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COMMERCIAL STATISTICS IN FISH POPULATION STUDIES

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The purpose of this paper is (a) to discuss the role of commercial statistics of catch and effort in sampling projects and fish population studies in general, and (b) to summarise, as far as is possible at the present time, the kind and quality of commercial statistics required for computing standardised measures of fishing effort and fishing intensity.

1. Introduction

The process of catch sampling to obtain data for fish population studies can, for practical purposes, be considered in two stages. The first is taking an individual sample and deducing from it the local abundance and structure of the population; this process might consist of an experimental haul with a particular gear from a research vessel or of estimating the composition of a commercial vessel's catch by market sampling. The second stage is combining the information from a number of individual samples of either kind to obtain a comprehensive picture of the total abundance and structure of the whole population.

It is in the second stage, and especially when estimating an index of total abundance, that adequate commercial statistics play an important if not an indispensable part, as is demonstrated by Gulland (No. 27). Going beyond the immediate problem of sampling to the interpretation of the resulting information and the use to which it is put, Beverton and Holt (contribution No. 24) have demonstrated the importance of a knowledge of fishing effort in the estimation of mortality rates, especially in the separation of total mortality into that due to fishing and that due to natural causes. Finally, when the need arises for regulating a fishery, commercial statistics of catch and effort are again indispensable - not only for the efficient administration of the regulation but as an adjunct to sampling data for testing whether a particular regulative measure is having the expected result.

These generalisations apply to every commercial fishery but with greater force as the size and complexity of the fish population and of the fleets fishing it increases. The North Sea herring illustrates this point as well as any. This stock consists of several 'spawning communities' whose degree of independence is still largely unknown but considerable mixing between them certainly occurs at some seasons. Moreover, there are a number of different types of gear in use in various parts of the North Sea; the result is that each spawning community, because of their migratory habits, is fished during the course of a year by several countries and gears. Over the years each country with an interest in herring fishing has exploited that part of the stock within the range of its fleet with its customary gear. Recently, the possibility of overfishing of herring has been raised and it is becoming clear that any real progress towards the solution of this problem must involve co-ordinated research among the nations concerned. But to obtain the comprehensive picture needed to assess the question of overfishing mere pooling of sampling data is not enough. Each gear, according to its selective properties, gives a somewhat different picture of the structure of that part of stock where it is used (see Parrish, this meeting). Also, the relation between density and catch per unit effort certainly differs greatly in some gears. The aim is to obtain measures of the total abundance and structure of each independent spawning community, or of the stock as a whole, to estimate its mortality rates and to relate the fishing mortality to the total fishing intensity exerted on it. Commercial statistics of catch and effort of each country, broken down into suitable units of time and area, together with calibration factors to enable estimates of abundance and structure from various sources to be adjusted to comparable measures, provide the means of integrating herring research so that this objective can be reached. Without them, the information that it is possible to obtain by sampling is seriously limited and its interpretation, especially when complex problems such as overfishing are concerned, largely a matter of guesswork.

2. Definitions and theoretical considerations

The ultimate objective can be stated quite briefly. It is to obtain a measure of the total fishing effort exerted on a stock or sub-divisions of that stock (e.g. races, size-groups or age-groups) in such units that when divided into the total catch it provides a true index of total abundance. This measure of fishing activity has been called the 'effective overall fishing intensity' (see Beverton and Holt, in press) and denoted by the symbol $\tilde{f}$; if the total catch of a population or part of a population is Y , then its abundance, N , is given by the equation

$$N = Y/c\tilde{f} \quad \ldots (1)$$

where c is a constant. It is important to note that the same constant c also relates $\tilde{f}$ to the instantaneous fishing mortality coefficient, F , generated by it and which would be estimated from catch samples of the same population; we have, in fact,

$$F = c\tilde{f} \quad \ldots (2)$$

Thus the problem of obtaining an index of total abundance by catch sampling is closely related to one of the most important uses to which the resulting data are put, namely the estimation of mortality rates and the relating of them to the fishing effort expended (see Beverton and Holt, No. 24). In both cases a knowledge of the effective overall fishing intensity plays an essential part.

We now consider the stages involved in computing an estimate of $\tilde{f}$ from commercial statistics of catch and effort, taking first the simple case of a stock fished by one method of fishing only. The two main factors are fishing power and fishing time, their product being fishing effort. For a given method of fishing and species of fish the <u>fishing power</u> of a vessel is defined, and measured in practice, as the ratio of its catch per unit fishing time or per unit fishing operation (e.g. per hour's towing or per shot) to that of a vessel and gear selected as a standard reference and fishing on the same density of fish. Thus time does not enter as such into the definition of fishing power, and is in fact eliminated by measuring fishing power from the ratio of catches obtained over equal periods of time or in the same number of fishing operations. Two of the factors which govern the fishing power of a vessel, at least with some methods of fishing, are its size and that of the gear it can use; these two factors are usually, but not always, closely associated. For example, it will be shown below that gross tonnage is a good measure of fishing power for steam trawlers, but in some methods of fishing it may be better to define fishing power in terms of gear dimensions rather than vessel size. Calibration of fishing power in this way therefore enables all the vessels of a fleet to be allocated a fishing power factor, in the units appropriate to that method of fishing.

A unit of <u>fishing effort</u> for a vessel can be defined as the product of its fishing power, in the standard units for its type, and an appropriate unit measure of the time or extent that its fishing power is in operation. Again, taking steam trawlers as an example, an 'hour's fishing' is a suitable time unit, so that for this type of vessel a 'ton-hour' is a standardised unit of effort. The fishing effort expended during a given period of time (e.g. a month or year) by a steam trawler could therefore be computed in standardised units by summing the product of its gross tonnage and the number of hours it had fished during that period.

It will be noted that fishing effort defined in this way is really an index of the chance that a fish in the area where the gear is operating will be caught during a given period of time; in this sense, therefore, fishing effort is related to the effective volume (or area) of water swept by the gear in that time. As this depends to some extent on fish behaviour and can seldom be estimated with accuracy from gear dimensions and length of tow alone (although a rough estimate may be possible in some trawl fisheries), it is not a convenient way of defining fishing effort for practical purposes. The spatial implication of the term fishing effort should, however, be borne in mind. Thus the need for standardising units of fishing power and time is really a question of ensuring that the fishing activities of different vessels and gears can be expressed in units which refer to equal effective swept volumes, even though these are not computed as such.

The final stage is to relate standardised fishing effort to the fishing mortality coefficient it generates. For this it is necessary to compute the fishing intensity, defined as the concentration of effort in space. Account must also be taken of the extent to which high concentrations of effort occur where fish themselves are most concentrated, since the greater this tendency the greater will be the catch obtained by a given total effort and hence the greater the fishing mortality generated in the stock as a whole. This problem is discussed more fully by Gulland (No. 27); here it is sufficient to note that the essential requirement is to be able to compute effort for sub-areas and for time periods small enough for the density of fish in each to be regarded as constant with respect to space and time. Suppose that in the sub-area i, of actual size a_i, the total standardised fishing effort in a period of time j is g_{ij}. Then the standardised fishing intensity in sub-area i during period j is

$$f_{ij} = g_{ij}/a_i \quad \ldots\ (3)$$

The quantity f_{ij} is, in fact a true index of the chance that a fish in sub-area i will be caught during the period j, and is therefore proportional to the fishing mortality coefficient F_{ij} in that sub-area and period, i.e. we have

$$F_{ij} = cf_{ij} \quad \ldots\ (4)$$

If the catch from sub-area i in period j is Y_{ij}, then the ratio Y_{ij}/f_{ij} i.e. the catch per unit fishing intensity, is proportional to the average density D_{ij} of fish in sub-area i over period j, as defined by Gulland (No. 27). Thus

$$Y_{ij}/f_{ij} = cD_{ij} \quad \ldots\ (5)$$

where c is the same constant as appears in (4). The effective overall fishing intensity during the period j, $\tilde{f}_j$, is the sum of the intensities f_{ij} in each sub-area weighted by the density of fish in each as estimated from (5). Thus, if there are z sub-areas in all, we have

$$\tilde{f}_j = \frac{\sum_{i=1}^{z} f_{ij}\left(Y_{ij}/f_{ij}\right)}{\sum_{i=1}^{z} Y_{ij}/f_{ij}}$$

which reduces to

$$\tilde{f}_j = \frac{\sum_{i=1}^{z} Y_{ij}}{\sum_{i=1}^{z} Y_{ij}/f_{ij}} \qquad \dots (6)$$

If it is necessary to work with periods of time less than a year to avoid large changes in sub-area densities, an annual value of $\tilde{f}$ is obtained by adding the values of $\tilde{f}_j$ over a year. The resultant estimate of $\tilde{f}$ is proportional to the annual fishing mortality coefficient estimated by random sampling of the catch, as defined by (2). It is important to note that to obtain a true value of $\tilde{f}$ from (6) it is necessary for estimates of catch per unit effort to be available from all sub-areas over which the fish population extends; obviously, if this is not so, it means that the abundance of part of the population is unknown. In this case the only procedure is to assume that the unfished part of the stock remains a constant fraction of the total stock; if this is valid a correct index of $\tilde{f}$ will be obtained by means of (6).

We have so far considered the case in which only one type of fishing method is used to exploit the stock. Where more than one method is employed it is necessary to express the amount of fishing by each in the same units before they can be combined, and the procedure depends primarily on whether the methods are such that it is possible to compare the catch per standardised unit of effort of each when fishing on the same density of fish. Suppose, for example, that the catch of a certain species obtained by a group of trawlers exerting a standardised effort g_T is Y_T, and that vessels fishing the same density of fish but using a different fishing method (designated as K) exerted a standardised effort g_K and obtained a catch Y_K. The two efforts g_T and g_K may be in quite different units of fishing power and time, but the ratio of the two catch per units provides the factor, ${}_TZ_K$, for expressing K-effort in terms of trawler effort, i.e.

$$\frac{Y_K/g_K}{Y_T/g_T} = {}_TZ_K \qquad \dots (7)$$

The total standardised fishing effort on the stock in trawler units is therefore

$$g = g_T + {}_TZ_K \cdot g_K \qquad \dots (8)$$

and in this way it is possible to estimate a value of $\tilde{f}$ using the catch and effort of both methods.

Where no direct comparison of catch per unit effort by different methods is possible, the only procedure is to select one method as a standard reference, to compute an estimate of $\tilde{f}$ from the catch and effort of the fleets using it, and to multiply this by the ratio of the catch obtained by all methods to the catch by the standard method. In this case the efforts of the other methods are not used as such - because they cannot be expressed in comparable units - and the accuracy of the resulting estimate of $\tilde{f}$ depends solely on that for the reference fishing method. The method selected as reference should therefore be that which gives the most reliable measure of overall intensity, choice depending on factors such as ease of standardising fishing power and time, freedom from complications such as gear 'saturation' and vessel 'interference', and extent of 'coverage' of the stock in question (see below).

3. Calibration of fishing power

One method of calibrating the fishing powers of a fleet of vessels of the same type is to use a research vessel as a standard reference and fish it side by side with a number of commercial vessels covering as wide a range of size as possible. This has the advantage that the details of the gear used by the reference vessel are known precisely and can be kept constant, and that it is easy to ensure that it fishes as nearly as possible on the same density of fish as the vessel to be calibrated. The limitation is that despite all precautions catches are usually highly variable; it may therefore be impracticable to fish a research vessel against a sufficient number of commercial vessels to obtain a reliable index of their fishing powers. If, however, the time and position of the catches obtained by commercial vessels are known, this information can be used to calibrate a large number of vessels.

This is the method used by Beverton and Holt (in press) to investigate relative fishing power in the English steam trawler fleet working in the Southern North Sea. British demersal statistics give the catch and position for each trip of each vessel, and by comparing catch per hour of vessels fishing at the same time and position a large number of estimates of fishing power were obtained relative to one particular vessel selected arbitrarily as a standard. Although the accuracy of any one of these estimates alone was not high the combined results showed that relative fishing power was fairly closely proportional to gross tonnage, the relation being shown in Fig. 1. For large-scale routine calibration of commercial statistics on an international basis a simple proportional index of fishing power is desirable, and it is clear from Fig. 1 that to take gross tonnage as proportional to fishing power would enable most of differences in fishing power within the fleet to be accounted for. The other possibility is to determine an individual fishing power factor for each vessel, or group of similar vessels, in arbitrary units (depending primarily on the particular ship chosen as a standard reference) without reference to vessel characteristics. This refinement may eventually prove to be worthwhile, but in the meantime a proportional index would seem preferable provided, of course, that it accounts reasonably well for the differences in fishing power.

This method of analysing commercial statistics of catch and effort has recently been extended by Gulland to other English steam trawler fisheries. In every case he has found gross tonnage to be a satisfactory index of fishing power. Gross tonnage has also been used by Hickling (1946) to calibrate the fishing 'performances' of Milford Haven trawlers for hake, and his results confirm in a general sense the usefulness of gross tonnage as an index of fishing power in steam trawlers.

Beverton and Holt (ibid.) have also found that gross tonnage could be used as an index of fishing power for English motor trawlers*, but with a different constant of proportionality. A motor trawler of a given tonnage was, in fact, found to have a fishing power 1.4 times greater than a steam trawler of the same tonnage, this being the factor needed to express motor trawler fishing power in terms of steam trawler power. An alternative index of fishing power in motor trawlers was found to be brake-horse-power, two B.H.P. units being roughly equivalent in terms of fishing power to one M/T-ton, and hence to 1.4 S/T-tons. B.H.P. has also been used extensively by Gilis (e.g. 1953) to calibrate fishing power within the Belgian herring trawler fleet, though he does not appear to have

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*Rounsefell (1948) states that the New England otter-trawl fleet (motor) is subdivided into three gross tonnage groups for estimation of fishing intensity.

published the actual relation between B.H.P. and fishing power. As horse power, rather than tonnage, is probably the more direct factor responsible for differences in fishing power between motor trawlers it may be a better unit to adopt for general use. Thus if more powerful engines come to be used by the same sized vessels, the B.H.P. unit would take account automatically of the increased fishing power of the fleet, whereas tonnage would not.

The fact that the larger of two trawlers has the greater fishing power may be partly due to the fact that it can tow the same sized gear faster, or further per unit fishing time, than the smaller vessel but also because it may use a larger gear. Provided the relation between size of vessel and size of gear remains constant, however, gear dimensions need not, for this purpose, enter into the index of fishing power. On the other hand, a gear modification increasing the efficiency of gear used by all vessels, including the reference vessel, would not alter relative fishing power within the fleet if tonnage alone is used as the unit. To make comparable estimates of fishing power before and after the gear change the increase in fishing power it causes must therefore be measured and incorporated in the fishing power index. For example, Bowman (1932) showed that the Vigneron-Dahl modification increased the fishing power of a trawl by a factor of about 1.4; hence the fishing power of a trawler of 100 tons would change from 100 to 140 units if it adopted the V-D gear. It is therefore essential that commercial statistics should contain enough description of gear used to include any permanent modifications affecting its fishing power. The other kind of gear characteristic that needs to be specified in commercial statistics is selectivity; in trawls and seines this involves recording the size of mesh used - at least, that in the cod-end. The obvious effect of gear selectivity is to cause fishing power to vary with size of fish, but in addition there are indications that the size of mesh in towed gears may influence the fishing power on fish of all sizes, quite apart from selection. This is presumably due, directly or indirectly, to the less resistance to tow offered by a large mesh than a small one, although the evidence is still not clear on this point. Nevertheless, a change in mesh size may require readjustment of fishing power indices by multiplying them by the increase in efficiency of gear with the new mesh to render them comparable, just as in the case of the V-D modification.

As far as we are aware, no detailed analysis of relative fishing power for other fishing methods has been published, but in most cases it is possible to deduce what might be a suitable index. From analysis of commercial statistics for demersal seiners landing mainly plaice in English ports, by the method described above for trawlers, Gulland has found that differences in fishing power are unrelated to vessel size, at least, over the range 20-50 gross tons. This is presumably because over this range of size of vessel the size of gear used is the same, and power of vessel does not appear to be an important factor, at least in this class of seining. Provisionally, therefore, a unit of fishing power for English seiners is simply '1-seiner', but analysis of seiner fleets of other nationalities and working on other species may show fishing power to be correlated with some characteristic of vessel or gear. Silliman and Clark (1945) give data for the Californian purse-seine fishery for sardine which show that the length of net fished is related to size of vessel and so presumably is fishing power, although the authors do not show this directly*. Schaefer (1953), however, states that fishing power is related to vessel size in the tuna purse-seine fleet. In drift-net fisheries the length of 'fleet', i.e. the number of nets shot, would seem to be the best measure of fishing power, and this information is recorded in the Scottish statistics for each landing of each vessel. Similarly, in long-lines, the number of hooks (or multiple of it) fished by a vessel is an appropriate index of its fishing power, and a unit of this kind (the 'skate', a length of line to which are attached about 140 hooks) is used in the Pacific halibut fishery. Thus Thompson, Dunlop and Bell (1931) have shown that the catch obtained with a

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* The authors use a function of length of vessel and horsepower to define a unit of fishing effort for the California sardine fishery, but this is partly a measure of the greater speed and hence greater searching power of a large vessel than a small one. This latter problem is considered here in connection with defining appropriate units of fishing time.

line having hooks attached at a constant distance apart is almost exactly proportional to its length, and hence to the number of hooks. With trailed lines (e.g. trolling) the number of lines operated by a boat presumably determines its fishing power, but the number of lines may be closely correlated with size of vessel, in which case a measure of vessel size may be an equally satisfactory and more convenient index of fishing power. Thus Schaefer (ibid.) states that catch per day of tuna fishing is related to vessel size in the American clipper fleet, thus being deduced from an analysis of commercial statistics as described above for trawlers.

Before leaving the question of fishing power, mention must be made of the problem of gear saturation. By this is meant any tendency for the fishing power of a unit of gear to vary with the amount of fish caught. Gear saturation is unlikely to be appreciable in demersal trawls or seines but the fishing power of a drift net or long line depends directly on the number of vacant meshes or hooks; in theory, it therefore begins to decrease from the moment the first fish is caught. The catch per unit effort of a gear liable to saturation therefore reflects correctly the direction of changes in abundance, but underestimates their magnitude to an extent which increases as the level of abundance increases; in other words, it makes abundance appear less variable than it really is. Pronounced gear saturation has been demonstrated by Kennedy (1951) for the gill-net fishery of Great Slave Lake. He showed that the catch obtained was not proportional to the length of time the net had been in the water but followed a curve bending over to an asymptotic limit - at which limit the gear would be fully saturated and its fishing power nil. Some correction can be made for saturation if the saturation catch is known*, since the fishing power of the gear when hauled is proportional to the ratio of the actual catch to the saturation catch. Gulland (in press) has shown that if it is assumed that fish encounter the gear continuously and uniformly along its length, the basic unit of fishing power for each haul of the gear in question must be multiplied by the quantity

$$\frac{s}{\log_e\left(\frac{1}{1-s}\right)}$$

where s is the ratio of the catch obtained in that haul to the saturation catch. A practical difficulty is that with shoaling fish a small section of the gear may be fully saturated and the rest contain few if any fish; in this case the saturation catch is that which could be taken by that part of the gear containing fish. Therefore, to adjust fishing power estimates for saturation not only should commercial statistics record the catch obtained per haul of each unit of gear but also, if possible, some measure of the way in which the fish are distributed along the gear, as is done in Scottish herring statistics. Clearly, adjusting for gear saturation is not easy, and it has yet to be established that it occurs to any extent in North Sea fisheries; it may, for example, be important only at times of particularly heavy catches. Nevertheless, it is a matter worthy of investigation because it could, potentially, cause serious errors if unadjusted catch per unit effort is used as a measure of abundance.

4. Measures of fishing time: standard units of fishing effort

The appropriate unit measure of fishing time to take for various gears, by which a standardised unit of fishing power is multiplied to obtain a standardised unit of fishing effort, is less readily determined experimentally than fishing power and usually has to be deduced from the method of operation of the gear in question.

With the majority of fishing methods, provided the process of catching fish is more or less continuous while the gear is being operated and not much time is spent in searching for fish without using the gear, a direct time measure of fishing activity is usually appropriate. Thus in trawling, whether for demersal

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* This is not necessarily the catch that would be obtained if every mesh or hook was occupied by a fish, and would need to be determined experimentally (e.g. as described by Kennedy).

fish or pelagic and whether by bottom or mid-water trawl, the unit 'hour's fishing' (or multiple of it) is appropriate. Thus a standardised unit of effort for stream trawlers is the 'ton-hour', multiplied by any additional factors for gear efficiency (e.g. mesh size or other modifications) that may be relevant. Similarly, in motor trawlers the 'B.H.P.-hour' would be a standard unit of effort; because the time units are the same this effort unit for English motor trawlers would be multiplied by 2 to convert it to 'steam trawler ton-hours' (see section 3).

The same time unit would also seem applicable to <u>seiners</u>, so that a unit of seiner effort would be a 'seiner-hour'. Comparison of catches of plaice by seiners and steam trawlers fishing at the same time and position (from English commercial statistics) has shown that 1 seiner-hour is equivalent, on plaice, to about 260 steam trawler ton-hours*. The fact that a seiner may not fish at night nor for as many days per year as a trawler, is automatically taken into account by computing annual fishing effort from the total hours spent fishing during the year by each vessel.

Direct fishing time (i.e. hours fishing) may also be applicable to some <u>drift-net</u> and <u>long-line</u> fisheries. In others, 'hours fishing' may not be a direct measure of the actual time during which fish are liable to capture. For example, in many drift-net fisheries for herring the fish 'swim' for a much shorter time than the gear is fished in each operation. Here, a 'net-haul' would be as good a unit of fishing effort as any, although if there should be any important and consistent differences in the duration of the 'swim' between one area or season and another, it would be desirable to adjust net-haul units correspondingly. In the long-line fishery for Pacific halibut, Thompson, Dunlop and Bell (ibid) state that the length of time the gear is left to fish (the 'soak') is effectively constant, and hence they use the 'skate' as a standardised effort unit without introducing fishing time as such.

Although the use of a unit of operation instead of actual fishing time leads to more convenient effort units, it is important to check that when fish are particularly scarce or abundant there is no tendency to change the duration of each unit operation. When fish are abundant during the East Anglian herring season, for example, the duration of each shot may be shortened; while at slack periods both the dusk and dawn swims are sometimes fished without lifting the nets. In this and similar fisheries, therefore, there may be a case for adopting a 'net-hour' as a unit of effort rather than a 'net haul'. Other instances of the bias that may be introduced by using a coarser measure of fishing time than the actual time the gear is in operation, is shown by considering the 'day's absence from port', which is a frequently used time unit for trawl fisheries. It is simpler to record than 'hour's fishing' and certainly easier to ascertain with accuracy, but it is linearly - not proportionally - related to true fishing time, the constant term being the time spent steaming to and from the fishing grounds. Thus 'day's absence' is not a true measure of fishing time for comparing, for example, the fishing efforts of two fleets fishing the same stock but based on ports at different distances from the fishing grounds, though within either fleet it will give a true picture of changes in effort resulting from changes in fleet size. A more serious drawback is that the contemporary abundance of fish may alter the relation between day's absence and actual fishing time within the same fleet. Examples of this are shown in Fig. 2, where the hour's fishing per day's absence for English steam trawlers at Bear Island and in the North Sea are plotted for the post-war years 1946-1952. In each case there is an increase in the hour's fishing per day's absence, but it is much more marked for Bear Island where the change covers a nearly three-fold range. The change in the North Sea can be largely accounted for by an associated increase in the length of trip as the post-war abundance of fish declined, thus decreasing steaming time relative to fishing time, but for Bear Island the length of trip, if anything, decreased. Here the main cause is that the relatively great abundance of fish in the immediate post-war years resulted in ships having to lie to clear decks for long periods before the gear could be shot again, thus decreasing the fishing time per day spent on the fishing grounds compared with later years. The conclusion from this is that wherever possible fishing time should be measured and recorded in commercial statistics in terms of the actual time the gear is in operation.

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* This figure is smaller than that obtained by Margetts ([illegible]) from a comparative fishing experiment, but individual trawler-seiner comparisons are highly variable and the two estimates are not inconsistent.

We come, finally, to those fisheries in which vessels locate specific shoals of fish before shooting the gear and hence in which much time is spent searching with the gear inoperative. A notable example of this, in which the problem of computing a standardised unit of fishing effort has been discussed in some detail, is the <u>purse-seine</u> fishery for California sardine (Silliman and Clark, ibid). As well as similar types of fisheries such as <u>ring-net</u> fisheries for herring, some <u>trailed-line</u> fisheries and even possibly some trawl fisheries for pelagic species may fall into the same category. The important characteristic of these kinds of fisheries is that time spent searching (more exactly, the distance covered during the search) with the gear ready to use may have to be reckoned as part of the effort expended; it is, in fact, as if the gear itself had been used to search for fish but gave no catch until a shoal had been encountered. An accurate knowledge of searching distance is therefore one essential for assessing 'fishing time', and this must be distinguished in records from distance steamed to and from the general area where fish shoals are present - which may vary greatly from one year to the next. Searching time is, in fact, the only measure of fishing activity used by Silliman and Clark, but this is not necessarily a satisfactory procedure in general. For example, in one year shoals may be relatively far apart and considerable searching time may be required before they can be located. In another the same total abundance of fish might be aggregated in similar sized shoals but with the shoals themselves rather closer together. Then the same, or perhaps a greater, catch would be obtained with less searching time, giving a greater catch per unit searching time although the total abundance was the same. In this case the number of hauls might be a better index of fishery activity than searching time alone. If vessels exchange information by wireless concerning the whereabouts of fish, a complication is that some vessels may not search even within the fishing area, but steam direct to where a shoal has been located. In some fisheries a further complication may be that if the local concentration of vessels becomes too high they make the fish more difficult to catch, either by dispersing shoals or by driving them to depths at which the gear cannot be operated; in this event the true fishing effort of a vessel would tend to decrease as the number of vessels fishing near it increased. This 'vessel interference' as it may be called is a difficult problem to investigate experimentally, but there are some indications that it is important in the Whitby ring-net fishery for herring, for example (I.D. Richardson, personal comm.)

It must be concluded, therefore, that no general statements can at present be made on appropriate measures of fishing time, nor hence of fishing effort, in fisheries where searching is important. To determine these, each fishery would need to be analysed from the point of view of the shoaling habits and movements of fish and the searching tactics adopted by the fishermen. It is clear, however, that solution of this problem is bound to require particularly detailed commercial statistics for each trip of each vessel, such as catch, time and position of catch, time or distance steamed while searching independently, and number of hauls.

5. <u>Calculation of fishing intensity: sub-division of area and time</u>

It is shown above that the need for breakdown of fishing effort statistics into sub-divisions of area and time arises when estimating the effective overall fishing intensity $\bar{f}$, or when computing an index of total abundance. The purpose is to reduce as far as possible the effect of changes in density of fish in space and time, and this in part determines the units applicable to the various species. The other factor is, of course, the accuracy with which fishing positions and times can be recorded, but to some extent these criteria go together. For demersal fish in the North Sea the statistical rectangle ($\frac{1}{2}^{o}$ latitude by 1^{o} longitude, or roughly 30 x 30 nautical miles) certainly enables the grosser effects of non-uniform fish density to be eliminated, while no great changes in density in a rectangle occur within a period of a month - which is a suitable time unit. For herring, on the other hand, both these units are too large, and British statistics are broken down for analysis into sub-areas of one-ninth of a statistical rectangle (approximately 10 x 10 miles) or even smaller, and time units of a day, week or fortnight, as required. Dutch and Scottish herring statistics are published in sub-area units of 1/9 of a statistical rectangle (Ann. Biol., vols VII-IX). This is possible for herring fisheries because the position and time of each catch can be recorded accurately on commercial returns; a sub-division as fine as this would be neither practicable nor so necessary in demersal fisheries. At the other extreme it may be noted that the sub-area unit adopted for the widely dispersed Pacific tuna fishery is in the order of 60 x 60 miles (Schaefer, ibid.).

6. Estimation of total fishing effort by sampling

A conclusion from the foregoing is that in every type of fishery the basic unit of commercial statistics should, if possible, be the individual record of each trip of each vessel. Not only is this necessary for computing effective overall fishing intensity and hence indices of total abundance, but the same information provides the best means of calibrating fishing power within a fleet and of standardising fishing effort units for different fishing methods.

The 'trip record' is the basic unit in British statistics, and the concentration of the British fishing industry in a relatively few major ports makes it possible to cover every landing of every first-class vessel. This is, of course, the ideal, and collecting detailed information for every landing may be impracticable in a more dispersed fishing industry. In such a case a properly designed method of sampling landings would almost certainly provide sufficiently accurate estimates of effort for research purposes, with but a fraction of the man-power needed to cover every landing.

A sampling method is most effective if the total catch and/or the total number of landings in each period is known; these can then be used as weighting factors to estimate the total effort and its distribution from that of the sampled effort. Gulland (in press) has analysed demersal landings at Lowestoft in this way, using data of landings on one day of each week, i.e. sampling about 1/7 of the total landings. He found that by raising the average effort (in standard units) of the sampled vessels for a month by the ratio of the total monthly catch to the sampled catch, the total monthly fishing effort could be estimated with a coefficient of variation of as little as 5%. This procedure also gave a fair picture of the distribution of effort, especially in the heavily fished areas. If the total catch or total number of landings during the period is not known, the effort of the sampled vessels has to be raised by the ratio of the total number of landing days in the period to the number of sampled days. The accuracy of the resulting estimate of total effort now depends much on the day-to-day variation in the number of landings. At Lowestoft the number of daily landings may vary over a several-fold range during a week, with peak landings at the beginning and end, and the estimate of monthly effort by this second method is very much less accurate than by the first. It should be noted that raising by the ratio of the total number of days to the number of sampled days assumes that the number of landings per day on the sampled days is an unbiassed estimate of the average number of landings per day during the whole period. With this method it is therefore very important that the sampling pattern should not coincide with any systematic weekly or monthly trend in the number of landings per day. This cause of bias does not exist in the first method, where the sampled effort is raised by the ratio of the total catch or number of landings to the sampled catch or landings; here it is only necessary to assume that the sampled catch per unit efforts provide an unbiassed estimate of the average catch per unit effort for the period in question. In a fishery where all or nearly all the fleet returns to port each day the daily landings will of course be nearly constant and the second method satisfactory.

7. Conclusion

We have endeavoured to show in this paper how sampling for abundance, and the use of the information in fish population studies, is dependent on a knowledge of the total fishing effort in standardised units and its distribution in space and time. This applies particularly in an internationally fished area such as the North Sea, where no one country can obtain a full understanding of its fisheries unless standardised international effort statistics are available, however intensive a sampling programme it may undertake. Yet it is noteworthy that while published commercial statistics give the catch of each species with great accuracy, few give statistics of fishing effort and none give them in a form that can be used to compute the total fishing intensity on a species in standardised units. We would suggest that where full collection of effort statistics on a trip basis is impracticable, sampling methods may well provide estimates of effort that are sufficiently accurate for research purposes.

In the meantime, the first step is to establish standard international units of fishing power and fishing effort for the major fisheries. This is essentially a matter for agreement between those countries concerned in each fishery, using in the first instance such information as is available from either commercial statistics or comparative fishing experiments. The units suggested in this paper are summarised in the accompanying Table.

8. Summary

1. The importance of commercial statistics of catch and effort for sampling and for population studies in general is discussed.

2. The terms fishing power, fishing effort and fishing intensity are defined. It is shown how these factors can be combined to compute the effective overall fishing intensity for a species; this is proportional to the fishing mortality coefficient as estimated by sampling, and when divided into the total catch gives a true measure of the abundance of that species.

3. Standard units of fishing power and fishing time, and hence fishing effort, are proposed for various fishing methods. Methods of correcting for certain complicating factors, such as gear saturation, are discussed. Standardisation of effort units is most difficult in fisheries where much time is spent in searching for fish, notably in purse-seine and ring-net fisheries for pelagic species. In these instances special investigations may be required.

4. Appropriate sub-divisions of area and time are considered for computing effective overall fishing intensity in demersal and pelagic fisheries.

5. The possibility of estimating fishing effort and its distribution by sampling a small fraction of the total landings is proposed as worthy of consideration where collection of full effort statistics is impracticable.

6. It is suggested that establishing agreed international units of fishing power and effort in the major international fisheries should be undertaken as soon as possible.

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