B. CHANGES IN PHYSICAL AND CHEMICAL VARIABLES

by C. H. MORTIMER.

Recent work in this laboratory has approached the problem of algal growth from three angles by studying—(1) the seasonal distribution of algae in the lakes, (2) the physiological requirements of different algal species, and (3) the seasonal variation of chemical conditions in water at various depths in lakes, with which I am concerned here. To these methods of approach may now be added Dr. Taylor's investigation of the influence of bacteria on the chemical cycle.

The choice of routine chemical tests has been limited by the capacity of the laboratory. It is not practically possible to test for all the chemical elements which plants are known to take up from the water, and probably not all of the substances taken up are known. Tests have been confined to substances which, in the light of present knowledge, have been shown by their presence or absence in the water to have a direct influence on phytoplankton growth. These are the " limiting substances " which, due to their extreme dilution in the water, become depleted and so limit plant growth, although large quantities of other necessary chemical elements may be present. The limiting substances include nitrogen as inorganic salt and, perhaps most important of all, phosphorus, both of which are discussed in my article in the sixth annual report (page 38). In Windermere silicon must also be included as a limiting element, because it is from this that the silica shells of the diatoms, which form a part of the plankton, are built up.

The routine tests made can be included under three heads: (1) General characteristics of the water, namely temperature, electrical conductivity (proportional to total dissolved salts), pH and alkalinity or carbonate hardness. This last test is the measure of the salt present in largest quantity, namely bicarbonates, mainly of calcium. The ratio of electrical conductivity to alkalinity indicates the ratio of bicarbonates to other salts such as sulphates and chlorides. (2) Estimation of limiting substances: nitrates with ammonia and nitrite, phosphates and silicates. (3) Estimation of living matter and its influence on the water. The amount of dissolved oxygen indicates the balance between diffusion into the lake from the air, production of oxygen due to plant photosynthesis, and oxygen consumption by living or decomposing organic matter. Quantitative samples of the plant and animal plankton are taken with a special net which registers the volume of water filtered. In this way it is possible to express the amounts of plant and animal plankton caught by the net in units of weight per volume of water (usually milligrams per litre or parts per million) comparable with the results of chemical analysis. Organic matter entering into solution as a result of decomposition of plankton in the water is measured by the rate at which the sample reduces acidified potassium permanganate. Daily readings of the lake level, surface temperature and rainfall considerably assist the interpretation of results.

Work along these lines was carried out by Miss Penelope M. Jenkin in 1932 and has been continued by myself since October 1935. Samples have been taken at regular intervals from the north and south basins of Windermere, from Esthwaite Water, and latterly from Thirlmere. The results outlined below are concerned with the water alone. More detailed consideration has been given to the mud and the lake as a whole in earlier reports of the Association.

Figure 5 shows the seasonal variation in the amounts of some dissolved substances in the surface water of Windermere during 1936. The proportions of the main chemical constituents, as shown by the alkalinity and electrical conductivity tests, exhibit only slight but definite seasonal variations. The amounts of the limiting substances, however, fluctuate considerably. Nitrate and silicate are high during the winter, but fall rapidly during phytoplankton growth in May and June, when the diatom *Asterionella* is the chief constituent of the phytoplankton, as shown by comparison with figure 6. It would seem that depletion of these and possibly other limiting substances put a stop to diatom growth half-way through June. During the latter half of June another effect of considerable importance is illustrated: a flood following about six weeks of drought added considerable quantities of nitrates, phosphates, silicate and probably other limiting substances to the surface water. The phytoplankton was apparently given a new lease of life and growth continued in July, until nitrate became depleted. In the meantime the large crop of diatoms had died, liberating silicate, phosphate and large quantities

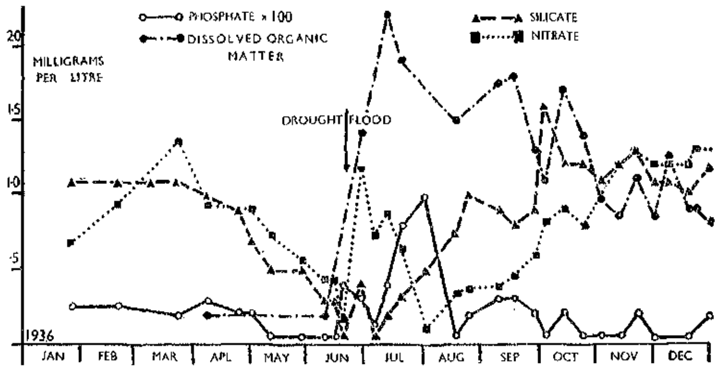

FIGURE 5. Seasonal variation in the amounts of dissolved substances in the surface water of Windermere (north basin).

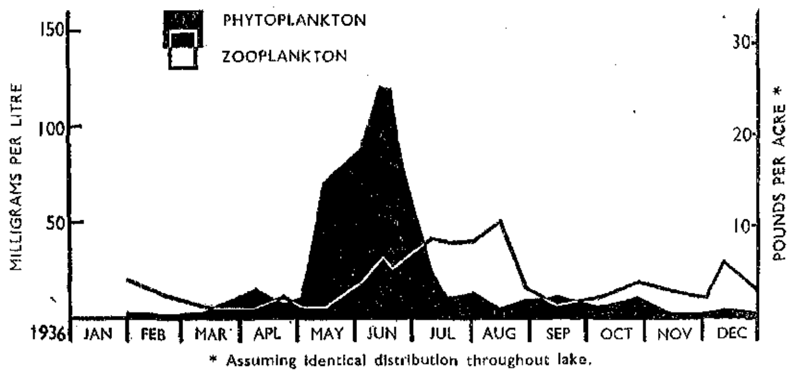

FIGURE 6. Seasonal variation in the dry weight of phyto- and zooplankton in Windermere (north basin).

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of dissolved organic matter. The chemical condition of the water had been altered to that favouring the growth of blue-green algae which continued throughout the summer, but the quantities produced were only a fraction of the spring diatom crop, even taking account of the fact that approximately one-half of the diatoms' dry weight is made up of silica. Figure 6 also illustrates the growth of animal or zooplankton which increases to a maximum during and after the diatom growth. Decomposition of dead plankton in the water (illustrated in figure 5 by the rise and subsequent fall in dissolved organic matter) and in the mud gradually restored the salts to the water and the amounts increased to the high winter level.

The main features of this sequence of events have been repeated during each year so far examined. In some years, e.g., 1938, the diatom crop was not as large and the depletion of dissolved salts was less complete than during 1936, but the same cycle of consumption of dissolved salts during the spring and summer and regeneration during autumn and winter can be followed. This description applies only to water from the surface to a depth of 10 to 15 metres, the region to which plant growth is restricted by the lack of sufficient light for photosynthesis at greater depths. The depletion of the dissolved salts in the surface layers is often marked in summer because it is cut off from the lower regions where the processes of salt regeneration take place. During the winter the lake water is at approximately the same temperature at all depths; wind keeps the whole of the water in circulation and there is equal distribution throughout all depths of the salts diffusing out of the mud and of oxygen diffusing in from the atmosphere. As the surface water warms up in summer it becomes increasingly difficult for wind to maintain complete circulation, since this involves considerable work in pushing less dense warm water down into dense cold water. Circulation thus becomes confined to a superficial layer (epilimnion) cut off from a cold, stagnating, lower layer (hypolimnion) and separated from it by a zone of sharp temperature gradient (thermocline). The level of the thermocline in most lakes is below the lower limit of photosynthesis. The effect of this is illustrated in the following table in which the approximate mean monthly values (in parts per million) at various depths are entered for a typical month during summer thermal stratification, and during winter circulation. The thermocline during August 1938 was at about 15 metres depth.

NORTH BASIN OF WINDERMERE:

CONDITIONS IN SUMMER AND WINTER COMPARED.

Depth in metres	Temperature °C.	Dissolved Oxygen % Saturation	Electrical conductivity $K_{18°}.10^{-6}$	Silicate (SiO_2)	Nitrate (NO_3)	Dissolved organic matter (O_2 absorbed from $KMnO_4$)
August, 1938.						
1	16	97	49	0.30	0.70	1.5
10	14	87	48	0.65	0.55	1.0
30	7	83	54	1.25	1.35	0.7
50 = 1m. from bottom	7	77	53	1.35	1.30	0.7
December, 1938.						
1	7	94	52	1.35	1.40	1.7
10	7	92	53	1.40	1.35	1.2
30	7	91	53	1.40	1.30	1.5
50	7	93	53	1.45	1.35	1.2

The depletion of nitrate and silicate, the rise of dissolved organic matter in the epilimnion and accumulation of salts in the hypolimnion during the summer are shown clearly. This accumulation, although most marked in the salts of biological importance, can also be detected in the total salt content (electrical conductivity). Decomposition in the hypolimnion and mud results in the depletion of oxygen below the thermocline, an effect which is only slight in Windermere, but may be complete in lakes with a higher organic production. These processes build up a store of substances which only reach the surface again in the winter period of complete circulation. Thus, during winter, the water is chemically homogeneous from top to bottom (see table) and is in a condition to support phytoplankton in the following spring.

It should be noted that a lake is by no means entirely a closed system. The importance of inflowing water is illustrated by the effect of a summer flood on the concentration of certain important substances shown in figure 5. Winter floods are equally important, because, as shown by W. H. Pearsall, wet winters are followed by large diatom crops in the spring, and dry winters by poor crops. The reason for the stimulating action of such floods on diatom growth is at the moment obscure ; it may be due to substances washed in from the soil, possibly the limiting substances considered in this article, but probably others also of which we know nothing.

This article is not intended to give the impression that chemical analyses of water enable a forecast to be made of the amount and kind of growth which will take place in a body of water, although this must be the ideal which anyone who wishes to control organic production in freshwater should set before him. It is possible in many cases to infer from analogy what is likely to happen, and sometimes, as for example during June, figure 5, it is possible from chemical data to forecast when a growth, already started, will stop. It is much more difficult however, even after the most exhaustive chemical analysis, to foretell with any certainty when and whether a certain growth will arise. Instances are common where the limiting substances considered in this article have all been present in ample quantity but no large growth has arisen. The conclusion from the chemical view point is the same as that from biological observation, that further knowledge of the complex physiological requirements of algae is required before the problem of the algal cycle and its controlling factors can be solved.

BACTERIA IN FRESHWATERS

by C. B. Taylor.

In the first place it was decided to concentrate upon the following subjects :—(1) the numerical distribution of bacteria in lakes, (2) a study of the types most commonly present, and (3) the nitrogen-cycle. Windermere was chosen as the most convenient body of water for initial work. Samples of water have been taken weekly from a sampling point in the north basin at depths of 1, 10, 30 and 50 metres during the summer and autumn of 1938 and at 1 and 10 metres since December. In the south basin of Windermere samples have been taken fortnightly from depths of 1, 10, and 30 metres. In addition periodic samples have been taken from Esthwaite Water and Blelham Tarn. More recently work has been started on Thirlmere and its inflowing streams (by permission of Manchester Corporation Waterworks).