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NUTRIENT AND PHYTOPLANKTON STUDIES OF LLANGORSE LAKE, A EUTROPHIC LAKE IN THE BRECON BEACONS NATIONAL PARK, WALES

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1. Introduction

Llangorse Lake is in the Brecon Beacons National Park in the lowlands of south-east Breconshire (50130265). Mountains to the west, south and east rise to over 305 m. (Fig. 1). Mountain tops are typified by bare moorlands and the steeper slopes are covered with tree plantations. The lowland areas consist mainly of arable and grassland, especially in the alluvial plain of the Llynfi valley.

The annual rainfall in the lowlands is 890–1,140 mm., while the Black Mountains may receive over 1,270 mm.; however, the entire area is in the rain shadow of the Brecon Beacons where the rainfall may exceed 2,290 mm. per annum.

The lake is approximately 2·5 km. in length, 0·8 in breadth and 5·6 km. in circumference (Fig. 2) and has an area of approximately 150 ha. It is 155 m. above sea level with depths generally ranging from 2·5 to 4·0 m. and a maximum encountered depth of 6·4 m. in the vicinity of sampling station 9.

Water inflow is from the Afon Llynfi and 5 small streams at the north and east shores of the lake. During the summer of 1961 several of the streams were dry and the remaining ones had minimal flow, being supplied by springs. In late autumn and winter of 1961/1962 the volume of water in the streams and Afon Llynfi had increased 20 to 50 times that of summer so that the lake had risen 0·8 m. by January 1962, causing extensive flooding of adjacent meadows. This flooding did not occur in winter 1966/1967.

Guile (1965) and Seddon (1964) describe the lake-side vegetation as consisting of damp pasture and meadows, marsh and reed swamp. The dominant grass in the pasture being *Lolium perenne* L. where the soil is a deep red-brown, base-rich loam. The marsh contains *Glyceria fluitans* (L.) R. Br., *Iris pseudacorus* L., *Caltha palustris* L., *Mentha aquatica* L. and other typical marsh plants. The reed swamp includes *Phragmites communis* Trin., *Scirpus tabernaemontani* C.C. Gmel., *Equisetum fluviatile* L. and *Phalaris arundinacea* L. Aquatic species included *Nuphar lutea* (L.) Sm., *Nymphaea alba* L., *Polygonum amphibium* L., *Elodea canadensis* Michx., *Potamogeton lucens* L., *Ranunculus aquatilis* L., *R. trichophyllus* L., and *Lemna* spp., especially *L. trisulca* L. *Nymphoides peltata* (S.G. Gmel.) O. Kuntze. has been introduced into the lake and, according to Guile (1965), has found conditions so suitable for proliferation that it has spread enormously in the open water zone where the water is sufficiently shallow, displacing *P. amphibium*. Two species new to Breconshire, *Zannichellia palustris* L. and *Hippuris vulgaris* L., were recorded by Seddon in 1964. He also listed the tolerance to water conditions of a number of aquatic species and found that

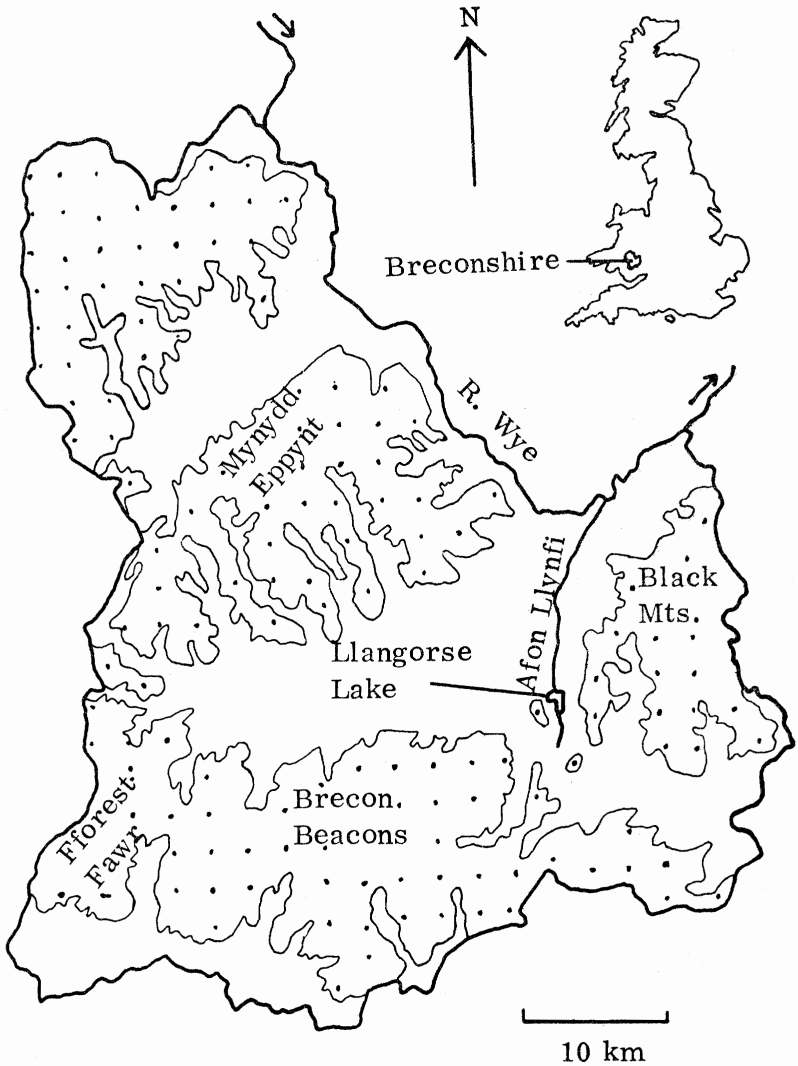

FIG. 1.
Breconshire—Relief map and location of Llangorse Lake. Areas over 300 m. elevation are stippled.

Polygonum amphibium and *Potamogeton lucens* were indicators of lakes rich in dissolved nutrients.

The shortage of lake waters in Britain and the incorporation of Llangorse Lake into the Brecon Beacons National Park with its proximity to large industrial areas of South Wales and the Midlands places a considerable recreational stress on the lake, especially in the past few years with the expansion of caravan sites and increased numbers of day trippers. Since limnological studies at Llangorse Lake have not been reported this study presents data collected in 1961/1962 and again in 1966/1967 concerning nutrients and phytoplankton in the lake.

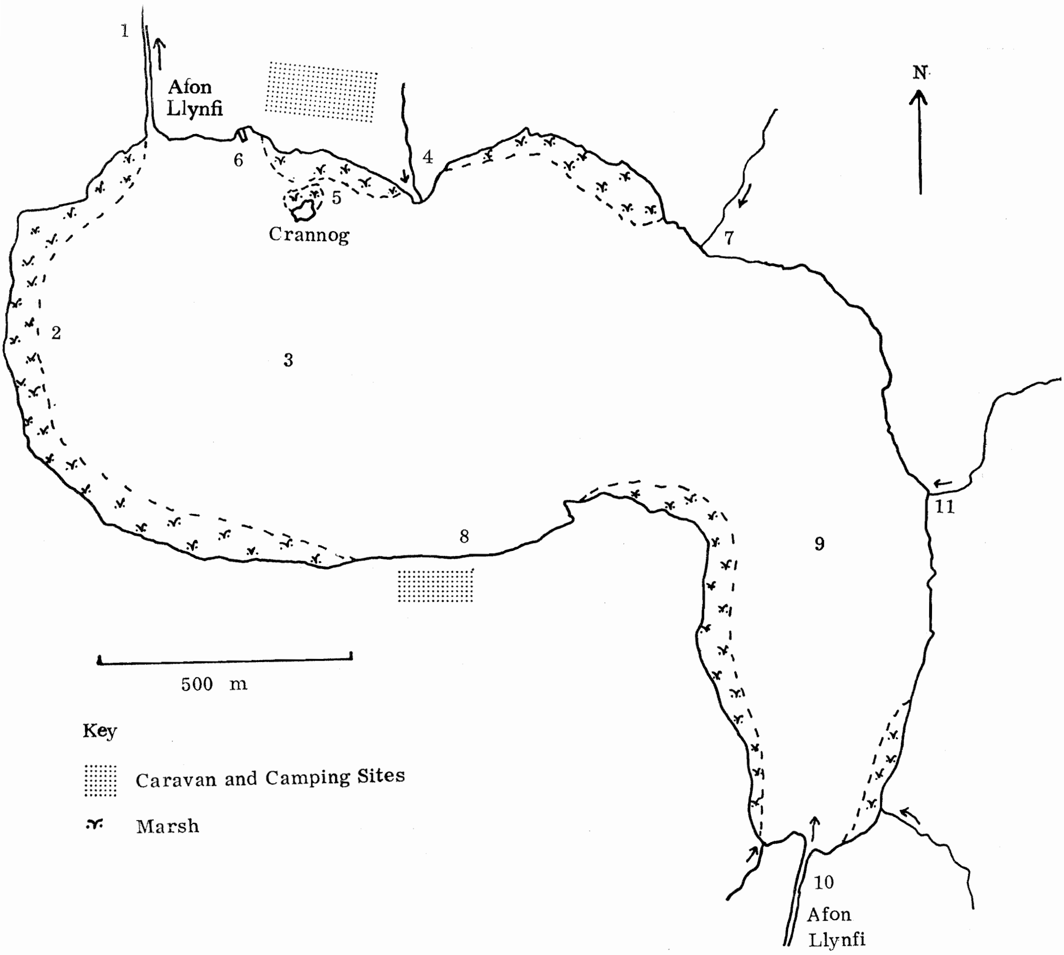

FIG. 2.
Llangorse Lake. Sampling Stations are Numbered 1–11.

2. Methods

Samples were collected at approximately monthly intervals from August 1961 to March 1962 and at two monthly intervals in 1966/1967 beginning in June and ending in April.

Of the 11 sampling stations (Fig. 2) 6 were in the lake, 4 were inflowing streams and one was in the Afon Llynfi approximately 275 m. from its outlet. Water depths at the stations are presented in Table 1. Sites 1, 6, 8 and 10 were sampled consistently at monthly intervals from August 1961 to January 1962 and at 2 monthly intervals from June 1966 to April 1967. Sites 3 and 4 were sampled consistently and the others infrequently during 1961/1962.

Phytoplankton samples were collected by passing a similar volume of water from just below the lake surface through a No. 25 plankton net. A few drops of iodine in potassium iodide were added as preservative. Counts were made in a Sedgewick-Rafter cell and converted to cell numbers per standard volume except that colonies

Table 1. *Sampling stations and depths at Llangorse Lake*

Station	Depth (cm.)
1. 275 m. downstream of exit of Afon Llynfi	50– 70
2. Near reed beds, west basin	65– 90
3. West basin	150–300 (450)
4. Nant Cui stream	3– 15 (65)
5. Behind the Crannog	50– 70
6. End of landing stage	75– 95
7. Heol Ddu stream	3– 30
8. Littoral zone, south shore of west basin	40– 60
9. South-east basin	580–640
10. Afon Llynfi	75–120 (88 above bank)
11. Cwm stream	5– 10

Figures in brackets are for January 1972 when flooding was extensive.

and filaments were scored as individuals. This method allows some comparison of densities of organisms from different stations and habitats as well as a qualitative assessment.

Epiphytes and epiliths were scraped from underwater stems and stones respectively in the laboratory and a species list compiled. Identifications were made using West and Fritsch (1927), Fritsch (1935), Hustedt *et al.* (1930–1959), Pascher (1913–1930), Patrick and Reimer (1966), Smith (1853, 1958), and Smith (1950).

Surface and bottom temperatures were recorded with a maximum/minimum thermometer.

A British Drug Houses (1961) colorimetric procedure was used to measure pH in the field in 1961/1962 while in 1966/1967 an E.I.L. pH meter was used on samples in the laboratory.

Surface water samples were collected in polyethylene bottles pretreated with iodine to reduce bacterial numbers. Samples were stored at 4 °C. until analysed, usually the following day.

Analytical methods for ammonia, nitrates, nitrites, phosphates, silicates and hardness were those of the British Drug Houses (1961 *et seq.*) and modifications of Mackereth (1963) and his method sheets prior to publication.

3. RESULTS

Average surface temperature and pH data are presented in Table 2; bottom data are not presented since the temperature differences between surface and bottom

Table 2. *Surface temperatures (°C.) and pH for Llangorse Lake and the Afon Llynfi*

	1961/1962						1966/1967					
	Aug. 3	Sept. 1	Sept. 29	Oct. 20	Nov. 17	Jan. 20	June 1	July 27	Oct. 13	Dec. 7	Feb. 7	Apr. 23
Temperature (°C.)												
Llangorse Lake	16·0	20·5	16·5	10·5	4·5	4·5	—	—	—	4·5	5·5	—
Afon Llynfi	—	25·5	11·0	10·5	5·0	6·0	—	—	—	7·0	6·0	—
pH												
Llangorse Lake	8·4	8·7	8·4	—	8·0	7·8	—	—	8·3	8·0	8·2	8·2
Afon Llynfi	—	7·6	7·3	—	7·3	7·1	—	—	8·1	7·8	7·2	7·8

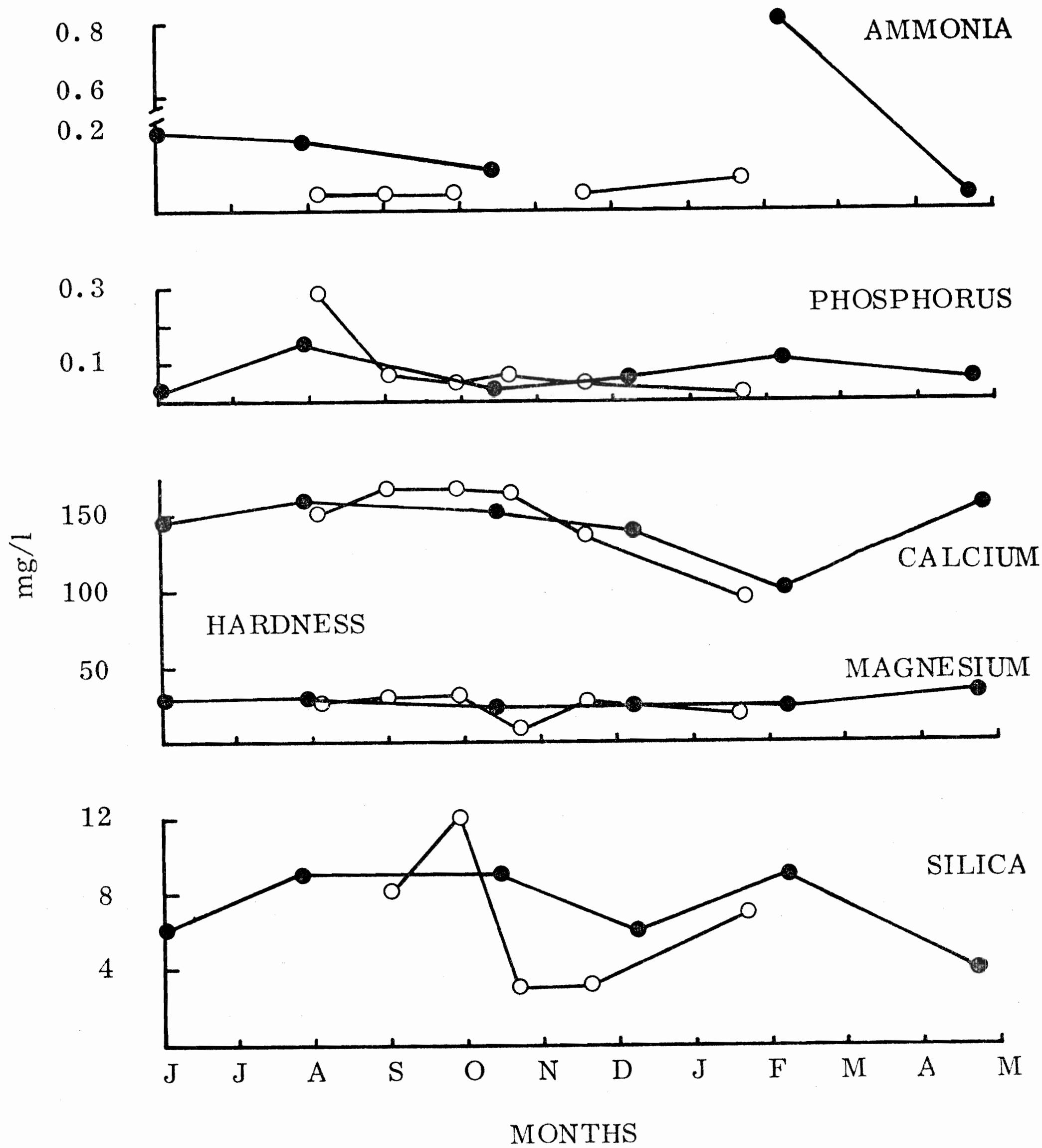

Fig. 3.

Chemical Data for the Afon Llynfi. o—o 1961/1962; ●—● 1966/1967. Phosphorus is expressed as orthophosphate and Hardness as mg./l. of calcium carbonate.

waters at the times of sampling did not exceed 1·5 °C. At site 9 (depth 6·4 m.) data are not available for 1961/1962 prior to 1 September 1961, so evidence for the occurrence or absence of summer stratification is lacking. Detailed temperature data for 1961/1962 are given in Jones (1962).

In summer and early autumn the lake pH increased (Table 2) probably because of carbon dioxide depletion by phytoplankton and vascular plants as evidenced by carbonate deposits on leaves and marl in the sediment in the western end of the lake. The pH of water entering the lake was lower at all times than that occurring in the lake.

Chemical data for the Afon Llynfi and the means of the data for lake stations are presented in Figs. 3 and 4 respectively. Nutrient levels in the Afon Llynfi tended to remain relatively constant except when the volume of water increased during winter months.

Obvious seasonal fluctuations of certain nutrients occurred in the lake. For instance, the silica content rose from 2–4 mg./l. in spring when diatom populations were high to a maximum of 10–12 mg./l. in late summer and autumn when a winter burst of diatoms again resulted in silica depletion to a level of 2–4 mg./l. (Fig. 4).

There appeared to be a seasonal cycle of phosphate content with levels being high in early summer and a gradual depletion occurring until winter when levels remained low (below 0·04 mg./l.). It also appears that the phosphate concentrations in the lake have increased between 1961/1962 and 1966/1967 (Fig. 4).

The very high free ammonia concentration (1·2 mg./l.) in February 1967 was probably an error; concentrations of 0·23 to 0·28 mg./l. as free ammonia, however, were recorded by the Wye River Authority on 30 July 1970.

The total hardness remained fairly constant at 140–150 mg./l. (as calcium carbonate) and obvious differences between 1961/1962 and 1966/1967 were not evident. The influence of winter rains on the total hardness in the Afon Llynfi is demonstrated in Fig. 3 indicating their diluting effect on nutrient concentrations in inflowing water.

Nitrate data are not available because of difficulties encountered with the technique; the Wye River Authority, however, were unable to detect nitrate-nitrogen on 30 July 1970 and 18 August 1970. Nitrite data for 1966/1967 are presented in Table 3 showing that nitrites reach their peak in the lake in early summer and in the Afon Llynfi in early winter.

Table 3. *Nitrite concentrations (mg./l.) for Llangorse Lake and the Afon Llynfi in 1966/1967*

	1966/1967					
	June 1	July 27	October 13	December 7	February 7	April 23
Llangorse Lake	0·0015	N.D.	0·0075	0·009	0·005	0·001
Afon Llynfi	0·01	0·025	0·01	0·004	0·007	0·005

The phytoplankton population was already very high (Fig. 5) when sampling commenced in 1961/1962 but in 1966/1967 the population had not reached its peak at the initiation of sampling. Maximum phytoplankton growth appeared to be associated with high lake water temperatures and macronutrients. When temperatures and nutrients declined in autumn and winter, phytoplankton numbers fell rapidly until a mid-winter burst of diatoms occurred. The data of spring 1966 indicate that the winter burst of diatoms is followed by a spring increase of green algae (Fig. 6), but by summer and early autumn the Myxophyta became dominant constituting 80 per cent or more of the plankton.

The periodicities of the major species in 1961/1962 and 1966/1967 are shown in Figs. 7 and 8. A rapid decline of *Tribonema bombycinum* (Ag.) Derb. et Sol. and

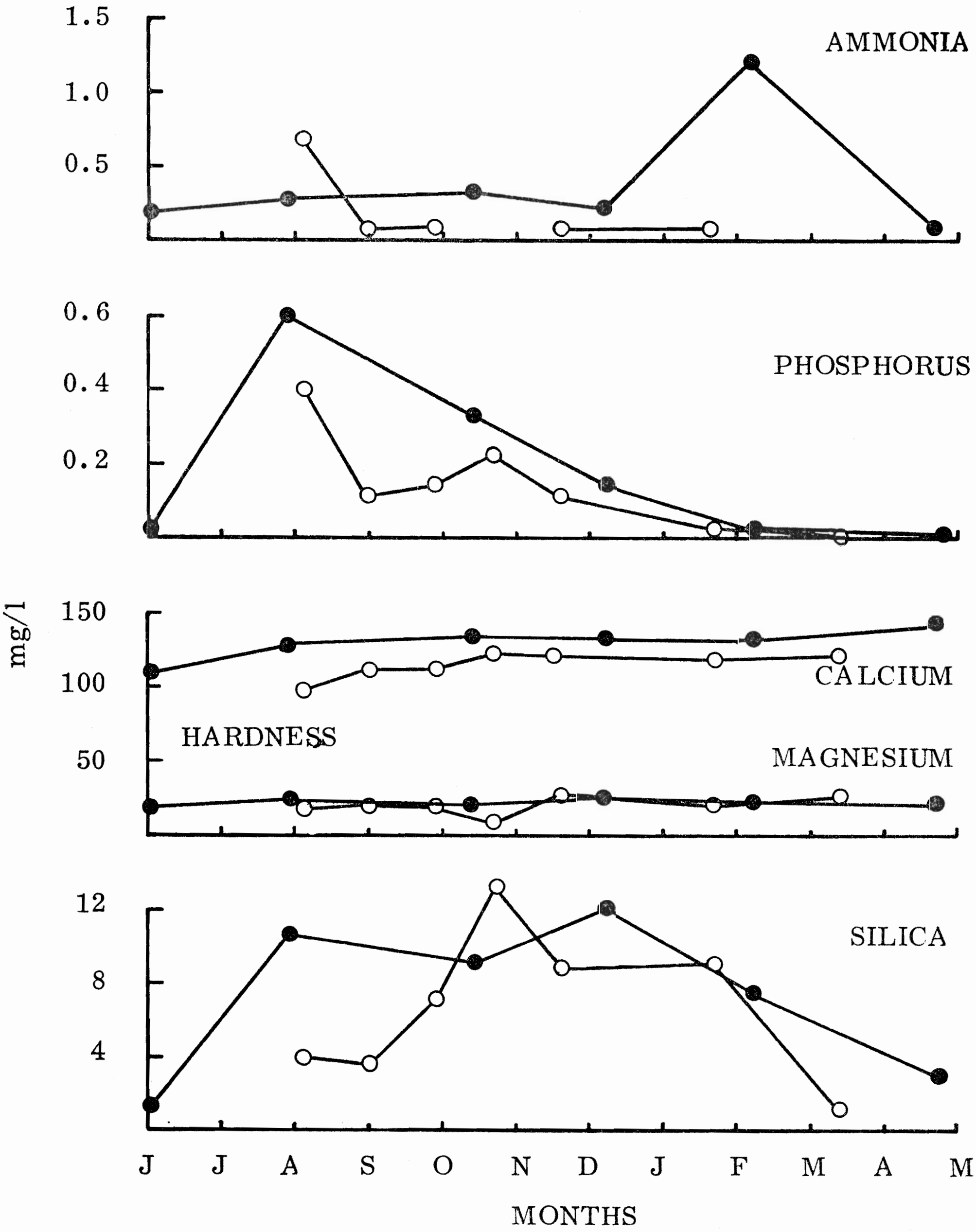

FIG. 4.

Chemical Data (Means) for Llangorse Lake. o——o 1961/1962; ●——● 1966/1967. Phosphorus is expressed as ortho-phosphate and Hardness as mg./l. calcium carbonate.

Anabaena flos-aquae Breb. from August through September in 1961/1962 was accompanied by a bloom of *Microcystis flos-aquae* (Wittr.) Kirchn. as water temperatures increased during late August and into early September. With falling temperatures, (10·5 °C. on 20 October 1961, to 4·5 °C. by 17 November), the population of *M. flos-aquae* declined. A winter burst of *Asterionella formosa* Hass. began in December

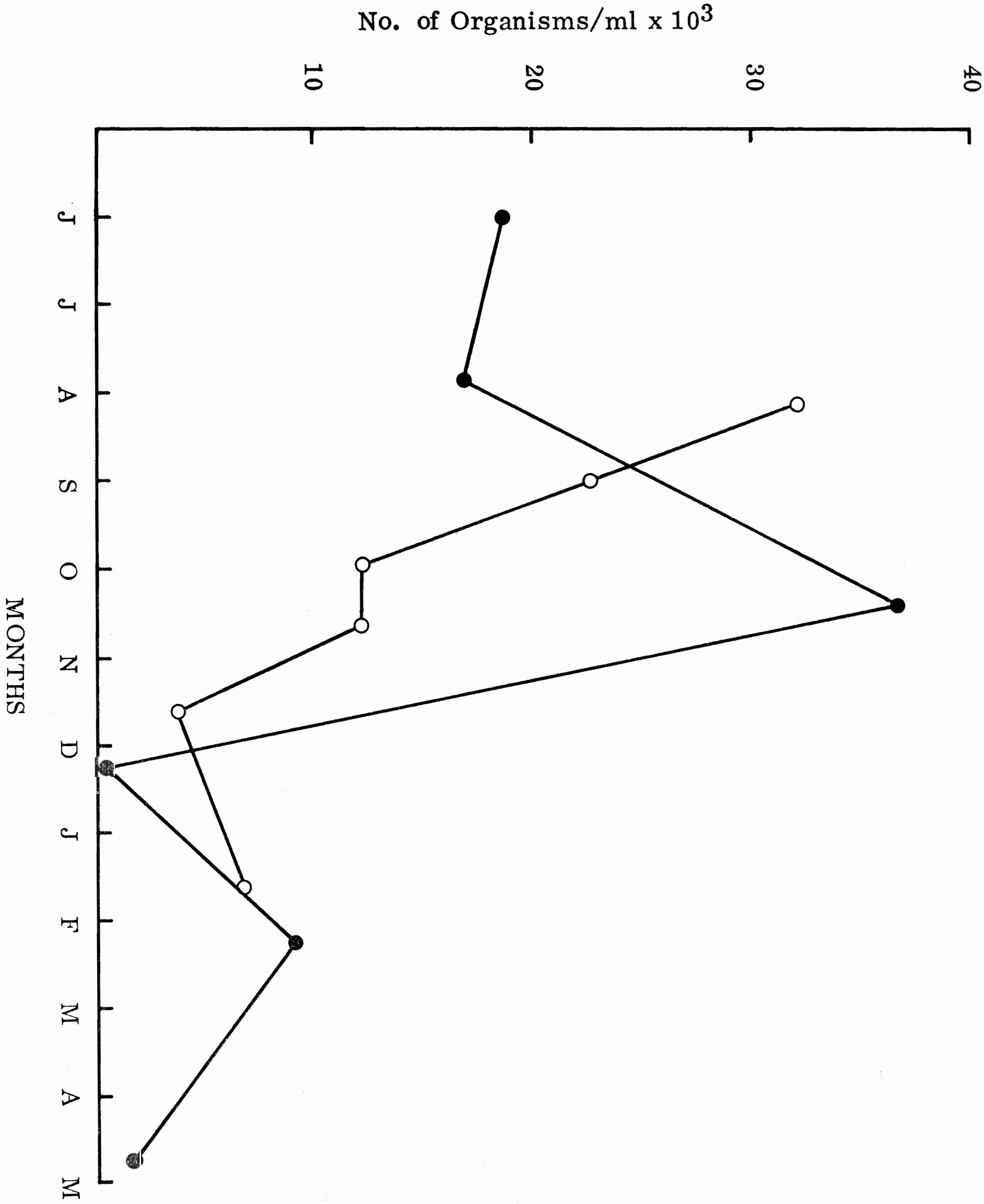

Fig. 5.
Periodicity of phytoplankton in Llangorse Lake in 1961/1962 o—o and 1966/1967 ●—●.

and continued into March 1962, when sampling ceased. At the same time the silica concentration in the lake fell from 12 mg./l. in October to 1 mg./l. by 13 March 1962. A similar winter depletion of silica and diatom increase were evident in 1966/1967. However, in contrast to 1961/1962, a burst of *A. formosa* did not occur.

As in 1961, a bloom of *Microcystis flos-aquae* formed in 1966, although the data

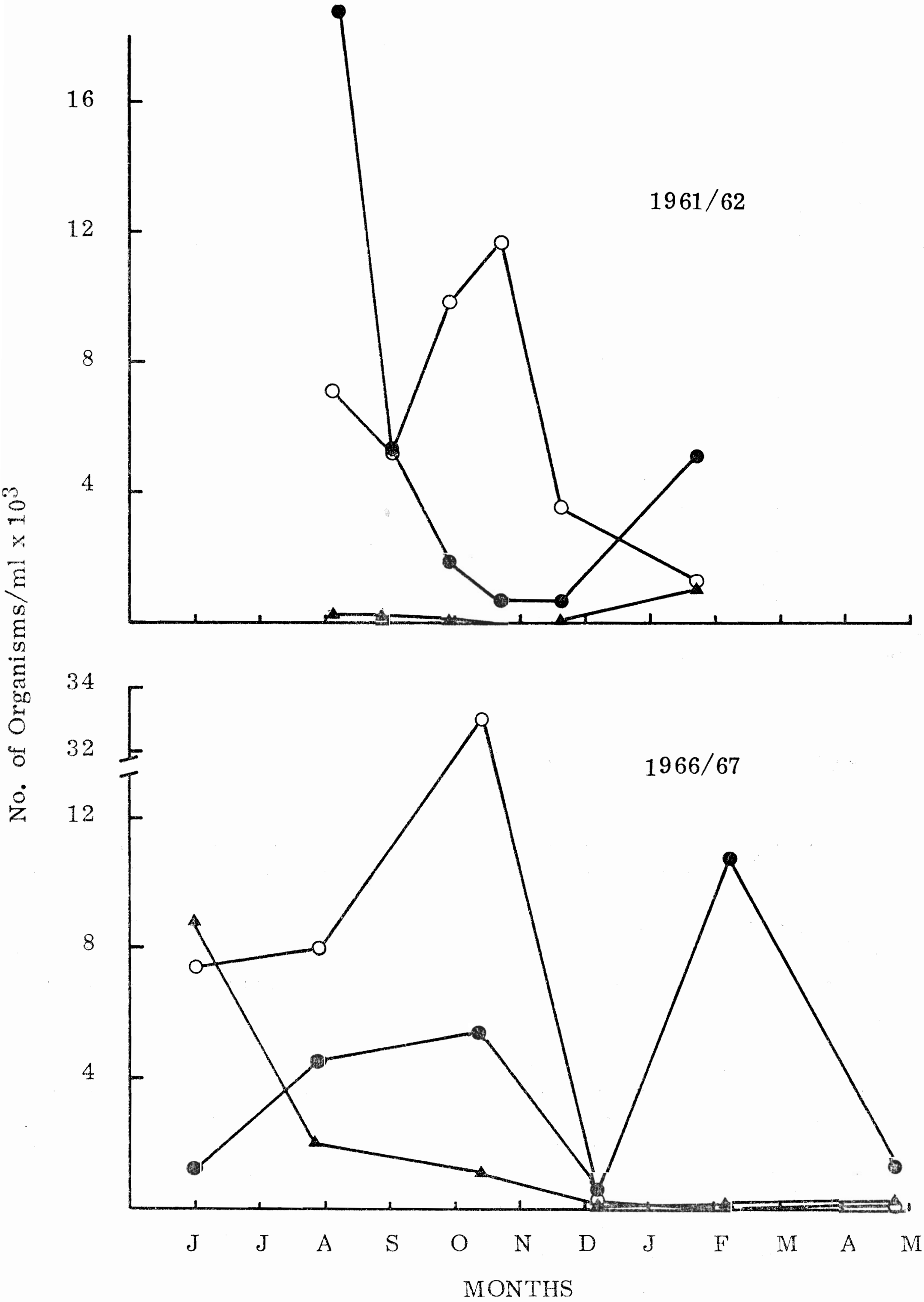

Fig. 6.

Periodicity of the major groups of phytoplankton in Llangorse Lake in 1961/1962 and 1966/1967
▲—▲ Chlorophyceae; ●—● Chrysophyceae; o—o Myxophyceae.

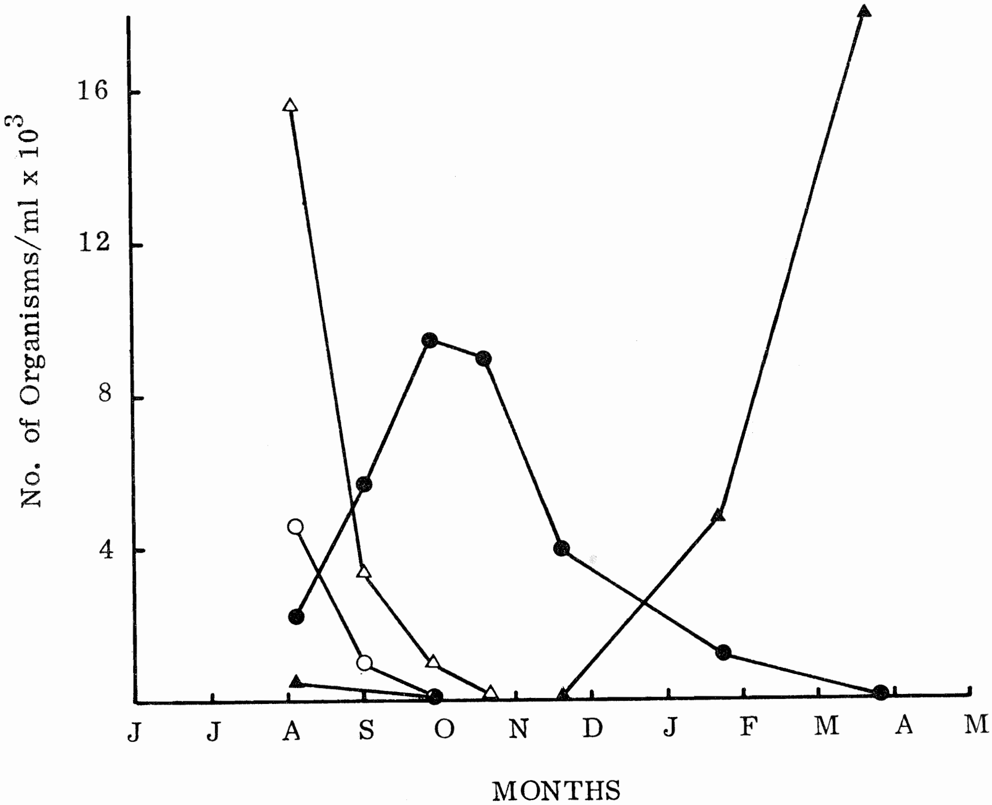

FIG. 7.

Periodicity of the major phytoplankters in Llangorse Lake in 1961/1962. ●——● *Microcystis flos-aquae*, o——o *Anabaena flos-aquae*, ▲——▲ *Asterionella formosa*, *Tribonema bombycinum*. △——△

seem to indicate that the bloom was greater in 1966 than in 1961. The dominant species preceding this bloom in 1966 were *Coelosphaerium kutzingianum* Naëgeli and *Dictyosphaerium ehrenbergianum* Naëgeli and both declined in numbers as the bloom of *M. flos-aquae* developed. A small burst of *Tribonema bombycinum* appeared between July and October 1966 but this appears not to have been as great as in 1961.

Species lists of the phytoplankton and of epiphytes and epiliths are presented in Tables 4 and 5.

4. DISCUSSION

Since Llangorse Lake is relatively shallow general stratification appears unlikely. When stratification does take place then it is probably a transient phenomenon confined to the deeper areas in the west part of the lake. One result of the general shallowness is the maintenance of a supply of nutrients for phytoplankton growth by mixing of waters during stormy periods. Another source of nutrients would appear to be from caravan sites and low lying grazing land around the lake which is flooded during winter because of impeded outflow caused by emergent hydrophytes in the Afon Llynfi. A further supply of nitrogen and phosphorus is in drainage from agricultural land, a problem which has probably increased in recent years since the

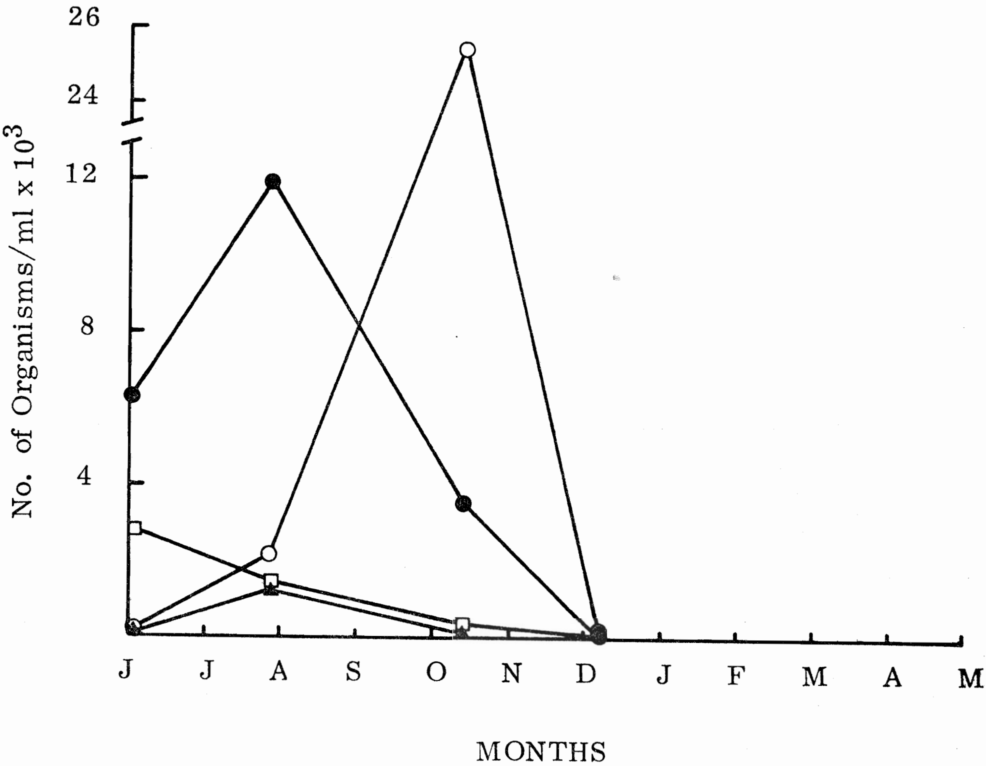

Fig. 8.

Periodicity of the major phytoplankters in Llangorse Lake in 1966/1967. ●——● *Coelosphaerium kutzingianum*, o——o *Microcystis flos-aquae*, ▲——▲ *Tribonema bombycinum*, □——□ *Dictyosphaerium ehrenbergianum*.

amounts of nitrogenous fertilizers applied to agricultural land in Britain doubled in the period 1957–1967 (Owens and Wood, 1968).

Intermittent attempts have been made to reduce the volume of flood water by straightening and deepening the outlet and Afon Llynfi. However, in recent years emergent hydrophytes have impeded water flow with consequent raising of winter lake levels.

Diatom blooms in winter and spring caused depletion of dissolved silica but when these growths subsided in summer and autumn the concentrations increased to former levels. Kilham (1971) determined the mean silica concentrations occurring when certain species of freshwater diatoms were dominant and found that the mean silica concentration when *Asterionella formosa* was dominant was 1·7 mg./l. In the winter of 1961/1962 increasing numbers of *A. formosa* coincided with a reduction of the silica concentration from 12 to 1 mg./l. by 13 March 1961, when sampling ceased, while the population of *A. formosa* apparently had not reached its peak. The winter diatom burst in 1966/1967 was followed by an increase in Chlorophyta in spring with *Dictyosphaerium ehrenbergianum* Naëgeli being prominent. Sampling during 1961/1962 commenced too late for the spring population of green algae to be collected.

Increasing lake water temperatures and pH in late summer were associated with a rising population of blue green algae and during 1961/1962 and 1966/1967 blooms

Table 4. *Species list and seasonal distribution of the common phytoplankters in 1961 Epiphytes and epiliths are marked with an* x

	Aug. 3	Sept. 1	Sept. 29	Oct. 20	Nov. 17	Jan. 20	Mar. 13*	Epiphyte	Epilith
CHLOROPHYCEAE									
Pandorina morum Bory.						R			
Chlorococcum humicola Rabenh.									x
Pediastrum boryanum Menegh.	R	R	R	R		R	R		
Scenedesmus quadricauda Breb.	R	R	R			R			x
Ankistrodesmus falcatus var. acicularis (A. Br.) G. S. West									x
Ulothrix zonata Kütz.	R	R	R				R	x	
U. moniliformis Kütz.							R		
Hormidium flaccidum Al. Braun.						R			x
Oedogonium acrosporum DeBary	R	R	R				R		
Stigeoclonium tenue Kütz.	R								
Chaetophora incrassata (Huds.) Hazen								x	
Coleochaete scutata Bréb.								x	
Pleurococcus naegelii Chod.								x	x
Cladophora fracta Kütz.								x	x
C. glomerata (L.) Kütz.									x
C. crispata (Roth) Kütz.								x	x
Spirogyra nitida Link.	R	R	R						x
Mougeotia capucina Agardh.		R	R						
Closterium ehrenbergi Menegh.	R	R	R						
Cosmarium reniforme (Ralfs.) Arch									x
MYXOPHYCEAE									
Microcystis flos-aquae (Wittr.) Kirchn.	I	F	F	R	I	I			
Oscillatoria limosa Agardh.		R	R	R					x
Anabaena flos-aquae Bréb.	F	I	R						
Chamaesiphon confervicola A. Br.								x	
BACILLARIOPHYCEAE									
Cyclotella operculata (Ag.) Kützing	R	I	R	R	R		R		
Melosira arenaria Moore				R	R	R			x
M. granulata (Ehrb.) Ralfs.				R	R	R	R		x
M. varians Agardh.		R	R	R	R		R		x
Achnanthes hungarica Grun.									x
Cocconeis placentula Ehrenb.				R				x	x
Asterionella gracillima (Hantzsch.) Heiberg	I	R	R	R	R	I	A		
Tabellaria flocculosa (Roth.) Kützing	R	R	R				R		
Meridion circulare (Grev.) Ag.		R	R	R				x	x
Fragilaria capucina Desmazières	I	I	I	R	R	R	I		
Synedra acus (Kütz.) Bacill.								x	x
S. pulchella (Ralfs.) Kütz.	R	R	R	R	R	R	I	x	x
S. ulna (Nitzsch.) Ehrenb.	R	R	R	R	R	R	R	x	x
Eunotia gracilis (Ehrenb.) Rabenh.			R						
Ceratoneis arcus (Ehrenb.) Kütz.									x
Rhoicosphenia curvata (Kütz.) Grun.				R					x
Amphora ovalis Kütz.			R	I	R		I		x
Cymbella lanceolata (Ehr.) Van Heurck.			R						x
Gomphonema constrictum Ehrenb.		R	R					x	x
G. geminatum Kütz.	R		R					x	x
RHODOPHYCEAE									
Batrachospermum moniliforme Roth.									x

13 March*—1 sample from station 8. R = Rare (<50 individuals per ml. of a standard net sample); I = Infrequent (51–500 individuals per ml.); F = Frequent (501–5,000 individuals per ml.); A = Abundant (>5,001 individuals per ml.).

Table 5. *Species list and seasonal distribution of the common phytoplankters in 1966/1967*

	June 1	July 27	Oct. 13	Dec. 7	Feb. 7	April 23	May 7*
CHLOROPHYCEAE							
Pandorina morum Bory.	R						
Chlorococcum humicola Rabenh.							R
Pediastrum boryanum Menegh.	I	R					
P. duplex var. recurvatum Meyen.	R	R				R	
Oocystis solitaria Wittr.			I				
Scenedesmus bijugatus Kütz.	R	R					
Dictyosphaerium ehrenbergianum Naëgeli	I	I					
Ulothrix zonata Kütz.					R	R	R
Oedogonium acrosporum De Bary					R	R	R
Stigeoclonium tenue Kütz.						R	
Spirogyra grevilleana Kütz.	R				R	R	
S. nitida Link.					R	R	R
Zygnema insigne (Hass.) Kütz.						R	
Closterium ehrenbergi Menegh.							R
Staurastrum anatinum Cooke and Willis	I	R					
MYXOPHYCEAE							
Gloeocapsa gigas W. et G. S. West	R						
Dactylococcopsis montana W. et G. S. West	R	R					
Microcystis flos-aquae (Wittr.) Kirchn.		I	F	R			
Coelosphaerium kützingianum Naëgeli	F	F	I	R			
Oscillatoria limosa Agardh.	R			R	R	R	R
Anabaena flos-aquae Breb.	R	R					
BACILLARIOPHYCEAE							
Cyclotella operculata (Ag.) Kützing	R	R	R			R	R
Melosira arenaria Moore						R	
M. granulata (Ehrb.) Ralfs.						R	
M. varians Agardh.				R	R		
Achnanthes hungarica Grun.					R		
Cocconeis placentula Ehrenberg.	R						
Asterionella gracillima (Hantzsch.) Heiberg.		R	I		R	R	
Tabellaria flocculosa (Roth.) Kützing	R	I					
Fragilaria capucina Desmazières				R	I	R	R
F. crotonensis Kitton					I	R	R
Synedra acus (Kütz.) Bacill.		R			R		
S. pulchella (Ralfs.) Kützing		R		R	I	R	R
Amphora ovalis Kütz.					I	R	
Cymbella lanceolata (Ehr.) Van Heurck	R				R		
Gomphonema geminatum Kütz.					R		
G. parvulum (Kütz.) Grunow					R		
Navicula cryptocephala Kütz.	R	R		R	I	R	
N. gracilis Ehr.						R	
N. humerosa Brébisson							R
N. minima Grun.				R	R		
N. rhynchocephala Kütz.		R	R		R		
N. viridis					R		
N. viridula Kütz.	R					R	
Frustulia rhomboides (Ehr.) De Toni	R	R		R	I		R
Pinnularia viridis (Nitzsch) Ehr.		R					
Pleurosigma attenuatum (Kütz.) Rabh.						R	
P. curvata Kütz.	R	R					R
Nitzschia sigmoidea (Ehr.) W. Smith				R			
Cymatopleura solea (Brébisson) W. Smith	R	R					
Surirella robusta Ehr.						R	
XANTHOPHYCEAE							
Tribonema bombycinum (Ag.) Derb. et Sol.		I	R				R
Botryococcus braunii Kütz.	I	R					
DINOPHYCEAE							
Gymnodinium sp.		R				R	
Ceratium hirundinella O.F.M.		R					

7 May*—1 sample from station 8. R = Rare (<50 individuals per ml. of a standard net sample); I = Infrequent (51–500 individuals per ml.); F = Frequent (501–5,000 individuals per ml.); A = Abundant (>5,001 individuals per ml.).

of *Microcystis flos-aquae* were recorded. It appears that the bloom problem has intensified since 1961/1962 as counts of *M. flos-aquae* were twice as high in October 1966 as in October 1961. This may be a consequence of the apparent increased nutrient supply to the lake during the period 1961/1962 to 1966/1967. For instance, there has been extensive development of lakeside caravan sites, increased recreational pressure on the lake by day-trippers and vacationers, and extensive cutting of littoral vegetation since 1961/1962. However, blooms have been observed over the centuries in Llangorse Lake (Griffiths, 1939) with the first record in 1188 by the Archbishop of Canterbury and Archdeacon of Brecon who were passing through the area. They noticed that the lake water and outflowing waters were tinged a deep green colour. Blooms were also recorded by sixteenth century observers (Griffiths, 1939). It would seem that blooms have recurred with increasing frequency, since local boatmen report that the lake now takes on a blue-green colour annually in late summer and early autumn. It may be that oxygen depletion occurs for short periods in localized areas; for example, among the broken reed beds when excess phosphorus, nitrogen and iron would be released from the lake bed and go into solution. At the autumn period of storms these nutrients become generally distributed throughout the water providing a favourable environment for the development of planktonic algae. The net result is the appearance of autumnal plankton blooms which become a regular feature (Chapman, 1970). A second period of deoxygenation at the decomposition of these annual masses of algae probably occurs.

In 1961/1962 a large population of *Anabaena flos-aquae* was present in the lake, certain strains of which have been reported to be toxic and to have killed fish and cows, and on some occasions have harmed man (Gorham *et al.*, 1964). Rose (1953) also indicates the possible severity of poisoning when he describes how a series of blooms of *Anabaena flos-aquae* at Storm Lake, Iowa, caused an estimated loss of about 8,000 domestic and wild birds and mammals of a wide variety of species. Strains of some *Microcystis* species, too, produce toxins which kill mice within 30 to 60 min. (Gorham *et al.*, 1964). A large fish kill involving roach but not pike and perch was reported in July 1970 which could have been due to a possible differential effect of toxins produced by blue-green algae since other possible causes of death were considered unlikely (Wye River Authority, 1971). A plankton sample collected by Dr. Jefferson of the Department of Zoology on 1 August 1970, indicated that *Microcystis flos-aquae* was again the dominant blue-green alga.

The increasing incidence of phytoplankton blooms and the cutting of littoral vegetation during shoreline development could account for the apparent increase of lake ammonia content in the period 1961/1962 to 1966/1967. The increased ammonia could be, in part, due to pollution from caravan sites and other activities of vacationers. High ammonia concentrations (0·25 mg./l.) were recorded also in 1970 by the Wye River Authority.

If Llangorse Lake is to continue as a multiple-use area then detailed limnological studies are required with a view to limiting nutrient input so that the already eutrophic condition of the lake is not exacerbated even further.

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