# Nitrate in the Sea. II.

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With 3 Figures in the Text.

In any attempt to analyse the factors controlling the fertility of extensive areas of the sea, the first and most definite fact which presents itself is the entire dependence of all marine animals upon the phytoplankton. The animals dissipate energy in the course of their metabolic processes during their whole lifetime, and utilise the energy of the carbon compounds in the food they consume to balance this loss, while the plants absorb radiant energy during photosynthesis and store it in the carbon compounds they build. If we define fertility as the quantity of organically combined carbon present in the living organisms inhabiting a particular and extensive area of the sea, it is the plants alone which can add *de novo* to this quantity. In consequence the fertility, in the above sense, will be limited by those factors which limit plant growth—by the intensity and duration of a sufficient supply of radiant energy from light and by the lack of any one nutrient salt. Of the latter there is an ample supply except, at times, of phosphate or of nitrate.

Subsequent to the publication in March, 1926, of an account of a rapid method for the approximate estimation of nitrate in sea-water and the data obtained over a period of nine months, observations in the English Channel have been continued at frequent intervals.

These have confirmed the picture which it was then possible to draw concerning the almost complete utilisation of this nutrient salt in the upper water layers during the outburst of diatom growth in spring.

## Seasonal Variation in the English Channel.

The nitrate content of the water in the English Channel between February, 1926, and May, 1927, is shown in Table I (which is a continuation of Table VIII, *Journ. Mar. Biol. Assoc.*, **14**, p. 81).

## TABLE I.

Nitrate Content in milligrams of Nitrate-$N_2$ per cubic metre at various depths (in metres, m.) of water in the English Channel on the line Plymouth-Ushant.

| | In Plymouth Sound Station $L_1$ | Off west end of Plymouth Breakwater Station $L_2$ | 9 miles S 21° W (true) from Plymouth Hoe Station $L_1$ | 22 miles S 21° W (true) from Plymouth Hoe Station $E_1$ | 59½ miles S 21° W (true) from Plymouth Hoe Station $E_2$ | 115½ miles S 21° W (true) from Plymouth Hoe Station $E_3$ |
|---|---|---|---|---|---|---|
| Feb. 3rd, 1926 | — | 0 m. **120** | 0 m. **73** | 5 m. **83** | — | — |
| | — | — | — | 25 m. **64** | — | — |
| | — | — | 40 m. **64** | 50 m. **64** | — | — |
| | — | — | — | 70 m. **64** | — | — |
| Mar. 11th & 12th | 0 m. <**190** | — | 0 m. **73** | 5 m. **68** | 5 m. **53** | 5 m. **75** |
| | — | — | — | 25 m. **68** | 25 m. **56** | — |
| | — | — | — | 50 m. **68** | — | 50 m. **75** |
| | — | — | — | 70 m. **78** | — | — |
| | — | — | — | — | 85 m. **52** | — |
| | — | — | — | — | — | 105 m. **75** |
| April 10th | 0 m. **135** | — | 0 m. **110** | 0 m. **75** | — | — |
| | — | — | — | 5 m. **50** | — | — |
| | — | — | 40 m. **79** | 25 m. **76** | — | — |
| | — | — | — | 50 m. **76** | — | — |
| | — | — | — | 70 m. **76** | — | — |
| May 17th & 18th | 0 m. **11** | — | 0 m. **5** | 0 m. **4** | 0 m. **30** | 0 m. **62** |
| | — | — | — | 5 m. **6** | 5 m. **32** | 5 m. **54** |
| | — | — | — | 25 m. **6** | — | — |
| | — | — | 40 m. **10** | 50 m. **6** | 50 m. **32** | — |
| | — | — | — | 70 m. **6** | — | — |
| | — | — | — | — | 90 m. **30** | — |
| | — | — | — | — | — | 105 m. **54** |
| July 8th & 9th | 0 m. **24** | — | 0 m. **5** | 0 m. <**5** | — | — |
| | — | — | — | 5 m. <**5** | 5 m. <**5** | 5 m. **6** |
| | — | — | — | 20 m. **9** | 25 m. **24** | 108 m. **35** |
| | — | — | — | 40 m. **10** | 50 m. **21** | 50 m. **35** |
| | — | — | — | 70 m. **11** | — | — |
| | — | — | — | — | 90 m. **36** | 108 m. **35** |
| Aug. 16th | 0 m. **20** | — | 0 m. **8** | 0 m. **10** | — | — |
| | — | — | — | 5 m. **12** | — | — |
| | — | — | — | 15 m. **12** | — | — |
| | — | — | — | 25 m. **14** | — | — |
| | — | — | — | 50 m. **20** | — | — |
| | — | — | — | 70 m. **20** | — | — |
| Sept. 22nd | 0 m. **17** | 0 m. **15** | 0 m. **7** | 0 m. **5** | — | — |
| | — | — | — | 5 m. **5** | — | — |
| | — | — | — | 25 m. **12** | — | — |
| | — | — | 40 m. **14** | 50 m. **13** | — | — |
| | — | — | — | 70 m. **14** | — | — |
| Nov. 24th | 0 m. <**300** | — | 0 m. **92** | 0 m. **100** | — | — |
| | — | — | — | 5 m. **100** | 5 m. **180** | 5 m. **57** |
| | — | — | — | 25 m. **92** | 25 m. **180** | — |
| | — | — | 40 m. **92** | 50 m. **83** | 50 m. **180** | 50 m. **65** |
| | — | — | — | 70 m. (**75**) | — | — |
| | — | — | — | — | 90 m. **195** | — |
| | — | — | — | — | — | 105 m. **75** |

TABLE I—*continued*.

| | In Plymouth Sound Station $L_1$ | Off west end of Plymouth Breakwater Station $L_2$ | 9 miles S 21° W (true) from Plymouth Hoe Station $L_4$ | 22 miles S 21° W (true) from Plymouth Hoe Station $E_1$ | 59½ miles S 21° W (true) from Plymouth Hoe Station $E_2$ | 115½ miles S 21° W (true) from Plymouth Hoe Station $E_3$ |
|---|---|---|---|---|---|---|
| Dec. 13th | 0 m. <**250** | — | 0 m. **95** | — | — | — |
| | — | — | — | 5 m. **65** | — | — |
| | — | — | 40 m. (**73**) | — | — | — |
| | — | — | — | 70 m. **62** | — | — |
| Dec. 31st | 0 m. **190** | — | — | 5 m. **68** | — | — |
| | — | — | — | 70 m. **61** | — | — |
| Feb. 15th & 16th, 1927 | 0 m. **100** | — | 0 m. **86** | 5 m. **55** | 0 m. **66** | 0 m. **27** |
| | — | — | 40 m. **71** | 50 m. **38** | — | 50m. **38** |
| | — | — | — | 70 m. **83** | — | — |
| | — | — | — | — | 92 m. **81** | — |
| | — | — | — | — | — | 109 m. **64** |
| April 20th | — | — | — | 0 m. **12** | — | — |
| | — | — | — | 5 m. **15** | — | — |
| | — | — | — | 25 m. **44** | — | — |
| | — | — | — | 50 m. **75** | — | — |
| | — | — | — | 70 m. **75** | — | — |
| May 23rd | — | — | — | 5 m. **7** | — | — |
| | — | — | — | 25 m. **7** | — | — |
| | — | — | — | 50 m. **7** | — | — |
| | — | — | — | 70 m. **7** | — | — |

During the spring of 1926 utilisation of nearly all the nitrate available for the growth of diatoms and other phytoplankton occurred between April 10th and May 17th. On April 22nd, 1925, considerable utilisation of the nitrate had taken place above 25 metres, and on April 20th, 1927, a partial utilisation had taken place in the upper strata. About the end of September—rather earlier in 1925 than in 1926—the rate at which nitrate is being utilised is greatly exceeded by the rate at which it is regenerated from the summer crop of plankton organisms which mostly die out towards the beginning of September.

Fig. 1 shows the seasonal variation in the upper 5-metre stratum of water 22 miles south-west of Plymouth. For the values relating to the phosphate in the water I am indebted to Dr. W. R. G. Atkins. The curves indicate that, during the summer months, plant life is at times limited by lack of nitrate and at times by lack of phosphate: when limited by phosphate (July, 1925, August, 1926) the nitrate tends to increase and vice versa (June and August, 1925, June and July, 1926).

Fig. 2 shows the seasonal variation in the bottom stratum of water. Here the utilisation by plant life is not so rapid as near the surface, owing to lack of light. From the data presented in the previous communication it was concluded that the final stage of the regeneration of nitrate takes place in the deeper water, and does not proceed in the surface layer during the summer. The curves in Fig. 2 indicate that an increase in phosphate tends to occur during the summer when plant life is limited by lack of nitrate (August, 1925, May–June, 1926).

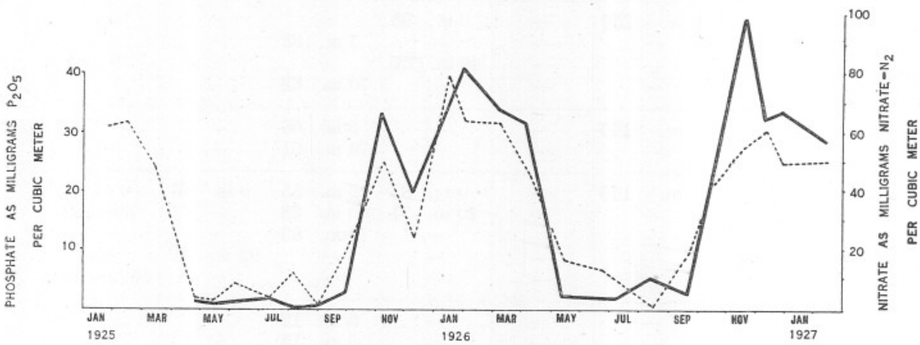


FIG. 1.—The seasonal variation of nitrate and of phosphate (Atkins) in the upper 5-metre stratum of water as shown by observations made at position E1, 22 miles south-west of Plymouth. The nitrate is represented by a thick line and the phosphate by a dotted line.

Inflowing oceanic water has an effect upon the nitrate and phosphate content of the water at position E3, lying north of Ushant. Between March 12th and May 18th, 1926, the water (*circa* 35·1 °/₀₀ S.) was replaced by more saline water (*circa* 35·3 °/₀₀ S.) containing more phosphate and

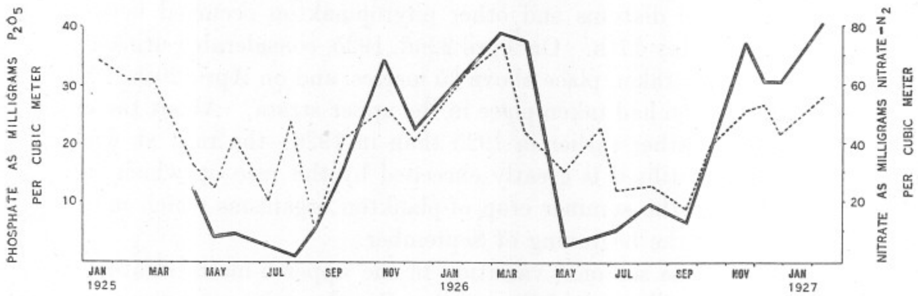


FIG. 2.—Seasonal variation in the nitrate and phosphate (Atkins) in the bottom water at *circa* 70 metres depth at position E1, 22 miles south-west of Plymouth. The nitrate is represented by a thick line and the phosphate by a dotted line.

almost as much nitrate, in spite of the fact that during this period a great outburst of diatom growth occurs. Meanwhile the nitrate and phosphate in the water at E1, 22 miles south-west of Plymouth, had both been largely used up by the phytoplankton. The conditions on the two dates are shown in the sectional diagrams in Fig. 3.

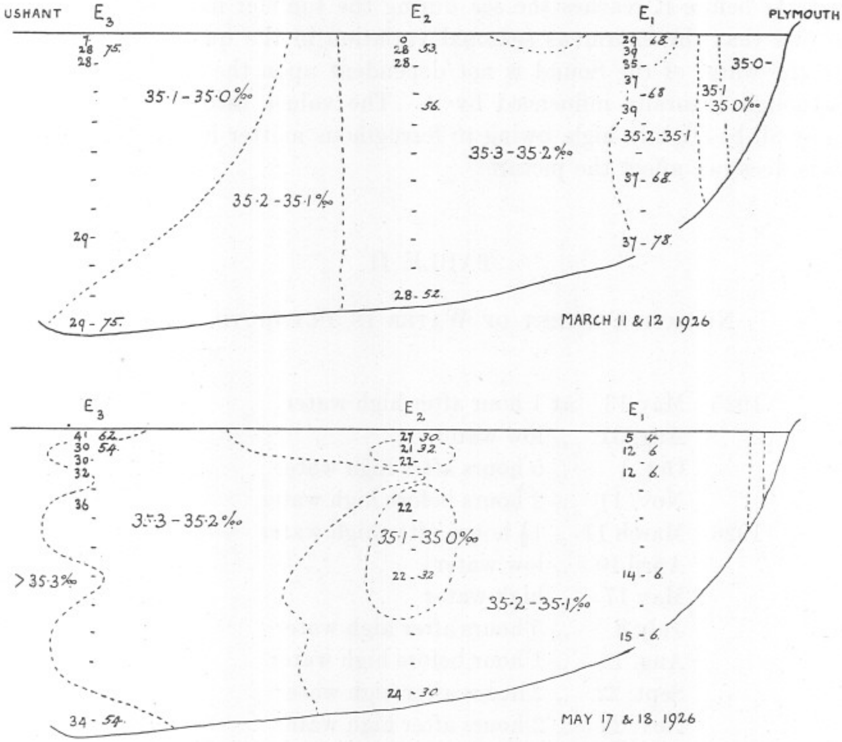


FIG. 3.—Sections across the English Channel between Plymouth and Ushant showing the distribution of salinity (°/$_{oo}$), of nitrate (slanting figures show milligrams of nitrate–$N_2$ per cubic metre), and of phosphate (upright figures show milligrams of $P_2O_5$ per cubic metre) as observed in March and May, 1926.

## Effect of Land Drainage upon the Fertility of Coastal Areas.

The nitrate content of the water in Plymouth Sound into which rivers and the sewage of a large town drains, is of particular interest, because it shows that plant growth in the rivers and estuary uses up most of the nitrate before it reaches the sea during the summer months. Table II shows that the enormous seasonal variation in the quantity of nitrate in the water of the Sound is not dependent upon the state of the tide although naturally influenced by it. The values throughout the year may all be slightly high, owing to ferruginous matter in suspension, but this does not affect the picture.

### TABLE II.

Nitrate Content of Water in Plymouth Sound.

| | | | Milligrams nitrate-$N_2$ per cubic metre. |
|---|---|---|---|
| 1925. | May 13 | at 1 hour after high water | (14) |
| | Aug. 31 | ,, low water | 9 |
| | Oct. 1 | ,, 5 hours after high water | 112 |
| | Nov. 11 | ,, 2 hours before high water | 176 |
| 1926. | March 11 | ,, $1\frac{1}{2}$ hours after high water | >190 |
| | April 10 | ,, low water | 135 |
| | May 17 | ,, high water | 11 |
| | July 8 | ,, 5 hours after high water | 24 |
| | Aug. 16 | ,, 1 hour before high water | 20 |
| | Sept. 22 | ,, 2 hours after high water | 17 |
| | Nov. 24 | ,, 2 hours after high water | >300 |
| | Dec. 13 | ,, 3 hours before high water | >250 |
| | Dec. 31 | ,, 5 hours before high water | 190 |
| 1927. | Feb. 15 | ,, 5 hours after high water | 100 |

An inspection of Table I, the table of which the latter is a continuation (*op. cit.*, **14**, p. 81), and of the data for phosphates in the inshore waters between September, 1923, and December, 1924, given in Table III, indicates that the effect of land drainage is not marked beyond a few miles offshore even during the winter months. It is masked by the large quantity of nutrient salts regenerated from dead organisms, which almost totally eclipses the quantity draining from the land into the broad waters of the English Channel.

## TABLE III.

Milligrams of Phosphate as $P_2O_5$ per cubic metre in the surface water at varying distances offshore (Atkins).

| In Plymouth Sound. | 2 miles S 21°W (true) from Plymouth Breakwater. | Off Eddystone Lighthouse. | 19 miles S 21°W (true) from Plymouth Breakwater. | 56½ miles S 21°W (true) from Plymouth Breakwater. | Date. |
|---|---|---|---|---|---|
| 23 | 18 | 9 | 0 | — | Sept. 13, 1923. |
| 12 | 17 | 15 | 22 | — | Oct. 15, 1923. |
| 23 | 32 | 36 | 38 | — | Jan. 2, 1924. |
| 35 | 30 | 35 | 32 | 31 | Feb. 15, 1924. |
| 3 | 2 | 3 | 2½ | — | June 17, 1924. |
| 3 | 2 | 0 | 2½ | 4* | July 9, 1924. |
| 13½ | 8 | 1½ | 1½ | — | Aug. 7, 1924. |
| 28 | 28 | 15 | 12 | — | Sept. 3, 1924. |
| 19 | 21 | 33 | 14 | 12 | Nov. 12, 1924. |
| 35 | 35 | 33 | 32 | — | Dec. 9, 1924. |

* At 5 metres.

### Nitrate in the Water of the Atlantic.

Samples collected from the surface in the tropical waters of the Atlantic in April were found to be poor in nitrate, as previously found in samples collected in September on the same route.

| Date collected. | Temperature. | Lat. | Long. | Nitrate-$N_2$ in milligrams per cubic metre. |
|---|---|---|---|---|
| April 16, 1926 | 27·4°C. | 0° 03′N. | 47° 00′W. | 3 |
| ,, 16 | 27·2°C. | 1° 27′N. | 45° 32′W. | 2 |
| ,, 17 | 26·1°C. | 6° 20′N. | 41° 18′W. | 3 |
| ,, 19 | 25·0°C. | 11° 08′N. | 37° 13′W. | 7 |
| ,, 20 | 23·6°C. | 17° 28′N. | 31° 36′W. | 3 |
| ,, 23 | 20·3°C. | 26° 52′N. | 22° 44′W. | 9 |

Samples from the west coast of Ireland, collected in August and analysed two months later, yielded the following results :—

Collected 17/8/26, at 50°34′N., 11°17′W.

| Depth. | Temperature. | Nitrate-$N_2$ in milligrams per cubic metre. |
|---|---|---|
| Surface | 17·1°C. | 9 |
| 100 metres | 11·13°C. | 170 |
| 770 metres | 9·18°C. | 180 |

Collected 12/8/26, at 49°20′N., 9°00′W.

| Depth. | Temperature. | Nitrate-$N_2$ in milligrams per cubic metre. |
|---|---|---|
| Surface | 18·25°C. | 84 |
| 146 metres | 10·26°C. | 110 |

## The Method of Estimation.

The preparation of the reagent has proved to be somewhat capricious. A batch prepared in the manner described (*ibid.*, **14**, pp. 72–76) has sometimes been tinted pink owing to impurities in the reagents used, has sometimes developed a pink tint during storage, and an apparently satisfactory batch has sometimes given a yellowish pink tint on adding to sea-water poor in nitrate and proved unsuitable for quantitative estimation. The most generally satisfactory batches were made as follows: 0·5 gms. strychnine sulphate dissolved in 30 c.c. boiling distilled water were added to 4 square inches of amalgamated zinc foil (free from iron) in a shallow evaporating basin on an electrically heated water bath. 30 c.c. concentrated hydrochloric acid were run in, about 5 c.c. at a time, over a period of 6 hours. A little distilled water was also added from time to time, evaporation never proceeding quite to dryness. After removal of the remains of the zinc, and cooling, 200 c.c. of concentrated sulphuric acid was slowly poured in, stirred, and after the zinc sulphate had settled, the clear reagent poured off.

Although, from the numerous concordant results, it is apparent that the method gives good approximate values in dealing with water from the open sea and shows clearly the very considerable variations in nitrate content which occur from place to place and during the passage of the seasons, it appears that the values obtained in certain cases are low (in the bottom water at E1, in November, 1925, and probably again in 1926). For the examination of nitrate in inshore waters containing suspended particles of iron oxide the method is obviously unsuitable.

## SUMMARY.

1. Observations made subsequent to December, 1925, confirm the conclusion that the nitrates in the water of the English Channel, twenty-two miles south-west of Plymouth, are almost entirely utilised by phyto-plankton in the summer, and are reformed in early autumn at a greater rate than they are utilised.

2. Movements of the water masses are shown to affect the quantity of nutrient salts available for phytoplankton in the waters immediately north of Ushant.

3. The effect of land drainage on the quantity of nitrate in the sea is not apparent beyond a few miles to seaward from Plymouth Sound, being masked by the nitrate which is regenerated from dead marine organisms.

4. The nitrate in the river and estuarine waters entering Plymouth Sound is nearly all utilised by plants in the rivers and estuaries themselves before reaching the open sea during summer.