# PHOSPHATE AND FISHERIES

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(Text-figs. 1–3)

A number of links in the food chain intervene between the presence of nutrient salts over fishing grounds and the marketing of commercial fish. Indeed not a chain but a network provides the better metaphor. The necessary study of each and every mesh must occupy many years. None the less as an empirical short cut it is well worth while to examine quantitatively whether a change in the nutrient resources of an area may be reflected in commercial landings.

The purpose of the paper is not to make positive assertions of fact but to suggest possibly valuable lines of investigation.

## Phosphate and the Spurdog

There are four ports exploiting the Eddystone-Lizard grounds of which International Hydrographical Station E1 is more or less the centre. Returns from the port of Plymouth and, to a lesser degree, Brixham are likely to be vitiated from the point of view of this study by landings from deep-sea trawlers operating on occasion hundreds of miles from their home port. The fishery of the port of Mevagissey is, however, carried on by small craft almost entirely on the Eddystone-Lizard grounds. Throughout this paper the serious limitations inherent in all fisheries statistics taken at small ports must constantly be borne in mind. Market conditions at Mevagissey sometimes lead to concentration of all effort on the capture of one species.

It was immediately apparent that dogfish landings at Mevagissey would repay study (Fig. 1, curve *A*). The species there completely dominant in the landings is the spurdog, *Squalus acanthias* (= *Acanthias vulgaris*), which, though classified with other dogfish in the fisheries statistics as demersal, is in fact truly pelagic. It is caught by an autumn line fishery on the Eddystone-Lizard grounds and is often landed by drifters working the winter drift-net fishery from Plymouth.

*S. acanthias* is noteworthy in that the eggs are developed into young fish within the mother (Ford, 1921) so that the young are never exposed to the vicissitudes of an independent planktonic existence.

The steady increase in landings between 1921 and 1926 might have been due to increased intensity of fishing, change in fishing gear or market conditions. That these cannot account for the whole of the increase is shown by the ratio of landings of dogfish at Mevagissey to (i) the total weight of demersal fish other than dogfish landed at Mevagissey (Fig. 1, curve *B*), and to (ii) the total landings of dogfish (all species) at English and Welsh ports (curve *C*). Both ratios show the same trends as curve *A* suggesting that the increased landings

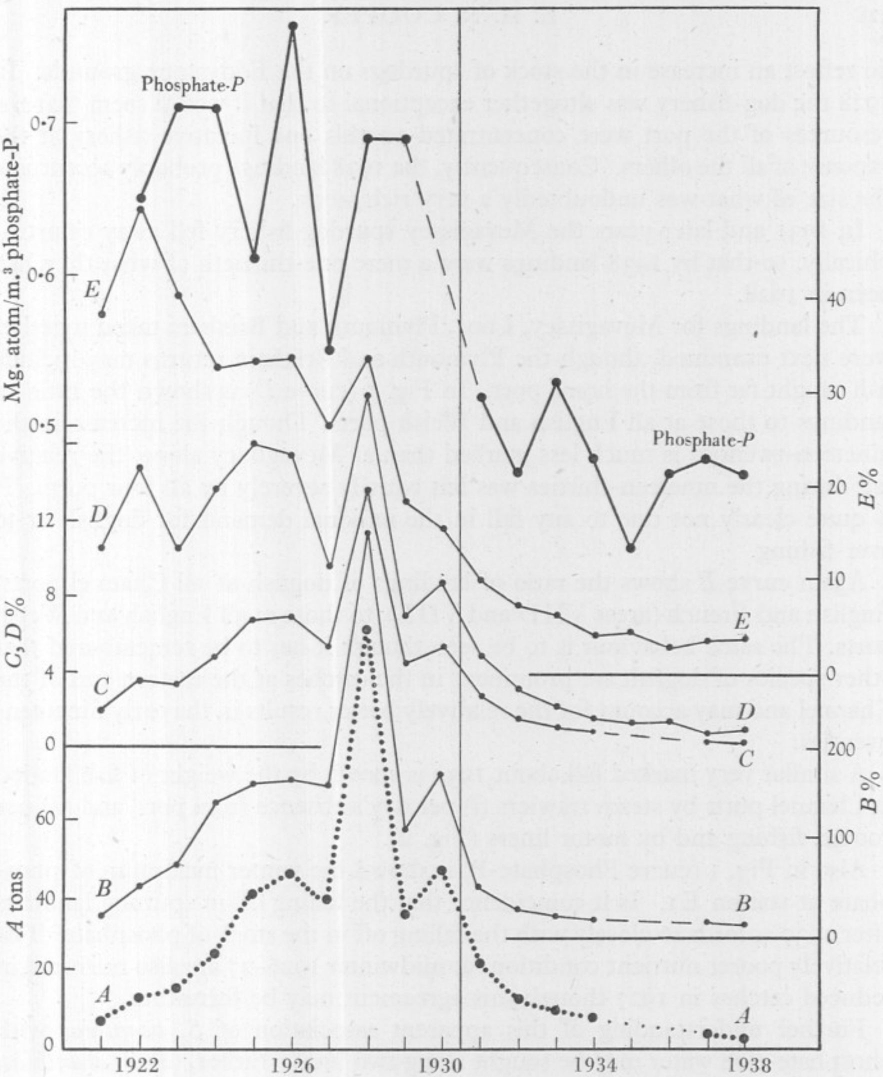


Fig. 1.

*A*, weight of dogfish landed at Mevagissey (tons).

*B*, percentage ratio: $\frac{\text{Dogfish landed at Mevagissey}}{\text{Total demersal fish less dogfish landed at Mevagissey}}$.

*C*, percentage ratio: $\frac{\text{Dogfish landed at Mevagissey}}{\text{Dogfish landed at English and Welsh Ports}}$.

*D*, percentage ratio: $\frac{\text{Dogfish landed at Brixham, Plymouth, Looe and Mevagissey}}{\text{Dogfish landed at English and Welsh Ports}}$.

*E*, percentage ratio: $\frac{\text{Dogfish landed from the English Channel (Areas VII D and E)}}{\text{Dogfish landed at English and Welsh Ports}}$.

Phosphate-*P*, mg.-atom/m.³, maximum content at E 1 in preceding winter.

The vertical line marks the change-over from predominantly phosphate-rich (*elegans*) to phosphate poor (*setosa*) conditions.

do reflect an increase in the stock of spurdogs on the Eddystone grounds. In 1928 the dog-fishery was altogether exceptional so that it would seem that the resources of the port were concentrated on this one lucrative fishery at the expense of all the others. Consequently, the 1928 landings probably accentuate the size of what was undoubtedly a very rich stock.

In 1931 and later years the Mevagissey spurdog fishery fell away catastrophically, so that by 1938 landings were a mere one-thirtieth of what they had been in 1928.

The landings for Mevagissey, Looe, Plymouth and Brixham taken together were next examined, though the Plymouth and Brixham returns may include fish caught far from the home port. In Fig. 1 (curve *D*) is shown the ratio of landings to those at all English and Welsh ports. Though the increase in the nineteen-twenties is much less marked than at Mevagissey alone, the relative fall during the nineteen-thirties was felt equally severely by all four ports. It is quite clearly not due to any fall in the national demand for dogfish or to over-fishing.

Again curve *E* shows the ratio of landings of dogfish at all Channel ports, English and French (areas VIID and VIIE), to those at all English and Welsh ports. The same behaviour is to be seen though it has to be remembered that other species of dogfish are prominent in the catches at the eastern end of the Channel and may account for the relatively better results in the early nineteen-twenties.

A similar very marked fall about 1930 is shown by the weight of fish landed at Channel ports by steam trawlers (i) per day's absence from port, and (ii) per 100 hr. fishing and by motor liners (Fig. 2).

Also in Fig. 1 (curve Phosphate-P) is shown the winter maximum of phosphate at station E1. Is it coincidence that the falling off in spurdog landings after 1930 accords so closely with the falling off in the stock of phosphate? The relatively poorer nutrient conditions at midwinter 1926–27 are also mirrored in reduced catches in 1927 though this agreement may be fortuitous.

Further understanding of this apparent association of *S. acanthias* with phosphate-rich water may be sought along two lines. Either, (*a*) *S. acanthias*, though an active far-ranging pelagic fish, markedly and directly favours high-phosphate western 'elegans' water of which it would then be an indicator; or, more probably, (*b*) the association traces directly through shoals of clupeoids and mackerel which it attacks and voraciously devours. A correlation exists between herring and phosphate. Presentation of this demands first a study of the 'fine structure' of phosphate distribution which will be attempted in a later paper. Pilchard eggs frequently occur in water of a very poor type (Russell, 1937–40). A quantitative study of the abundance of *S. acanthias* associated with shoals of (*a*) the (eastern) Channel race of herring, (*b*) the 'western' race of herring (Ford, 1928), (*c*) pilchard and (*d*) mackerel might therefore lead to an advance on the central problem of productivity.

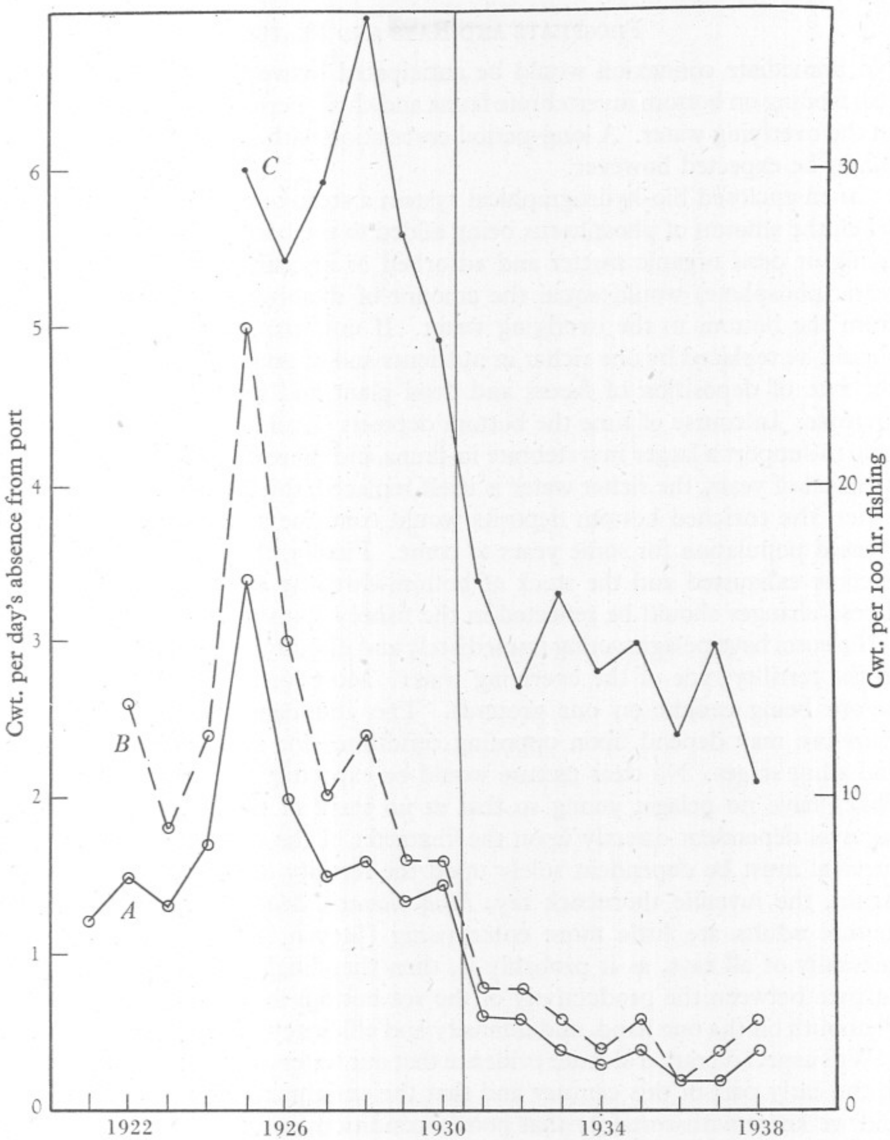


Fig. 2. Landings of dogfish (cwt.), at English ports in the English Channel from:
*A*, steam trawlers per day's absence from port.
*B*, steam trawlers per 100 hr. fishing.
*C*, motor liners per day's absence from port.

The vertical line marks the change-over from phosphate-rich (*elegans*) water to phosphate poor (*setosa*) water.

## Phosphate and Rays and Skates

No immediate connexion would be anticipated between quantity of bottom fish feeding on bottom invertebrate fauna and short-period changes in nutrients in the overlying water. A long-period correlation with a considerable time lag might be expected however.

In an enclosed bio-hydrographical system a steady state should be reached when the amount of phosphorus being added to the bottom deposits as faeces, living or dead organic matter and adsorbed or insoluble phosphate (such as ferric phosphate) would equal the amount of dissolved phosphate returned from the bottom to the overlying water. If now this overlying water mass should be replaced by one richer in nutrients and of greater biological fertility, the rate of deposition of faeces and dead plant and animal remains should increase. In course of time the bottom deposits should become enriched and able to support a larger invertebrate in-fauna and more demersal fish. If, after a period of years, the richer water is itself replaced, this time by nutrient-poor water, the enriched bottom deposits would continue able to support the increased population for some years to come. Finally, the reserve store would become exhausted and the stock of bottom-dwelling animals would decline. These changes should be reflected in the fishery statistics.

Teleosts have pelagic young immediately and directly influenced by a change in the fertility type of the overlying water. Moreover, they may voyage far before being caught on our grounds. The abundance of mature teleosts therefore may depend upon opposing conditions for survival in their larval and adult stages. No clear picture would be expected. By contrast, rays and skates have no pelagic young so that at no stage of their existence is their survival dependent directly upon the character of the overlying water. Their survival must be dependent solely upon the fertility of the bottom deposits. Again, the juvenile thornback ray, *Raia clavata*, does not migrate and the mature adults are little more enterprising (Steven, 1936). If this is true generally of all rays, as it probably is, then they ought to reflect closely the balance between the productivity of the sea bottom in the neighbourhood of Plymouth on the one hand, and intensity and efficiency of fishing on the other.

We suspect on rather slender evidence that our waters were poor in phosphate in the early part of this century and that the enrichment occured about 1921 and we know with certainty that poorer conditions returned to the overlying water at the end of 1930 (Matthews, cf. Cooper, 1938) (cf. Fig. 1, curve *P*). If the argument is sound, some years would have had to pass before the enrichment of the water was reflected in increased catches of rays. Similarly, once the stock of fish and bottom food was built up, a lucrative fishery should have persisted for some time after the rich water had departed.

With this hypothesis in mind the landings of rays and skates at Mevagissey between 1921 and 1938 were examined (Fig. 3, curve *F*). The drop in landings

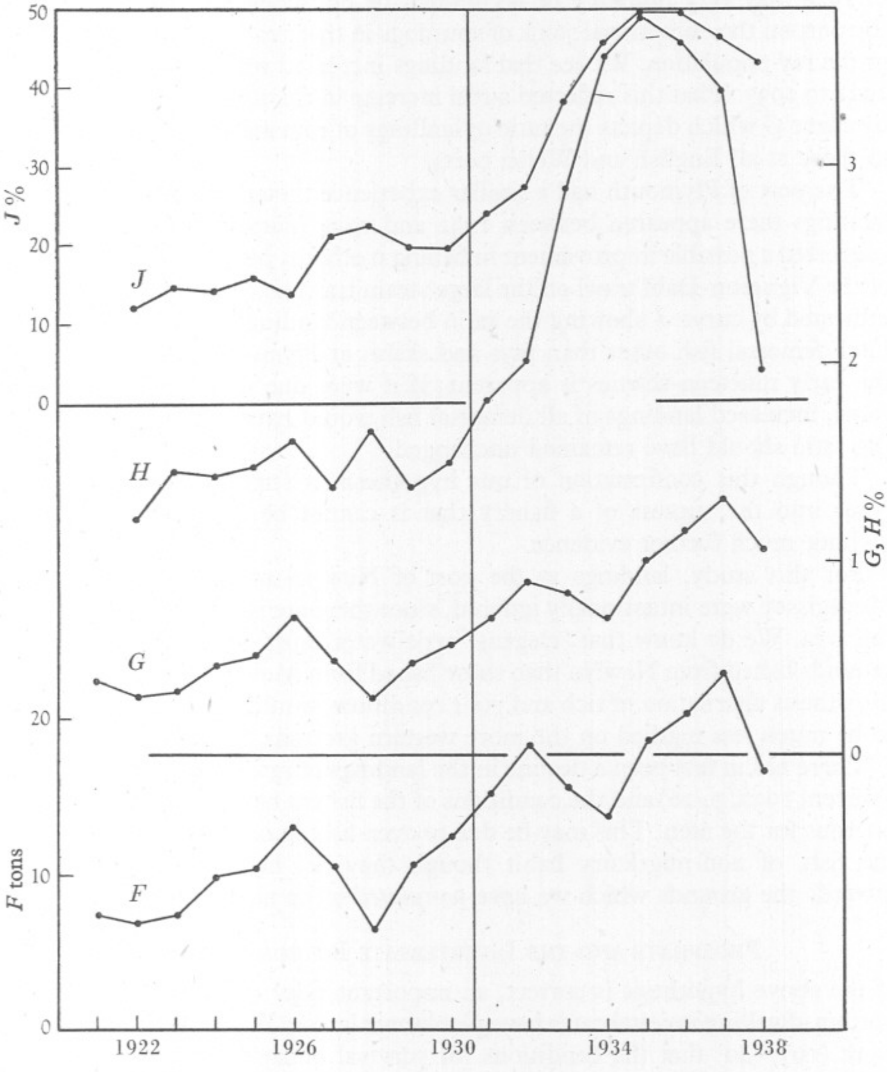


Fig. 3.

*F*, landings of rays and skates at Mevagissey (tons).

*G*, percentage ratio: $\dfrac{\text{Rays and skates landed at Mevagissey}}{\text{Rays and skates landed at all English and Welsh ports}}$.

*H*, percentage ratio: $\dfrac{\text{Rays and skates landed at Plymouth}}{\text{Rays and skates landed at all English and Welsh ports}}$.

*J*, percentage ratio: $\dfrac{\text{Rays and skates landed at Plymouth}}{\text{Demersal fish other than rays and skates landed at Plymouth}}$.

in 1928 may very probably be accounted for by the evident concentration of the port on the exceptional stock of spurdogs in that year and not to any decline in the ray population. We see that landings increased reasonably steadily from 1921 to 1937. That this reflected a real increase in the stock of fish is suggested by curve *G* which depicts the ratio of landings of rays and skates at Mevagissey to those at all English and Welsh ports.

The port of Plymouth had a similar experience though the main increase in landings there appeared between 1932 and 1934 (curve *H*). This sharp rise suggested a possible improvement in fishing methods, perhaps the introduction of the Vigneron-Dahl trawl on the large steam trawlers. That this was not so is indicated by curve *J* showing the ratio between landings of rays and skates to total demersal fish other than rays and skates at Plymouth. The same rise in the early nineteen-thirties is apparent; if it were due to use of an improved trawl, increased landings of all demersal fish would have been anticipated and the ratio should have remained unchanged.

Though this confirmation of our hypothesis is striking, so many factors enter into the success of a fishery that it cannot be considered as proved without much further evidence.

For this study, landings at the port of Newlyn 40 miles to the west of Mevagissey were intentionally ignored, since there are no nutrient salt data for the area. We do know that 'elegans'-type water must more often overlie the grounds fished from Newlyn than those fished from Mevagissey. On the above hypothesis alternation of rich and poor conditions would therefore be expected to be much less marked on the more western grounds.

There has in fact been a decline in the landings of rays and skates at Newlyn (Steven, 1932, p. 26) and the conditions of the fishery have become much more onerous for the men. This may be due to over-fishing or it is just possible that the fish, of non-migratory habit though they be, had moved up-Channel towards the grounds which we have *postulated* to be newly enriched.

## Phosphate and the Invertebrate Bottom In-fauna

If the above hypothesis is correct, an important rider follows. Practically all bottom-dwelling invertebrates have planktonic larvae. We know from Russell's work (1937–40) that the conditions for survival of zooplankton deteriorated sharply in 1931 and in subsequent years became steadily worse. This seems to be true for all species without exception. The number of larvae of bottom invertebrates surviving to settle and metamorphose on the bottom must therefore have been considerably less in the nineteen-thirties than in the nineteen-twenties. Once successfully metamorphosed and established in their adult home they should have found richer food for which there would have been reduced competition. Each single organism had therefore the opportunity to grow to a larger size. In the first place this argument applies to detritus feeders. Probably it may be extended to the whole of the bottom in-fauna, but not necessarily to the members of the epi-fauna taking their food by filter-feeding mechanisms and the like from the overlying water. The rider is therefore that during the nineteen-thirties the in-fauna probably decreased in numbers but that each organism became relatively larger.

No estimate can be made as to whether the *mass* of invertebrate food available for demersal fish changed for better or worse. An increase in the average size of the prey might however adversely affect the ability of small fish to catch and swallow their food, leading to relatively greater mortality during the first years of life.

The improvement in the ray fishery discussed above would suggest that the mass of food must have increased. As against this the adverse conditions for the pelagic young of teleost fish and of carnivorous invertebrates may have resulted in the rays being subjected to less severe competition for the available food.

That arguments such as these, by themselves, prove nothing needs to be stressed. As Mr G. A. Steven has remarked to the writer, we have no positive evidence that food supply is dominant amongst the many factors which may govern the survival and numbers of elasmobranch fish. A single coincidence between the stock of a nutrient in the water and the landings of a commercial fish may be due to chance or to some associated more fundamental but unrealized variable. Phosphate itself, primary though it is as a *plant* nutrient, is better regarded as an indicator of water type comparable with salinity. Though water with a high content of phosphate and probably of other nutrients and growth-promoting substances has the potentiality for producing a greater biomass than one with a lower content, it need not be better fitted for a particular species of animal and the food on which it feeds.

### Fertilizing the Ocean

There is nothing new in the idea that the productivity of a limited body of water may be improved by adding plant nutrients, and in some circumstances it may be economic as in carp ponds and Norwegian oyster pools. That enclosed arms of the sea may be treated in the same way is now the subject of study by Gross and his colleagues (1942–6) and shows distinct promise. To fertilize considerable areas of the open sea provides a fascinating theme for dialectic with little factual data for a real assessment. Ritchie (1944), with a natural distaste for the compulsory restriction or moderation of fishing activity which is the remedy for over-fishing offered by fisheries naturalists, proposes that the International Council should arrange the allocation of sums of money contributed by the several nations for chemical nutrients with the assurance that these distributed in the sea will support a larger fish population and an increased rate of fishing. Qualitatively none would disagree with this proposal which has received approval, unsupported by figures, from experience of the fisheries of Mauritius (Wheeler, 1945). Quantitatively the idea seems hopelessly uneconomic and has been assailed by Graham (1944) and by

Atkins (1944) on account of the 'mountainous' amounts of phosphate and other nutrients which would be needed. Ritchie riposted with figures which do not bear examination. He pointed out that 201,000 tons of phosphatic nutrients (as $P_2O_5$ which equals 88,000 tons as P) were used in agriculture in the United Kingdom and Eire in 1937 and that this is considerably in excess of the phosphate turnover in the English Channel. Maybe, but the phosphate *added* to the land helped to produce about 42,000,000 tons of crops and supported 12,900,000 cattle as well as numerous horses, sheep and pigs (figures are for 1939 from Whitaker's *Almanac*, 1941, pp. 632 and 704). The same amount of phosphate *present* in the English Channel in 1937 resulted in the landing of 76,000 tons of fish. Though doubling the amount of phosphate and other nutrients in the Channel might more than double the amount of fish, there remains an enormous gap to be closed between 76,000 tons of fish and 42,000,000 tons of crops plus millions of stock animals.

The very low economic efficiency of utilization of phosphate in the sea may be illustrated by the following figures.

McCance & Shipp (1933, table A) published large numbers of analyses of phosphorus in cooked fish flesh which were surprisingly uniform, around 0·25% of the weight of cooked edible flesh. Allowing a 20% loss in weight on cooking, this becomes about 0·2% of the raw flesh, a figure confirmed by a few analyses of raw fish fillets in their table H. The offal from the fish, mainly head, bones and gut will contain more phosphorus than the flesh, as was shown by the analyses of whitebait and sprats which were cooked whole. Though the fish curing or processing factory will be likely to convert its offal into agricultural fertilizers, domestic offal and that from retail shops will go to the rubbish bin. Only phosphate in fish flesh is of value to the domestic consumer. The significant ratio is thus:

$$\frac{\text{Phosphorus in fish flesh}}{\text{Wet weight of whole fish}}.$$

If two-thirds of the wet weight of the fish is considered to be edible flesh, this ratio will be $2/3 \times 0{\cdot}2\%$ wet weight of whole fish $= 0{\cdot}13\%$. This figure, though not very accurate, is a sufficient measure of the usable phosphorus recovered from the sea in fish and may be combined with figures for total landings of marketable fish to give a measure of the efficiency of recovery of phosphorus from the sea. Data for the years 1925–37 have been extracted from the *Bulletin Statistique* for areas VIID+VIIE (English and French Channel ports). The area of the English Channel is about 82,100 sq.km. and its average depth about 72 m. Its volume is therefore about $5{\cdot}9 \times 10^{12}$ cu.m. To derive a round figure for the phosphate available for plant growth, the winter maximum for station E1 has been assumed to represent an average figure for the whole of the Channel, enabling the total phosphate content of the Channel to be calculated for each year. The ratio of edible phosphorus in marketable fish to the available stock of phosphorus in the water has then been calculated.

| Year | Weight of fish landed (tons) | Edible phosphorus in fish landed (tons) | Phosphorus available for growth in Channel (tons) | Usable phosphorus landed as percentage of phosphorus available for growth (%) |
|---|---|---|---|---|
| 1925 | 81,000 | 115 | 111,000 | 0·104 |
| 1926 | 79,000 | 103 | 137,000 | 0·075 |
| 1927 | 74,000 | 96 | 100,000 | 0·096 |
| 1928 | 71,000 | 92 | 126,000 | 0·073 |
| 1929 | 95,000 | 123 | 126,000 | 0·098 |
| 1930 | 58,000 | 75 | — | — |
| 1931 | 76,000 | 99 | 95,000 | 0·104 |
| 1932 | 88,000 | 114 | 86,000 | 0·133 |
| 1933 | 95,000 | 123 | 97,000 | 0·127 |
| 1934 | 93,000 | 121 | 88,000 | 0·137 |
| 1935 | 65,000 | 85 | 77,000 | 0·110 |
| 1936 | 79,000 | 103 | 86,000 | 0·120 |
| 1937 | 76,000 | 99 | 88,000 | 0·112 |

Thus, during many years of intensive fishing, each year 0·1 % of the available stock of phosphorus has been recovered in a form usable by man. Though the fertility of the water might well be increased rather more than in proportion to the amount of fertilizer added, the prospect of dumping phosphate in a body of water such as the Channel appears most unattractive. Even if the efficiency of recovery could be increased ten times, the yield would still be much less than could be got from the soil dressed with the same amount of fertilizer.

As matters now stand, very large amounts of nutrients are being poured into the sea, the great sink, as sewage from coastal towns and by way of the rivers from inland towns and farms fertilized and unfertilized. Phosphorus is a very precious commodity which in not so many years will become very scarce. The scale on which phosphorus even now is being dissipated to the sea is more than the world can afford. In years to come the cry will be for more methods for recovering phosphorus from the sea, not for putting it in.

Millennia ago, nomadic man, realizing that hunting was an uncertain and wasteful method of gaining a livelihood, changed to an economically far more efficient, pastoral and agricultural existence. Fishing remains as the major hunting pursuit still followed by civilized man. If it is to become more productive it must cease to be feral and become pastoral. To that extent I agree with Ritchie. But an efficient exploitation of the soil—or the sea—demands full control of weeds and pests which otherwise take an undue share of any plant nutrients added. Until fishing becomes pisciculture, and weeding of unwanted algae and control of unwanted pests, i.e. competitive predators and parasites, take their due place, fishing can never be more than ruthless and non-selective hunting.

The writer wishes to express his indebtedness to Mr E. Ford and Mr G. A. Stevens for stimulating discussions and pertinent criticism.

## Summary

Landings of the spurdog, *Squalus acanthias*, at Mevagissey reflect the changes in phosphate at the neighbouring International Hydrographic Station E 1.

It is suggested that commercial landings of rays and skates ought to follow major changes in nutrient content of the overlying water with a time lag of some years. Fishery statistics for English Channel ports support this view. The dependence of the bottom in-fauna upon the fertility of the overlying water is also discussed.

Proposals to improve commercial fisheries by artificially fertilizing considerable areas of the open sea are critically examined. Such artificial enrichment is considered to be grossly uneconomic unless fishing becomes pisciculture in which weeding of unwanted algae and control of unwanted pests—competing predators and parasites—is undertaken.


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