

The primary production in the Norwegian Sea
June 1954, as measured by an adapted ^{14}C -technique

by

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Introduction.

The movements of fish shoals during their feeding period should be expected to be influenced by the different waters' food supply. In the research of the fish movements the knowledge of the oceans productive and unproductive areas, their extension and intensity would be of interest, as well as the knowledge of the primary production would give valuable informations as to the resources of the oceans.

During the hydrographical cruise with the research vessel "G.O.Sars" in the Norwegian Sea 21.V.-1.VII. 1954, - a cruise which takes place yearly as part of the herring investigations - opportunity was given to undertake observations on the primary production. By such observations at the hydrographical stations it was hoped to be able to draw maps of the productive areas, and relate the results to the hydrography, zooplankton and fish registrations.

Certain claims were put to the method of observation: The sampling should cause a minimum of delay for the research vessel, which already had a rather strained programme. The method should give comparable values, where differences in production due to changes in the weather conditions were eliminated, and the results should be given for a mean day of the investigated area.

Furthermore, the method should be useable in all weather conditions both day and night as often as desirable.

To satisfy these claims a modification of the Steemann Nielsen (1952) ^{14}C -method was used.

Methods.

The primary production by algae is proportional with the light energy up to certain values characteristic for the time and area in question. Above this value the production increase per additional light unit is retarded. Jenkins (1937) estimated the proportionality to be valid up to 14000 lux in the English Channel. Steemann Nielsen (1937) found maximum photosynthesis at 7000 lux for Danish autumn plankton.

In the waters near Bergen there was found proportionality to nearly 10000 lux in plankton from 10 metres in May.

Within the proportional part of the light/production curve the production P is:

$$P_T = K \cdot \int_0^T I_e dt \quad (1)$$

where $\int_0^T I_e dt$ is the effective part of the incoming light energy during the time T. (Sverdrup 1953). K is a factor which is characteristic for the plankton population in question. If the light energy is measured in lux hours, the K means the production per lux hour. The production per liter and lux hour is in this paper referred to as the production capacity of the water.

Letting the identical mean day for the comparisons of the productions be represented by the arithmetic mean of n measurements of the effective incoming light energy, we have that

$$\bar{S} = \frac{S_1 + S_2 + \dots + S_n}{n} \quad (2)$$

where the S 's for simpleness represent the integrals of the effective light energy during a day.

By knowing the \bar{S} the production on the mean day, P_d , can be calculated from observations on the production capacity, by the formula

$$P_d = K \cdot \bar{S} \quad (3)$$

Direct measurements of the different S 's would be difficult since the effect of the qualities of the light on production is very little known. Since, however,

$$S_1 = \frac{P_{d,1}}{K_1}, \quad S_2 = \frac{P_{d,2}}{K_2}, \quad \text{and so on,} \quad (4)$$

we get from (2) and (4) that

$$\bar{S} = \frac{\frac{P_{d,1}}{K_1} + \frac{P_{d,2}}{K_2} + \dots + \frac{P_{dn}}{K_n}}{n}$$

The formula is valid for the $\frac{P}{K}$ - relations in depths corresponding to a certain % of light energy income.

In the measurements done in the Norwegian Sea nine such simultaneous observations on production and production capacity were undertaken for the estimation of \bar{S} in depths corresponding to 100%, 26.5% and 7% of the penetrating daylight.

The maximum light intensities on these days varied between 4.800-7.000 lux. just below surface, with a mean maximum of 5.800 lux. This mean value corresponds well with the mean light intensity income in June at 73° N. where Mosby (1937) gives the maximum at noon to 5.800 lux.

Determinations of P.

The penetration of light into the sea was found by photoelectric measurements, using Jerlov's submarine photometer. Samples were taken with the Steemann Nielsen all glass water bottle, (Steemann Nielsen 1953) from depths corresponding to 100%, 26.5% and 7% of penetrating light at noon. After addition of accurate measured amounts of $\text{Na}_2^{14}\text{CO}_3$, the 100 ml, s samples were placed in a thermostatic bath at the top deck of the ship. The samples were covered with neutral light filters corresponding to the depths they were sampled. The experiments lasted from noon to midnight, after which time they were filtered, dried and stored for countings ashore. The results are given as 1/2-day production in gramme Carbon per litre.

Determinations of K.

Determinations of the production capacity of the waters were carried out at nearly 60 stations. Except for the simultaneous determinations of P and K the sampling depths for these measurements were standardized to 0-10m. and 20m. After addition of the $\text{Na}_2^{14}\text{CO}_3$ the samples were put in a thermostatic bath under artificial daylight illumination of 4.800 lux. In level with the samples was a photoelectric cell and the light income during the 4 hours of experiments were registrated on a integrating lux-meter. After filtration and treatments as above, the final results were given as mg. Carbon per litre and lux hour. For the filtrations were used collodiumfilters and press-air filter apparatus. (Calvin et al. 1949).

The light depths in question were in many cases near to the standard sampling depths for the production capacity determinations. In deviating cases the K in question were determined by interpolations between the three measurements done. From these K-values and the mean value of the corresponding P/K-relation, the production per litre and day were calculated as described. Determinations of the production below 1 square metre of the surface are done by integrations of the production curves, between the depths for 1% of penetrating daylight and the surface.

Discussion of the method.

As the observations of P in all experiments were undertaken at very low light intensities, the estimation of \bar{S} should be correct. According to Mosby (1932) the energy income on a clear day may be more than twice the value of that on a cloudy day. If the measurement of 4.800 lux at noon represent a dark day, light intensities might be expected to reach values of nearly 12.000 lux. In this case the light intensity for the surface sample will exceed the value until proportionality between production and light income exists. Estimations of the \bar{S} can, however, be undertaken using neutralfilters for light absorption, and multiplying the S-value such obtained by the filter factor.

If the production at all stations should be calculated on a such extreme day, the calculated P value in 0 metre would be a little too high. In the calculation of the production below 1 sq.m., namely the integral of the production curve, the deviation from the correct value would hardly be detectable within the accuracy of the analyses. The total production below 1 sq.m. on a quite clear day with sub-surface illumination at noon of 12.000 lux, should therefore be nearly twice the value found for the mean day. However, such extremes hardly existed in the Norwegian Sea during the cruise. The calculated differences, however, show the importance of doing comparisons on an identical day. According to Steemann Nielsen (1952) the estimation of P should be undertaken by hanging bottles with samples back into the sea. The use of daylight baths and neutral filters did not, however, show any significant differences from parallels in the sea for the filters used, as will be seen from the following experiment:

26.4% daylight		7% daylight	
In sea	In bath	In sea	In bath
495 c/m	470 c/m	206 c/m	206 c/m
267 "	298 "	27 "	32 "
40 "	37 "	15 "	15 "

The differences are all within the accuracy one has been able to obtain by the ¹⁴C-technique in the nature.

The calculated mean value of the incoming light energy will be useful only within certain latitudes and time of the year. Within what borders of latitude and time the same \bar{S} shall be used, depends on the accuracy claimed of the observations. The technique used has the advantage that comparisons of production may be undertaken at a desirable mean day. Differences in production due to varying weather conditions is thereby eliminated. Observations may be taken at any time of the day, and the delay at each station will be minimized.

Results.

The results from the measurements of the production capacities are presented in Figure 1 for the three sampling depths 0-10m. and 20m. The maps have been constructed by drawing lines through points with the same production capacity. On the basis of these maps the vertical distribution of the same factor has been drawn, and is given as an example for the 70th longitude in Figure 3.

The most productive area is situated in the middle of the ocean, and can be traced as a river through the Norwegian Sea up to Spitsbergen. The north-western and south-eastern part of the investigated area has a lower production capacity. The south-north distribution may, however, be some affected by the time factor, since the observations in the far north were undertaken nearly a month later than the most southerly observation.

In Figure 2 the results from the simultaneous P/K - relation is demonstrated graphically for the three depths in question. The mean value $P/K = \bar{S}$ is the drawn line. By the use of these relations and the corresponding production capacities found, the production is calculated as described. The production below 1sq.m. of the surface is shown in Figure 4. The map gives the same main features of the productivity as shown in the maps for the production capacities, but less pronounced. This is to be expected since a factor causing a rise in the production, in the total production below 1 sq.m. will be counterworked by a less transparency of the water. Variations in the productivity therefore, will be most pronounced in the Figure 1.

On the cruise observations of temperature, salinity, oxygen and phosphate were taken, as well as samples of zooplankton and phytoplankton. This material has not yet been worked up or published, but with the courtesy of Dr. J.Eggvin the map in Figure 5 is presented. The Atlantic water is covering the central parts of the Norwegian Sea, limited by the 35 o/oo isohaline. In the west and north-west the Arctic water is found, and against the Norwegian coast the 35 o/oo isohaline marks the border to the coastal waters off Norway.

In comparing the production capacity for 20 metres with the hydrographical conditions, it will be seen that the main production area is situated in the western part of the Atlantic water, below salinities of 35.15 o/oo. The purer Atlantic water in the east are less productive. Production capacities above $6 \cdot 10^{-7}$ mg.C/L/Lux.Hour are hatched. The hatched area corresponds almost in details with the distribution of the Atlantic water with salinities between 35 and 35.15 o/oo. The admixture of the Arctic water east of Iceland is causing the decrease in salinity in the western part of the Atlantic water. The combination of these two poor productive water-types seem to cause the very high productive water in the central part of the Norwegian Sea. The same connection to hydrography may be seen by comparisons with the map of total production, but the facts are here less pronounced.

A reproduced map (J.J.Marty, 1956) of the herring feeding area is shown in Figure 6. Since this map is based on observations through more years, to close correlations with the production, maps cannot be expected. However, the distribution of herring during the feeding period fits very good with the productive area of the Atlantic water, and the eastern border of the feeding area corresponds very closely with the isoline for the production of 0.8 g. Carbon/day in Figure 4.

Since the measurements of the production capacity is undertaken at very like conditions, there might be expected some positive relation between the production capacity and the standing crop of phytoplankton, and therefore also a certain relation between transparency of the water and the production capacity. This relation might, however, only hold in times before the culmination of the blooming. In the last figure the production capacity found are plotted against depths of 26.5% and 7% of submarine daylight. There seems to be almost a logarithmic correlation between depth for the light and the value of the production capacity above. It should therefore be possible by light-observations to do helpful estimations of the production capacity and the production for each of these depths.

References.

- Aabye Jensen, E. and Steemann Nielsen 1953: "A water-sampler for Biological purposes". Journ. du Cons., 18, 3.
- Calvin M., Heidelberger, C., Reid, J.C., Tolbert, B.M., and Yankwich, P.F. 1949: "Isotopic carbon. Techniques and its measurements and chemical manipulation". New York.
- Jenkins, Penelope M. 1937: "Oxygen production by the diatom Coscinodiscus excentricus Ehr. in relation to submarine illumination in the English Channel". Journ.Mar. Biol. Assoc. U.K., 22, pp 301-342.
- Steemann Nielsen, E. 1937: "The annual amount of organic matter produced by the phytoplankton in the Sound off Helsingør". Medd. Komm. Danm. Fisk. og Havunders., Ser. Plankton 2, (4).
- " 1952: "The use of radio-active carbon (¹⁴C) for measuring organic production in the sea". Journ. du Cons., 18, 2.
- Sverdrup, H.U. 1953: "On conditions for the vernal blooming of phytoplankton". Journ. du Cons. 18, 3.

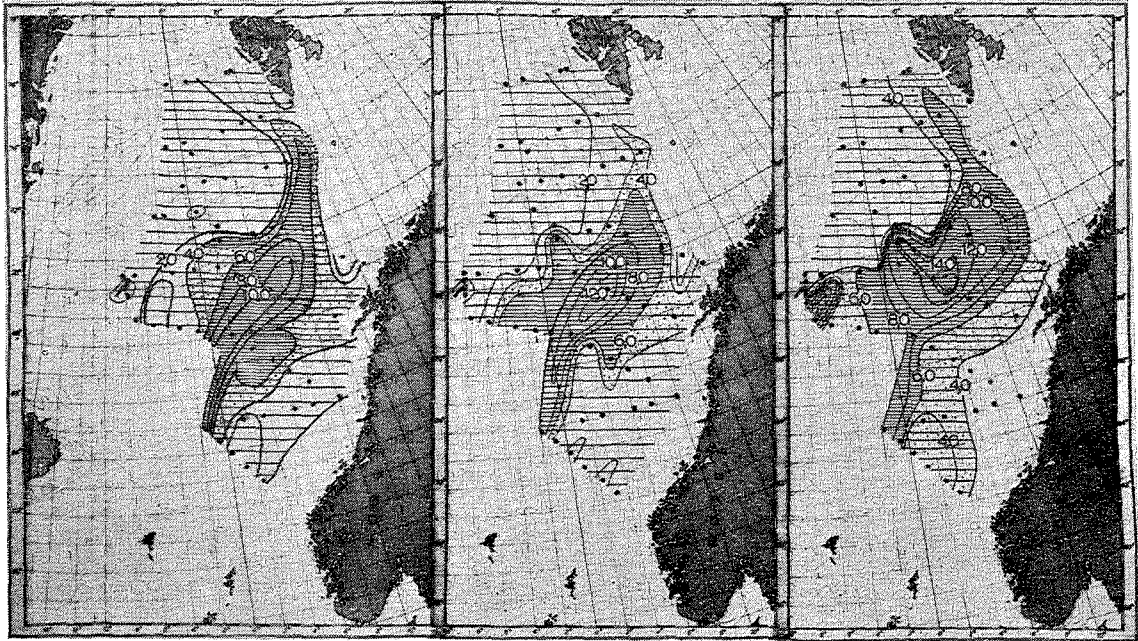


Figure 1. The production capacity (10^{-7} mg.C/L/Lux hr.) for three different depths. 24/V-25/VI, 1954.

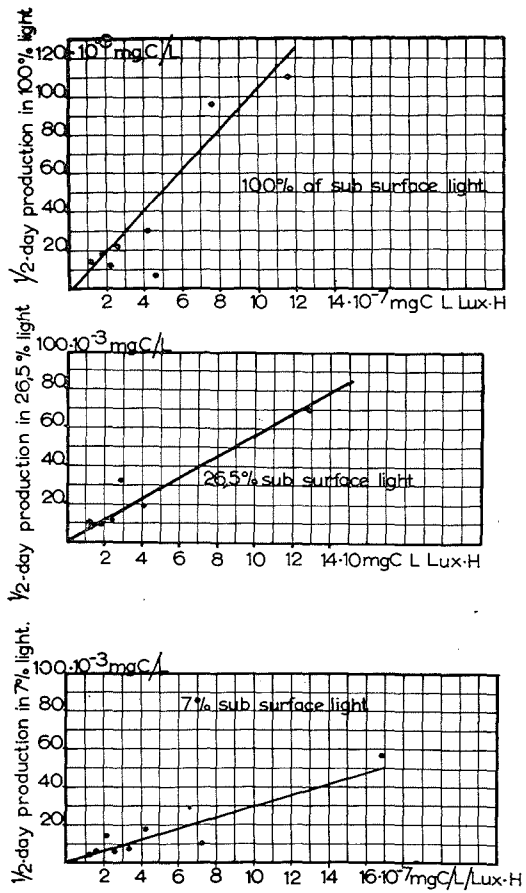


Figure 2. The correlation between 1/2 day production, and the production capacity for three different light-dephts.

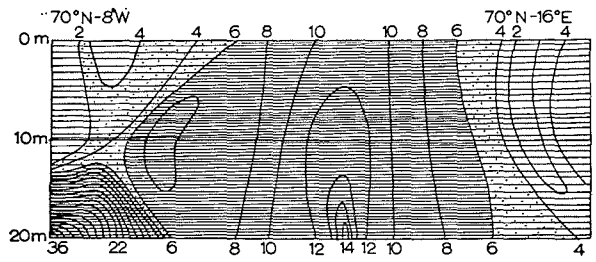


Figure 3. Vertical distribution of the production capacity along the 70th circle of latitude. All values are 10^{-7} mg.C/L/Lux hr.

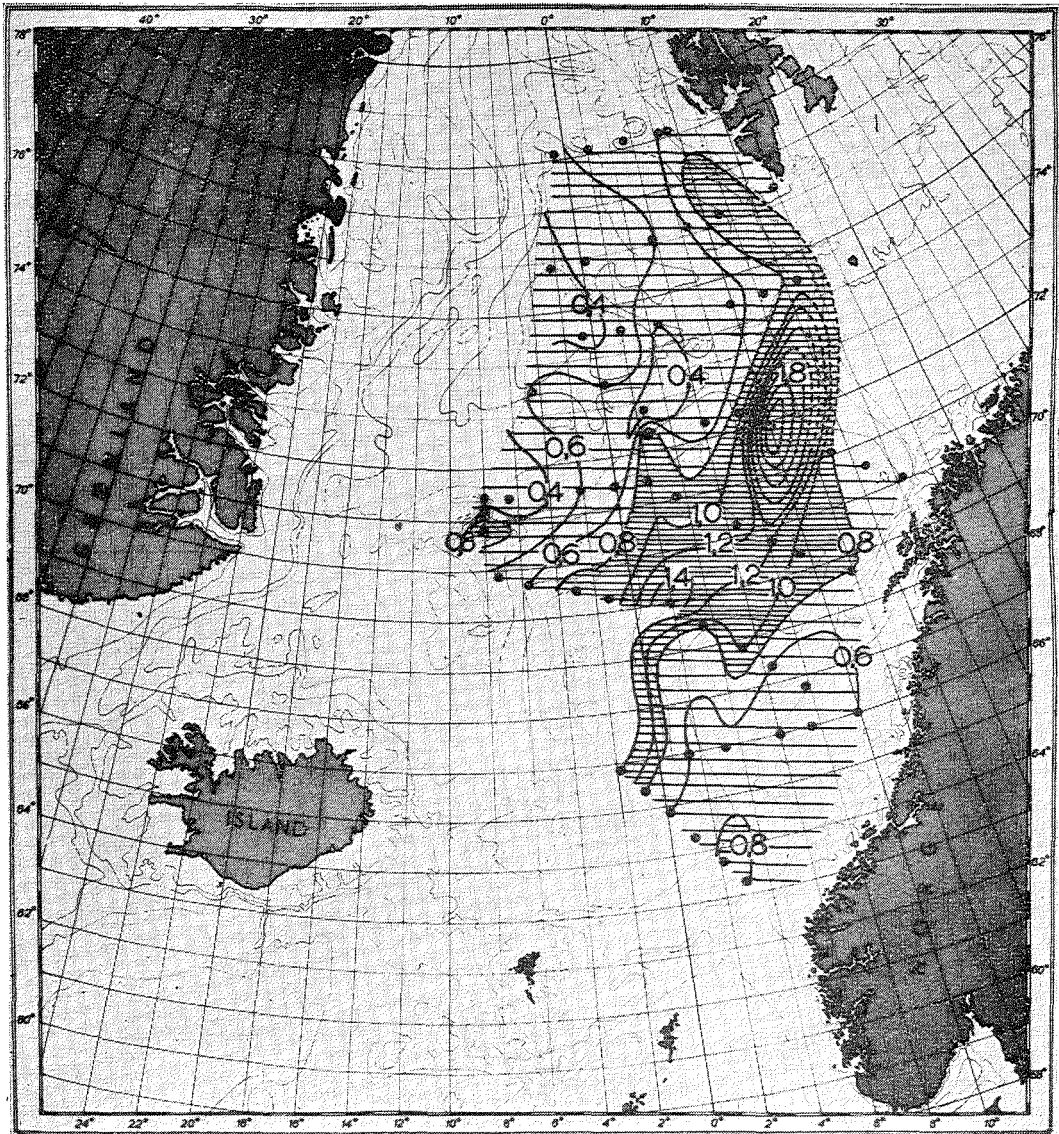


Figure 4. The production in g.C/day below 1 m². of the surface.

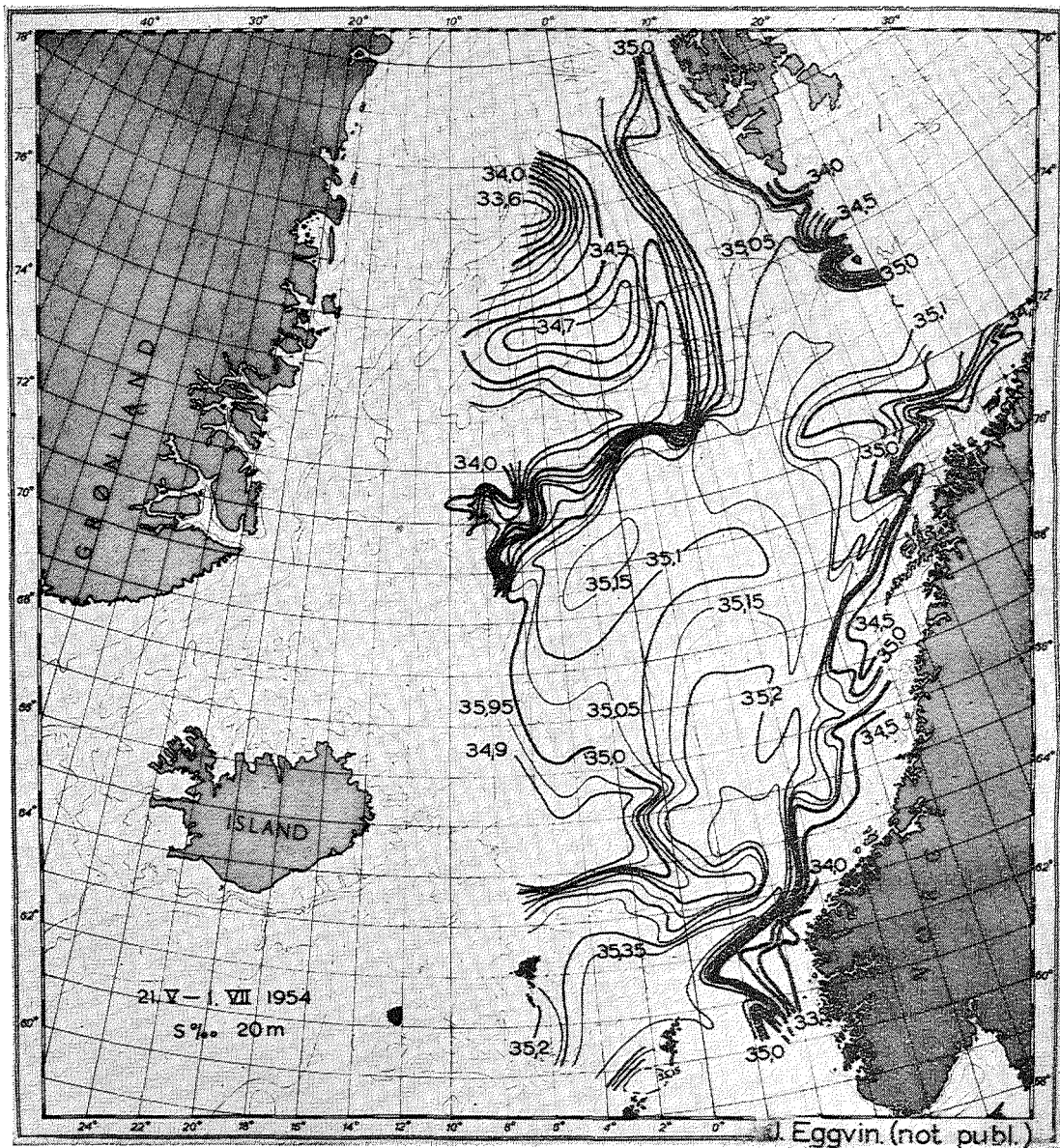


Figure 5. The salinity in 20 m. depth 21.V-1.VII, 1954. (With the courtesy of J. EGGVIN.)

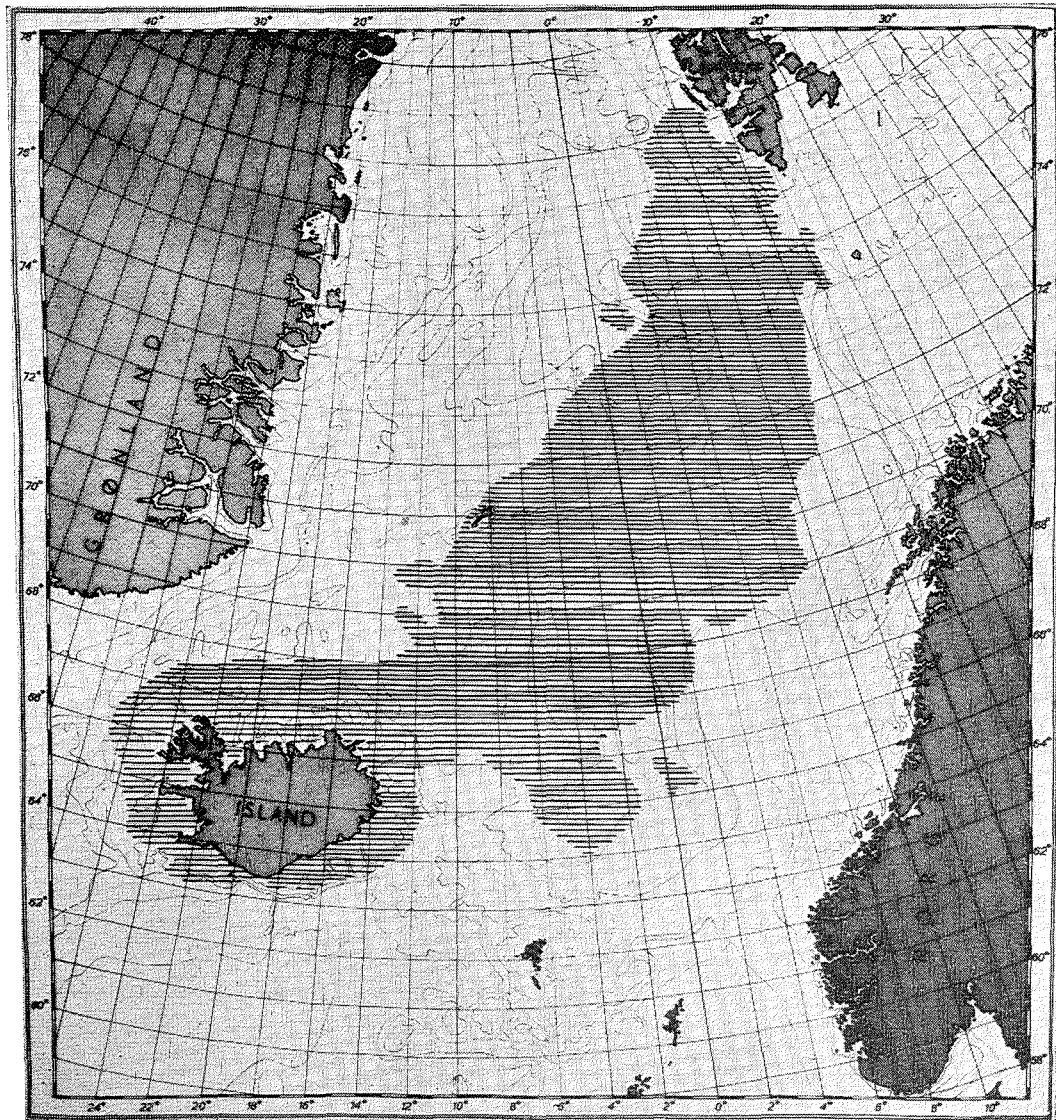


Figure 6. The feeding area of the atlantic-scandinavian herring. (Repr. after. J. J. MARRY, 1956.)

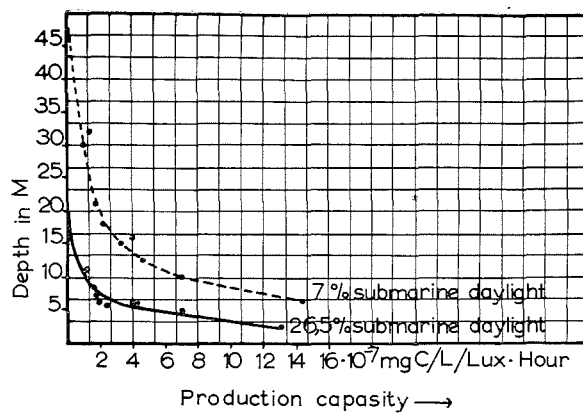


Figure 7. The correlation between depths for 26.5% and 7% of submarine daylight and the mean value of production capacity for the water column above.