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International Council for the
Exploration of the Sea

C.M. 1963
Symposium on the Measurement
of Abundance of Fish Stocks
No. 16

Effective Fishing Effort and the Catchability Coefficient q

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The simple theory of the dynamics of exploited fish populations makes the fundamental assumption that one unit of fishing effort will exert a given unit of fishing mortality with respect to a particular stock. Beverton & Holt (1957) gave this assumption its formal expression

$$F = cf$$

where F = the instantaneous coefficient of fishing mortality.

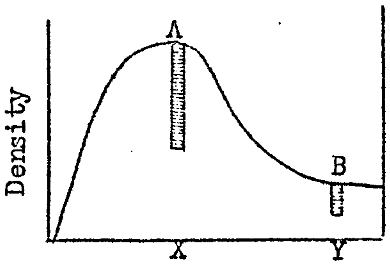
f = the fishing effort per unit area (fishing intensity) which is synonymous with total fishing effort in the special case where the relative distributions of fish and fishing remain constant.

c = a constant which is the ratio of fishing mortality to the particular unit of fishing intensity or effort.

This proportionality constant has been termed the catchability coefficient, c or p (Beverton & Holt, 1957) or q in the international notation (Holt et al., 1959). By definition this constant also relates the catch per unit effort to the true density so that the catchability coefficient is synonymous with the availability coefficient, the choice of nomenclature depending upon the standpoint of an investigation, i.e. q refers to catchability in relating fishing effort to fishing mortality, and to availability in relating catch per unit effort to density. In this paper the constant q will be discussed in its connection to the estimation of fishing effort.

In practice any estimate of q will be an average value for the cumulative interaction of the variables discussed by Gulland (1955). These are

(i) the fishing power of a vessel for a type of fish;
(ii) the vulnerability of that type of fish;
(iii) the aggregation of fishing units on the fish;
(iv) the concentration of fishing units on the fish.



These can be illustrated from the diagram, which represents the distribution of density in time or space of a fish stock which is exploited at two positions or periods X and Y.

The two areas A and B represent the unit fishing mortality as an equal proportion of the ordinate of density at X and Y.

Any change in fishing power of a vessel will alter the areas of A and B as a proportion of the local density at X and Y and, since the tendency is for fishing power to increase, the unit fishing mortality will be increased, as occurred with the introduction of Vigneron-Dahl trawl gear. A second aspect of changes in fishing power may be distinguished where the efficiency of a standard gear varies with stock density. This is evident in the gear saturation of gill nets or long lines although it is less readily identifiable in trawl fisheries. At high stock densities the fishing power of a gear may decrease so that the proportion of the local stock removed per unit effort at X and Y is reduced.

Systematic or randum fluctuations of the vulnerability of the fish will have the same effect. It may be that at certain times of the year the condition of the fish is such that they are less able to escape an oncoming trawl. In this event their vulnerability will be increased and, with it, the proportion of the local fish stock taken per unit effort.

These two effects of fishing power and vulnerability are independent of the relative distribution of fish and fishing unless there is a change between the local populations X and Y. This distinguishes them from the effects of aggregation or concentration of the fishing units which refer to the relationship between these distributions. Although the proportion of the local density removed at X and Y is constant when the fishing power and vulnerability are constant, the absolute magnitude of the catch per unit effort is very different. It follows that the effective fishing mortality at X and Y on the entire stock will also be different.

If the diagram represents the distribution of a stock in space, the use of echo-sounders may enable the fishing units to operate at X, improving the aggregation of the fleet on the stock by reducing the amount of search which would involve a disproportionate amount of fishing at Y. The same amount of fishing time thus becomes more effective.

It is also convenient to distinguish a special type of aggregation where the location of fishing activity is fixed (e.g. by the range of the vessels) but the distribution of the fish stock varies in relation to it. For example, the duration of a seasonal fishery may be determined by the rate of dispersion of the fish shoals. In years when this dispersion is delayed, a greater proportion of the fish stock is exposed to the fishing effort though this may itself remain constant. Again the effectiveness of the fishing effort is increased. Strictly speaking this could be distinguished as the vulnerability of the stock as opposed to the vulnerability of the fish, but it makes for simplicity to regard this as an instance where fishing effort has been able to aggregate more effectively upon the stock.

The concentration of fishing units upon the fish is usually determined by economic considerations. If the diagram represents the spatial distribution of a stock, the fleet might fish at Y because a second more valuable type of fish is especially abundant at this point. In this case the fishing units will not be concentrating on the fish stock represented.

The variation of any one of these factors will influence the proportionality coefficient of the basic assumption, $F = qf$, altering the effectiveness of the unit of effort f. The types of variation to be expected can be viewed from a different standpoint which is discussed by Gulland (this Symposium). The most important sources of change are cyclical (seasonal variations) and long-term trends. The long-term trends in q are usually associated with changes in fishing power of the vessels and may be accommodated by the correct choice of unit of fishing effort, but the cyclical variations of q and their association with the estimation of fishing effort are also important.

From Beverton & Holt's derivation $F = qf$, f represents the fishing intensity, or fishing effort per unit area; the total fishing effort conforms to this relationship only in the special case where the relative seasonal distributions of fish and fishing activity remain constant from year to year. Gulland (1955) has discussed this in detail in the dual aspect of the problem, the estimation of an annual density index which is proportional to the true density of the population. He has demonstrated that the best estimate of this index of density is the weighted mean of the catch per unit effort in each sub-area, or month, the weighting factors being the areas or months, depending upon whether the variation occurs in time or space or both. This will be independent of the cyclical variation of q, or at least take the best estimate of a mean q which may be constant from year to year.

However, in his consideration of the estimation of density, Gulland points out that the density d_j in the jth time or space interval is related to the true density D by a further constant k_j i.e. $D_j = k_j D$. Paraphrasing his comment (p.31) "when the seasonal distribution in consecutive years is different, k_j will not be the same". In such cases there is no single figure which is a completely adequate measure of density for the whole year (which can be compared with the density of the stock in the previous year).

With respect to fishing effort we have the relationship $F_j = k_j F$ or $q_j f_j = k_j F$. Thus if there is a change in the cyclical variation of q_j the constant k_j will also vary and the effective fishing intensity measured by Gulland's method will not be comparable between consecutive years.

Fishery biologists find it convenient to assume that k_j does not vary, but this may rarely be true when one considers the factors that influence q_j. This is evident in complex fisheries. For example, consider two species of equal value which normally have comparable densities so that fishing is equally distributed between them. In a second year the stock of one species may contain a particularly abundant year-class. Fishing activity will then concentrate upon this species and q_j will change with respect to both. An estimate of fishing effort will remain the same because the weighting factors between areas or months have not changed, but the effectiveness of that effort will have been distorted.

This situation can arise in an ostensibly simple single species fishery, such as the English Bear Island cod fishery. Figure 1 of the monthly fishing effort shows that in 1960 the winter fishery was not exploited, although in 1957 fishing activity at this time was comparable to the main summer fishery. The total fishing effort in these two years is not strictly comparable because the distribution of its effectiveness has varied.

These errors have considerable theoretical importance in the conventional determination of the regression $Z = qf + M$, where Z and M have the usual notation. Paloheimo (1961) has pointed out that the use of regression techniques in fitting the relationship is only valid where q is constant and f is free of error. If this condition is not satisfied it becomes of a functional relationship since Z and f are not independent.

In current practice the necessary assumptions are made, even to the extent of assessing the total fishing effort on a stock exploited by varied gears and countries in terms of the effective effort of a single gear. This may be adequate in long-term investigations where a large variance of the data may not obscure the fundamental relationship, but in other situations, e.g. short-term prediction, or in species with a short life span and potentially large variation of q, e.g. Sprats, the extrapolation of the method becomes dangerous.

The computations necessary to provide a complete series of correction factors for the potential variation of q would be very complex, and critical data are lacking. However, since the regression technique of estimating $Z = qf + M$ requires that q should be constant, it is possible to base the density estimates necessary for the estimation of Z upon data from comparable periods of the year when q may be expected to be constant from year to year. For example, many species have a peak of abundance at a certain time of year or in a particular area, when it can be confidently assumed that all vessels fishing at that time, or that area, will be aggregating or concentrating upon the species in question, e.g. White Bank Sole in March/April. Variation in fishing power of the vessels may be corrected by the choice of unit of fishing effort (Gulland, 1956) so that the only remaining course of variation of q is the vulnerability of the fish themselves. This is less reliable, but for most years the vulnerability of fish at the same phase of their annual cycle will be the same.

Evidence that this is so can be taken from direct estimates of q obtained for whiting from English tagging experiments. Five experiments have been carried out on the Brixham and Irish County Down whiting stocks at a comparable phase of their annual cycle, in the seasons 1957/58 (two experiments) and 1958/59 in the County Down fishery, and in 1958 and 1959 in the Brixham fishery. Detailed analysis of these experiments will be published elsewhere, but Figure 2 shows the plot against time of the logarithm of the tags returned per unit effort expressed as a percentage of the initial releases, according to the method described by Gulland (1961). The intercept of these regressions is an estimate of q. The precise value of the intercept in these experiments is open to criticism according to the choice of numbers of initial releases but, provided the same correction factor for initial tagging mortality and non-reporting of returns is applied to each experiment, it can be seen that the estimate of q is extremely similar in each experiment (c.a. Log_e -o.6 = o.5 per cent per 1oo hours fishing). During the brief seasonal Brixham and County Down single species whiting fisheries the value of q was much the same in three consecutive years, 1957/58, 1958/59 and 1959.

Cyclical variations of q which are not constant between years may thus be overcome by selecting data for an estimate of a standard unit of density from a period of the year when q can be expected to be constant, e.g. at the height of a particular season. Then, by definition, the effective fishing effort will be the number of standard density units removed during the year. The second requirement for the correct interpretation of the relationship Z = qf + M can therefore be estimated with a minimum of error, provided statistics of total catch are known. Moreover, particular species may have more than one period in the year when such estimates can be obtained, so that several estimates of the mortality/effort relationship could be deduced.

In practice this is nothing more than applying the usual method of estimating total fishing effort in fisheries exploited by more than one country or gear to the fishing effort within a year by a single country, or gear, in order to overcome unpredictable cyclical variations of q caused mainly by changes in the aggregation or concentration of the fishing fleet. Indeed, this is the method applied to some pelagic fisheries by force of circumstances where the fish are only vulnerable to commercial fishing activity at certain times of the year. The fact that data on demersal stocks can often be collected throughout the year does not justify the assumption that it is all equally useful, though obviously care must be taken in relation to the biology of the particular species in selecting from the annual data.

Provided that the unit of fishing effort has been correctly chosen to minimise trends in fishing power the variance of data about the regression $Z = \overline{qf} + M$ will reflect more accurately true changes in the vulnerability of the fish from year to year, instead of an indeterminable complex of factors. This approach has been applied to the Bear Island cod fishery for the years 195o-6o. The relationships between fishing effort and total mortality are compared from a basis of three different estimates of the catch per unit effort taken from the catch per 1oo steam trawler ton hours for English vessels. These estimates of abundance were estimated as (1) the annual catch/total annual effort, (2) the mean of the monthly catch per unit effort and (3) the catch per unit effort recorded in May, June, July and August, during the feeding season when the recorded density reaches its annual maximum, the vulnerability of the fish could be expected to be constant from year to year and any vessel in the area will be fishing for cod. From these indices of abundance of age groups 5-9 the effective effort on each has been assessed from the total annual international catch of cod of each age group. The estimate of total mortality on each age group is plotted against the mean effective effort in the relevant two years in Figure 3, showing the three relationships derived from the separate indices of abundance used. No systematic differences were evident for different age groups, so the data have been grouped according to the level of effective fishing effort.

Disregarding the implications of the regressions obtained it can be seen that the third method gives a clear improvement in the interpretation. Using the linear form y = a + bx the constants are

	a	b	Var y about regression	Significance of regression
1	o.874	.oo243	o.o2o7	o.1 - o.o5
2	o.78o	.oo319	o.o279	$<$ o.o5
3	o.595	.oo627	o.oo97	$<$ o.o1

From this treatment it would be possible to derive a further relationship between the effective fishing effort and the effort actually expended. This may be of some value in assessing the economic implications of varied distribution of fishing effort with time, or the improvement obtained with new types of fish detection devices.

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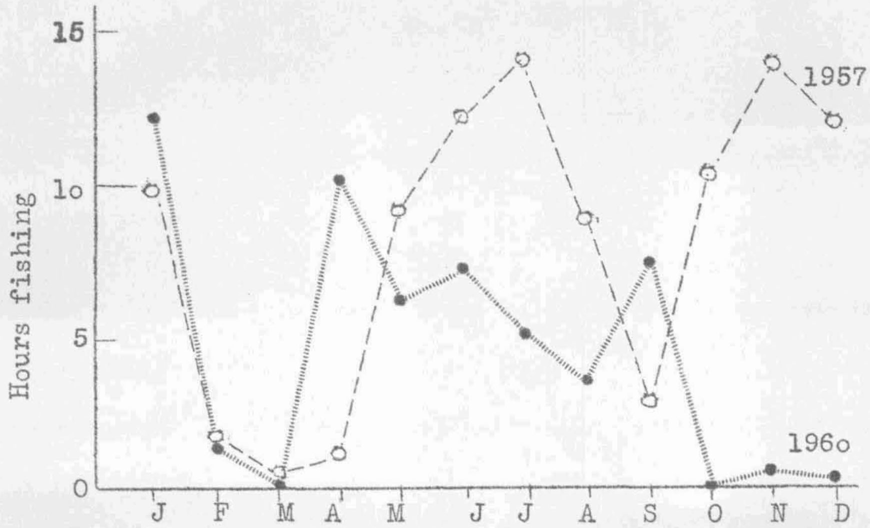
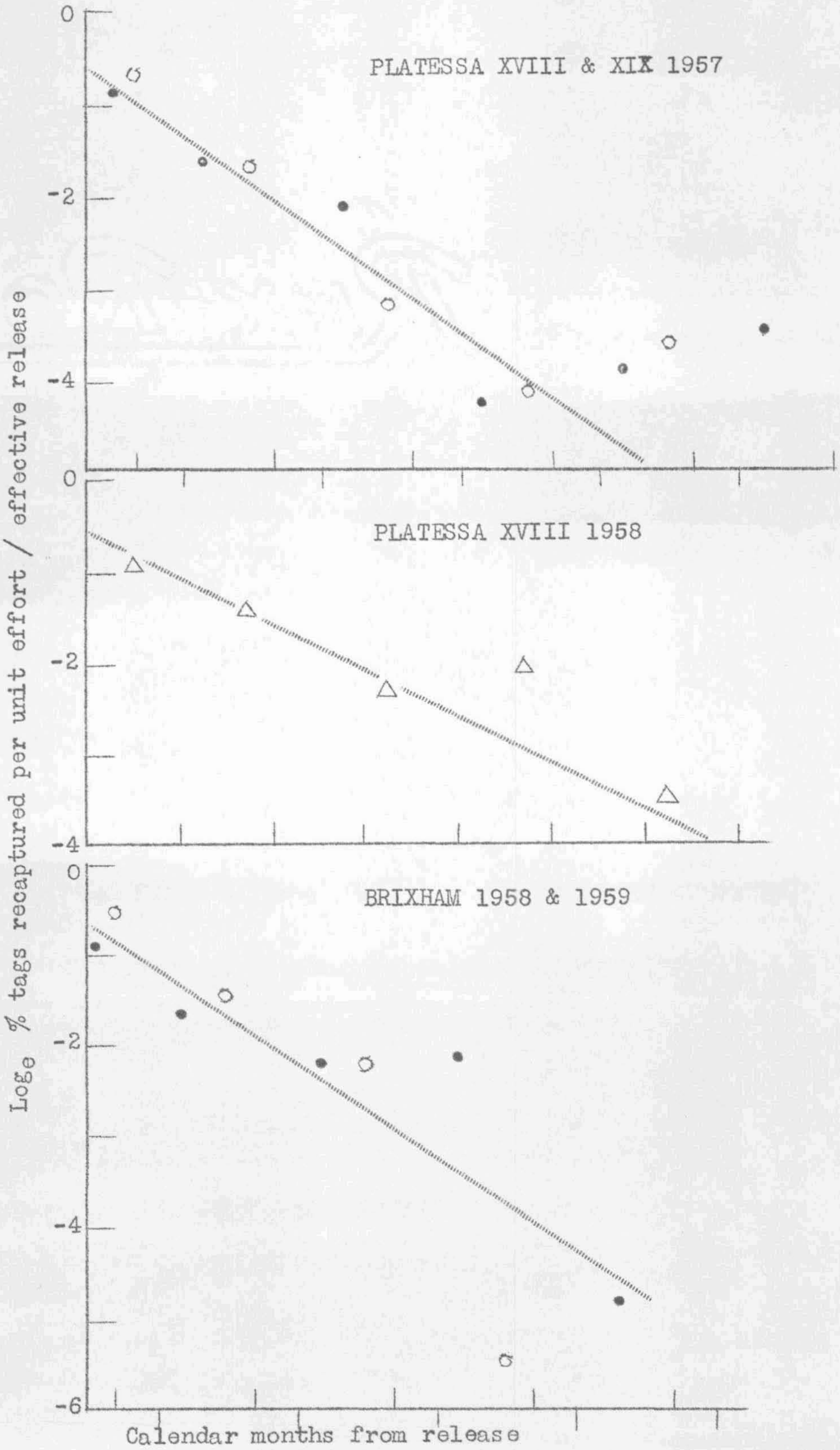


<u>Figure 1.</u> English fishing effort at Bear Island in 1957 and 196o.



<u>Figure 2.</u> The logarithmic plot of tags returned per unit of effort in English whiting tagging experiments in the Irish Sea and off Brixham (North Devon).

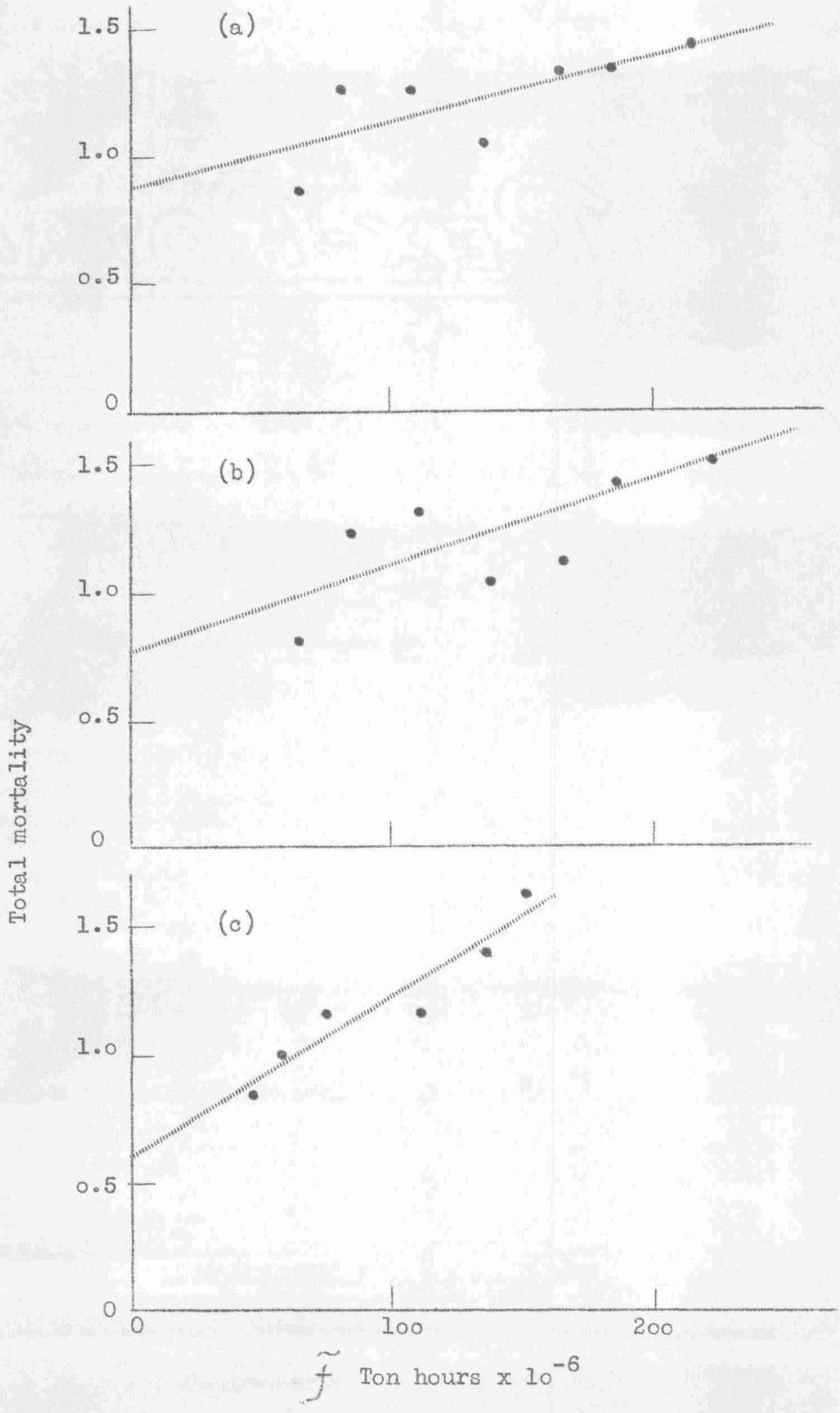


Figure 3. The regression of total mortality against total effective international fishing effort on Bear Island cod, 1950-1960, based on three different estimates of catch per unit effort.

(a) Total English catch/Total English effort.

(b) Mean of the monthly catch per unit effort from English data, as in (a).

(c) Mean of the monthly catch per unit effort from the summer feeding season, May, June, July and August.