FRESHWATER BIOLOGICAL ASSOCIATION

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Report to North West Water

THE GREENING OF GRASMERE :

ITS PLANKTON PERIODICITY IN 1988

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1. Introduction

This short annual report is the sixth in a series that commenced in 1984; it summarises the continuing observations on the water quality in Grasmere in relation to the loads and performance of the Grasmere STW. In many ways, the plankton behaviour during 1988 was typical for the lake over the last eighteen years or so, despite signs of an ongoing increase in nutrient concentrations, although the relative predominance of chlorophyceae ("green algae") in the plankton is remarkable.

2. The Grasmere environment, 1988

The weather events influencing the physical environment of Grasmere in 1988 were, in the main, unextreme. The striking feature of the lake conditions was their temporal variability. Long spells of either cold or particularly warm weather were lacking, the incidence of high winds was scattered and several phases of relatively rapid flushing were experienced in the summer, besides the typical wet periods in winter.

The early part of the year was mainly mild and wet. The lake stratified during April, with the thermocline centred between 4 and 8 m depth (see Fig. 1a). Warm spells in mid-May, mid-June and early-July each brought about intensified stratification (the thermocline extending to within 2 m of the surface), though these alternated with periods of net cooling and wind-assisted penetrative convection, each time depressing the mixed depth to up to 8 m. Gales around 24/25 July were particularly effective in deepening the surface circulation to 10 m.

These alternations, with a frequency of about 4-20 days continued well into autumn: some weak restratification was observed in September and October, separated by the October holomixis.

The duration and extent of hypolimnetic anoxia was less pronounced in 1988 than in 1987 (see previous report, Reynolds, 1988), as judged by the area enclosed (in Fig. 1a) by the 0.5 mg O_2 l^{-1} isopleth. However, the inclusion of the area enclosed by the 5 mg O_2 l^{-1} isopleth serves to illustrate a point made previously (Reynolds, 1988) that, in addition to the expected consumption in the hypolimnion, oxygen becomes noticeably depleted around 7-8 m depth from quite early in the summer.

Also included in Fig. 1a is a representation of the changes in the Secchi-disk depth ($\underline{z}_s$) roughly corresponding to fluctuations in the minimal vertical extinction coefficient of between 0.4 and 0.9 m^{-1}. Overall, the clarity of Grasmere was as good as in any other recent year and there was no extended period of high turbidity.

The phases of high throughflow ("discharge"; subdivided to distinguish flushing of > 5% and > 10% of the volume each day), of wind mixing actually or potentially penetrating more than 3 m from the surface and the relation of the wind-mixed depth to the Secchi-disk depth, $\underline{z}_s$, are shown respectively in the bands labelled (b) to (d) in Fig. 1.

Of the major nutrients monitored regularly - soluble reactive silicon (as SiO_2) total and soluble reactive phosphorus, ammonium and nitrate + nitrite nitrogen - only the oxidised nitrogen species seemed to have departed from the trends of the last few years. Yet although DIN levels (i.e. $NO_3.N + NO_2N + NH_4N$, as summated in Reynolds & Lund, 1988) only briefly exceeded 400 μg N l^{-1} (close to the levels experienced in the early 1970s), there was no point when DIN even approached 80 μg N l^{-1} (Fig. 1g), the concentration hitherto adopted as being critical to phytoplankton selection (minimum: 162 μg N l^{-1}: 12 July). Winter levels of SRSi (~2.0 mg SiO_2 l^{-1}) were preserved with little reduction until May, when, coinciding with the vernal maximum of the diatom, Asterionella (see later), the recorded concentration fell to 0.05 mg SiO_2 l^{-1}. The heavy August rainfall, aided by wind-mixing, was instrumental in quickly restoring the dissolved silicon to its winter level but a second September growth of planktonic diatoms (this time dominated by Tabellaria flocculosa) temporarily reduced lake concentrations to a measured minimum of 1.2 mg l^{-1}. By the end of the year, however, values around 2.0 mg l^{-1} as SiO_2 again obtained.

TP levels remained within the range regarded as typical of the lake since 1979 (viz: 12-43 μg P l^{-1}; mean: 23.1; SE ± 7.3; $\underline{n}$ = 27), while SRP levels detected at the beginning and the end of the year (again typically) exceeded 10 μg P l^{-1}. Through most of the growing season, however (mid-February to late-October), concentrations hovered in a range (1-5 μg l^{-1}) suggesting possible limitation of growth though it fell below 0.6 μg l^{-1} only briefly, during mid-July (Fig. 1f). As pointed out in a previous report (Reynolds, 1988), limitation of algal crops by the level of P-loading on the lake may well be weakening.

3. Plankton in Grasmere, 1988

In Fig. 1(i), semilogarithmic representations of the fluctuations in the more conspicuous planktonic algal species are presented. Apart from a persistent, residual and slowly accreting population of *Chlorella* species, together with 'background' concentrations of *Chlamydomonas*, *Rhodomonas* and *Chrysochromulina*, the biomass of most other algae was insignificant until April. A recognisable spring maximum occurred in late-April, dominated by *Chlorella* (30 000 cells ml^{-1}) and Dinobryon (800 cells ml^{-1}), and was closely followed by a maximum recorded concentration of *Asterionella* of 2 800 cells ml^{-1}. With surface temperatures exceeding 14C (Fig. 1a), zooplankton production, first of ciliates, then of *Daphnia*, responded to the relative abundance of ingestible foods by eventually reducing the standing crops of the algae.

Warm, stable, clear-water conditions in June provided the conditions anticipated to support prolific *Sphaerocystis* increase (maximum, 20 June: 9 300 cells ml^{-1}), until increased mixing initiated a 'new' succession involving *Asterionella*, *Cryptomonas* and a resurgence of *Chlorella* (9000 ml^{-1}), followed by a phase of renewed activity of grazer populations. The late-July mixing was sufficient to truncate and introduce another successional phase, eventually culminating in dominance by *Tabellaria* (max. 700 cells ml^{-1}) and *Chlorella*, (> 7 000 cells ml^{-1}), the latter persisting at steadily reducing levels to the year end.

The total algal biomass in the lake, as judged by its chlorophyll content (Fig. 1j), fluctuated through the growth period, between 2 and 17 µg Chlorophyll l^{-1}; between 1 March and 31 October, the summer chlorophyll concentration (chl_s) averaged 8.6 µg chl *a* m^{-3} (SE ± 4.5; n = 12), one of the lowest values derived since 1972. The corresponding annual average (6.2, ± 4.8; n = 27) was similarly diminuitive.

Taking the year as a whole, the 'traditionally' conspicuous species have tended to be strongly represented by nanoplankters, *Asterionella*, *Dinobryon*, and Tabellaria, while Anabaena, Cryptomonas and Rhodomonas have fared relatively poorly. The most striking feature of the year has been the abundance of Chlorella and the size of the Sphaerocystis maximum. Both taxa are supposed to respond to conditions of good insolation, in this instance, perhaps, biassed by high average clarity rather than long spells of sunny weather; collectively, they contribute to an impression that 1988 was the year of the green algae in Grasmere.

4. Discussion and Conclusions

Nothing occurred in Grasmere during 1988 that detracts from the oft-stated view that its planktonic production is generally truncated below the level that its nutrient loading has the potential to support. For this reason, the 1988 data have happily compounded the string of annual reports that primarily limnological controls have been responsible for maintaining a comfortable lack of the water-quality problems that might have been suggested at the time of the commissioning of the Grasmere STW was proposed.

Nevertheless, it cannot be stated with the same certainty that the explanation is entirely due to frequent phases of hydraulic flushing (cf. Reynolds & Lund, 1988). The events of 1988 seem to be due, in at least equal measure, to the brevity of any given set of limnological constancy (either thermally stable or cool, well-mixed conditions) to sustain the growth of any single group of typically respondent species. Rather, alternations between physical stability and well-mixed conditions have provided the ultimate control in limiting successional progress short of its predictable outcome, within the expanding potential capacity of the nutrient loads upon the lake to support. This potential continues to pose a counter to any complacency about the perceived water quality in the lake. So far as the current year's observations are concerned, the bias towards the relative success of the Chlorophytes (the green algae) in Grasmere should serve as an apposite reminder of latent probabilities.

Acknowledgements. In presenting this report, I am extremely conscious of the contribution of Dr G. Hall who has included the collection of all field samples and data within his busy programme of observations in the lake. His equanimity about this added responsiblity is most appreciatively acknowledged. Eric Rigg, Jean Lishman and Julie Corry have, together, carried out most of the direct analyses on the collected materials and it is a pleasure, once again, to be able to praise their continued collaboration: they have made my task of interpretation so much lighter. I am pleased to be able to thank Joyce Long for her careful preparation of the typescript.

References

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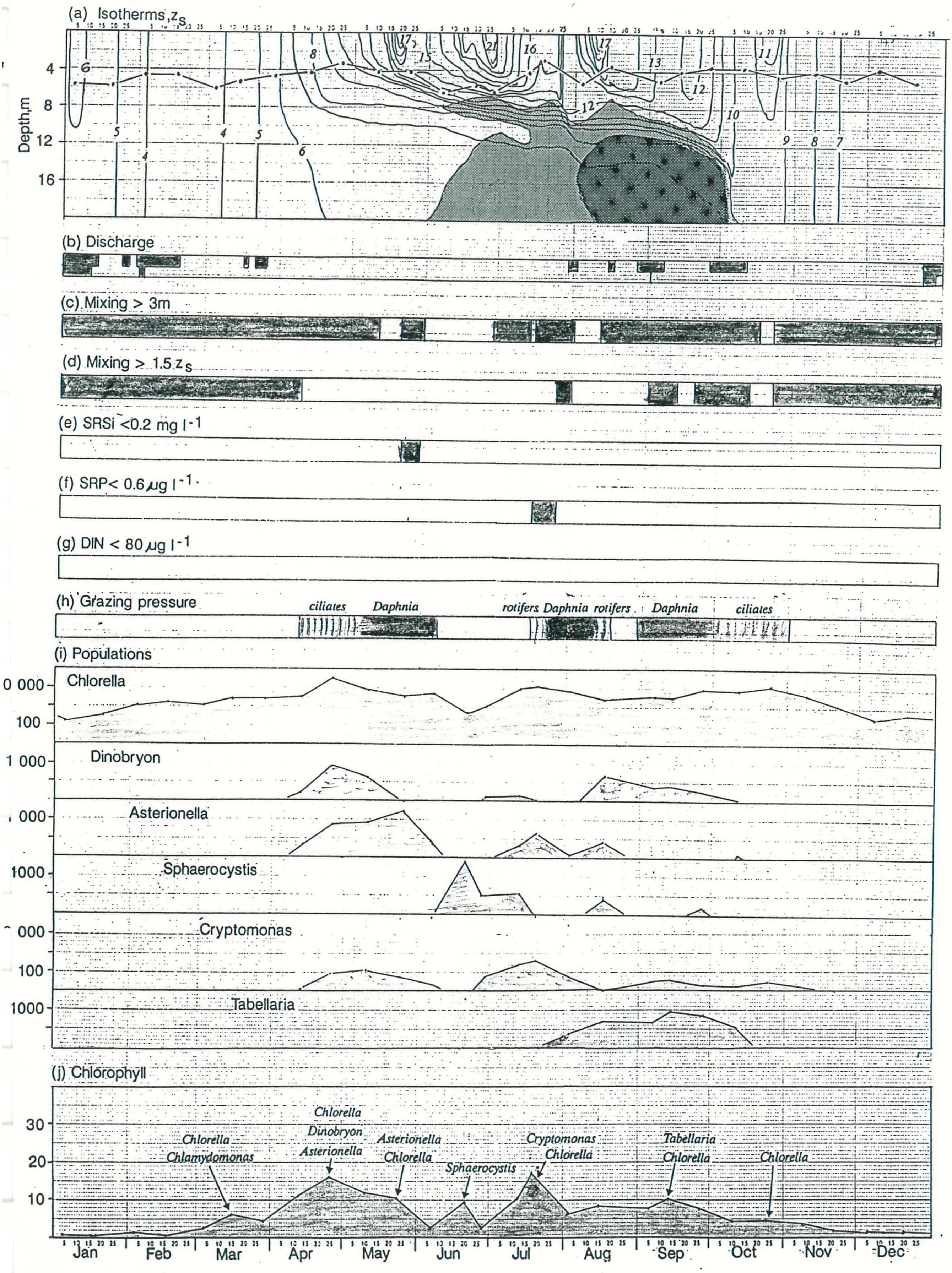
Reynolds, C.S. & Lund, J.W.G. (1988). The phytoplankton of an enriched, soft-water lake subject to intermittent hydraulic flushing. Freshwater Biology, 19, 379-404. (Published version of the Freshwater Biological Association report to North West Water, WI/207/5).

Fig. 1. Grasmere, 1988 (a) Depth time distribution of isotherms, Secchi-disk transparency and the extent of O_2-deficient water (light stippling, $[O_2] < 5$ mg l^{-1}; heavy shading, < 0.5 mg O_2 l^{-1}); (b) flushing of the lake exceeds (above) 5% of the lake per day; (below) 10% per day; (c) periods when mixing penetrates > 3 m and (d) > 1.5 Secchi-disk depth; periods when (e) soluble reactive silicon < 0.2 mg l^{-1} as SiO_2; (f) soluble reactive phosphorus < 0.6 μg l^{-1} as P; (g) dissolved inorganic nitrogen species (NH_4N, NO_3N and NO_2N) together total < 80 μg l^{-1} as N; (h) grazing rate > 0.3 d^{-1}; (i) shows semilog plots of cell concentrations of the species named; (j) shows the fluctuations in recorded chlorophyll a concentration (in μg l^{-1}) in the upper 5 m of Grasmere and notes the seasonal variation in its dominant algal contribution.



(a) Isotherms, z_s
Depth,m
(b) Discharge
(c) Mixing > 3m
(d) Mixing > 1.5 z_s
(e) SRSi <0.2 mg l^{-1}
(f) SRP< 0.6 µg l^{-1}
(g) DIN < 80 µg l^{-1}
(h) Grazing pressure
ciliates
Daphnia
rotifers
Daphnia
rotifers
Daphnia
ciliates
(i) Populations
Chlorella
Dinobryon
Asterionella
Sphaerocystis
Cryptomonas
Tabellaria
(j) Chlorophyll
Chlorella
Chlamydomonas
Chlorella
Dinobryon
Asterionella
Asterionella
Chlorella
Sphaerocystis
Cryptomonas
Chlorella
Tabellaria
Chlorella
Chlorella
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec