Some theoretical Considerations on the "Overfishing" Problem.

By

E. S. Russell,
Ministry of Agriculture and Fisheries, London.

I. Elementary Formulation of the Problem.

1. To decide in any given instance whether fishing operations are or are not being carried out in a manner ultimately wasteful to the stock is admittedly a difficult task, for the conditions to be taken into account are extremely complex and extremely variable, and the data available are as a rule incomplete and not always easy to interpret in an unequivocal way. Yet notwithstanding this difficulty of application to the concrete case there are certain general principles about which there can be no reasonable doubt and about which everyone should be agreed. It is my aim here to formulate in a simplified and general way, and without mathematical treatment, the broad facts of the case, to state in simple language those elementary principles that are at the back of everyone's mind who deals with the problem of the rational exploitation of the fisheries. Most of the truths to emerge will appear as obvious truisms, but there is, one feels, a distinct advantage to be gained by formulating in a simple way the essential conditions of the problem, as a help towards its more detailed study.

2. Let us simplify the problem down to its bare essentials by considering a completely self-contained stock of fish of one particular kind living in a large area which is systematically fished. Let us further assume that the fishing gear used is standardised and is such that all the fish reaching a length l are liable to capture and that none of length less than l are caught. The total stock in the area may then be divided into those of l and upwards in length and those less than l, and we shall call these respectively the catchable stock and the non-catchable stock.

Let us consider what will happen to a given catchable stock of initial total weight S_1 over a period of time which we may take for convenience as one year. We will assume that the individuals comprising the total stock grow, i. e. increase in weight, during the period, and that the total stock is recruited in the normal way by annual broods.

Considering first the catchable stock with which we start (S_1), we may say that each individual either survives to the end of the year, having grown in the interval, or is caught, with a growth-increment depending on the length of time it has survived, or is otherwise eliminated after a varying period, also with the equivalent growth-increment. The catchable stock will, however, during the year receive additions due to the non-catchable stock growing up to the limit l. The individuals comprising this added stock will, as soon as they enter the catchable stock be subject to the same chances as those making up S_1, i. e. will either survive to the end of the year, or be caught, or die from other causes before the end of the year, in each case with the appropriate growth-increment. We can accordingly deduce the weight of the catchable stock at the end of the year (S_2) from the weight at the beginning of the year (S_1) as follows.

On the credit side we must start with S_1, and to this add the sum of the initial weights of all individuals (new stock) transferring from the non-catchable to the catchable category, as they reach the length l. Let us call this sum Σa; to this we must add the sum of the growth-increments of all individuals surviving at the end of the year (Σg) whether belonging to S_1 or to the new stock; from this total we must subtract the sum of the weights of all fish caught during the year (Σc) and the sum of the weights of all fish which have died from natural causes during the year (Σm). Σc and Σm of course include the growth-increments of the fish which have been caught or have died.

We get then $S_2 = S_1 + \Sigma a + \Sigma g - (\Sigma c + \Sigma m)$ or, using capital letters for the sums,

$$S_2 = S_1 + (A + G) - (C + M).$$

S_2 will therefore be $> = \text{or} < S_1$ according as $(A + G)$ is $> = \text{or} <$ $(C + M)$. In other words, if more is taken out of the catchable stock in a year $(C + M)$ than is replaced by natural processes $(A + G)$ the total weight of the available or catchable stock will diminish; if the loss balances the gain the available stock will be the same at the end of the year; if the natural replenishment is greater than the loss due to fishing and other mortality the available or catchable stock at the end of the year will have increased. This is self-evident, and the sole value of the exact formulation given above is that it distinguishes the separate factors making up gain and loss respectively, and is therefore an aid to clear thinking.

(A) conveniently represents in terms of weight the influx of smaller individuals (belonging for the most part to younger year-groups) which have just reached catchable size. (A) accordingly separates out mainly the effect of "fluctuations", due to good or bad brood-years, upon the catchable stock. (G) represents the total growth-increment of the surviving individuals — of the remnant of S_1 and A. It will presumably vary according to the conditions in the area as regards e. g. food and temperature. (C) is a datum to which an approximately accurate numerical value can in certain cases be assigned. It does not necessarily coincide with the total landings from the area, for to the landings must be added the weight of all individuals caught but discarded.

3. In this formulation of the problem we have essentially to do with a number of processes, the rate of which may vary. This applies to all those factors which were treated above as summations, namely A, G, C and M. The value of A depends upon the rate of introduction of new individuals to the catchable stock, which is in turn dependent (1) on the number growing up, and (2) on their rate of growth, while belonging to the non-catchable stock; G clearly varies according to the rate of growth; C varies according to the rate of catching, M according to the rate of natural mortality. It is important then to consider what is the effect upon the stock of variation in the rate of these processes, having regard also to their necessary inter-connections.

Here it is important to make quite clear in which terms, whether of number or of weight, we state the rate of change of the processes whose summated values we have so far treated only in terms of weight. It is clear that rate of growth should by definition be stated in terms of increment of weight. Rate of capture, rate of natural mortality, and rate of introduction of new stock, might be stated in terms either of numbers or of weights, but there is an obvious advantage, for clarity of thought, if we state them in terms of numbers, for these rates will then be independent of variations in rate of growth. We shall accordingly in the following discussion use rate of capture, rate of natural mortality, and rate of introduction of new stock as referring to numbers.

4. We shall consider first the effect of variation in the rate of catching. This we define as the number caught per unit of time by the standard fishing gear. There seems no objection to defining the rate in terms of number and not of weight, because the chances of capture (above length l) are, so far as we know, independent of the size of the fish. We may con-

veniently start from the theoretical case where in a specified year $A + G$ just balances $C + M$: a condition of stabilisation, in which $S_2 = S_1$. The rate of catching (number) is such as to give the value C (weight). We may call this Case (1). Let us now assume that in Case (2), the rate of growth, the rate of natural mortality and the rate of introduction of new stock remain constant, but that the rate of catching is lower than in Case (1). It follows immediately that in Case (2) $C + M$ must be less than in Case (1), for total mortality is by hypothesis less. Similarly G will be increased in value, since the number of survivors is greater in Case (2) than in Case (1). The total weight and number of the stock will therefore be greater in Case (2) than in Case (1); the stock will therefore have increased, owing to the decreased rate of catching. In the above argument we deal with the individuals making up both S_1 and A. If we now assume that in Case (3) the rate of catching is increased we arrive by the same simple reasoning at the conclusion that the stock in this case will diminish in total weight and total number.

But it is important to note the assumptions on which these conclusions depend, namely the constancy of rate of growth, rate of natural mortality, and rate of introduction of new stock. Are these assumptions justifiable on biological and mathematical grounds? Have we the right to assume that the rate of capture may vary independently of each and all of the other factors? Taking A first of all, it is difficult to see how variations in the intensity of fishing could in the course of a year have any direct effect upon the numbers of the new stock growing up i. e. upon the numbers of the non-catchable stock — unless of course the species were cannibalistic. Even if fishing were so intensive as to wipe out all potential spawners, the direct effect of this would under present conditions of fishing not be seen till at the earliest 18 months after the spawning season (taking the case of the haddock as a typically fast growing fish). An indirect effect through the rate of growth of the non-catchable stock is, however, conceivable, for a vast clearing out of catchable stock might leave more food available for the non-catchable stock and increase their growth-rate so that they reached size l more rapidly. A in such a case might be increased, if more survived to length l owing to their passing through the vicissitudes of early life more rapidly.

This brings us to a consideration of the possible effect of variations in the rate of capture upon the growth-rate of survivors. It is quite conceivable that increase in capture-rate should result in increase of growth-rate of survivors, since the amount of food made available would, *ceteris paribus*, increase. One condition must, however, be fulfilled before this conclusion follows — the supply of food must not be in excess of requirements. If the food supply were superabundant, the growth-rate in all three cases considered would be at the maximum possible under the other conditions prevailing; variation in rate of capture would then be of no effect on rate of growth. If, however, — and this seems the more likely case — the food supply is relatively limited and there is consequent competition for it by many species, it seems reasonable to suppose that increase in rate of capture might result in increase of growth-rate, both of catchable and of non-catchable stock. Whether it is possible in such circumstances for the increase in G, due to increased growth-rate to equal or exceed the decrease in G due to increased capture-rate is a complicated problem which cannot be considered here. It may, however, be remarked in passing that any food "released" by increase of capture-rate would be eaten by other species besides the one considered.

As to the effect of variations in capture-rate upon the rate of natural mortality it is impossible to say much from the biological point of view. If any part of the natural mortality were due to starvation, or to cannibalism, then increase in capture-rate would tend to lower natural death-rate. There is of course on purely arithmetical grounds a certain inverse relation between C and M; $C + M$ represents total mortality (in terms of weight); if C increases it will diminish M, since some individuals will be caught which would otherwise have died a natural death; similarly if M is increased it must diminish C as some individuals will die which would otherwise have been caught.

5. We have established the fact that A, G, C and M are or may be inter-connected biologically. It is therefore a little dangerous to attempt to treat the variations in rate of each of these factors singly. We have attempted to do so with the rate of capture, but it is necessary to bear in mind the qualifications and corrections to be applied. We may now consider the broad effects of variation in the other rates, namely rate of introduction of new stock (expressed in numbers), rate of growth (expressed in weight) and rate of natural mortality (expressed in numbers). It is clear first of all that A is a highly important source of variation. We know that in practice the numbers of the on-coming new brood may vary enormously from one year to another. Starting out from our standard Case (1) and assuming the other rates specified to be constant, a big increase or decrease of A would clearly make a considerable difference to resultant stock (S_2). In practice a big increase might depress rate of growth, but, leaving this out of consideration, it would certainly increase C, M and S_2, as compared with their values in Case (1).

An interesting result emerges if we assume that, for any reason unconnected with variation in capture or mortality rate, the growth-rate is increased. As compared with our standard Case (1), C and M would be increased, and G also, and the increase in G would over-compensate the increase in C and M, so that S_2 would be greater than S_1, though there would be no increase in numbers. The truth of this conclusion is easily checked by considering that in both cases the *number of survivors is the same, but their weight is greater in the second.* So too the number caught and the number naturally eliminated are the same in the two cases, but in weight they are greater in the second case than in the standard case. Increase in growth-rate in such conditions means increase in weight of catch and at the same time increase in weight of surviving stock. The importance of high growth-rate in increasing the yield of a fishery is clearly brought out by these considerations.

The effect of variations in rate of natural mortality has already been dealt with in part in the preceding section, where it was shown that M would increase partly at the expense of C. The effect of a large increase in natural mortality rate in decreasing resultant stock is obvious and needs no detailed comment.

The main object of the above discussion has been to show that in considering changes in catchable stock from one year to another there are several other factors to consider besides variation in the rate of capture, and an attempt has been made to indicate the direction in which these other factors would work, whether as increasing or as decreasing the resultant stock.

6. From the theoretical point of view it is of interest to discuss the two extreme cases of variation in rate of capture — (1) where the rate is nil, and (2) where it increases to an indefinitely large degree. Let us take (1) in its most extreme form and let us consider the case of an area which has never been fished at all. Knowing that the total amount of available food cannot be unlimited, we can deduce that there is a maximum value for S which cannot be exceeded. Let us assume that on a virgin ground the stock tends to approximate to this maximum and that the amount of food remains constant from year to year. S will under these conditions remain stationary, and for any year we may write $S_2 = S_1$. It follows also that $A + G = M$. This means that the mortality rate and the rate of replenishment and growth of the catchable stock must vary together; if M is small the annual increase $(A + G)$ must likewise be small.

Let us see how this would work out in practice. Assuming the supply of food to be limited in relation to existent stock and the stock eating up the food as fast as it is produced, there must inevitably be competition between the fish for the available food. There is a broad difference between the old fish and the young fish in respect of their utilisation of the food — the young fish put relatively more to growth and less to maintenance. If therefore on the whole the older fish win, the stock will gradually become composed of large old fish which utilise all the food for mere maintenance and do not grow, and M will consist mainly of small fish which have been starved out of existence. If on the contrary the younger fish manage to annex more than their share they will grow at the expense of the older fish, which will die of starvation; M will then consist mainly of the larger fish. Without some knowledge of the actual facts it is impossible to say what theoretical formulation comes nearest to the actual conditions found on a virgin ground.

Even the few theoretical conclusions arrived at above as to the state of things on a virgin ground, may not correspond accurately to what is actually found; in particular the assumption that a maximum is reached and steadily maintained may be a wrong one. This much is, however, certain, that there is a theoretical maximum to S and that mortality and replenishment must in some way balance one another possibly in a cyclical manner.

Coming now to the second limiting case of variation in rate of capture, it is easy to see that an indefinite increase in the rate would lead to a virtual extermination of the stock, first by reducing to indefinitely low numbers the existent stock and, through destruction of the spawners, reducing A in course of time to nearly zero. This is of course a limiting case, never actually met with so far as fish are concerned, but it brings out the possible danger to stock through undue destruction of spawners brought about by very intensive fishing.

7. If now we consider the size-distribution of the catch, under different rates of capture and different rates of growth, certain obvious deductions can be drawn. Other factors being constant, an increase in rate of capture will mean a diminution in the average size of the catch, as compared with that in the standard case, since the individual fish will on the average be caught earlier, i. e. at a smaller size, than if fishing is less intensive. An increase in rate of growth will obviously act the other way — if capture-rate is constant, but rate of growth increases, the average size of those caught will be greater. Decrease in growth-rate will give the same kind of result as increase in capture-rate — a decrease in the average size of those caught.

8. Coming back now to our starting point, we may say that the formula stated in paragraph 2 above represents a balance-sheet. We start with a working capital S_1; to this is added in the course of a year

$(A + G)$, and from it is taken away $(C + M)$. At the end of the year our working capital is S_2, which will be greater than, equal to, or less than S_1, according as income $(A + G)$ has exceeded, equalled or fallen below expenditure $(C + M)$. S_2 is what is carried over as capital from one year to the next. It does not represent merely the difference between income and expenditure but that difference added to or subtracted from S_1. S is therefore a continuing value which alters according to the difference between income and expenditure.

It is clear that if expenditure is consistently higher than income, S will be a diminishing quantity, and that if the amount of fishing remains constant during this process C must also fall. The practical problem then appears to be to keep S at such a level, or to bring S to such a level, that the maximum value of commercially utilisable fish can be drawn from it annually without causing a progressive diminution of S. If the annual increment represented by A were fairly constant from year to year, the problem would be one of obtaining a constant maximum yield. It might be theoretically possible to evaluate this optimum yield and to estimate the amount of fishing required to obtain it. A stabilised fishery would be the result. It is, however, common knowledge that A is a fluctuating quantity and that in certain important fish, e. g., haddock, the fluctuations are very great.

It appears therefore that the ideal of a stabilised fishery yielding a constant maximum value is impracticable. It might, however, be practical politics to attempt to adjust the amount of fishing each year to the variations in the stocks of particular fish in particular regions, as even now fishing does shift to some extent according to the abundance or scarcity of fish in particular regions. If such variations in abundance could be foretold a year or so in advance this adjustment could be made more rapidly and with more certainty of success.

9. The problem of rational exploitation is, however, an exceedingly complicated one. Let us arbitrarily simplify it by assuming that A is constant from year to year, i. e. that fluctuations do not exist. (Probably if we take a sufficiently long series of years fluctuations do average out). It is clear that a condition of stabilisation exists when $C + M = A + G$; S_2 in this case equals S_1, and the stock remains constant from year to year. But it is also clear that this stabilisation may take place at various levels, depending on the magnitude of C. If $C + M$ is small, $A + G$ will also be small, and the annual product of the fishery will be well below the maximum possible. But the aim of rational exploitation is to get the maximum yield annually, compatible with maintaining stocks at a steady level.

Regarding M as a constant factor, and in any case as outside control, our problem is to increase C as much as possible while keeping S constant from one year to another.

An increase on the credit side $(A + G)$ would be achieved if it were possible to increase the rate of growth (as can be done for example to a limited extent by transplantation in the case of plaice). This would result, if other conditions were constant, in an increase in C, as was shown in paragraph 5 above.

With regard to the debt side $(C + M)$, clearly much depends upon l, the theoretical limit between catchable and non-catchable stock. Hitherto we have assigned no particular value to l, but in practice, as we all know, l tends to approximate to, but to be less than, the size at which the fish becomes of marketable value. In what follows we shall assume that the value of l corresponds roughly to something less than the commercial minimum.

It would seem that C might be increased by lowering l, but clearly this would be of no value commercially, and it would of course decrease A, and lead in the long run to a diminution of S. Let us consider what would be the effect of increasing l by a moderate amount, say the amount represented by one year's growth in length (n).

If the limit were increased to $l + n$, the catch would at first be less, but $A + G$ would increase. Now consider the state of affairs after one year, when the fish of length l had grown to $l + n$. If M were low there would not be many fewer fish of length $l + n$ at the beginning of the year than there were of length l a year before, and, since weight increases as the cube of length, their weight would be very much greater. The catchable stock at the beginning of the second year would be increased in weight, and C would therefore be greater during the second year. A and possibly G would also be increased. The net result should be that with equal intensity of fishing the yield would be greater. But the process of increasing l could not be carried very far without entailing drawbacks. There would be an increasing wastage from natural mortality among the non-catchable stock, and it is at least conceivable that rate of growth would be diminished; it is probable also that as heavier stocks of non-catchable fish were accumulated there would be less room and food for the incoming new brood, and renewal of stocks would be slowed down.

It is clear that this question of the best size at which to commence capture raises problems of great complexity which require a fullness of treatment which cannot be attempted here. In particular the effects, both beneficial and harmful, of the "thinning" of the stock above and below the commercial minimum size demand most careful analysis.

11. We have attempted in the preceding paragraphs to give a simple and general formulation of the problem of "rational exploitation"; it is obvious, however, that an abstract formulation is of little value if it cannot be applied in practice. This raises at once the question, can we measure or estimate the changes in the stocks of fish? I propose to consider this question in the second part of this paper, leaving to a later occasion the concrete study of the "overfishing" problem in the light of the available statistical evidence.

II. Can we Measure Changes in the Stock?

The measure commonly adopted of the abundance of fish on a ground is the catch — more properly the landing — per day's absence from port. In Great Britain of recent years a more accurate measure, the landing per 100 hours' actual fishing, has been employed. The landings are of course given in terms of weight.

It is clear that these values do not give any definite indication of the absolute quantity of catchable fish on the grounds visited, and do not allow of any actual value being allotted to S. They represent the weight of commercially valuable fish taken over a certain period of time with certain fishing implements, but what proportion this weight bears to the total catchable stock (S) on the grounds fished remains unknown[1]).

They have, however, relative or comparative value. We may assume that a trawl of a certain spread, a certain height of head-line, a certain cod-end mesh, fished at a certain speed, takes on the average a constant proportion of the total number of fish of catchable size present at the time, whether the fish be numerous or scarce. If this fundamental assumption is sound, then the amount of the catch per unit of time is a valuable index of the total weight of catchable fish on the ground, and may be used for studying the variations of S in space and in time. Without information as to the size of the fish caught it cannot of course be used as an index of the number of fish of catchable size on the grounds.

As has already been indicated, we have to deal in the commercial statistics not with catches, but with landings. This makes our index less accurate, for a varying amount of fish is caught which is not brought to market, owing to its negligible commercial value. On occasions the weight of the discarded fish may amount to a considerable fraction of

[1]) Total catchable stock might be estimated in a rough way from the results of extensive and successful marking experiments.

the total catch, if fishing has taken place in areas where undersized fish abound. Nevertheless, with due precautions, the landings per unit of fishing time may be used for comparative purposes as roughly equivalent to the catches.

It will, however, be apparent that certain conditions must be fulfilled before the landing, or even the catch, per unit of fishing time, can be safely used as an index of the comparative abundance of the catchable stock.

The single haul, or group of hauls, on the same ground on the same day, gives an index of abundance which is valid only for that particular ground at that particular time. If we wish to have a reliable index of the abundance of the stock over a large area we must have numerous hauls well distributed over the whole extent of the area in question, especially if, as is almost invariably the case, the abundance of the fish varies with locality. Furthermore, since the stock (weight) of the fish in a given area is a varying quantity, constantly affected by migration into or out of the area, by the effect of fishing operations, by increase of weight due to growth, by the introduction of new stock, and by other causes, the value of the catch per unit of fishing time, deduced for the area as a whole, *during a given short period of time*, is valid only for that period.

It follows then that for the catch per unit of time to have general validity for any area the sampling must be adequately distributed over that area; even then, the values can be accurate only over limited stretches of time, since the stock is a changing one. The catch (or landing) per unit of fishing time should therefore, strictly speaking, be used as an index only over short periods of time, since the quantity of which it is an index is a constantly changing one. Practical considerations make it difficult, if one is dealing with large masses of data, to use a shorter period than a month, and our British fishery statistics are accordingly for the most part tabulated by months. In practice, however, it is found that the landing per unit of fishing time can be usefully employed even over such periods as a year, but of course only when very extensive and adequate data are available. Used over such long periods it gives an *average* index for the weight of catchable stock during the period and in the area considered, i. e. a value which is or may be accurate only for a short time during the period. Nevertheless this average index has a perfectly definite meaning mathematically. Its meaning may also be expressed in practical terms as follows — it gives the relation between yield and expenditure of time over the period of a year's fishing in the area considered. This is of course a matter of primary importance from the commercial point of view.

In dealing with the commercial statistics of landings we do as a matter of fact commonly apply the landing per unit of fishing time over periods of a year, which incidentally are natural cycles in the life-history of the fish. It is calculated as a rule on total landings by vessels of a particular class divided by the total number of hours' fishing. It would be possible also, and in some respects preferable, to calculate it by months, and take an average of the monthly values. Actually, when fishing is large in amount and well distributed in time and space, the values obtained by either method are practically the same. The following example may be given:— In 1927 the average landing per 100 hours' fishing by British steam trawlers of all bottom fish from the North Sea was 141 cwts., calculated on total landings divided by total number of hours' fishing. The monthly values (in cwts.) of the landings per 100 hours' fishing were 127, 134, 151, 152, 153, 145, 136, 125, 130, 153, 144 and 135, giving an average value of 140.4 cwts. Taking a single rectangle, namely G6, which is well fished throughout the year, the landing per 100 hours' fishing was 89 cwts. calculated in the first way, and 88.5 cwts. calculated in the second way. It will be seen that the differences are insignificant.

Where the data are adequate, the landing per unit of fishing time even over a period of a year may accordingly safely be used as an index of the average abundance of the catchable stock, as affected by the amount of fishing and by all other modifying factors, such as the influx of new stock, and the growth of the fish. It is, mathematically speaking, an average of the landings per unit fishing time which have been made continuously throughout the year.

It is clear from this discussion that the primary condition for the validity of the catch (or landing) per unit fishing time is that the sampling shall have been adequate, having regard to the particular area and period considered. To get any broad and reasonably accurate picture of the comparative abundance of stocks over wide areas it is necessary to have at one's command accurate statistics of a large and well distributed fishery. Data which relate merely to a small and restricted fishery will be apt to give an inadequate and probably a misleading picture. Where an area is inadequately sampled, as for instance the Barents Sea in the early years of its exploitation, no great reliance can be placed on the value of the landings per unit fishing time.

There is a second condition of great importance, especially when comparisons are made over a long range of time, namely that the fishing power employed, as gauged by size of vessel, and type and catching power of the gear employed, must have remained approximately constant during the period considered. This is a point of rather special interest, in view of the developments which have taken place since the war in the size and effectiveness of trawling gear. The general shift over from the ordinary otter trawl to the VIGNERON-DAHL trawl in one or other of its numerous modifications has undoubtedly made the interpretation of any changes in the landings per unit fishing time more difficult and uncertain. The general direction of the change due to this development of trawling gear is of course known, but its exact effect is difficult to estimate accurately, owing to the great diversity of types of trawling gear now in use.

A third point which must be taken into consideration in appraising the value of the landing per unit fishing time as an index of stock is the possible variation in the requirements of the market. The statistics relate to the quantities landed for sale; if the demand for fish grows the small fish previously rejected at sea as unsaleable may acquire a marketable value and be brought to port to swell the landings. So too, when we are considering the landings of all demersal fish taken together, and comparing the landings per unit fishing time over a series of years, our deductions may be affected by the fact that species previously discarded at sea are now brought to market, having acquired a marketable value. It is common knowledge that in the course of the last twenty years and more, several kinds of fish formerly rejected as of no commercial value have gradually come on the market, and so have helped to increase the landings per unit fishing time of total demersal fish.

The three conditions of validity mentioned are the most important, though other minor difficulties may arise, as everyone knows who has attempted to deal with fishery statistics. But if these three conditions hold good, or if the effect of any alterations in them can be allowed for, the landing per unit fishing time may be expected to afford a generally reliable index of the comparative abundance of the catchable stock, so far at least as weight is concerned.

It will be convenient and helpful at this stage to consider certain detailed objections raised by KYLE[1]) to the use of this measure of the relative abundance of the stock. Some of these objections are perfectly valid, and he has performed a useful service in emphasising the dangers of an uncritical use of this measure of abundance; we shall see, however, that his criticisms do not invalidate the use of the criterion, provided it be applied with due caution.

[1]) Die Statistik der Seefischerei Nordeuropas, Handbuch der Seefischerei Nordeuropas, Bd. X, Heft 4, Stuttgart, 1928.

He sets out to prove that the methods for determining the quantitative distribution of fish recommended by ARCHER (average catch per voyage, per hour, etc.) are inadequate, and can lead to no scientific conclusions (p. 23).

After referring to the landings per day's absence by German and English vessels in 1925 from the various Regions — which as a matter of fact show considerable agreement — he goes on:—

"From the English statistics for the same year the quantities per hour's fishing can also calculated, which give to a certain degree a still more accurate picture.

	kg per hour's fishing
Barents Sea	453
Iceland	521
North Sea	62
Channel	51
South of Ireland	125
Biscay	109

It appears therefore that the North Sea, in respect of its richness in fish, is not comparable with Iceland or the Barents Sea, since both of these yield 7—8 times as much fish per hour. It is, however, necessary to regard such figures with reserve.

The regions are for one thing not equally intensively fished: although for example the German and English data for the Barents Sea in respect of total catch agree with one another, the number of hauls is too small and limited to too few months for them to be regarded as representative.

In the second place, there may be great differences between the catches, when the areas are very large; thus the German catch, i. e. per day's absence, for the North Sea is considerably greater than the English, simply because the Germans fish relatively little in the North Sea, and then mostly in the best spots and in the best months, while about 600 English steam vessels are almost constantly at work in the North Sea.

Thirdly, if 600 vessels fish an area, their individual catches cannot be expected to be as high as when only 150 are at work. This is about the relation between the English fishery in the North Sea and in Icelandic waters. The North Sea is accordingly fished 4 times as intensively as the latter, and on this ground alone one might expect that the Icelandic catches would be at least twice as large as the North Sea catches.

Again, the catching power of the vessels is very different, and it is easily seen that the size of the catches increases with distance from the North Sea ports; that is to say the vessels are larger and have a greater catching power. The Iceland steamers for instance catch at least 50 per cent. more than the ordinary North Sea steamers.

Fifthly, the choice which the fishermen find on the distant grounds affects the statistical data. As will be further shown below, the Germans bring very few plaice but many coalfish to their home markets, because they get in England a better price for their plaice but a worse price for their coal-fish than in Germany; this probably explains the lower German average catch shown for Icelandic waters.

These various difficulties and others to be mentioned later are here specially brought into prominence, because great importance has been attached to these factors. It has been thought that from such data conclusions can be drawn as to the exploitation (overfishing or otherwise) of an area, and so they can — but whether these conclusions are always valid is a matter for grave doubt" (pp. 24—25).

Of these five objections, all but the third are perfectly valid, and they have already been recognised in principle in our discussion above. The first, second, and fifth are merely particular instances of inadequacy of sampling, which would be looked for and allowed for by anyone having experience in the difficult art of treating fishery statistics. The fourth caveat is also one which we have specifically mentioned.

More interest, both theoretical and historical, attaches to the argument outlined in the third objection. It is here pointed out that the difference in the average landing per day's absence between Iceland and the North Sea is in part accounted for the fact that the North Sea is fished much more intensively — a perfectly correct conclusion. The amount of fishing is obviously one of the principal factors affecting the magnitude of S. During the War, the amount of fishing in the North Sea was greatly reduced and the l. p. d. a. from this area was in 1919 nearly double the pre-war average. Similarly, if the intensity of fishing in Icelandic waters were to be suddenly increased one would expect to find a diminution in the l. p. d. a. The l. p. d. a. is in fact a running index of the weight of commercially valuable stock left on the grounds, and one therefore expects it to be influenced by the actual amount of fishing, since fishing is one of the main factors in reducing stock. Accordingly KYLE's objection has no weight whatever against the validity of the l. p. d. a. as a comparative index of commercial stock remaining on the grounds. It gives an indication of the state of S as affected by the amount of fishing and by the other factors, G, M and A, which modify it. It does not purport to do more.

I said above that the question was one of historical, as well as theoretical interest. I had in mind the important evidence given by GAR-

STANG so long ago as 1904 before a Hourse of Lords Committee[1]) in which he expressed the opinion that "it is impossible merely from the evidence of the decline in the average catch of the fishermen with an increasing number of boats to conclude that there has been an improverishment of the grounds". He has recently discussed the question again in a most interesting way in his third Buckland Lecture[2]) and has come to the conclusion that the average catch is not invalidated as a measure of abundance. "It registers the abundance truly enough, and when it falls with an increase in the intensity of fishing, it does so because, pending replenishment, there is greater depletion, the greater the rate of capture; and there is an inevitable lag in the process of replenishment" (p. 29).

The factor of replenishment is of course in practice extremely important — as indicated in our general formula by G and A — but the catch per unit time would be valid even if we supposed this factor to be absent.

At the risk of being tedious, let us consider this point again. Let us imagine an area of limited size, populated by a stock of catchable fish of a certain definite number and evenly distributed over the area. We shall assume, in order to simplify the case as much as possible, that this stock is not added to by the introduction of new stock growing up. Let us consider what will happen if this stock is fished (1) by 10 vessels, or (2) by 100 vessels, of equal size and fishing power, over the same period of time, say one month. If our original assumption is correct, that a vessel with standard gear, fishing under standard conditions, takes on the average a fixed proportion of the catchable fish present on the ground covered, then it is apparent that in the first few hours of fishing the catch per hour will be practically the same for the 100 vessels as for the 10 vessels. But the 100 vessels will take more away from the stock than the 10 vessels; hence in case (2) the catch per hour will fall at a greater rate than in case (1), and by the end of the month the catch per hour by the 100 vessels will be definitely less. The average catch per hour over the whole of the month will also be less for the 100 vessels than for the 10. This difference indicates that the stock at the end of the period is less when 100 vessels have been fishing than when only 10 vessels have been at work — which is self-evident. The point is in fact so elementary as hardly to require proof. But it does bring out the cardinal fact that the average catch per hour at any particular

[1]) Report on Sea Fisheries Bill (H. L.), London, H. M. Stationery Office, 1904, p. 115.

[2]) The Fishing News, Aberdeen, Vol. XVIII, No. 888, June 7th, 1930.

time is an index of the stock remaining on the ground at that time. Taken over a period of time, the catch per hour indicates the average state of the stock during the period, as affected by the amount of fishing going on.

The catch per unit of fishing time is clearly affected by the amount of fishing which is being carried on contemporaneously. But this is simply because the amount of the stock is being affected by the amount of fishing, which again is self-evident.

KYLE in the paper referred to above appears to think that this characteristic of the catch per unit time invalidates its use as an index of stock. He apparently argues as follows. If we compare an area during a period when fishing has been slight with the same area during a period of intensive fishing, and find that in the second period the catch per unit time is less, we cannot conclude that the stock has diminished in the second period as compared with the first — it may simply be that a stock of the same size as the original stock has been shared out among a larger number of vessels. The argument is perfectly sound up to a point, but it does not take all the facts into account. It is true only as regards the stock to start with, before fishing operations have begun. In illustration, let us take our case of the 10 and the 100 vessels, and let us assume that the stock on which the 100 vessels set to work is not necessarily the same in magnitude as the stock fished by the 10. If the catch per unit time by the 100 vessels is less than that by the 10 we cannot infer that the stock to start with was less — it may have been equal to, or even greater than, the original stock which the 10 vessels started to exploit. Hence a difference in the catch per unit time does not *per se* indicate a corresponding difference in original stock.

But the decreased catch per unit time by the 100 vessels does indicate that the final and the average magnitude of the stock, under the influence of fishing, was less than when the 10 were fishing. That is all it can show, but it is quite sufficient for all practical purposes. We rarely encounter a case where we can speak of an original stock prior to fishing. The nearest approach to such a case is when large shoals of fish approaching the shore in a body become the object of a coastal fishery, as in the Norwegian cod fishery. If in such a fishery there are large fluctuations in the amount of fishing from year to year it is difficult or impossible to draw conclusions merely from changes in the catch per boat per unit time as to the relative abundance of the successive yearly stocks, as they come in, before they have been affected by fishing.

In actual practice, however, in dealing with the modern trawl-fishery, which is in most areas both intensive and continuous, the question of "original" stock simply does not arise; we have to deal with stocks which are constantly and considerably being reduced by fishing operations, and the catch per unit time shows us sufficiently well what is actually taking place. Under present-day conditions, fishing is one of the most potent factors affecting the magnitude of stocks, and our index, the catch per unit time, takes account, and rightly, of this as well as of the other factors concerned. The amount of the stock is as we have seen, a constantly fluctuating one, depending upon the amount of fishing, the rate of natural mortality, influx of new stock, and rate of growth — as indicated in our elementary formula. As we have to deal with actualities, with stocks subjected constantly to intensive fishing, it is of little interest to speculate as to what the state of stocks would be if this factor were eliminated, or reduced to what is was twenty, thirty or fifty years ago. What we have to study are the changes in S under the present conditions of intensive fishing, and our best guide to these changes is the catch or landing per unit fishing time.

KYLE prefers as an index of productivity the total yield of fish, but makes no attempt to relate this with catching power, — although it is obviously in the main a function of the amount of fishing, — for the reason that total catching power cannot be estimated accurately. Overfishing will be indicated, he considers, if there is a progressive diminution in quantity or quality of the total yield over a period of years — "If in a long series of years the yearly quantities decrease, or if the quality becomes constantly poorer, we can then say that the productivity of the area in fish is too small for the intensity of the fishery" (pp. 29—30).

Total yield is undoubtedly a most important datum, corresponding approximately to C in our elementary formula, but it gives merely what is taken out, and affords no indication of what is left in the sea. For an index of remaining stock it is absolutely necessary to have recourse to some index relating catching power to weight of catchable fish on the ground. The catch or landing per unit fishing time can, if certain conditions be fulfilled, be used as such a measure or index.