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Certain aspects of phytoplankton growth which are so generally recognized as to be practically axiomatic are presented graphically in Figure 36. They are explained as follows:

The plankton crop \((A, A')\) represents the momentary state of the cumulative balance between the results of phytoplankton production \((F)\) and phytoplankton removal, or reduction \((I)\). Phytoplankton production, i.e., the synthesis of new organisms, is dependent on the accumulation of new building stuffs by the plankton association, namely photosynthesis \((G, G')\) and the utilization of nutrients \((H)\). Consumption of nutrients is favored by a high concentration of nutrients in the water \((E_1)\); such utilization automatically reduces the concentration \((H_2)\). The nutrient concentration is replenished by regeneration and vertical transport \((L\ and\ M)\); regeneration is dependent on phytoplankton death \((I_3)\). The latter may be a process of natural death due to depletion of energy, as when there is an unfavorable balance between photosynthesis and respiration. This is generally a result of the plant's sinking below the phototrophic zone \((K_1)\). Another important factor in phytoplankton reduction is zooplankton grazing \((J)\).

Temperature probably has a direct effect on all metabolic processes. These include the synthesis of new plankton material \((C_1)\), photosynthesis \((C_2, C_3)\), respiration \((C_4)\), zooplankton activity \((C_6)\), and bacterial metabolism \((C_7)\). Temperature also has a physical effect on the rate of vertical transport \((C_8)\) through its influence on density, and on the sinking rate \((C_9)\) through viscosity and perhaps density, although the latter is less likely to be of primary importance because the sinking diatoms, as well as the sea water, are affected by temperature, so that the change in relative densities is dependent only on the slight differences that exist in their coefficients of thermal expansion.

Light generally has a direct effect on photosynthesis \((D_2, D_4)\), although strong radiation may be inhibitory at the surface \((D_3)\). It also influences zooplankton activity \((D_6)\) and is of course related with temperature \((D_4)\).
In tropical waters and in temperate regions during the summer the effective regeneration, that is, the rate of vertical transport, is influenced by depth ($B_3$). Moreover, the total crop of phytoplankton is affected by depth when the latter is less than the potential thickness of the phototrophic zone or when bottom influences reduce the transparency ($B_1$). On the other hand, depth may be an important factor in reducing the surface concentration of plant material when vertical turbulence carries it to lower levels ($B_2$).

The size of the plankton crop influences photosynthesis ($A_1$, $A_1'$), since the quantity of the catalyst is an essential feature of the reaction; however, this effect may be partially invalidated by the fact that the size of the crop is inversely related with light penetration ($A_2'$).
QUALITATIVE ANALYSIS

The diagram as presented is admittedly far from complete. It is adequate, however, for an introductory analysis of the relationship of the plankton with its environment.

On the basis of the diagram equations may be drawn up by which the value of one term may be expressed by the value of other terms. For example, \( A = F_1 - I_1 \), or expanding into the indirect relations, \( A = G_1 + H_1 - I_1 - J_1 - K_1 \). Going still further afield, the plankton may be at least partly expressed in the terms of the simple environmental factors. The relation between temperature and plankton, for example, may be stated as \( A = C_1 + C_2 + C_7 - C_4 - C_5 - C_6 - C_8 \). In this case the relationship becomes highly indirect, since temperature is acting through several physiological processes as well as upon two physical factors which in turn influence some of these processes. Thus it is evident that the farther we progress into indirect relations, the more complex and vague their expression becomes. Unfortunately, however, in the application of such systems to practical problems the expression cannot be made very simple, for the accurate measurement of physiological processes, such as \( F \) to \( M \), is difficult if not impossible, and the simple biological and environmental variables, such as \( A \) to \( E \), are generally all that we know of a plankton association. Moreover the degree of relationship of the various factors is such that they seldom have a single, simple effect on the plankton. Thus the qualitative analysis of such diagrams is both difficult and vague.

As an example of such analysis we may begin with nutrients. There is an obvious positive relation between nutrients and phytoplankton \((E_1 H_1 F_1)\), but since the reaction can go in the opposite direction \((F_1 F_3 H_2)\) (the direction of the arrows is of no significance in correlations, which of course test the degree of relationship irrespective of causal principles), it is not possible to predict whether the net correlation between the two variables will be positive or negative. It depends on the relative importance of the two processes. The relation of this part of the diagram to other parts, however, may be tested by introducing a third variable. For example depth has a positive relation with the nutrient-phytoplankton reaction chain through \( B_1 \), and a negative relation with nutrients through \( B_3 M_1 \). Thus, while we do not know what the correlation between depth and nutrients is, we can predict that the elimination of \( B_1 \) would shift the correlation toward the negative side. This can be put to a practical,
<table>
<thead>
<tr>
<th>Total Plant Pigments</th>
<th>Group I: Temperature, Light, and Depth</th>
<th>Temperature</th>
<th>+ Factors</th>
<th>C&lt;sub&gt;1&lt;/sub&gt;, C&lt;sub&gt;3&lt;/sub&gt;, C&lt;sub&gt;7&lt;/sub&gt;</th>
<th>D&lt;sub&gt;4&lt;/sub&gt;</th>
<th>Depth</th>
<th>Nutrients</th>
<th>Plant Pigments</th>
<th>Oxygen Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;, C&lt;sub&gt;8&lt;/sub&gt;</td>
<td>D&lt;sub&gt;4&lt;/sub&gt;, A&lt;sub&gt;2&lt;/sub&gt;' (D&lt;sub&gt;4&lt;/sub&gt;, G&lt;sub&gt;1&lt;/sub&gt;' F&lt;sub&gt;3&lt;/sub&gt;, H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>B&lt;sub&gt;3&lt;/sub&gt;</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Group II: Temperature, Light, Depth, and Nutrients</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;1&lt;/sub&gt;, C&lt;sub&gt;3&lt;/sub&gt;</td>
<td>D&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>- Factors</td>
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<td>D&lt;sub&gt;5&lt;/sub&gt;, A&lt;sub&gt;2&lt;/sub&gt;'</td>
<td>(F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>B&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Plant Pigments</td>
<td>Group I: Temperature, Light, and Depth</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;1&lt;/sub&gt;, C&lt;sub&gt;2&lt;/sub&gt;, C&lt;sub&gt;7&lt;/sub&gt;</td>
<td>D&lt;sub&gt;4&lt;/sub&gt;, (D&lt;sub&gt;3&lt;/sub&gt; G&lt;sub&gt;1&lt;/sub&gt; F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;, B&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;, C&lt;sub&gt;8&lt;/sub&gt;</td>
<td>D&lt;sub&gt;4&lt;/sub&gt;, D&lt;sub&gt;3&lt;/sub&gt; (D&lt;sub&gt;2&lt;/sub&gt; G&lt;sub&gt;1&lt;/sub&gt; F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;, B&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group II: Temperature, Light, Depth, and Nutrients</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;1&lt;/sub&gt;, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
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<td></td>
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<td></td>
<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;</td>
<td>D&lt;sub&gt;5&lt;/sub&gt;, D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;, B&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group III: Temperature, Light, Depth, Nutrients, and Oxygen Production</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>D&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
</tr>
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<td></td>
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<td></td>
<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;</td>
<td>D&lt;sub&gt;6&lt;/sub&gt;</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen Production</td>
<td>Group I: Temperature, Light, and Depth</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;, C&lt;sub&gt;7&lt;/sub&gt;</td>
<td>D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>- Factors</td>
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<td>D&lt;sub&gt;3&lt;/sub&gt;, D&lt;sub&gt;5&lt;/sub&gt;</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;, B&lt;sub&gt;3&lt;/sub&gt;</td>
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<td></td>
<td></td>
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<td></td>
<td>Group II: Temperature, Light, Depth, and Nutrients</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;</td>
<td>D&lt;sub&gt;3&lt;/sub&gt;, D&lt;sub&gt;5&lt;/sub&gt;</td>
<td>B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Group III: Temperature, Light, Depth, Nutrients, and Plant Pigments</td>
<td>Temperature</td>
<td>+ Factors</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depth</td>
<td>Nutrients</td>
<td>Plant Pigments</td>
<td>Oxygen Production</td>
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<td>- Factors</td>
<td>C&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;5&lt;/sub&gt;, C&lt;sub&gt;6&lt;/sub&gt;</td>
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<td>B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(F&lt;sub&gt;3&lt;/sub&gt; H&lt;sub&gt;2&lt;/sub&gt;)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE I**  
**Qualitative Classification of Correlations**
quantitative test because $B_1$ is statistically eliminated* by deriving the partial correlation of depth and nutrients in respect to phytoplankton.

Further predictions are obtained in Table I, which utilizes this method on a larger and more complex scale. The effects associated with the physical quantities depth, temperature, and light are assigned in the fashion indicated by the diagram to the biological variables total and surface phytoplankton and surface photosynthesis. Nutrients and other factors are then introduced which change the effect of the primary variables in a way that can be predicted according to the diagram.

There are three orders of predictions that can be made from the table. The first order consists of those factors which are simple and direct and to which a positive or negative sign may be assigned definitely. These are as follows: temperature under Group III of the oxygen production correlation; light in Group III of the surface plant pigments; depth in Group II, total plant pigments, and in all groups under surface plant pigments and oxygen production; oxygen production in Group III of surface plant pigments; and plant pigments in Group III under oxygen production. The second order of predictions is concerned with changes in successive groups which, by the elimination of certain factors, cause the correlations to move either in a positive or negative direction. Thus, in the temperature column, between Groups II and III of surface plant pigments, the positive factor $C_2$ is eliminated, which should cause the correlation to move in a negative direction, and in the oxygen production section the temperature correlation should move in a positive direction between Groups II and III with the elimination of the negative factors $C_4$ $C_5$ $C_6$. In the light column positive changes can be predicted between Groups I and II of the total plant pigments and between Groups II and III of oxygen production. In the depth column the elimination of $B_3$ causes a positive change between Groups II and III of all three sets of correlations.

The third order of predictions is concerned with the simultaneous removal of positive and negative factors. This is not a strictly valid method, since there is nothing in the diagram itself that permits

* Statistical elimination by partial correlations is, in the mathematical sphere, comparable to the experimental procedure of holding a particular factor constant. In the case under consideration, the partial correlation of depth and nutrients in respect to phytoplankton is equivalent to a simple correlation between depth and nutrients in a series of experiments in which the quantity of plankton is held at a mean level. In either case the phytoplankton may be an important factor, but its variations do not exert any influence on the depth-nutrient relation.
predictions to be made on these grounds. It is considered permissible, however, when, on other logical grounds, one factor is obviously much more important than the other. The case in point is the simultaneous removal of $C_7$ and $C_8$ between Groups I and II of all three sets of correlations. $C_8$ obviously takes precedence over $C_7$ because the regeneration of nutrients can have no effect on the surface concentration unless vertical transport occurs. It is therefore predicted that the removal of $C_7$ and $C_8$ will cause the correlations to move in a positive direction.

**QUANTITATIVE ANALYSIS**

The practical application of the theory built upon the fundamental assumptions of the diagram is derived by means of regional averages obtained from the four previous papers of this series. They are split up into six groups of data: Stations 1 and 2 at the Dry Tortugas (Riley, 1938) are treated separately, also the southern and northern

**TABLE II**

**Regional Averages**

<table>
<thead>
<tr>
<th></th>
<th>Surface Oxygen Production</th>
<th>Surface Plant Pigments</th>
<th>Total Plant Pigments</th>
<th>Total Depth</th>
<th>Phosphate mg. Atoms per m$^3$ at the Surface</th>
<th>Temperature</th>
<th>Light G. Cal./cm$^2$/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tortugas, Station 1</td>
<td>0.30</td>
<td>1520</td>
<td>31</td>
<td>19</td>
<td>0.057</td>
<td>28.42</td>
<td>450</td>
</tr>
<tr>
<td>Tortugas, Station 2</td>
<td>0.13</td>
<td>680</td>
<td>2</td>
<td>3</td>
<td>0.042</td>
<td>28.30</td>
<td>450</td>
</tr>
<tr>
<td>Southern Stations, N. Atlantic</td>
<td>0.09</td>
<td>1300</td>
<td>345</td>
<td>2300</td>
<td>0.062</td>
<td>25.15</td>
<td>460</td>
</tr>
<tr>
<td>Northern Stations, N. Atlantic</td>
<td>0.18</td>
<td>4100</td>
<td>143</td>
<td>1000</td>
<td>0.163</td>
<td>13.69</td>
<td>460</td>
</tr>
<tr>
<td>Long Island Sound</td>
<td>0.47</td>
<td>54800</td>
<td>1096</td>
<td>20</td>
<td>0.918</td>
<td>11.29</td>
<td>300</td>
</tr>
<tr>
<td>Georges Bank</td>
<td>0.34</td>
<td>12500</td>
<td>807</td>
<td>185</td>
<td>0.728</td>
<td>8.48</td>
<td>380</td>
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<tr>
<td>Mean</td>
<td>0.25</td>
<td>12498</td>
<td>404</td>
<td>588</td>
<td>0.323</td>
<td>19.22</td>
<td>417</td>
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<tr>
<td>Standard Deviation</td>
<td>0.13</td>
<td>19346</td>
<td>411</td>
<td>842</td>
<td>0.356</td>
<td>8.28</td>
<td>59</td>
</tr>
</tbody>
</table>

**TABLE III**

**Correlations of Variables Listed in Table I**

<table>
<thead>
<tr>
<th></th>
<th>Surface Plant Pigments</th>
<th>Depth</th>
<th>Phosphate</th>
<th>Temperature</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Oxygen Production</td>
<td>0.8226</td>
<td>-.6353</td>
<td>.8558</td>
<td>-.5972</td>
<td>-.8849</td>
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<tr>
<td>Surface Plant Pigments</td>
<td>-.3432</td>
<td>.8638</td>
<td>.9611</td>
<td>-.7742</td>
<td>-.9550</td>
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<td>Total Plant Pigments</td>
<td>-.1525</td>
<td>-.3881</td>
<td>.1473</td>
<td>-.8326</td>
<td>-.9564</td>
</tr>
<tr>
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<td>Phosphate</td>
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<td>Temperature</td>
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</tbody>
</table>
stations of the western North Atlantic (1939); the list is completed by the means of the seasonal cycles in Long Island Sound (1941) and on Georges Bank (1941a). These values are shown in Table II and the simple correlations in Table III.

First of all, it is necessary to examine just what these correlations mean. Mathematically, they are simply an expression of the degree of relationship between two sets of numbers. Biologically they represent the sum of the relations between any two variables as indicated by every possible set of arrows connecting them on the diagram. Thus, for example, the correlation between total plant pigments and temperature represents the fairly direct relations emanating from \( C_1 \) to \( C_6 \); it also represents the more indirect ones \( C_7, C_8, D_1 (C_1 \text{ to } C_8), \) and \( C_1 F_3 H_2 E_1 H_1 F_1 \). The degree to which temperature represents these latter is of course dependent on the degree of relationship of temperature with light and phosphate. It follows that the mathematical procedure of deriving partial correlations, which makes allowance for such inter-relations, will eliminate these puzzling indirects, and the partial correlation of plant pigments in respect to all the other environmental factors will be simply a statement of \( C_1 \) to \( C_6 \), with \( C_7 \) and \( C_8 \) partly eliminated (in respect to phosphate).

Therefore in order to test the theory developed in the previous section, partial correlations are calculated which correspond to the groupings given in Table I. These are shown in Table IV.

\[ \text{TABLE IV} \]

**Partial Correlations of Physical and Chemical Factors with Total and Surface Plant Pigments and Oxygen Production**

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Light</th>
<th>Depth</th>
<th>Phosphate</th>
<th>Plant Pigments</th>
<th>Oxygen Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Plant Pigments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Group I</td>
<td>-.7129</td>
<td>-.9650</td>
<td>.8404</td>
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<tr>
<td>Group II</td>
<td>.9338</td>
<td>-.0514</td>
<td>.9782</td>
<td>.9982</td>
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<td><strong>Surface Plant Pigments</strong></td>
<td></td>
<td></td>
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<tr>
<td>Group I</td>
<td>.3060</td>
<td>-.9376</td>
<td>.3965</td>
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<td>-.9883</td>
<td>.9983</td>
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<tr>
<td>Group II</td>
<td>-.9750</td>
<td>-.9947</td>
<td>.9097</td>
<td>-.9868</td>
<td>-.9868</td>
<td>.9983</td>
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<tr>
<td>Group III</td>
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<td>.9090</td>
<td>-.9868</td>
<td>-.9868</td>
<td>.9983</td>
</tr>
<tr>
<td><strong>Oxygen Production</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>Group I</td>
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<td>-.7622</td>
<td>-.4029</td>
<td></td>
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<td>Group II</td>
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<td>-.5862</td>
<td>.0564</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group III</td>
<td>.8890</td>
<td>.9168</td>
<td>-.9962</td>
<td>.9980</td>
<td></td>
<td>.9983</td>
</tr>
</tbody>
</table>

The first prediction made from the diagram was that the depth-nutrient correlation would be shifted in a negative direction in deriving the partial correlation in respect to plant pigments. This is vindicated in that the correlation changes from \(-.3881\) to \(-.8848\). All
the predictions in regard to total plant pigments are correct. In regard to surface plant pigments there are four exceptions. Temperature between Groups I and II changes in a negative rather than a positive direction, and all the correlations with depth are positive instead of negative. Two exceptions occur in regard to oxygen production. A high negative correlation with depth is obtained in Group III, whereas the effect of depth should have been eliminated entirely, and between Groups I and II the change was negative rather than positive. Out of a total of twenty predictions there are six exceptions, and five of these are in respect to depth. Thus it appears likely that the theoretical treatment of depth is false, or at least incomplete; but there is nothing that would deny the essential correctness of the rest of the diagram.

Aside from theoretical considerations, the correlations are high enough to have considerable empirical value. Equations derived from the correlations for predicting total and surface plant pigments and surface photosynthesis from the primary environmental factors are as follows:

\[ \text{TPP} = 1567P + 14t + 0.281L + 0.15D - 587 \]  
\[ \text{SPP} = 2.371D - 117200P - 1528t - 862.7L + 438661 \]  
\[ \text{OP} = 0.000065\text{SPP} - 0.0002D + 7.69P + 0.0988t + 0.0549L - 27.744 \]

where \( \text{TPP} \) is thousands of units of plant pigments per \( m^2 \), \( \text{SPP} \) is units of surface plant pigments per \( m^3 \), \( \text{OP} \) is grams of oxygen produced per \( m^3 \) per day at the surface, \( t \) is temperature, \( L \) is g. cal. of solar radiation per \( cm^2 \) per day, and \( D \) is depth in meters.

The multiple correlation coefficients for these equations range from .9984 to .9992, and the relation between the amounts observed in the water and those calculated from the equations is shown in Table V.

### TABLE V

**Oxygen Production and Plant Pigments Calculated from Equations (1) to (3)**

<table>
<thead>
<tr>
<th></th>
<th>Total Plant Pigments</th>
<th>Surface Plant Pigments</th>
<th>Oxygen Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Equa-</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tion (1)</td>
<td></td>
</tr>
<tr>
<td>Tortugas, Station 1</td>
<td>31</td>
<td>29</td>
<td>1520</td>
</tr>
<tr>
<td>Tortugas, Station 2</td>
<td>2</td>
<td>1</td>
<td>680</td>
</tr>
<tr>
<td>Southern Stations, N. Atlantic</td>
<td>345</td>
<td>345</td>
<td>1300</td>
</tr>
<tr>
<td>Northern Stations, N. Atlantic</td>
<td>143</td>
<td>143</td>
<td>4100</td>
</tr>
<tr>
<td>Long Island Sound</td>
<td>1096</td>
<td>1097</td>
<td>54800</td>
</tr>
<tr>
<td>Georges Bank</td>
<td>807</td>
<td>808</td>
<td>12590</td>
</tr>
</tbody>
</table>
It would be interesting to know how general is the application of these equations. Unfortunately, however, the only other region that can be used for comparison is the English Channel. According to data given by Harvey, Cooper, Lebour, and Russell (1935), the mean temperature at station L4 during 1934 was about 11.1°, and the surface phosphate was 0.26 mg.-atom. The average solar radiation for the region, estimated from figures given by Kimball (1928) for latitude 52° N., longitude 10° W., is about 222 g. cal. per cm² per day. With a depth of 45 m. at L4, the average total plankton crop according to equation (1) should be about 45000 Harvey units per m². Actually the mean annual net plankton crop was about 760 units per m³ or 34000 units per m². Since a fraction of the plankton undoubtedly escaped the net, the result of the calculation does not seem unreasonable.

Theoretically, the equations cannot be expected to apply to any set of data that requires extrapolation—that is, any figures that are beyond the limits of the variables used in setting up the equations. Actually, a small amount of extrapolation may be possible in some cases. It depends on whether or not the regression lines remain linear. In fact extrapolation was employed in the English Channel example, since the value for radiation was lower than in any of the original data. An extreme case, however, the results of which are completely false, is illustrated by an attempt to apply equation (1) to the seasonal cycle on Georges Bank. The calculated and observed values for total plant pigments are shown in Table VI. The most

<table>
<thead>
<tr>
<th>Table VI</th>
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</thead>
<tbody>
<tr>
<td>Total Plant Pigments on Georges Bank</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Plant Pigments</th>
<th>Calculated</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>343</td>
<td>560</td>
</tr>
<tr>
<td>January</td>
<td>1258</td>
<td>118</td>
</tr>
<tr>
<td>March</td>
<td>1319</td>
<td>828</td>
</tr>
<tr>
<td>April</td>
<td>931</td>
<td>2303</td>
</tr>
<tr>
<td>May</td>
<td>719</td>
<td>871</td>
</tr>
<tr>
<td>June</td>
<td>768</td>
<td>478</td>
</tr>
</tbody>
</table>

striking error is in the January results in which the very high calculated value is based on the large concentration of phosphate, which in reality cannot be utilized because light at the low January intensity inhibits growth more strongly than is indicated in the equation. In April the calculated values for plant pigments fall as the phosphate
decreases, whereas the plant pigments actually are going up in accordance with the amount of phosphate present at the beginning of the spring flowering. Special phenomena such as these—nonlinear regressions and lag periods—cannot be expressed by a simple equation. The equations are concerned with longer periods of time which average out special phenomena and leave a residuum of general regional variation, a situation analogous and somewhat more strikingly presented by Deevey (1940), who in a series of Connecticut lakes correlated the summer chlorophyll content of the plankton with the winter nitrate.

With these considerations in mind it is reasonable to suppose that the equations should apply with a fair degree of accuracy to the seasonal averages of any region in which the environmental factors fall within the limits of variation of the original data—namely, temperate and tropical waters. They might apply, though with lesser accuracy, to shorter periods provided the plankton was relatively constant (temperate and perhaps arctic regions during the summer, the tropics throughout most of the year).

Much remains to be done in this field. The equations need to be tested and probably altered to include a larger variety of environments. It might be advantageous to include other factors. The logical treatment of depth as a factor, including as it does several other concepts, remains an enigma. But the results obtained so far indicate that eventually the quantitative aspects of plankton growth can be predicted with considerable accuracy.

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