

# YALE PEABODY MUSEUM

P.O. BOX 208118 | NEW HAVEN CT 06520-8118 USA | PEABODY.YALE. EDU

## JOURNAL OF MARINE RESEARCH

The *Journal of Marine Research*, one of the oldest journals in American marine science, published important peer-reviewed original research on a broad array of topics in physical, biological, and chemical oceanography vital to the academic oceanographic community in the long and rich tradition of the Sears Foundation for Marine Research at Yale University.

An archive of all issues from 1937 to 2021 (Volume 1–79) are available through EliScholar, a digital platform for scholarly publishing provided by Yale University Library at <https://elischolar.library.yale.edu/>.

Requests for permission to clear rights for use of this content should be directed to the authors, their estates, or other representatives. The *Journal of Marine Research* has no contact information beyond the affiliations listed in the published articles. We ask that you provide attribution to the *Journal of Marine Research*.

Yale University provides access to these materials for educational and research purposes only. Copyright or other proprietary rights to content contained in this document may be held by individuals or entities other than, or in addition to, Yale University. You are solely responsible for determining the ownership of the copyright, and for obtaining permission for your intended use. Yale University makes no warranty that your distribution, reproduction, or other use of these materials will not infringe the rights of third parties.



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.  
<https://creativecommons.org/licenses/by-nc-sa/4.0/>



# A FISH FARMING EXPERIMENT IN SCOTTISH SEA LOCHS<sup>1</sup>

By

J. E. G. RAYMONT

*University College, Southampton, England*

The practice of stimulating dense growths of marine phytoplankton in laboratory cultures by the addition of nitrate and phosphate is now well established. Since in the sea the food chain leading ultimately to fish begins with inorganic nutrient salts, and passes through plankton and bottom fauna, it seemed feasible to attempt to stimulate the food cycle by the addition of artificial fertilizers to seawater areas. Nitrate and phosphate alone were considered since these are the nutrients in short supply in the sea.

The work was carried out by Dr. F. Gross and the author, working from the Zoology Department, Edinburgh University, with the collaboration of Drs. S. M. Marshall and A. P. Orr of Millport, and later of two research workers, Mr. Nutman and Dr. Gauld. The cost of the work was generously defrayed by Imperial Chemical Industries, Ltd., Billingham, England.

## THE LOCH CRAIGLIN EXPERIMENT

In order to obviate as far as possible a great loss of fertilizer, experiments were commenced on a very small, much enclosed, sea-loch (Loch Craiglin), about eighteen acres in extent. The loch is comparatively shallow and has a very narrow channel open to the sea, which was dammed off, so as to restrict fertilizer loss. Loch Craiglin, however, had relatively few features to recommend it apart from its small size. We could not admit outside sea water regularly to the loch, as we had planned, and as a result there were great fluctuations in hydrographic conditions:—variations in salinity particularly at the surface; very high pH in the upper water layers; low pH and oxygen content and some H<sub>2</sub>S production in deeper waters due to decomposition, especially of seaweed.

The distribution of fertilizer consisted in the application throughout 1942 and 1943 of some twelve hundred pounds of sodium nitrate and

<sup>1</sup> One of a series of papers presented at a symposium, "Fertilization of Aquatic Areas," sponsored by the Limnological Society of America. Boston, 1946.

six hundred pounds of superphosphate. This mixture was distributed usually as a powder at intervals throughout spring, autumn and winter, but no fertilizers were added in summer as they encouraged at that time an extremely heavy growth of seaweed and *Zostera*. The quantities of fertilizers added were calculated so as to obtain a concentration of 100 mg/m<sup>3</sup> of nitrate and 20 mg/m<sup>3</sup> of phosphate throughout the water immediately after fertilization.

## RESULTS

*Plankton.* Most unexpected was the rapidity with which the fertilizer was utilized. During the ordinary growth season the bulk of that added was completely used within a week. Of the various categories of phytoplankton organisms, the very small flagellates (from 1 to 8  $\mu$  in diameter), or nanoplankton as they are termed, showed the most striking response. On several occasions their numbers rose immediately after fertilization and at times there were tremendous concentrations of up to 8,000 per cu. mm.—that is, 8,000,000 per cc. The effect on diatoms throughout 1942 and 1943 was less obvious, but these also increased at times to very high densities (7,000 cells per cc.); dinoflagellates were also fairly abundant throughout that period of the work.

It is a remarkable fact that the heaviest growth of phytoplankton for 1942–1944 was experienced in winter, early in 1944, with maxima of 8,000 peridinians, 52,000 diatoms and 6,000,000  $\mu$ flagellates per cc. of water. During this period the water was to the eye green or brown according to the dominating form. Very striking responses to fertilization of diatoms and dinoflagellates, as opposed to  $\mu$ flagellates, were found in 1945.

As regards the zooplankton, in the spring of 1943 the population in Loch Craigin reached a very high density, but afterwards there was no response, although the phytoplankton was very high. The limitation in the zooplankton production is considered to have been due to hydrographic conditions—particularly high H<sub>2</sub>S concentration in deeper layers, high pH in upper layers, and possibly the much reduced salinity.

*Bottom Fauna.* The bottom fauna changes were followed by grab samples taken at fixed stations before fertilization began and throughout the course of the work. This method of control was found to be much superior to selecting an outside control area, since the bottom fauna of Loch Craigin was very specialised. The response of the bottom fauna was not obvious during the first year of the experiment, but by the summer of 1943 it had reached an average density over the

whole loch 240% greater than that of the summer before (1942). Comparing the average *winter* densities in Loch Craiglin, by January 1944 the average density was 300% greater than in the previous winter. An average population of 15,000–16,000 animals per sq. m. throughout the summer and early autumn of 1943 is especially remarkable in view of the fact that the figures represent a dynamic balance between the number of bottom animals reproduced and the amount grazed down by feeding fish. Some 3,000 flatfish were transferred during 1942 to Loch Craiglin and about 23,000 in 1943, in addition to a considerable native population of fishes, so this grazing effect was very considerable.

*Fish Growth.* Although the samples of fish obtained were on the whole disappointingly small, the growth rates were fortunately fairly consistent.

About 170 plaice of under 9 cm. length were transferred to Loch Craiglin. They grew about 12 cm. in a year, as compared with annual increments of 3 to 8 cm. by plaice of the same age on various natural grounds.

Two thousand flounders under a year old (*i. e.*, Age Gp.—O), transferred in 1942 (Stock I), had reached an average length of 12 cm. at the end of their first year in Loch Craiglin. This growth may be compared with flounders of the same age trawled from the natural area from which they were taken. On the natural ground the flounders grew in one year to an average length of only 5.5 cm. In 21 months, Stock I completed an amount of growth equivalent to five to six years of "normal" growth on various natural grounds. The growth of these flounders is three to four times faster by length, and between 16 and 19 times faster by weight.

One thousand flounders, between one and two years old (*i. e.*, Age Gp.—I) were transferred to Craiglin in the spring of 1943 (Stock II) in order to test whether or not the acceleration in growth rate applied only to the youngest fish. Stock II flounders completed about two years' normal growth in approximately six months.

A further 22,000 flounders (Age Gp.—O) were transferred in the summer of 1943 (Stock III). These showed considerable improvement in growth as compared with their controls, but the acceleration was not nearly as great as that of Stock I during the first year. This lesser growth rate cannot have been due to any food scarcity, since the bottom fauna had remained exceedingly rich. More likely the slowing down of growth was caused by increasingly unfavourable hydrographic conditions, especially the high concentration of H<sub>2</sub>S over the bottom late in 1943.

To test this hypothesis, during 1944 and 1945 the dam sluice was opened for long periods to allow considerable water exchange with the outside seawater. The growth of Stock III flounders showed a very marked acceleration after this, and in fact the increment of 13 cm. from June 1945 to March 1946 (9 months) is the largest so far recorded.

As it appeared that Loch Craigin was rather unfavourable as regards hydrographic conditions, fertilization was begun in Kyle Scotnish, another arm of Loch Sween, which is larger and deeper than Craigin. It must be appreciated, that in one respect the experiment in Kyle Scotnish was entirely new; in Kyle Scotnish no dam was erected, but the loch was left freely open to the outer parts of Loch Sween in order to test the possibilities of fish cultivation in *unenclosed* areas of the sea.

#### THE KYLE SCOTNISH EXPERIMENT

Kyle Scotnish is about 160 acres in extent. Near its connection with the main Loch and for a distance of several hundred yards it is very narrow, at one place only about 100 yards wide (the Narrows region). Further up, however, it widens out into two large basins (the South and North Basins). The maximum depth is about 20 metres in the South Basin, but the greater part of the Loch varies between about six and ten metres.

Fertilization began in January 1944;  $2\frac{1}{2}$  tons of fertilizer were distributed usually every month, which means about 3 cwts. per acre per annum. Superphosphate was always used as phosphate fertilizer, but as regards nitrogen, we began with sodium nitrate and later changed to ammonium sulphate. The fertilizers were raked dry into the water from a tray carried by a small motor boat.

One of the main problems was to estimate the amount of water exchanged between Kyle Scotnish and the outside. After some preliminary experimenting the phosphate concentration itself was used as an indicator of water movements. In order to do this, on several occasions the fertilizers were distributed only in the North Basin of Kyle Scotnish so as to obtain there a relatively very high concentration of nutrients, initially confined to a small area. We studied the subsequent extent and rate of dispersal of the phosphate from the North Basin. For several fertilizations, during the first 24 hours after the phosphate was added, it did not become dispersed beyond the North Basin, but during the second and third days after fertilizing it spread to the South Basin. Phosphate did not reach the Narrows region till the third day and water samples from the mouth of Kyle Scotnish showed phosphate only in the same low concentration as was

found outside right up to approximately a week after fertilizing, by which time the bulk of the phosphate added had been used.

The rapidity of this utilization (the same as was found in the Loch Craiglin experiment) is one of the most important features of the fertilization work. Only approximately one quarter of the phosphate added dissolved immediately at fertilization; the rest of the fertilizer presumably sank to the bottom. But a considerable amount of the phosphate going to the bottom subsequently went into solution and became available to the phytoplankton.

Even with adverse winds and tides, as far as our experiments went, the loss of fertilizer was never sufficiently great to cause anxiety. It must be appreciated that water masses are relatively stable and mix comparatively slowly.

#### THE EFFECTS OF FERTILIZATION

*Phytoplankton.* An outside arm of Loch Sween (Sailean More) was used as a control area for both phytoplankton and zooplankton, and it should be emphasized that before fertilization began the plankton populations of Kyle Scotnish and of Sailean More were very similar both as regards species and density.

$\mu$ flagellates occurred in Kyle Scotnish generally in lesser numbers than we found them in Loch Craiglin. In Scotnish it was the larger members of the phytoplankton which were usually more important. Perhaps some sort of competition exists between the  $\mu$ flagellates on the one hand and the diatoms and dinoflagellates on the other, for the fertilizer added. Even so  $\mu$ flagellates occurred in Scotnish in numbers up to 1,500 per cu. mm., so that their contribution to the general organic production is in no sense to be disregarded, and they are probably of great importance as a food supply for small larvae.

As regards the diatom and dinoflagellate populations, at times this phytoplankton responded very favourably to fertilizer application, for instance in April 1946 when in five days the phytoplankton of Kyle Scotnish rose to between two and three times the population in Sailean More. Similar increases followed fertilizer distribution in May, and June, when the population was four times as high in Scotnish as outside.

These results would appear to be highly satisfactory, but on other occasions there was *apparently* little if any response from the phytoplankton to fertilizer distribution. This was particularly true during summer, when actually the phytoplankton of Sailean More was sometimes even richer.

The reason for this apparent lack of response in phytoplankton in Scotnish was, we believe, the tremendous grazing activities of the zooplankton.

*Zooplankton.* Before fertilization began in Kyle Scotnish there was no significant difference between the zooplankton populations in Kyle Scotnish and in Sailean More. But from March 1944 the zooplankton of Kyle Scotnish became steadily more numerous. In May there were, on the average, 10 animals per litre in Sailean More, as compared with between 30 and 60 per litre in different parts of Scotnish. In July there were 50 in Sailean More, as compared with over 200 in the South Basin of Scotnish and over 370 in the North Basin.

Throughout most of the year, both in 1944 and 1945, the zooplankton density was considerably greater in Kyle Scotnish than in Sailean More, and on those few occasions when the zooplankton of Sailean More was richer, the populations were very low in both areas.

In Loch Craiglin, during the comparatively few periods when the zooplankton was rich, the phytoplankton crop remained relatively very small in spite of the addition of fertilizers. This phenomenon was much more common in Kyle Scotnish where the conditions for the growth of a rich and varied zooplankton population were more favourable. It seemed that dense zooplankton must keep down the phytoplankton production.

On those occasions when zooplankton in Kyle Scotnish was poor and, it is claimed, conditions for phytoplankton growth were therefore favourable, the rise of phytoplankton population, following the addition of fertilizer, was very great. Thus, during October 1945, when zooplankton was rather low, the population of diatoms and dinoflagellates together in Kyle Scotnish rose from 700, before fertilization, to 3,800 a week after—an increase of more than five times. As compared with this, the phytoplankton population in the control area showed a slight decline.

*Bottom Fauna.* The bottom fauna was analysed, as in Craiglin, by grab samples taken at fixed stations in the loch, both before fertilization and throughout the following two year period.

On the whole the muddy areas of the North and South Basins were comparatively poor both in species and in actual densities, and not every station showed an increase after fertilization was started. If the populations during the winter (January) of 1945 and 1946 be compared with the populations at the same stations in January 1944 (*i. e.*, before fertilization started), of altogether 27 stations, 14 showed an increase in both years of fertilization, while a further six stations showed a decline in one year (mostly in 1945) and then an increase in the second year of the work (1946). The percentage changes show that some stations experienced very striking increases, such as in the Narrows stations (up to 700%), in the South Basin (up to 250%), and

in the North Basin (up to 600%). Only a single station showed a striking decline.

The average bottom population for the whole of Kyle Scotnish, calculated from the various densities at each station, shows a steady rise throughout the two years to three and four times the prefertilization value. Table I shows that this steady increase over the two

TABLE I. EFFECT OF FERTILIZATION ON THE BOTTOM FAUNA OF KYLE SCOTNISH. NUMBERS REPRESENT THE AVERAGE POPULATION OF BOTTOM FAUNA PER SQUARE METRE, CALCULATED FROM DENSITIES AT INDIVIDUAL STATIONS

	No. of Stations	Pre-fertilization		Post-fertilization
		1943-44	1944-45	1945-46
SUMMER (Grab Series)	6	640	1000	1950
WINTER (Grab Transects)	23	460	850	1420
WINTER (Regular Stations)	7	680	1400	3160

fertilization years holds, whether summer or winter samplings be considered.

The most striking change in the bottom fauna on shore between tide levels was the tremendous settlement of the common mussel which took place over the only extensive area of shore in the Loch. Table II

TABLE II. EFFECT OF FERTILIZATION ON MUSSEL SETTLEMENT, SUMMER, 1945. ALL FIGURES REPRESENT NUMBER OF LIVING MUSSELS PER SQUARE METRE. TWO DIFFERENT AREAS WERE SAMPLED IN BOTH KYLE SCOTNISH AND LINNE MHURICH; ONE AREA ONLY IN SAILEAN MORE

		<10 mm	10-40 mm	>40 mm
KYLE SCOTNISH	Area 1	9,300	4,300	ca. 10
	Area 2	396,000	556	136
LINNE MHURICH	Area 1	0	160	184
	Area 2	32	8	72
SAILEAN MORE	(Unfertilized)	9,712	2,088	1,068

shows the total density per square metre of young mussels in Scotnish during the summer of 1945, and comparative figures are also given for unfertilized arms of Loch Sween. These figures illustrate the extraordinary high density of settlement in Scotnish, and this despite the fact that the area is a very soft mud, highly unsuitable for mussel settlement. This suggestion of the unsuitability of Scotnish shore is borne out by the fact that the breeding stock of large mussels is found in much greater numbers in the outer arms of Loch Sween than in Kyle Scotnish. For instance, there existed in Kyle Scotnish in the summer of 1945 between 900 and 3,000 young mussels for every large



one, whereas in two outside areas there were less than 10 young spat for every adult (Table II).

The average population of the shore, apart from the mussels, consisting of *Hydrobia*, chironomid larvae, polychaetes, bivalves, etc., also rose from November 1943 to November 1945 by 40%, the increase affecting practically all the individual species.

*Fish Growth.* Apart from some flounders and a few plaice, Kyle Scotnish possessed a very sparse natural fish population. It was obvious that the area would have to be stocked just as in the case of Loch Craigin.

In studying the growth, both of flounders and plaice, throughout the work, Dr. F. Gross removed otoliths from the fishes to verify their age determinations.

In the spring of 1944 only a comparatively few artificially fertilized eggs of plaice, cod and haddock were introduced. In the spring of 1945, however, stocking with 2,000,000 plaice eggs and fry from a new hatchery was achieved. These Gp.—O plaice were then studied by means of successive samplings by seine-net fishing in the Loch, and although the samples were sometimes small, the mean sizes of the successive samplings obtained showed clearly and conclusively a very satisfactory growth. In their first season these Gp.—O plaice grew to 13 cm. and reached 25 g. in weight. This represents five times the normal weight increment. Furthermore, there were some Group—I plaice from the previous year that came into the samplings. They reached a size by September 1945 (when they were  $1\frac{1}{2}$  years old) of 20 cm. and 100 g.—approximately three times heavier than naturally good growing fish of the same age.

The natural population of flounders in Kyle Scotnish was sufficient to yield some good confirmatory data on the beneficial effects of fertilizer on fish growth. Group—O flounders grew to about 10 cm. in their first year and weighed 10 g. This is an improvement by about 400% in weight over the growth on normal grounds. Group—I flounders reached an average size of over 20 cm. and a weight of nearly 120 g. This is a great improvement on normal conditions and in fact approaches the best growth observed in the earlier experiment in Loch Craigin.

Even these figures, satisfactory as they are, underestimate the improvement in growth in Scotnish under conditions of fertilization. For we have considered only the mean sizes of the various groups of fish, but the means are not a true index of growth rate. Owing to the migration of fish to and from the fertilized loch the size range of any one Age Group becomes unusually large and the size-distribution

curves become skewed. A careful study of successive growth curves showed further that the migration was not even a random movement, but that small specimens migrated in from outside and the larger specimens (older inhabitants of Scotnish) moved out of the Loch. It is well known that as flatfish grow up, apart from any random dispersal, they tend to move offshore. As their growth rate is increased their departure to offshore areas is presumably accelerated, but this reduces the improvement in growth that can be shown by means of distribution curves.

This implies that fertilization of an open sea loch such as we have been practising will benefit flatfish only during the first year or two of their lives; after that they tend to migrate outwards. For similar reasons no data were obtained on the growth rate of round fish.

### SUMMARY

In both enclosed and unenclosed small sea areas, the addition of nitrate and phosphate fertilizer stimulates phytoplankton growth, which in turn can maintain a high density of zooplankton and bottom fauna, and this in its turn leads to a great acceleration in the growth of flatfish. In two years, flatfish attained the equivalent of approximately four or five years' growth under normal conditions; and in fact they reach what might be called marketable size at the end of the two-year period.

Owing to the offshore migrations of flatfish, any further development should be carried out in an area with a natural fairly rich fish population, and this area must include waters of considerable depth so that fish can migrate there and still benefit from fertilization.