ = numbers caught with the new gear immediately following the change
W_t = average weight of fish in the size group
$_tS_1$ = proportion retained by present gear
$_tS_2$ = proportion retained by the new gear

Of these quantities $_tS_1$ and $_tS_2$ may in principle be directly estimated by the usual selectivity experiments — though there is often a practical problem in determining what precisely is the average effective mesh size in use. Shrinkage of new nets and subsequent stretching makes the mesh size when fishing very different from the nominal size when new, while chafing gear may make the effective mesh very different again. Also the average mesh size in use in a regulated fishery is unlikely to be the same as the minimum legal size, and will generally be rather larger. $_tC_1$ may be best estimated directly from samples of the commercial catches.

If the pattern and intensity of fishing remain unaltered, then, because the population will not have had time to change, the only factor which could change the catches is the selectivity, and $_tC_K$ can be directly estimated as

$$_tC_K = {}_tC_1 \times {}_tS_2/{}_tS_1$$

Then we have, adding for all length groups,

total catch in numbers with small mesh, $C_1 = \Sigma_t C_1$
immediate catch in numbers with large mesh, $N_K = \Sigma_t C_2$
catch in weight with small mesh, $Y_1 = \Sigma_t C_1 W_t$
immediate catch in weight with large mesh, $Y_K = \Sigma_t C_2 W_t$
number of fish released, $N_R = C_1 - C_K$
immediate loss in weight, $Y_R = Y_1 - Y_K$

In estimating the long-term effect of the mesh change we will at first assume that the selection is knife-edge, such that at present no fish with lengths less than l_1 are caught, but that all fish larger than l_1 are exposed to the full fishing mortality. Similarly, for the new mesh all fish are retained above length l_2. Suppose that the ages corresponding to l_1, l_2 are t_1, t_2; then the change in selectivity will not alter conditions among fish older than t_2, so that the numbers in the population and in the catches will be proportional to the numbers of fish reaching age t_2. That is, if

Y_2 = long-term yield above t_2 after selectivity change
N'_2 = numbers reaching age t_2 with present selectivity
N_2 = numbers reaching age t_2 when population has reached a steady state with the new selectivity

then $Y_2/Y_K = N_2/N'_2$, and the problem is essentially to estimate the latter ratio, (i. e., the increase in numbers of fish reaching the higher age at first capture).

HOLT (1958) has obtained a simple expression for this in terms of the fishing mortality, for if N_1 = numbers of fish reaching age t_1, which will be the same for both conditions, then in the usual notation

$$N'_2 = N_1 e^{-(F+M)(t_2-t_1)} \qquad N_2/N'_2 = e^{F(t_2-t_1)}$$
$$N_2 = N_1 e^{-M(t_2-t_1)} \qquad \text{and} \qquad Y_2 = Y_R\, e^{F(t_2-t_1)}$$

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This gives a simple compact formulation in terms of only two quantities — the fishing mortality and the time interval. However this simplicity is in appearance only, if the fishing mortality is not the same for all ages of fish, e.g., due to the different distribution of the smaller fish. Then, following HOLT, the ages t_1, t_2 must take into account the pattern of recruitment and are the mean resultant selection ages for the two selectivities, obtained from the resultant selection ogive (the product of the recruitment and selection curves), c. f. BEVERTON and HOLT (1957), Figure 8.3. If recruitment occurs sharply at age t_r, and t'_1, t'_2 are the ages corresponding to the two gear selectivities, then

$$t_1 = \text{greater of } t_r,\ t'_1$$
$$t_2 = \text{greater of } t_r,\ t'_2$$

Hence $e^{F(t_2-t_1)}$ will be less than $e^{F(t'_2-t'_1)}$ unless t_r is less than t'_1, i. e., unless recruitment is complete before gear selection occurs, and will in fact become zero when t_r is greater than t_2. Thus estimating the time interval solely from gear selectivity could overestimate, perhaps seriously, the increase in long-term catch.

Alternatively, we can see that $N_2 = N'_2 +$ those of the fish caught by the small mesh, but released by the larger mesh, which survive to age t_2. If the time interval t_1 to t_2 is small, then the reduction due to natural mortality in this period is small and, neglecting this mortality,

$$N_2 = N'_2 + N_R$$

Also if a proportion E* of the fish reaching age t_2 are caught ($E = F/F + M$ in the usual constant parameter case), then

$$C_2 = EN_2,\ N_K = EN'_2,$$
$$\text{hence } C_2 = N_K + EN_R$$
$$\text{and } C_2/N_K = 1 + EN_R/N_K$$
$$\text{and therefore } Y_2/Y_K = 1 + EN_R/N_K$$

This gives an estimate in terms of quantities N_K and N_R, which are directly observable from samples of the present catch, and the simple quantity E. This latter is not an instantaneous rate, but is the probability of capture during the whole of the fishes' subsequent life, and thus is not greatly biassed if in fact the fishing mortality of the small fish is not the same as that of the larger fish.

A closer estimate can be obtained by allowing for the natural mortality among the N_R fish released, that is

$$N_2 = N'_2 + N_R e^{-Mt'}$$

where t' is the average time between being released and reaching age t_2. If fish are released uniformly between ages t_1 and t_2, then $t' = \frac{1}{2}(t_2 - t_1)$, and this is probably the most useful approximation. Strictly, if fish are fully recruited before t_1, then slightly more fish will be released in the early part of the interval, so that t' will be rather greater than $\frac{1}{2}(t_2 - t_1)$, but it may be that recruitment is still taking place between t_1 and t_2, in which case more fish would

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*E in the standard notation is the "exploitation rate" or "expectation of death by capture", referred to some defined time interval, and is therefore equal to $(1 - S)\ F/Z$. Here S is the fraction of those fish present at the beginning of a time period which survive to the end of that period. The term "exploitation rate" is usually applied to the *annual* expectation, but in this paper E is expressed on a life-time basis (so $S = 0$) and is referred to throughout as the "expectation of capture". It may be noted that RICKER (1958) distinguishes "rate of exploitation" (expectation of capture) from "rate of utilization" (annual expectation of capture and subsequent landing).

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be released in the later part of the time interval, and t' would be less than $\frac{1}{2}$ $(t_2 - t_1)$.

Apart from the approximation to t' in the second method, the two forms are clearly closely related, and this relation may be shown by expanding the two expressions. For the first we have

$$N_2/N'_2 = e^{F(t_2-t_1)}$$

or, writing $t_2 - t_1 = t$, and expanding,

$$= e^{Ft} = 1 + Ft + \tfrac{1}{2}(Ft)^2 + 0\,(t^3), \qquad (1)$$

where $0\,(t^3)$ denotes terms of the order of t^3 and smaller; for the second

$$N_2/N'_2 = 1 + E\frac{N_R e^{-Mt'}}{N_K} \qquad (2)$$

Expressing the right hand side of (2) in terms of F and M,

$$E = F/F + M$$

$$N_R = N_1 \frac{F}{F+M}\left(1 - e^{-(F+M)t}\right)$$

$$N_K = N_1 e^{-(F+M)t}\frac{F}{F+M}$$

Hence
$$N_2/N'_2 = 1 + \frac{F}{F+M}e^{(F+M)t}\left(1 - e^{-(F+M)t}\right)e^{-Mt'}$$

$$= 1 + \frac{F}{F+M}\left[1 + (F+M)\,t + \tfrac{1}{2}\,O\,(t^2)\right]\left[(F+M)\,t - \tfrac{1}{2}(F+M)^2t^2 + O\,(t^3)\right]\left[1 - Mt' + O\,(t^2)\right]$$

$$= 1 + F\left[1 + (F+M)\,t\right]\left[t - \tfrac{1}{2}(F+M)\,t^2\right](1 - Mt') + O\,(t^3)$$

$$= 1 + Ft + \left[\tfrac{1}{2}F^2 + FM\left(\tfrac{1}{2} - \frac{t'}{t}\right)\right]t^2 + O\,(t^3) \qquad (3)$$

A comparison of expressions (1) and (3) shows that the first two terms are identical, and also the third, if t' is put equal to $\frac{1}{2}\,t$; in fact, for constant F and M

$$t' = \frac{t - \dfrac{1}{F+M}\left(1 - e^{-(F+M)t}\right)}{1 - e^{-(F+M)t}}$$

which expanded in terms of t becomes

$$\tfrac{1}{2}t - \tfrac{5}{12}(F+M)\,t^2 + O\,(t^3)$$

Selection over a Range of Sizes

Both methods can be applied without formal modification to the more realistic situation in which selection occurs over a range of sizes. Thus the differences between an assumed knife-edge selection and the real selection ogive have been studied by GULLAND (1957), who showed that there was usually little difference, and in particular the assumption throughout of the simple knife-edge selection gave a good estimate of the effect of change in mesh size. The present situation is rather different, in that the first step of calculating the immediate effects of using a larger mesh is based on the true selection curve, and only the long-term change is based on the assumption of knife-edge selection. The errors involved are likely to be rather larger, though still small. The biggest errors are likely to occur when a large proportion of the catch is

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taken within the selection range of the larger mesh. Thus in the first method, the factor e^{Ft} will give the correct increase for numbers of fish above the 100% retention size of the larger mesh, but the numbers of fish within the selection range will not have increased quite so much, so that the increase of the total catch will be slightly overestimated.

In the second method, on the other hand, it is assumed that of the fish that are released, those that are caught later will have the same size composition as the retained catch. In fact some fish at the top of the selection range will, when released, be bigger than the smallest fish in the retained catch. Thus the average size of the released fish, at the time of subsequent capture, will be greater than the average size in the retained catch. The method therefore underestimates the actual increase in weight, but not in number caught. This is clear if we write equation (2) as

$$Y_2/Y_K = C_2/N_K = N_2/N'_2 = 1 + Ee^{-Mt'} \frac{N_R}{N_K} \qquad (4)$$

$$\text{or} \quad Y_2 = Y_K + Ee^{-Mt'} N_R \frac{Y_K}{N_K}$$

$$= Y_K + Ee^{-Mt'} N_R \bar{W}_K$$

where $\bar{W}_K$ is the average weight in the retained catch.

Now, $Ee^{-Mt'} N_R$ is the number of the "released" fish which are subsequently caught by the larger mesh, and if $\bar{W}_2$ is their average size when caught, $\bar{W}_2$ is greater than $\bar{W}_K$, and the true long-term catch with the large mesh is

$$Y_2 = Y_K + Ee^{-Mt'} N_R \bar{W}_2 \qquad (5)$$

The methods may be best illustrated and compared by using a hypothetical example (see Table 1). This example has been taken to bring out as far as possible the shortcomings of the various methods, and should therefore be treated as an unusually unfavourable situation. The computations have for ease been made in terms of age-groups rather than size groups, but the steps in calculation are formally the same. The latter type of data will be the more common in practice. Values of fishing mortality and natural mortality of 0·2 and 0·1 respectively have been used. Recruitment to the fishery is assumed to take place over a wide range of sizes; this is given in the third column of Table 1, where q_R denotes the proportion of the total number of fish of that age which are exposed to fishing; e. g. for age-group 7 $q_R = 0{\cdot}55$, so that apart from gear selection the potential fishing mortality on these fish is $0{\cdot}55 \times 0{\cdot}2 = 0{\cdot}11$. The selectivities for the old and new gears are given in columns 4 and 5, which show that while all fish of age 7 are retained by the old mesh, only 30% are retained by the new mesh, i. e. the fishing mortalities caused by the two gears are 0·11 and 0·033 respectively. The numbers caught in each age-group by the two gears were calculated by the precise formulae, using the known mortality rates for each year, and these precise figures are given in columns 7 and 10. In any practical situation the known quantities would be the present catch (column 7) and the selectivities (columns 4 and 5). From these the immediate catch following the increase in mesh, (column 9), and the numbers of fish released (column 8) can be calculated at once. The total numbers and weight of the fish in the original catch, respectively released and retained by the larger mesh, are easily obtained as the appropriate column totals, and the sums of products of these columns and the weights given in column 2. In practice, if

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Table 1

Hypothetical example of a fished population to illustrate methods of assessment

(For full explanation see text)

Age	W	q_R	S_1	S_2	S_2/S_1	C_1	N_R	N_K	C_2
2	10	0·05	0	0	0	0	0	0	0
3	12	0·10	0·05	0	0	0	0	0	0
4	14	0·15	0·30	0	0	62	62	0	0
5	17	0·25	0·70	0	0	234	234	0	0
6	20	0·40	0·95	0·05	0·053	470	445	25	25
7	24	0·55	1·0	0·30	0·300	533	373	160	181
8	28	0·70	1·0	0·70	0·70	542	163	379	471
9	31	0·85	1·0	0·95	0·95	510	26	484	612
10	34	0·95	1·0	1·0	1·0	431	0	431	552
11	37	1·00	1·0	1·0	1·0	338	0	338	433
12	39	1·00	1·0	1·0	1·0	250	0	250	321
13	41	1·00	1·0	1·0	1·0	185	0	185	238
14	43	1·00	1·0	1·0	1·0	137	0	137	176
15+	46	1·00	1·0	1·0	1·0	393	0	393	504
					Number	4,085	1,303	2,782	3,513
					Weight × 10^{-2}			984	1,248

Actual increase in numbers retained = 3513/2782 = 1·2628
Actual increase in weight retained = 1248/984 = 1·2683
First estimate of $\triangle t = 3$ $e^{F\triangle t} = 1{\cdot}82$
True value of $\triangle t = 1{\cdot}28$ $e^{F\triangle t} = 1{\cdot}282$

the length-weight data are not available, then a satisfactory alternative is to use the cube of the length as being proportional to the weight. The table shows that the actual gross long-term increases in weight and numbers caught (Y_2/Y_K and C_2/C_K) are 1248/984 = 1·2683, and 3513/2782 = 1·2628 respectively. The slight difference is because the catch in the selection range does not increase by the same amount as the rest, so that the average size of fish in the catch increases slightly.

The estimates that would be made in practice depend on the data available. Using HOLT's method we may assume that for the fully recruited fish the fishing mortality has been accurately estimated as 0·2. The difference in mean selection age of the two meshes is 3 years (5 years to 8 years) which gives a maximum estimate of t, and an estimate $e^{+Ft} = e^{+0.6} = 1{\cdot}82$, which is a gross overestimate of the gain. A more satisfactory estimate may be obtained by examining the left hand edge of the age (or length) composition of the present catches; this shows that the mean effective recruitment age is certainly greater than the 5 years given by the present mesh selection curve, and may perhaps be about $6\frac{1}{2}$ years. Correspondingly, the mean selection age with the larger mesh is over 8 years, say $8\frac{1}{2}$ years; this gives $t = 2$ years, $e^{+Ft} = 1{\cdot}49$, which is closer to the true value. In fact the mean selection ages with the two meshes are 7·34 and 8·58 years respectively; this gives $t = 1{\cdot}24$, $e^{Ft} = 1{\cdot}282$. This is the real increase of fish above the selection range of the larger mesh, but is larger than the increase for fish within the selection range, and so gives a slight overestimate of the benefit as a whole.

Using the method of the present paper, we have $N_R = 1303$ and will assume again that accurate estimates of $M = 0{\cdot}2$, $E = 0{\cdot}67$ have been obtained from

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the fully exploited population. The first estimate of t obtained from the two selection curves is again 3 years. This gives $e^{-\frac{1}{2}Mt} = 0{\cdot}8607$, so that the number of extra fish reaching the mean retention size of the large mesh is 1121, and the extra number caught $= 0{\cdot}67 \times 1121 = 748$. The catch of the larger mesh is therefore estimated to increase by a factor of $1 + \frac{748}{2782} = 1{\cdot}2689$. This is slightly greater than the true increase in numbers, but almost exactly equal to the increase in weight. This very close agreement is probably mainly a coincidence; more important is the fact that estimates of t which are rather far from the true value will give reasonably close estimates of the benefit: for instance, taking $t = 1$ or 5 years gives values of $e^{-\frac{1}{2}Mt} = 0{\cdot}9512$ or $0{\cdot}7788$, and increases of 1·2970 or 1·2431 – errors of under 3% above and below the true value.

An estimate of t' which may be rather better than $\frac{1}{2}\, t$ may be obtained as the difference between the mean age of the N_R fish, (which is relatively easy to measure in practice) and the mean effective selection age of the larger mesh. This will in general be greater than the mean selection age as measured by mesh selection experiments, to an extent depending on the recruitment pattern. (It may well be difficult to measure in practice.) In the example the mean age of the N_R fish is readily calculated as 6·82 years; the true mean effective selection age of the larger mesh is 8·58 years. Though this value cannot easily be estimated from the data available in practice, the catches of the larger mesh would suggest a value reasonably close to it. This gives a value of $t' = 1{\cdot}76$ years, which is in fact very close to the value of 1·5 years estimated from half the difference in mean selection ages of the two meshes.

Fisheries with more than one Gear

The methods may be directly extended to cover fisheries where more than one gear is used. The number N_R of fish released will be given by the catches and selectivities of only those gears whose selectivity is changed. The number N_K will however depend on the catches of all gears which may later catch the released fish. Generally it will be assumed that the probability of being caught by any particular gear is the same for all fish of the same size, whether they are part of the N_R released fish, or of the N'_2 originally in the stock. An example of possible exceptions is when two gears, e. g. trawls and lines, are fishing slightly different areas; then the fish released by the trawl are, compared with the average fish of their size, more likely to be caught by trawl, and less likely to be caught by line until mixing has taken place.

Assuming that the probabilities are in fact equal, then equation (2) may be re-written, using prefixes T for "trawl" (the selecting gear) and o for other gears, as

$$_TY_2/_TY_K = {}_oY_2/_oY_K = N_2/N'_2 = 1 + E\,e^{-Mt'}\,\frac{_TN_R}{_oN_K + {}_TN_K} \quad \ldots\ldots\ldots\ldots (5)$$

where $_oN_K$ is the number of fish above the selection size which are caught by the other gear.

In the simplest case the catches of the non-selecting gear are of fish all greater in size than the larger selection size of the selecting gear, and $_oN_K$ is equal

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to the total catch of the non-selecting gear. In this case no detailed size composition of the catches of the non-selective gear is required — only the average size, which is required to calculate the numbers caught. Clearly, also, any fish caught by the non-selecting gear which are smaller than the lower selection size will not be affected at all by the change in selection, and these will not be included in ${}_oN_K$. Fish within the selection range will be affected, but not to the full extent, and should be only partially included in ${}_oN_K$. The correct weightings would appear to be to write ${}_oN_K$ as the sum of the contributions of the various sizes i

$$ {}_oN_K = \sum_{l_1}^{l_2} p_i \, {}_oN_i + {}_oN' $$

where l_1, l_2 are the two selection sizes
p_i = proportion of the N_R fish smaller than l_i
${}_oN_i$ = number of fish in the i th length group caught by the gear
${}_oN'$ = number of fish greater than l_2 caught by the gear.

An alternative method would be to apply the trawl selection curve to the catches of the other gear. This will give nominal values of ${}_oN_R$ and ${}_oN_K$, and the latter can be used in calculating the long-term effect.

If no detailed data are available about the sizes of fish caught by the non-selecting gear, then some estimate may be made from the trawl catches. Probably the best is to assume that the sizes are the same as those caught by trawls using the larger mesh size. If in fact the fish are larger, then the number of fish in the catch will be overestimated and hence the long-term catches by all gears equally underestimated. If they are smaller, then the catch in numbers will be underestimated. However, some of these fish will presumably be below the selection range, and should not be included in N_K; thus the estimated value of N_2/N'_2 etc. may well be not so far from the true value. Hence the long-term catches by the trawl fleet will be nearly correct, or underestimated, but those by the non-selective gear (because only the part above the selection size will increase), will probably be overestimated.

Discards

The analysis so far has treated catches as being equivalent to landings. In fact numbers of fish, predominantly small ones, are often discarded at sea. If the calculations have been based on catches, then they correctly estimate the effects on catches, and also the long-term effect on landings of fish too large to be discarded. However, the immediate losses to the landings of small fish below the selection size of the larger mesh will be less than the losses to the catches, to the extent that the latter include fish which would have been discarded. If the discarding practice is known in detail, so that for each size of fish the proportion discarded is known, then this proportion can be used to correct each size group in the estimate of the immediate losses to the catches. Hence the immediate losses to the landings can be determined.

More often data on size-composition will refer to landings. The estimate of the immediate effect on landings will therefore be correct, so long as the discarding practice is unchanged (i. e. the fraction of each size group discarded is constant). However, N_R and hence also the long-term increase will be underestimated to the extent that the true number includes fish that would have been

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caught and discarded (and presumably killed) as well as fish that would have been landed. The correct value of N_R can be obtained at once from data of the number and sizes of fish discarded and the selection in the usual way. If such data are not available then some reasonable assumption concerning the discards will have to be made.

By ignoring discards, therefore, an unduly pessimistic view of the introduction of a larger mesh would be taken, even if the discarding practice was unchanged. In fact the use of the larger mesh will reduce the absolute numbers of small fish in the catch. This is likely to increase the market demand for the remaining small fish and reduce the work of handling the catch (the main influences on discarding practice) and therefore reduce the proportion of each size discarded. The results obtained by considering discards by the above methods are therefore themselves likely to be too pessimistic. More precise consideration of the extent of change of discard practice following a mesh change is however beyond the scope of this paper.

The analysis so far has assumed that the pattern of fishing after the change in selectivity is the same as that before. For most fish stocks, there are differences, often considerable, in the proportion of small fish in the catches on various grounds. When trawlers (or other vessels) are using a gear which can catch small fish they may tend to fish on the small fish grounds, particularly when the larger and older fish which make up the bulk of the catches on other grounds have been reduced by intense fishing. If the selectivity is changed, so that they cannot catch so many small fish, they will naturally tend to move to grounds where the larger fish predominate. Their catches after the selectivity change will therefore be larger than suggested by the "immediate loss" figures calculated from the catches on the small fish grounds. The long-term catches will also be changed because of heavier fishing than previously on the larger fish, though this will be counteracted by even less fishing than calculated on the small fish around the selection range. What happens in any particular situation requires individual study, especially of the possible alternative fishing grounds for the trawlers, and the catches to be taken from them. Probably even then too much will depend on the particular ideas of the fishermen and of the market for an exact forecast of the changes to be made. Generally, however, such changes in the pattern of fishing, additional to changes in the selectivity of the gear, will not greatly affect the total catch. Of this total the trawlers will take a larger proportion than expected solely from the selectivity change, though smaller than the proportion caught by them before the change. Conversely the non-selecting gear will take a smaller proportion than expected solely from the selectivity change, though larger, both absolutely and relatively, than before the change.

Theoretical situations could however be imagined in which the catch of the non-selective gear was actually greater than following the selectivity change alone, or in which the total catch was substantially increased or decreased.

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Summary

A method of estimating the effect on catches, both immediate and long-term, of changes in the selectivity of the gear, is described.

This depends essentially on knowing the size-composition of the present catches. From this, and a knowledge of the selection curves of the new and old gears, the immediate effect in terms of the numbers of fish retained (N_K), and released (N_R) can be calculated. Of the N_R fish, some ($= N_R\, e^{-Mt'}$) will live through the average time interval, t', needed to grow to the size retained by the new gear; of these a proportion, E, will ultimately be caught. Thus the immediate catch will be increased in the ratio $N_K : N_K + EN_R e^{-Mt'}$.

The method can be easily extended to cover fisheries in which more than one gear is operating, not all of which change their selectivity.

If fish are discarded at sea, the method gives too pessimistic an estimate of increases in size at first capture.

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