LIGHT PENETRATION INTO FRESH WATER.

III. SEASONAL VARIATIONS IN THE LIGHT CONDITIONS IN WINDERMERE IN RELATION TO VEGETATION.

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(With Three Text-figures.)

IN the last paper of this series (Pearsall and Hewitt, 1933) changes in the transparency of the water of Windermere were described. It was shown that the penetration of blue light (5100 Å to 4000 Å), as measured by the sulphuric acid-iodide method, was very much greater in 1920 than it was in 1932. The present communication deals with the results of observations on changes in the transparency of the water of Windermere throughout the year March, 1932, to March, 1933. The causes of the differences in the light penetration at different times of the year are discussed.

The light-sensitive element used for making the measurements of light intensity was a vacuum potassium-on-copper photoelectric cell (type K.M.V. 6, General Electric Co., England). As the measuring instrument a neon lamp photometer, modified after the recommendations of Atkins and Poole (1930), was used for the earlier observations (up to May, 1932), but later it was found more convenient to use a thermionic potentiometer (Ullyott, 1933). The spectral sensitivity of the cell, and the arrangement of the potentiometer have already been described (Pearsall and Ullyott, 1933), and all that need be said here is that the particular cell used for the under-water measurements has a maximum sensitivity in the region 4000–4900 Å. It therefore measures much the same quality of light as is effective in causing the sulphuric acid-iodide reaction.

In each series of measurements the cell in its water-tight container was lowered into the water, and readings of the light intensity taken at one metre intervals. The photometer was hung from a 6 ft. boom over the side of the Laboratory's launch which was always anchored so that the boom pointed towards the brightest region of the sky. This procedure reduced shading effects to a negligible minimum. A similar photometer was kept on deck in an unshaded position, so that readings of full daylight could be taken whenever necessary. If the conditions of illumination tended to be at all variable, deck readings were taken at each new position of the under-water photometer. In this way it was always possible afterwards to express the under-water readings as percentages of full daylight.

More than seventy series of readings were taken between March, 1932, and March, 1933, but it is not proposed to tabulate them in detail, because most of them repeat certain constant features of the typical series which have already been described (Pearsall and Ullyott, 1933). Instead, certain series have been chosen for a number of dates during the year, and set out in Table I. Two depths have been selected at which figures for the percentage value of the light intensity are given. The 1 metre readings serve to show what was the transparency of the most superficial layers of the lake water. The second depth, 4·3 metres, represents the lowest limit of the rooted vegetation, and consequently light intensities at this particular depth are of special interest. The dates have been chosen either because the results obtained on them are typical of the month which they represent, or because they illustrate some fundamental point in the yearly cycle of light conditions. For example, the data for June 12th were selected because on that date the maximum number of diatoms was recorded, and those for March 25th because the lake water was at that time at its clearest.

Table I.

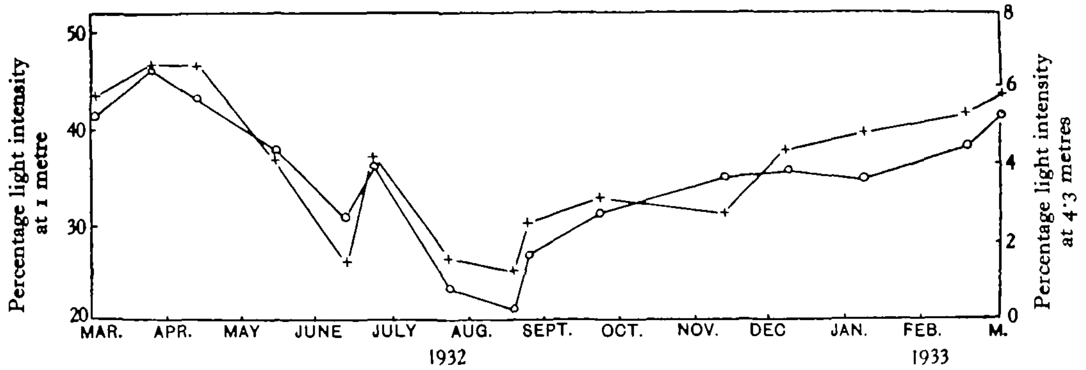
Date	Percentage of full daylight	
	At 1 m.	At 4·3 m.
1932. March 25	46·9	6·69
April 12	43·9	6·69
May 15	38·0	4·17
June 12	30·6	1·53
June 20	36·2	4·52
July 21	23·4	1·59
August 19	21·0	2·20
August 22	26·3	2·52
September 19	31·2	3·09
November 12	34·7	4·35
December 6	34·6	4·42
1933. January 6	34·5	4·85
February 10	39·0	6·15

The difficulty of reducing the results obtained throughout the year to some comparable working basis is very great, for not only are there absolute differences in the intensity and composition of the light, but also the average angular elevation from which it comes is much less in winter than in summer. The sun's rays, striking the water at a low angle, have to travel very much farther through the water in winter than they have in summer to reach any particular depth. In order to make the results as nearly comparable as possible, the original readings have been corrected by a factor which gives values corresponding to an angular elevation of light of 30°. This is the average angle of diffuse or sky light, and appears in many ways to be preferable to the zenith, which has been taken by Birge and Juday (1929–32) as a standard. In the English Lake District the sky is frequently more or less overcast, and in any case the sun never reaches an angular elevation of more than 60°, so that the re-calculation of the light penetration, taking the diffuse light angle as a standard, allows the data to represent a close approximation to average light conditions.

It is now possible to consider the data in greater detail. The figures given in Table I have been plotted as a graph in Fig. 1, which shows clearly the differences in penetration of the light at different times of the year. In March and during the beginning of April the lake water was remarkably clear, but during the latter half of April and the whole of May the transparency of the water gradually decreased, until it reached a minimum in early June. Towards the end of June it became temporarily clear again. The decrease in transparency during this period was due to the increasing number of diatoms, and the minimal light penetration in early June was associated with the diatom maximum. A very rapid decrease in diatom numbers occurred during the week June 13th–20th, with the result that on June 20th the water was clearer than it had been since the development towards the maximum during the early part of the previous month. After the short period of clearness in June the light penetration was again reduced by a steady increase in numbers of blue-green algae, which occurred during July. The maximum was at the beginning of August, but the algae persisted in decreasing numbers until the end of October, after which the phytoplankton was comparatively scarce.

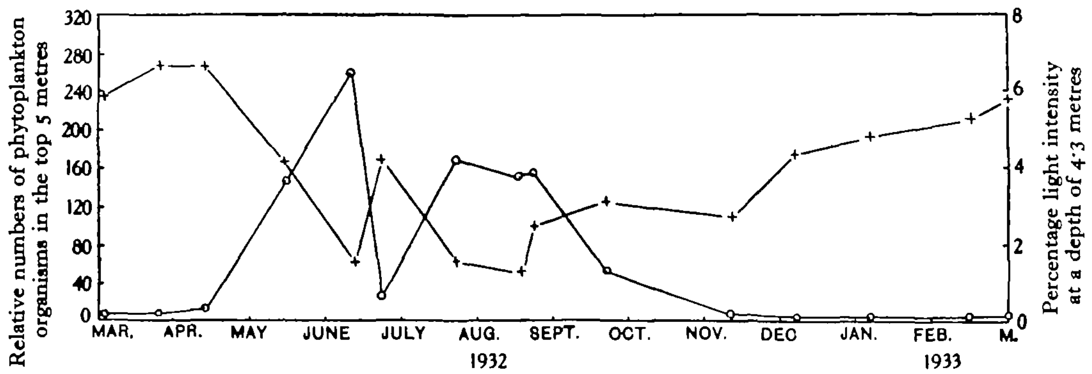
In Fig. 2 the relative numbers of phytoplankton organisms in the surface 5 metres throughout the year are shown alongside the percentage values for light intensity at 4·3 metres. This correlation shows how clearly the light penetration into the water is associated with the number of organisms present. The results for the light penetration into the water at significant times during the year are given in Fig. 3. The curves for June 12th and July 21st are of special interest, because they illustrate what happens during the diatom maximum and during the blue-green maximum. It is well known that diatoms usually show a fairly uniform depth distribution down to 4–5 metres, whereas the blue-green algae always accumulate close to the surface. The curves for light penetration indicate these differences clearly. This difference in depth distribution of the two plants also explains why minimal percentage light intensities at 1 metre always occur during the blue-green maximum, while minimal percentage light intensities at greater depths can occur equally well during the diatom maximum.

The fact that the blue-green algae collect in the most superficial layers of the water was responsible for considerable variability in the light penetration during July and August. Readings were taken almost every day, and the light penetration in different parts of the lake was found to depend on the prevailing weather conditions. On August 19th, which was very calm, all the algae had assembled in the surface half-metre, with the result that the light intensity at 1 metre was only 21 per cent. of the full daylight value. But on the same day the percentage value of the light intensity at 4·3 metres (the vegetational limit) was not less than on July 21st, when the value at 1 metre was 31 per cent. When a wind was blowing the algae tended to be mixed with the less superficial layers, and also they were blown across the lake, so that many more were present on the exposed shore. As a result, light penetration at different places was by no means the same. Nevertheless, the results for July and August lay within the range limited by the values for July 21st as a maximum, and August 22nd as a minimum.



+ Light intensity at 4·3 metres; O light intensity at 1 metre

Fig. 1. Light intensities at the limit of aquatic vegetation (4·3 metres) and at a depth of 1 metre in Windermere during the year March, 1932, to March, 1933.



+ Light intensity at 4·3 metres. O Number of phytoplankton organisms.

Fig. 2. Light intensity at the limit of aquatic vegetation (4·3 metres) compared with the numbers of phytoplankton organisms in the top 5 metres. (Windermere, March, 1932, to March, 1933.)

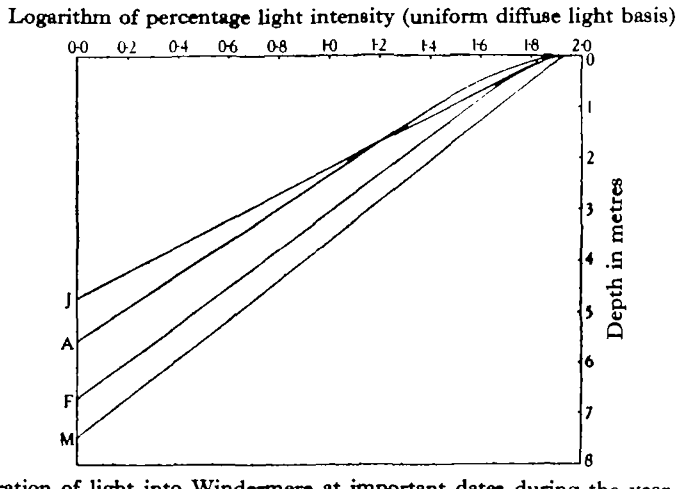


Fig. 3. Penetration of light into Windermere at important dates during the year. *J*. June 12th. Uniform distribution of diatoms at the diatom maximum. *A*. Aug. 22nd. Blue-green algae in the surface water at the blue-green maximum. *F*. Feb. 17th. Average condition of clearness. *M*. Mar. 25th. Maximal clearness of the water.

During November and December a gradual clearing of the lake water was to be expected, but no specially marked change seemed to occur immediately after most of the blue-green algae had disappeared. During November the littoral vegetation dies down for the winter, and quantities of detritus formed in this way, along with the products of algal decomposition, may have been responsible for the continued turbidity of the water. The rough weather and floods which occurred during the latter half of November and during December probably contributed towards prolonging the effect. In any case, during the whole of January and February a progressive clearing of the lake water took place.

The combined results leave little doubt that the amount of light penetrating down to the limit of rooted vegetation depends very largely on the quantity of phytoplankton in the surface layers of the water. This is specially true during spring and summer. For the rooted vegetation the period of maximum activity is July and August, so that the amount of phytoplankton present at this time will be of the utmost importance. But Fig. 1 shows that during this period the actual percentage light intensity at 4·3 metres is 1·5–2·5 per cent., whereas, if no blue-green maximum occurred, it would be 4–5 per cent. So it is clear that at precisely the time of greatest activity of the submerged plants, the blue-green algae cut down the light intensity at the limit of vegetation by approximately 50 per cent., and, since light is the factor limiting the downward extent of the aquatic plants, the effect of the presence of the blue-green algae on the limit of vegetation itself cannot fail to be of great importance.

SUMMARY.

1. The penetration of light into Windermere is dependent chiefly on the numbers of phytoplankton organisms in the epilimnion.

2. It appears that the greatest depth at which rooted aquatic plants can grow must therefore be affected by the abundance of phytoplankton. The rooted plants are most active during July and August. Observations show that at this time the presence of blue-green algae reduces the light intensity at the limit of submerged vegetation (4·3 metres) by more than 50 per cent.

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