Institute of Freshwater Ecology

A short pilot study of the phytoplankton of rivers of the Humber catchment

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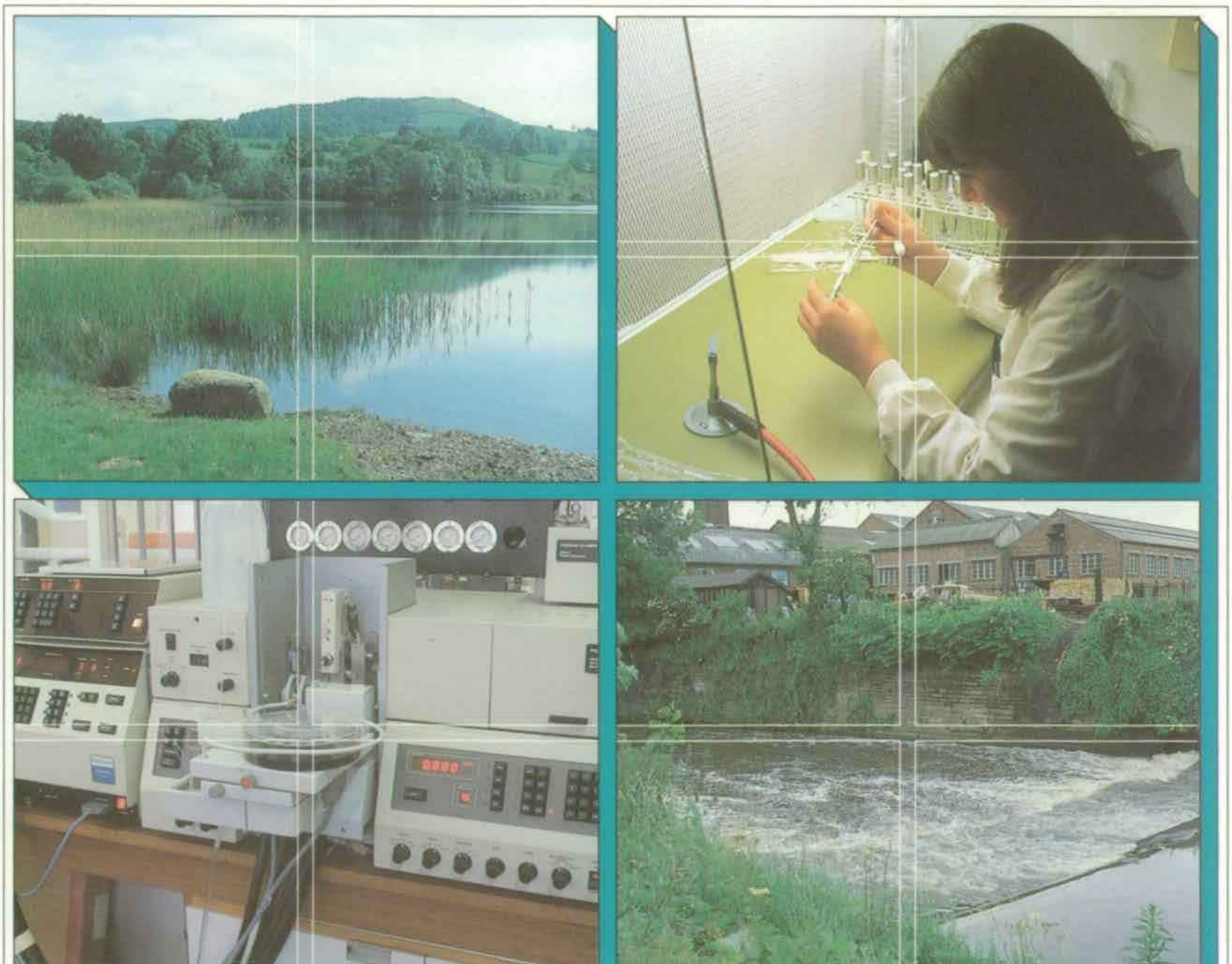

Natural Environment Research Council

A short pilot study of the phytoplankton of rivers of the Humber catchment

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Report submitted to RACS(r), LOIS special topic committee and NERC grants committee

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SUMMARY

This short survey of the phytoplankton of the Humber feeder-rivers was undertaken in two parts. Firstly, data from the NRA and Yorkshire Water were assessed. Secondly, five Humber rivers were sampled at fortnightly intervals between May and September 1993. Phytoplankton chlorophyll *a* and cell number were assessed in relation to discharge. Comparative studies were carried out on the River Great Ouse on which IFE holds five years data. These Humber feeder rivers have long tidal sections which tend to be very turbid. These reaches were not studied and were considered outside the scope of this project.

Hydrology has an important role in determining the extent and timing of the phytoplankton populations in rivers. 1993 was a particularly wet year and, in the more northern rivers, only small phytoplankton populations were observed. But large populations developed in the River Trent despite the adverse conditions. Archived data, obtained from Yorkshire Water plc indicates that significant phytoplankton populations will develop in drier years and in intermediate years. The feeder-streams of the Humber offer a range of contrasting river types on which to the dynamics of phytoplankton populations and the factors controlling the flux of phytoplankton to the estuary.

GLOSSARY

IFE	Institute of Freshwater Ecology
LOIS	Land-Surface-Interaction-Study
RACS	Rivers-Atmosphere-Coast-Study
RACS(r)	RACS(River basins)
NRA	National Rivers Authority

1. INTRODUCTION

This pilot study arose out of a special topic proposal for LOIS RACS(r):

> "The effect of environmental conditions on the plankton production dynamics in feeder rivers of the Humber Estuary and the flux of autochthonous carbon to the estuary."

The objectives of the original proposal were:

> "To quantify the size, composition, production and *in situ* growth rates of the phytoplankton of the Yorkshire Ouse. To quantify the major loss processes (grazing and sedimentation). Develop models relating environmental conditions to phytoplankton levels and the output of autochthonous production to the Humber estuary."

The original proposal is given in Appendix 1. The referees comments together with the senior author's responses, submitted in autumn 1992, are given in Appendix 2. This project requires there to be a significant phytoplankton in the rivers. Since the referees questioned the presence of phytoplankton, this pilot study was commissioned by the LOIS Steering Committee to assess the distribution of phytoplankton in the rivers feeding the Humber. This study is concerned with this aspect only and not the much wider part of the original proposal.

Of the larger British rivers only the phytoplankton of the Thames has been studied extensively (Fritsch, 1902, 1903; Rice, 1938a & b; Lack, 1971; Lack & Berrie, 1976; Whitehead & Hornberger, 1985) but there have been some studies on others (Shroeder, 1930; Southern & Gardiner, 1938; Swale, 1964, 1969). In both this and the original proposal the authors are not directly concerned with drifting material which has become detached from the river bed, although the smaller the river the more likely this is to be a significant component (Marker & Gunn, 1977). More recently two important pieces of research have been undertaken by the

Institute of Freshwater Ecology (IFE). Firstly, Dr C.S. Reynolds has studied the distribution of phytoplankton in the River Severn, particularly in relation to dead zones (Reynolds *et al.*, 1989, 1990, 1991). Secondly, IFE set up the Eastern Rivers Laboratory to study large river ecosystems in the east of England. Part of this work, commissioned by the Department of the Environment (and subsequently the NRA), concerned the nature of the turbidity in the River Great Ouse and the associated phytoplankton (Marker & Collett, 1991). The Thames, Great Ouse and Trent are large, slow-flowing regulated rivers in southern and eastern England which carry significant phytoplankton populations. Increased nutrient concentrations over recent decades may well have favoured this phytoplankton growth. Thus the original proposal to the LOIS committee was a natural extension of this work, making use of contrasting river types in the Humber catchment.

2. METHODS

2.1 Archived Data

Severn Trent NRA, Northumbria and Yorkshire NRA and Yorkshire Water plc provided some data which is assessed in the next section.

2.2 Sampling Sites

The RACS(r) core programme managers are charged with the responsibility of estimating the flux of key anions, cations and organic materials to the estuary. Primary sampling sites are therefore, for the most part, at downstream points on each river. Since the purpose of this pilot study was to determine the magnitude and duration of phytoplankton populations, these downstream locations were considered to be the most useful. Eastern Yorkshire and Lincolnshire are very low lying and as a consequence there are long stretches of tidal river. For example, on the R. Trent there is ca 80-90km of tidal river from Cromwell lock to the Humber and for the Yorkshire Ouse ca 30 km from Naburn Lock to the Humber. Many of these tidal reaches are very turbid and the phytoplankton dynamics will be quite different from the non-tidal river. It is not the purpose of this pilot study to include the tidal zone, although it may well explain one of the referees comments on the Yorkshire Ouse. The sites used for the field programme are briefly described below (see also Fig. 1).

Site 1. River Derwent SE706364 at Derwent Bridge. Selected for ease of access although ca 8 km from the tidal barrage.

Site 2a. Yorkshire Ouse at Naburn lock SE594445 (just above the tidal limit). This is an NRA sampling point at which discharge data are available. There is no simple access to the middle of the river for routine sampling upstream of a wide spill weir which marks the tidal limit. Samples had to be taken close to the bank with the risk of profound edge effects.

Site 2b. Yorkshire Ouse at Clifton Bridge in York SE589528. Upstream of the tidal limit but with easy access for sampling from the centre of the river at the bridge.

Site 2c. Boating marina at Naburn SE599462. This marina is directly linked to the Yorkshire Ouse but is not flushed out during spates to the same extent as the main river.

Site 3. River Aire at Chapel Haddlesey, SE578262. This site is just above the tidal limit and was chosen in preference to Beal (SE534255) because of ease of access.

Site 4. River Don. Sprotbrough, SK538016. There were two locks and a weir upstream, so the river was well mixed. This site was chosen because it is upstream of major divisions into separate channels in Doncaster.

Site 5 River Trent at Cromwell lock (SK808612). There is a large commercial lock system and the river side area is very wide so that the upstream point is well into the river, away from the lock and upstream of the weir. Sampling was from clear water at the most downstream non-tidal point, ca ⅓ of the distance across the river. This river carries between 30 to 50% of the discharge into the Humber. However, because of its midlands catchment it has more in common with the other large south-eastern rivers (ie the Great Ouse and Thames) than the more northern rivers supplying the Humber estuary.

Site 6. River Great Ouse at Huntingdon, TL243715. This river was chosen for comparative purposes because the IFE has five years phytoplankton data at this site.

2.3 Field and Laboratory Methods

At fortnightly intervals water samples were routinely collected from just below the river surface using polyethylene wide-mouthed bottle, weighted with lead. For analysis of phytoplankton chlorophyll *a*, samples of well mixed river water were filtered through 9 cm diameter glass-fibre filters (Whatman GF/C) and extracted in ethanol, followed by spectrophotometry on a Philips PU8740 following the procedures outlined in Marker *et al.* (1980 a & b) and Marker and Jinks (1982). Corrections were made for chlorophyll degradation using the acidification procedure recommended for ethanol (Marker & Jinks, 1982; DIN, 1986). Phytoplankton composition was estimated by examining samples of river water preserved in Lugol's iodine. Algae from the Humber rivers were counted at the IFE Windermere Laboratory by sedimentation in previously calibrated split sedimentation chambers using a random field method, under a Nikon TMS microscope. Algae from the Great Ouse counted under a Leitz Fluovert at Monks Wood (Lund *et al.*, 1958).

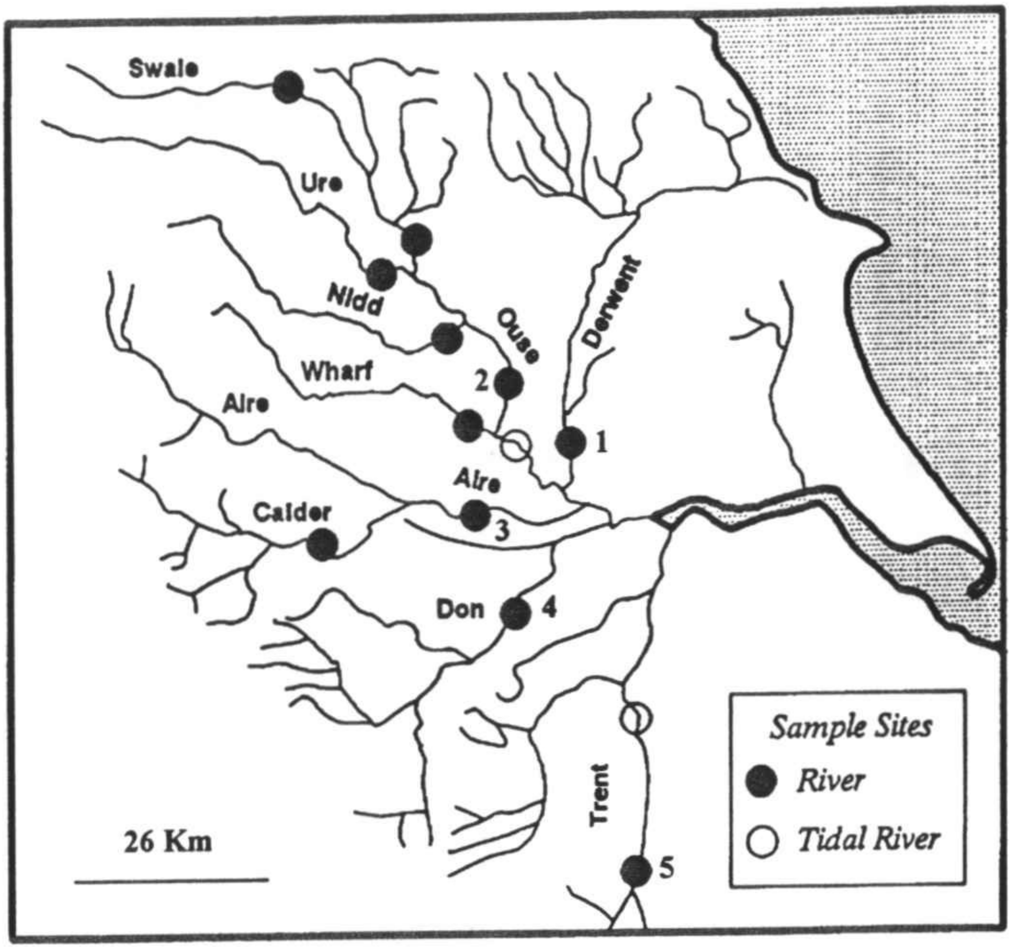

Fig 1. Primary sampling sites for the routine core programme. Sites used in this pilot study are numbered.

3. ARCHIVED NRA AND WATER COMPANY DATA

Data were obtained from the following rivers.

1. Yorkshire Water plc supplied phytoplankton data for the Yorkshire Ouse and the River Derwent for the period between 1989 and 1992.
2. Northumbria and Yorkshire NRA provided matching discharge and nutrient data for the Yorkshire Ouse and Derwent. They also supplied a limited amount of chlorophyll *a* phytoplankton data for the Yorkshire Ouse.
3. Severn-Trent NRA provided a report from the Water Research Centre (Medmenham) on the River Trent phytoplankton between 1972 and 1974.

3.1 The Rivers Derwent and Yorkshire Ouse

Yorkshire Water provided phytoplankton counts for the River Derwent at Barmby Dam between mid-summer 1989 and mid-summer 1990 and the data are summarised in Fig. 2. This data are useful because they cover the first part of a very dry year. Centric diatom numbers (*Stephanodiscus*) reached over 11000 cells ml^{-1} at the end of May 1990. Most of the other algae occurred in far lower numbers, frequently little more than few hundred per ml. Data were available for the Yorkshire Ouse for a much longer period and show interesting differences between years. High numbers of centric diatoms numbers were recorded in all three years but the timing varied between years (Fig. 3), with maxima reached slightly later in the year, both in 1991 and 1992. Pennate diatoms (largely *Nitzschia* spp) were present in higher concentrations than in the Derwent and may have arisen from the periphyton but this is not clear from the level of identification. Discharge data (Fig. 4) indicate that the rise of the phytoplankton is associated with reduction in river flows. Nitrate and phosphate data indicates that both nutrients were present in abundant supply during the summer (Fig. 5).

Low phosphate concentrations were associated with high discharge.

3.2 River Trent

The National Rivers Authority (Severn-Trent Region) could only provide phytoplankton data for 1973 and 1974. These data were obtained from near Nottingham on a contract carried out by the Water Research Centre and are restricted to total algal numbers (Fig. 6). In both 1973 and 1974 highest numbers occurred between the middle of May and the beginning of June, strongly suggesting dominance by *Stephanodiscus*. We offer no explanation for the point maximum of over 20000 cells per ml at the beginning of August when the counts on both the preceding and succeeding weeks were so much lower.

Only the most basic phytoplankton chlorophyll *a* data were provided and these are summarised below:

	Chlorophyll —— $mg\ m^{-3}$		
	mean	**max.**	**min.**
1968	26	150	0
1969	24	93	0
1970	26	170	0
1971	19	62	0

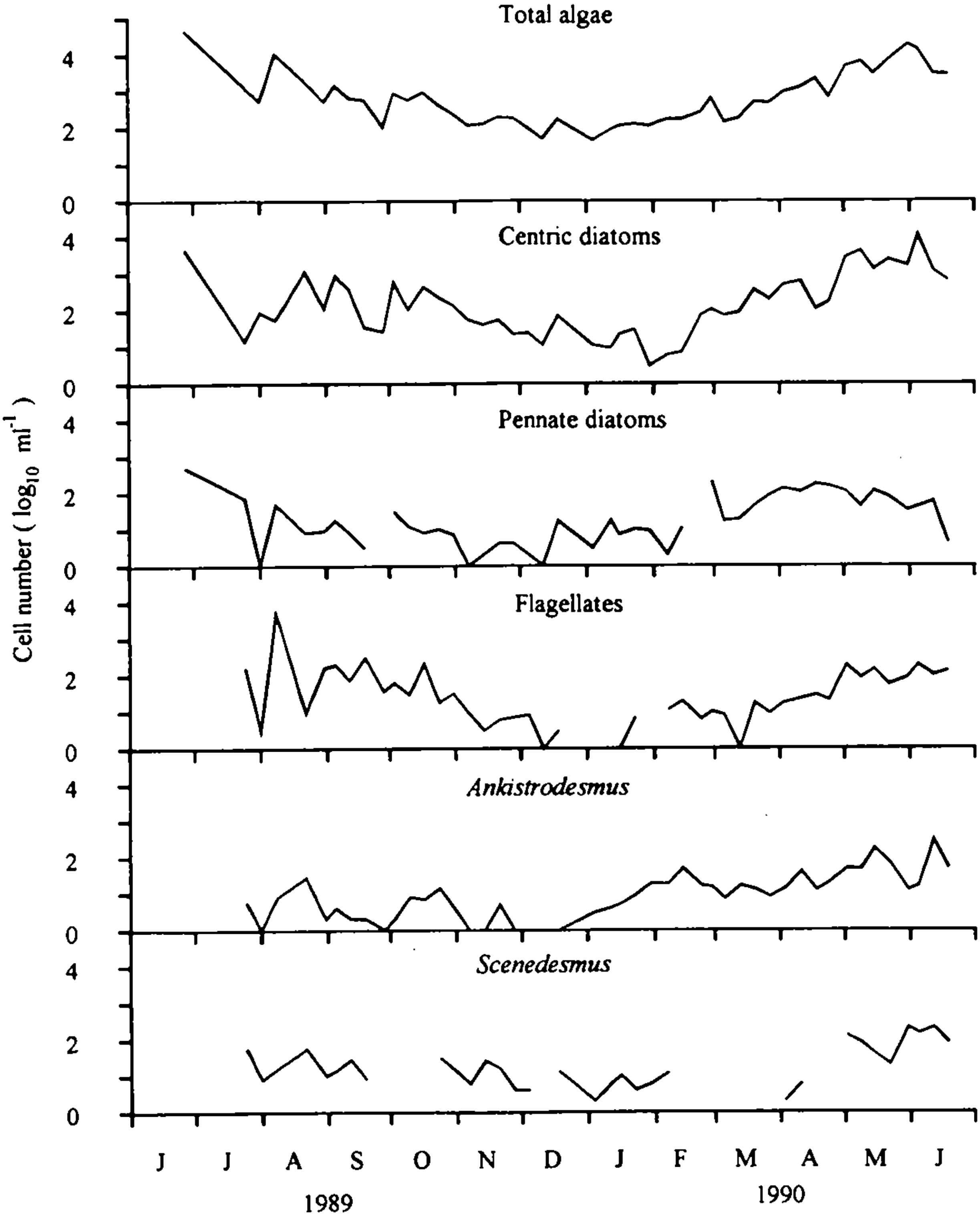

Fig. 2. Seasonal variation in phytoplankton numbers in the River Derwent.
Data provided by Yorkshire Water plc.

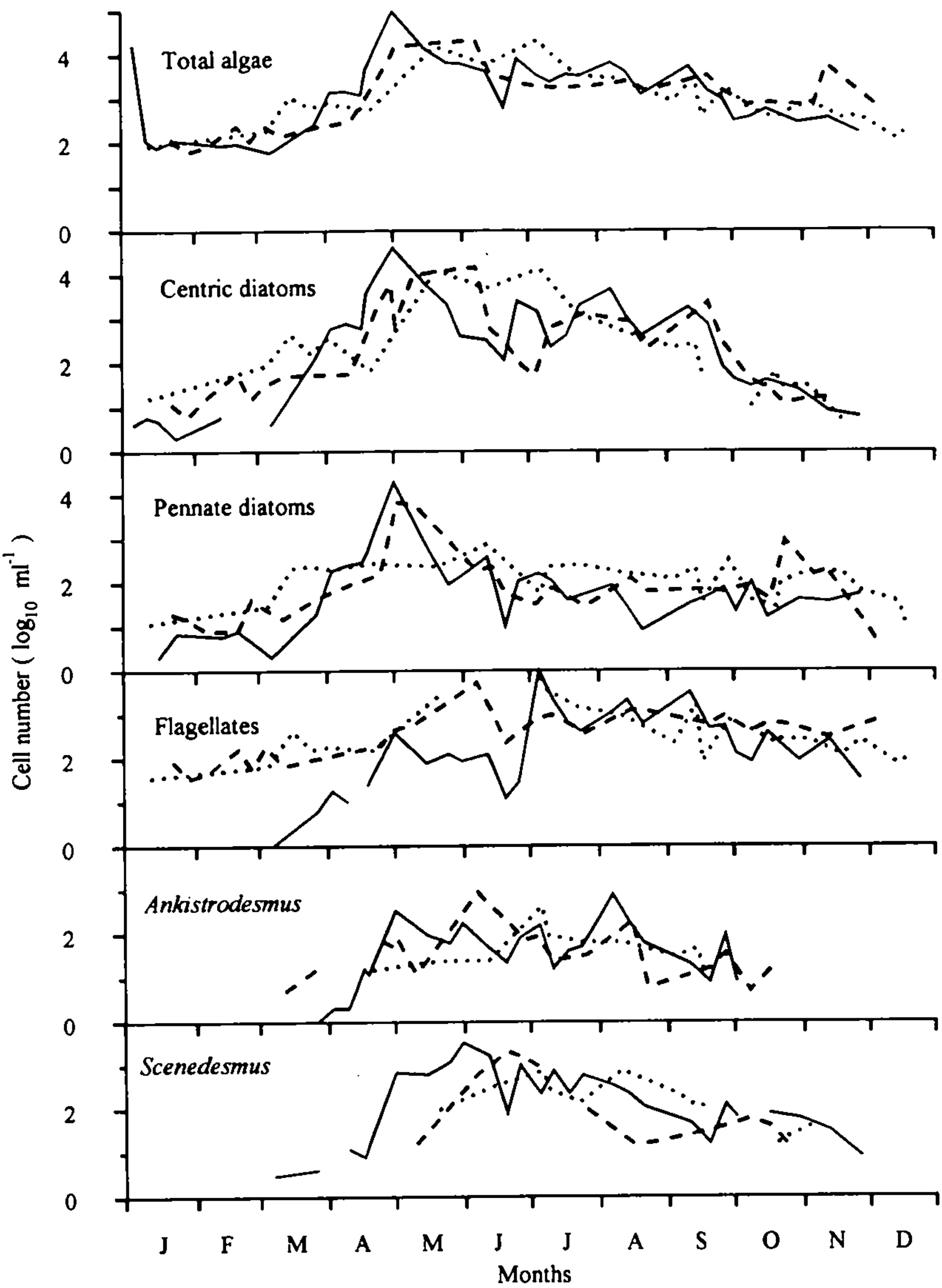

Fig. 3. Seasonal variation in phytoplankton numbers in the Yorkshire Ouse:
——— 1990,
– – – – 1991,
· · · · · · 1992.

Data provided by Yorkshire Water plc.

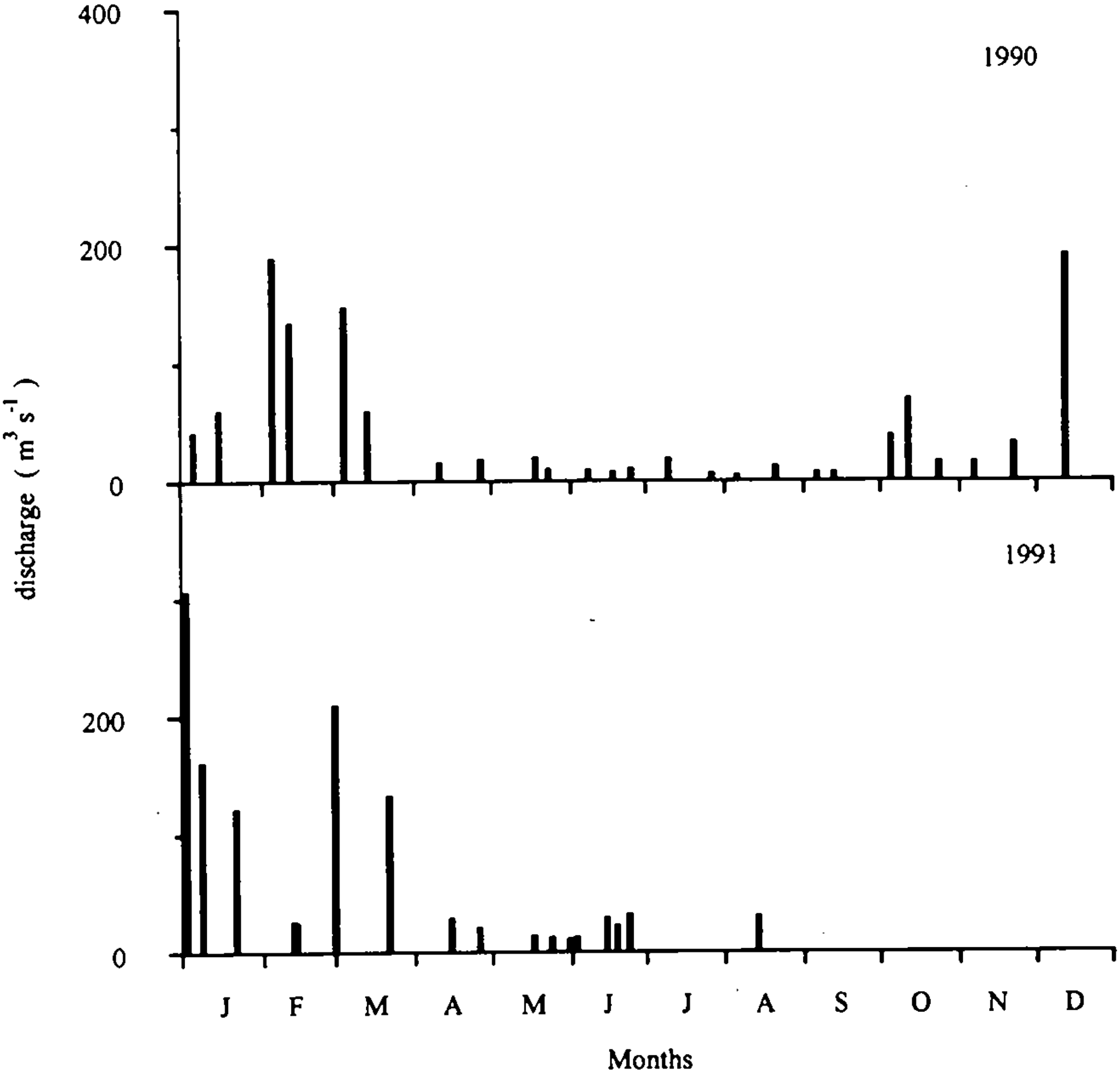

Fig. 4. Discharge of the Yorkshire Ouse at Naburn Lock during 1990 and 1991. Individual data points are spot mean daily flows.

Data provided by the National Rivers Authority (Northumbria and Yorkshire Region).

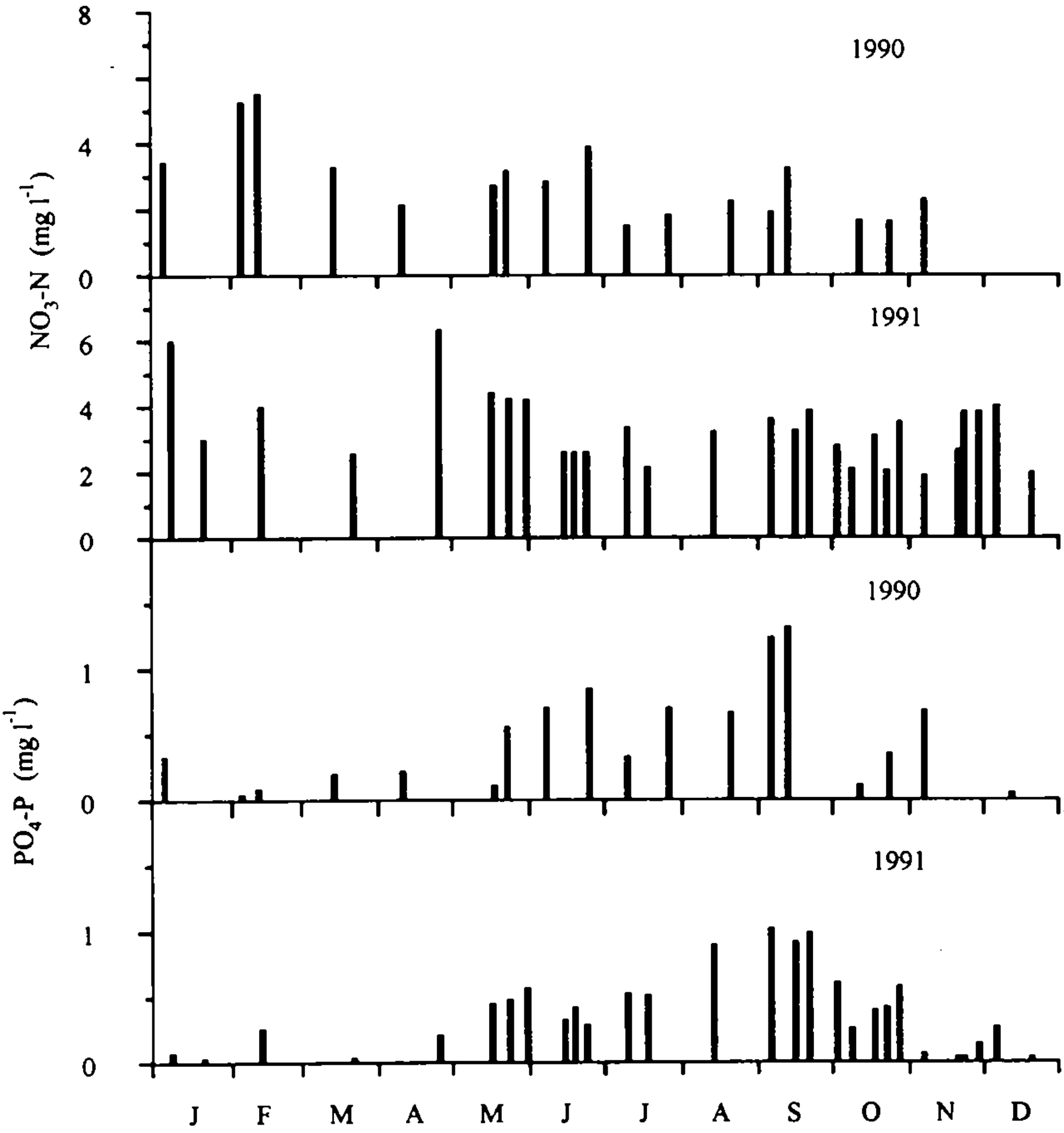

Fig. 5. Nitrate (NO_3-N) and phosphate (PO_4-P) concentrations in the Yorkshire Ouse at Naburn Lock during 1990 and 1991.

Data provided by the National Rivers Authority (Northumbria and Yorkshire Region).

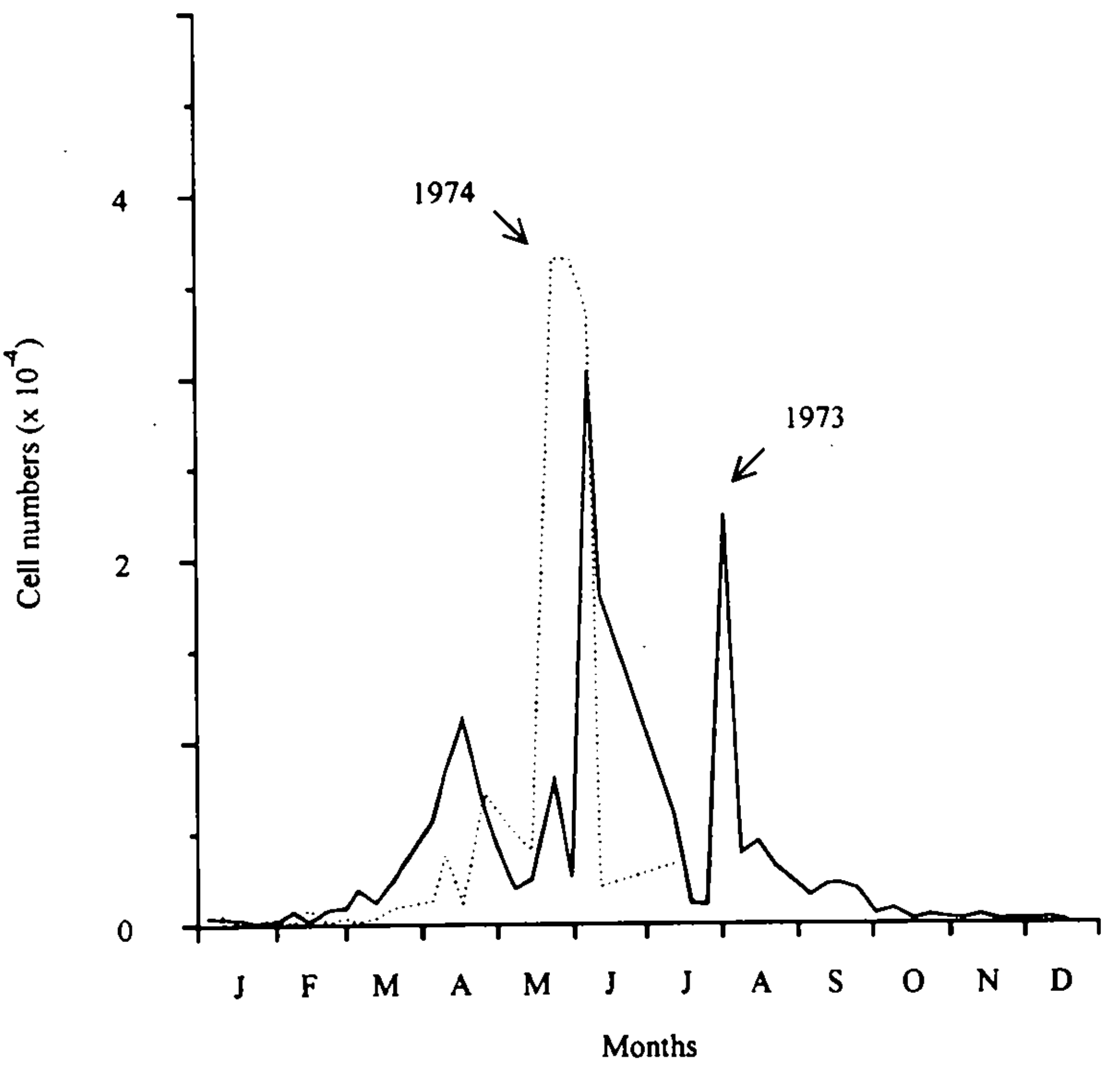

Fig. 6. Seasonal variation in phytoplankton in the River Trent between 1973 and 1974.

Data provided by the National Rivers Authority (Severn-Trent Region).

4. IFE SAMPLING PROGRAMME IN 1993

The five Humber rivers sampled during 1993 will be discussed individually and then finally compared with the River Great Ouse.

4.1 River Derwent (Fig. 7)

The R. Derwent catchment is to the north and east of Yorkshire. The spring period was associated with a series of spates until the middle of May, and apart from relatively small fluctuations in June, the next spates were in August and September. Only limited nutrient data were available indicating moderately high nitrate levels and apparently low nitrite concentrations (calculated as TON - NO_3-N). Phosphate concentrations were also low with, unfortunately the lowest quoted concentrations being <30 $\mu g\ l^{-1}$ which is well above truly nutrient limiting concentrations. Phytoplankton chlorophyll *a* concentrations were generally low throughout the summer and for this reasons cell counts were not carried out.

4.2 Yorkshire Ouse (Figs 8 and 9)

This river rises in the north and east of Yorkshire. There are three main tributaries upstream of York, the Swale, the Ure and the Nidd; the Wharfe enters in the tidal reaches well downstream of York. Discharge and nutrient concentrations were determined from Naburn Lock and hence includes the sum of the inputs from the Swale, Ure and Nidd but excludes that from the Wharfe. High nitrate concentrations were associated with low nitrite levels. Phosphate concentrations were moderate for plant nutrition except during spates when they were quoted by the NRA at <30 $\mu g\ l^{-1}$, presumably their lower detectable limit. Silica was only measured on three occasions and was high in every case. There were major spate events through the spring until the beginning of June, followed by a dry spell for six weeks. Further spates occurred from the middle of July. At Clifton chlorophyll concentration rose during June to 25 mg m^{-3} before collapsing as discharge increased. There were somewhat lower

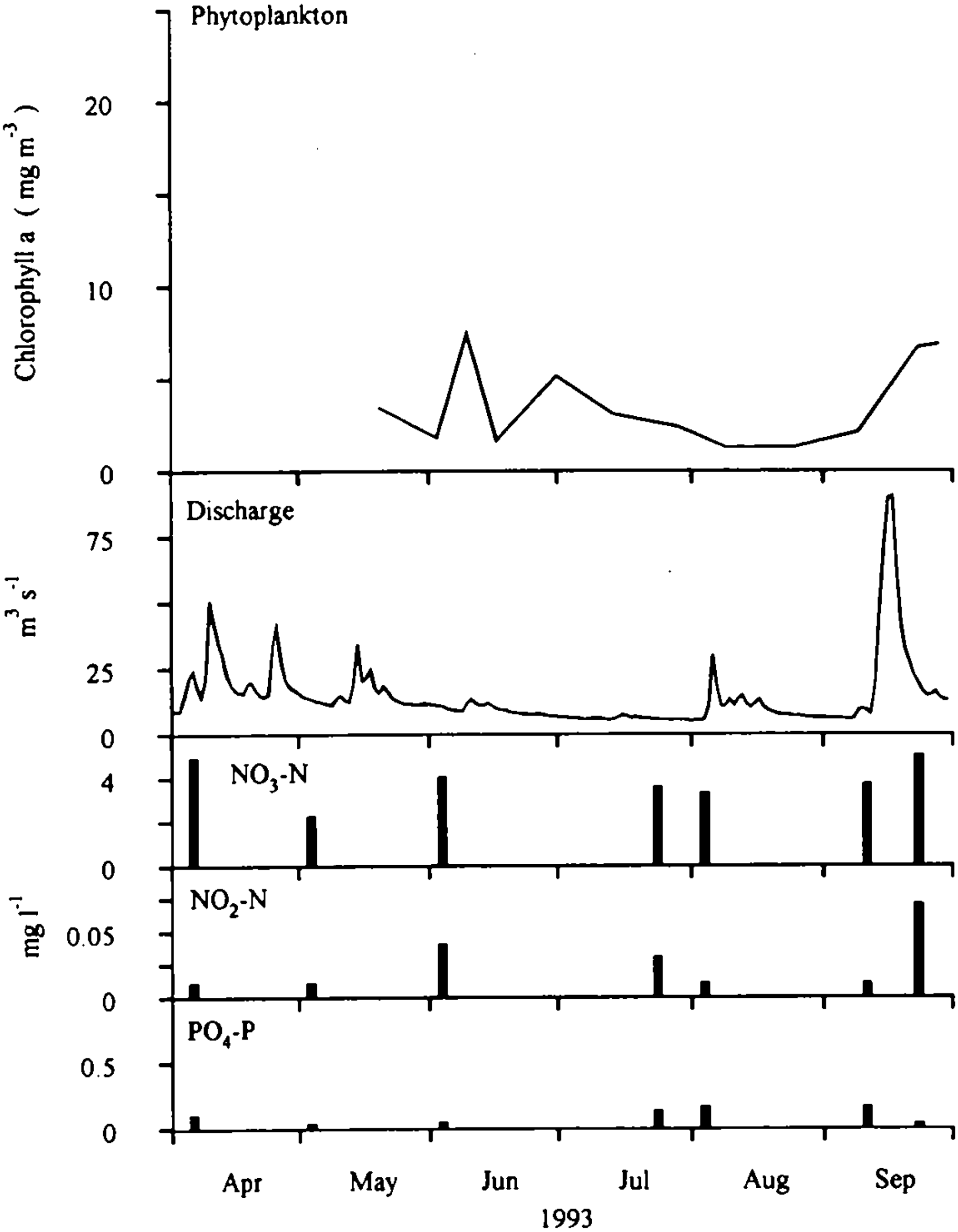

Fig. 7 Variation in phytoplankton chlorophyll *a* and associated variables in the River Derwent.

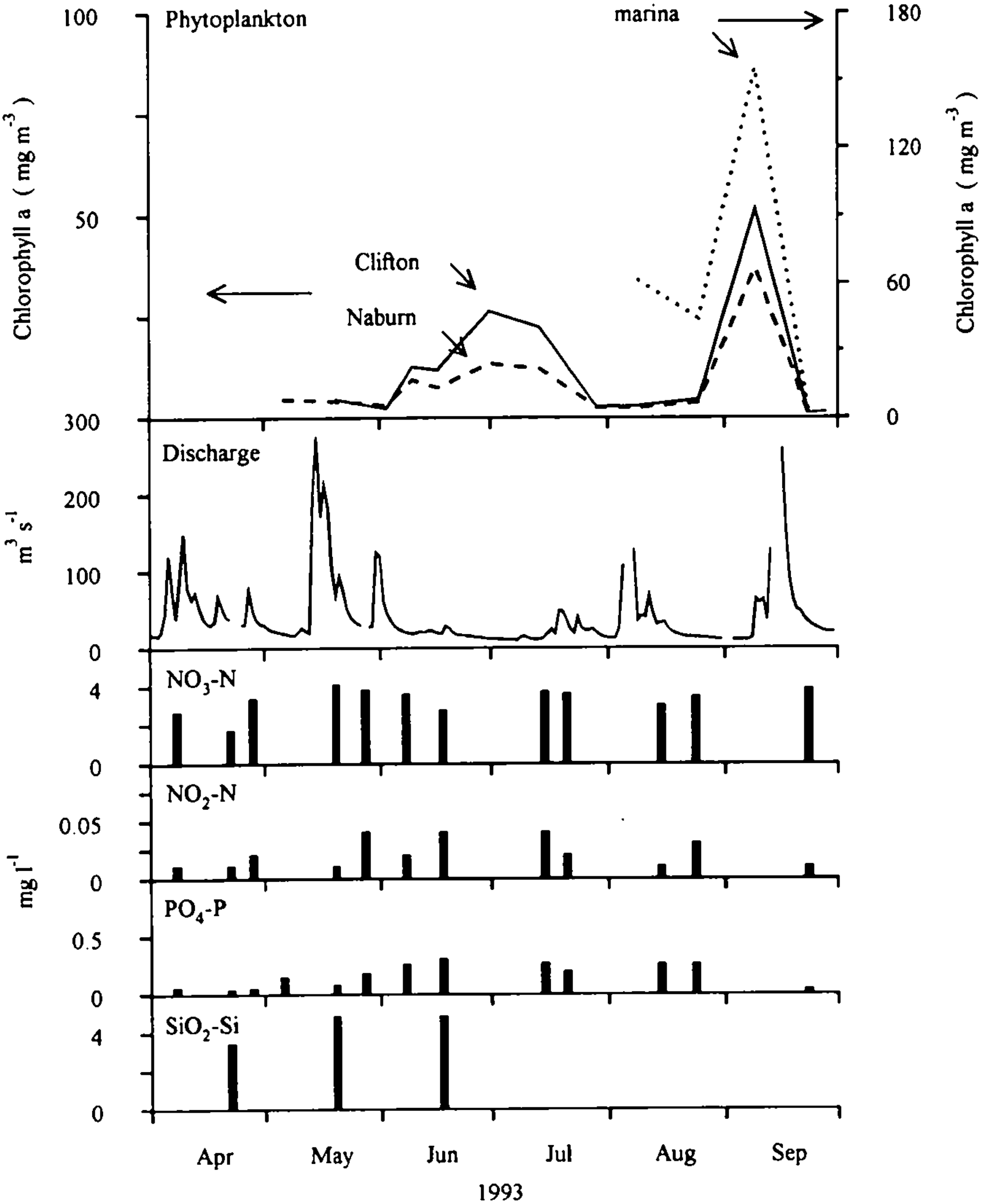

Fig. 8 Variation in phytoplankton chlorophyll *a* and associated variables in the Yorkshire Ouse. Note that for the phytoplankton chlorophyll data, there are two y-axes. The right hand axis refers to the marina only.

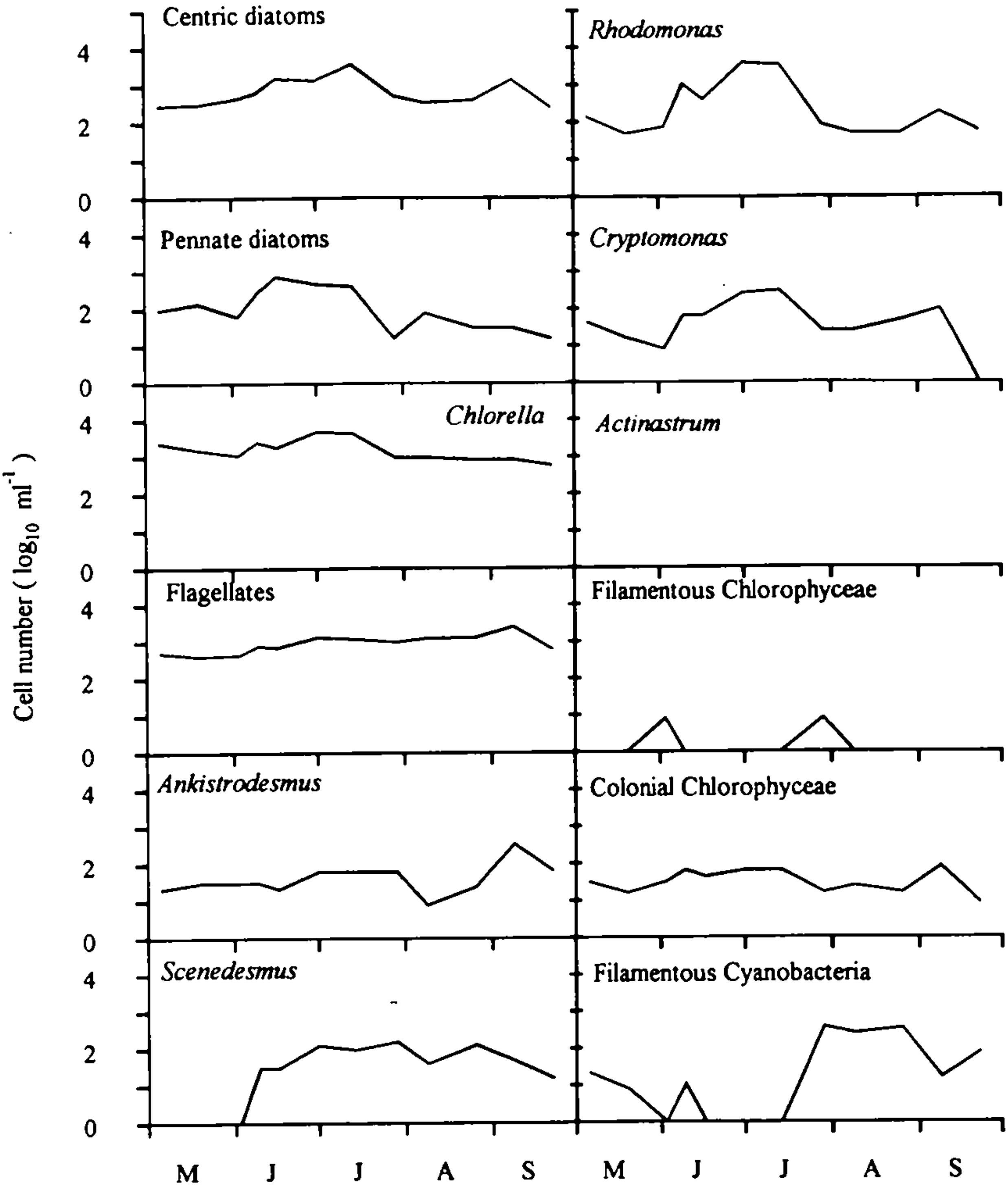

Fig. 9 Variation in phytoplankton numbers in the Yorkshire Ouse at Clifton, during summer 1993.

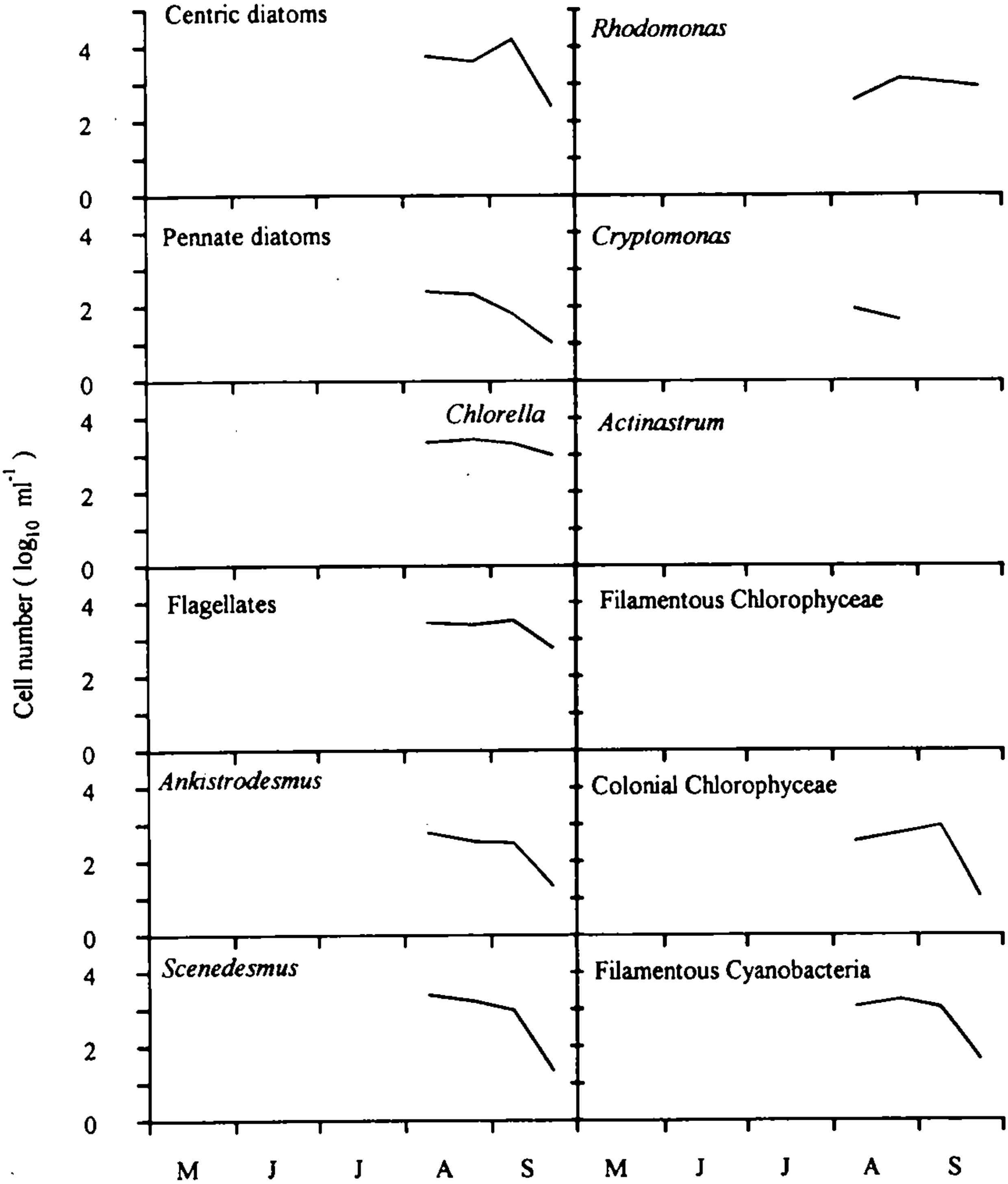

Fig. 10 Variation in phytoplankton numbers in the marina, adjacent and linked to the Yorkshire Ouse at Naburn, during summer 1993.

concentrations at Naburn but samples were not taken from the river centre and therefore may be directly comparable. Concentrations of centric diatoms (largely *Stephanodiscus*) and *Rhodomonas* exceeded 10^3 ml^{-1} at this time. The chlorophyll maximum during September was not apparently associated with a significant change in phytoplankton numbers although the flagellates were nearly all large (ca 20 µm diameter). There may also have been benthos disturbance upstream.

4.3 <u>The Marina at Naburn</u> (Figs 8 and 10)

The boating marina at Naburn is a discrete water body is directly linked to the Yorkshire Ouse but partially protected from the impact of spates. High phytoplankton concentrations were observed.

4.4 <u>River Aire</u> (Figs 10 and 11)

The R. Aire flows from the west and the sampling point was well downstream of the Calder input. Nitrate concentrations are high and calculated nitrite concentrations are significantly higher than the Derwent and Yorkshire Ouse. Phosphate concentrations are generally high frequently exceeding 1ppm. Discharge was characterised by a series of spates during the spring with no settled period except for one month in mid-summer. Phytoplankton concentrations were low, never exceeding 20 mg m^{-3} chl *a*. Centric diatoms and flagellate numbers exceeded 10^3 ml^{-1}.

4.5 <u>River Don</u> (Figs 12 and 13)

The River Don flows in from the south west passing throught the industrial towns of Sheffield, Rotherham and Doncaster. Nitrate and phosphate concentrations are high and there are carrying significant levels of nitrite. Discharge patterns were interesting in that three low periods were observed in early May, mid-June to mid-July and in August, corresponding to increases in phytoplankton chlorophyll. Concentrations in mid-summer exceeded 30 mg m^{-3}.

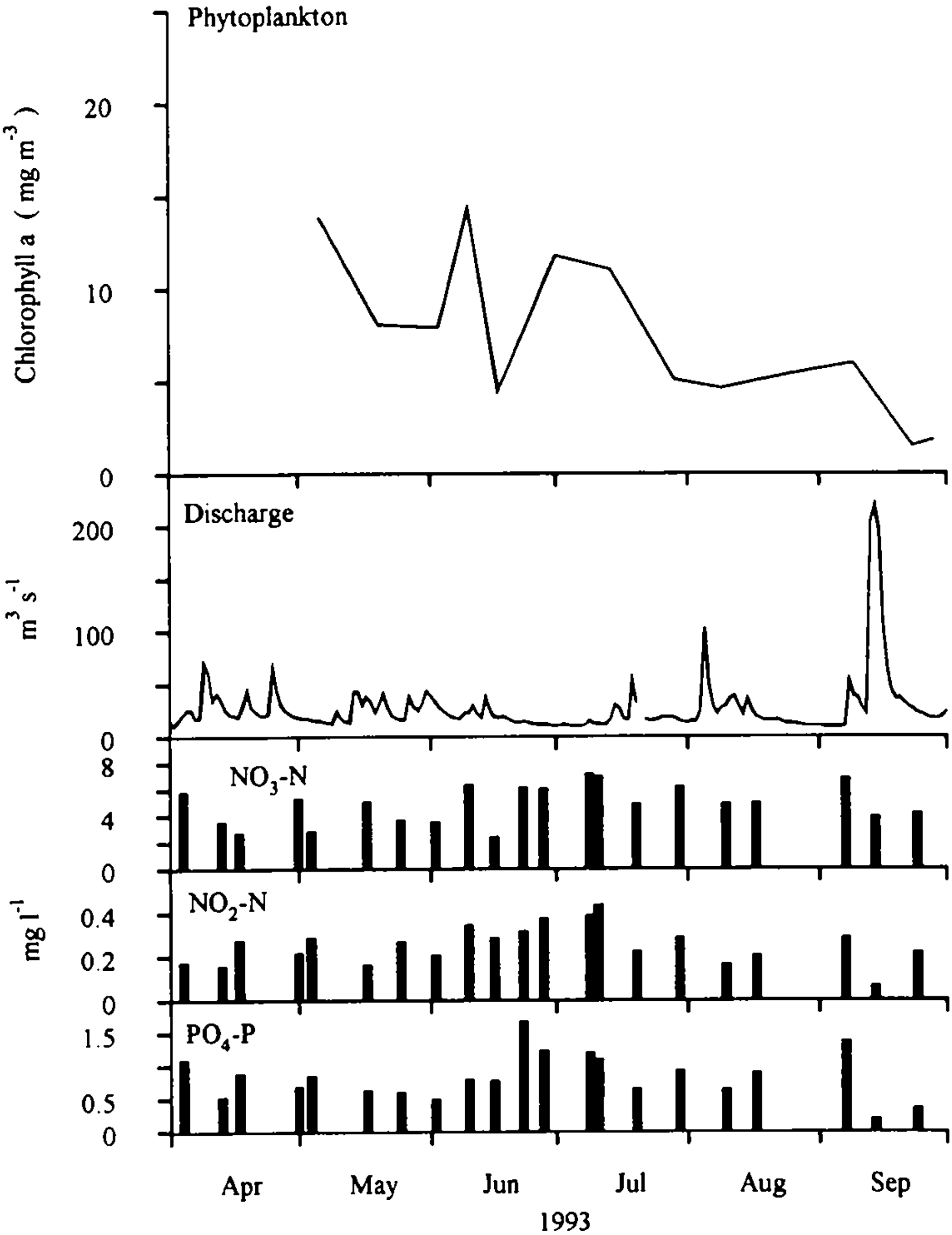

Fig. 11 Variation in phytoplankton chlorophyll *a* and associated variables in the River Aire.

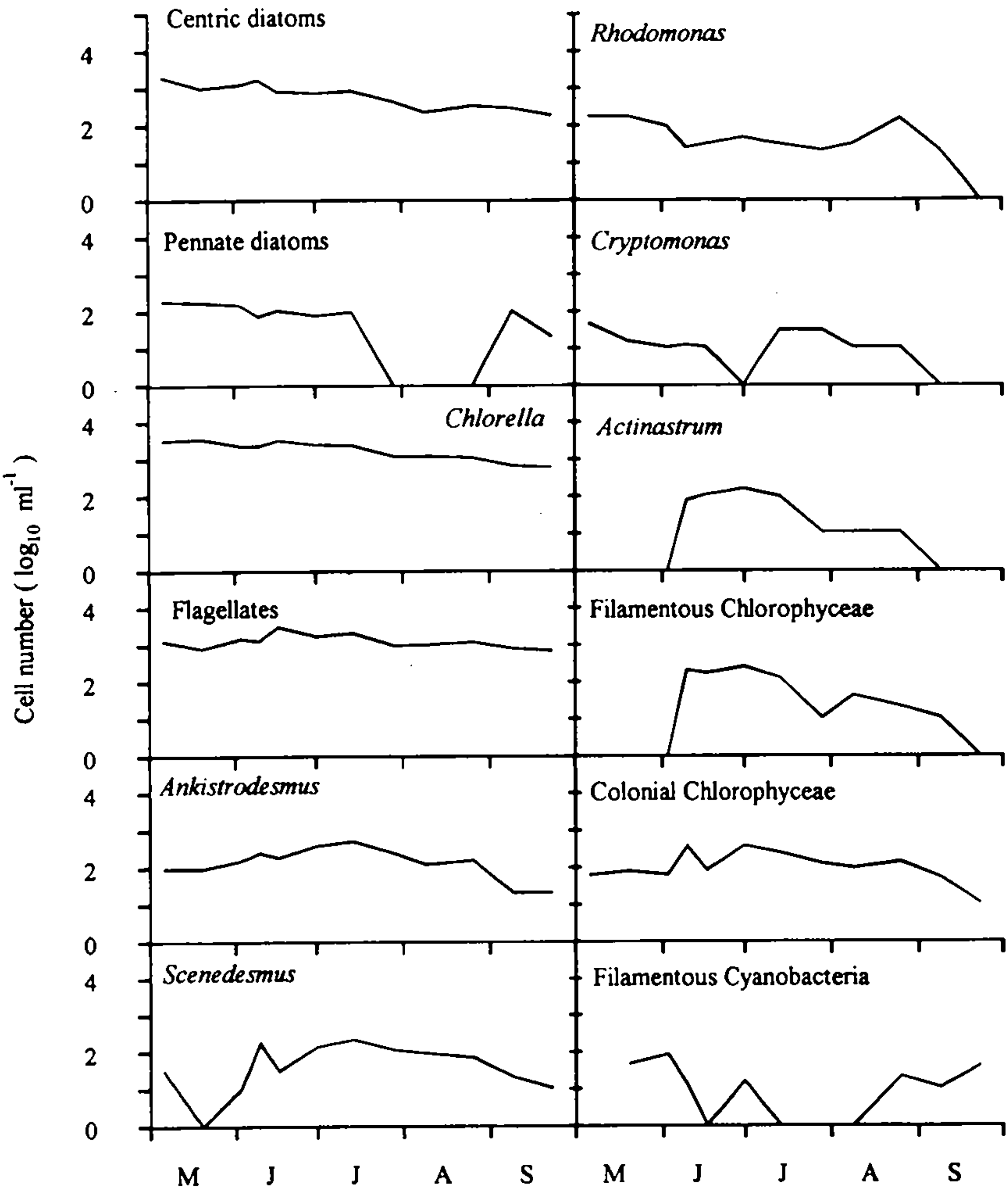

Fig. 12 Variation in phytoplankton numbers in the River Aire, during summer 1993.

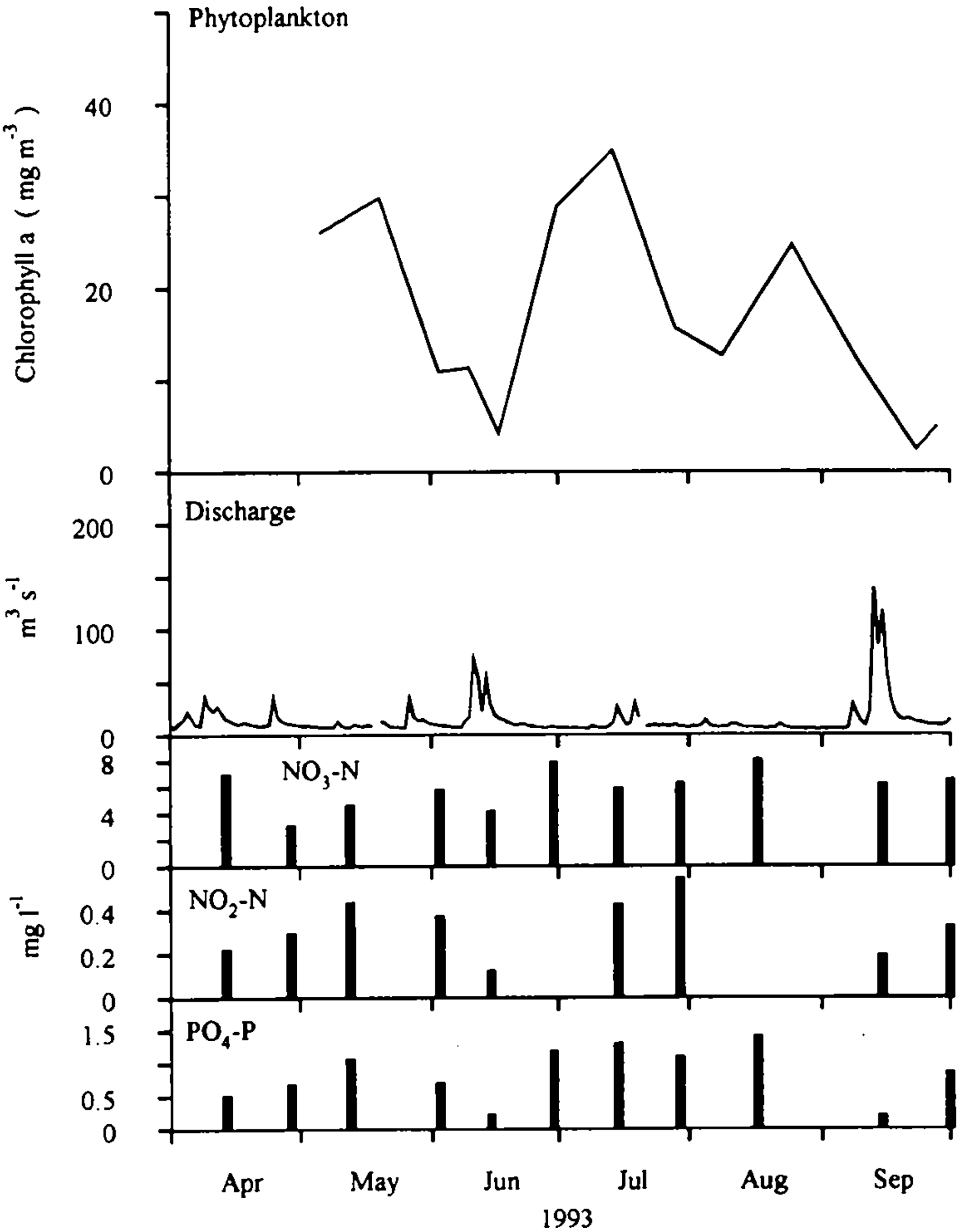

Fig. 13 Variation in phytoplankton chlorophyll *a* and associated variables in the River Don.

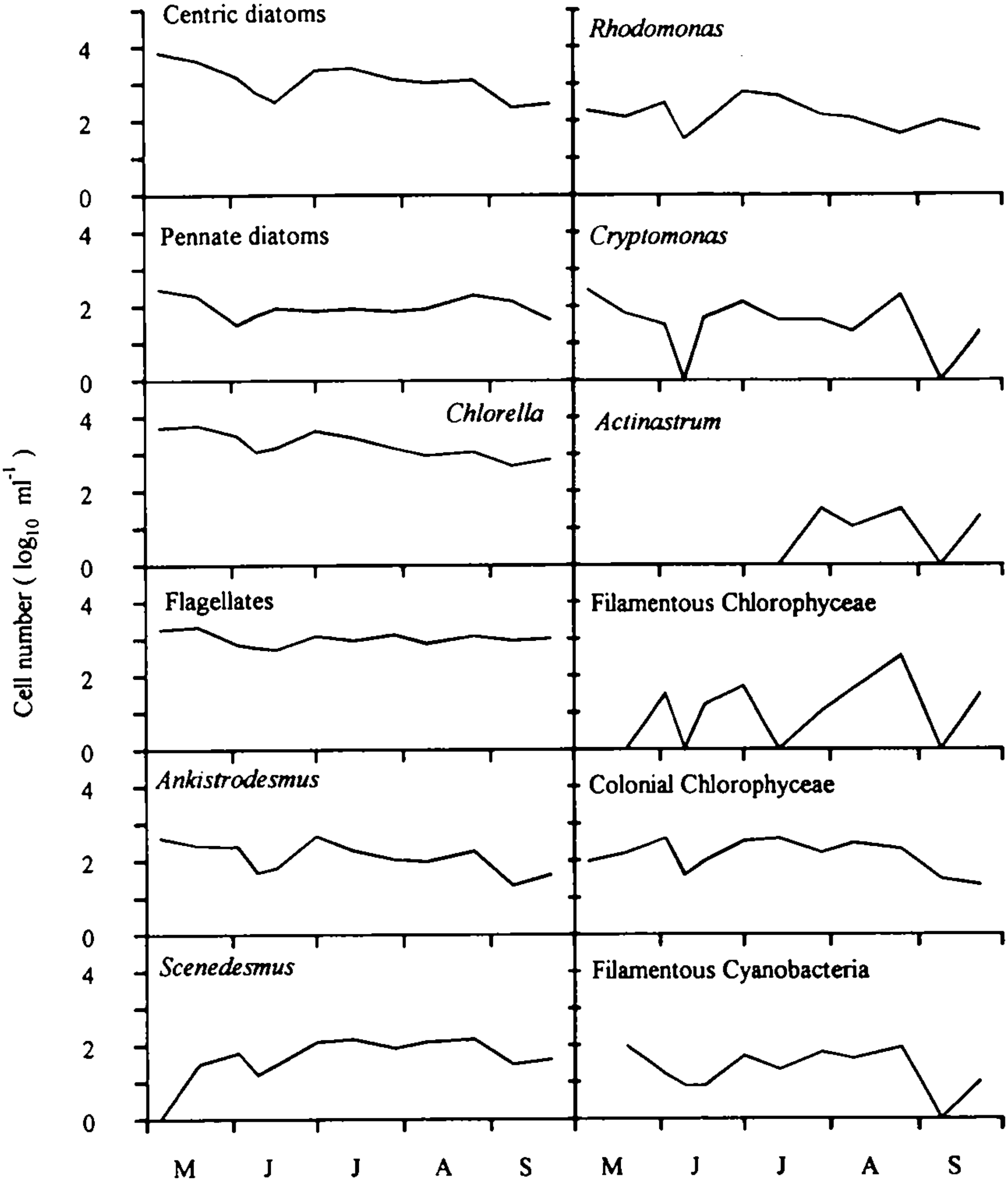

Fig. 14 Variation in phytoplankton numbers in the River Don, during summer 1993.

Centric diatoms exceeded 6000 cells ml^{-1}.

4.6 River Trent (Figs 14 and 15)

The R. Trent flows into the Humber from the south and drains the midlands. Total oxidized nitrogen (largely nitrate), phosphate and silica (measured on only three occasions) were all high. Discharge reflected the wet spring and summer with a series of spates. Phytoplankton responded with maxima in May, early June and early July, corresponding to the drop in discharge. Centric diatoms reached nearly 14000 cells ml^{-1} on June 10th. But interestingly the low August concentrations occurred when nutrients were high and discharge was low.

4.6 River Great Ouse (Figs 16 and 17)

This river drains from the south west to the Wash and is fed from aquifers in the Jurassic and Cretaceous rocks. There were two major spates during the period, the first in mid-April and the second in mid-June. Early phytoplankton populations in March collapsed with the April spate but recovered in May, reaching over 200 mg m^{-3} chl *a* in mid-May. The collapse apparently started before the onset of the June spate. Centric diatoms numbers exceeded 60000 cells ml^{-1}.

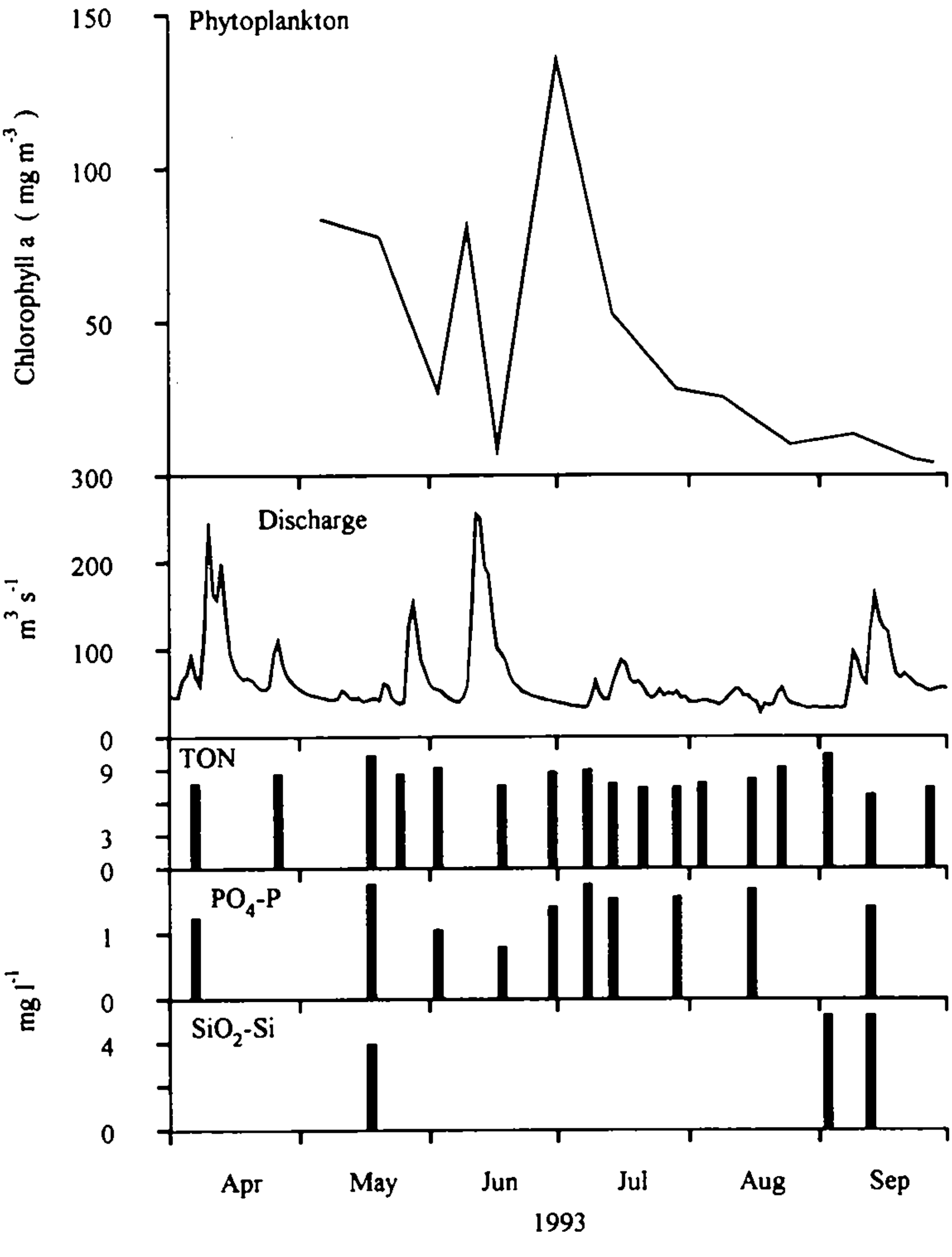

Fig. 15 Variation in phytoplankton chlorophyll *a* and associated variables in the River Trent.

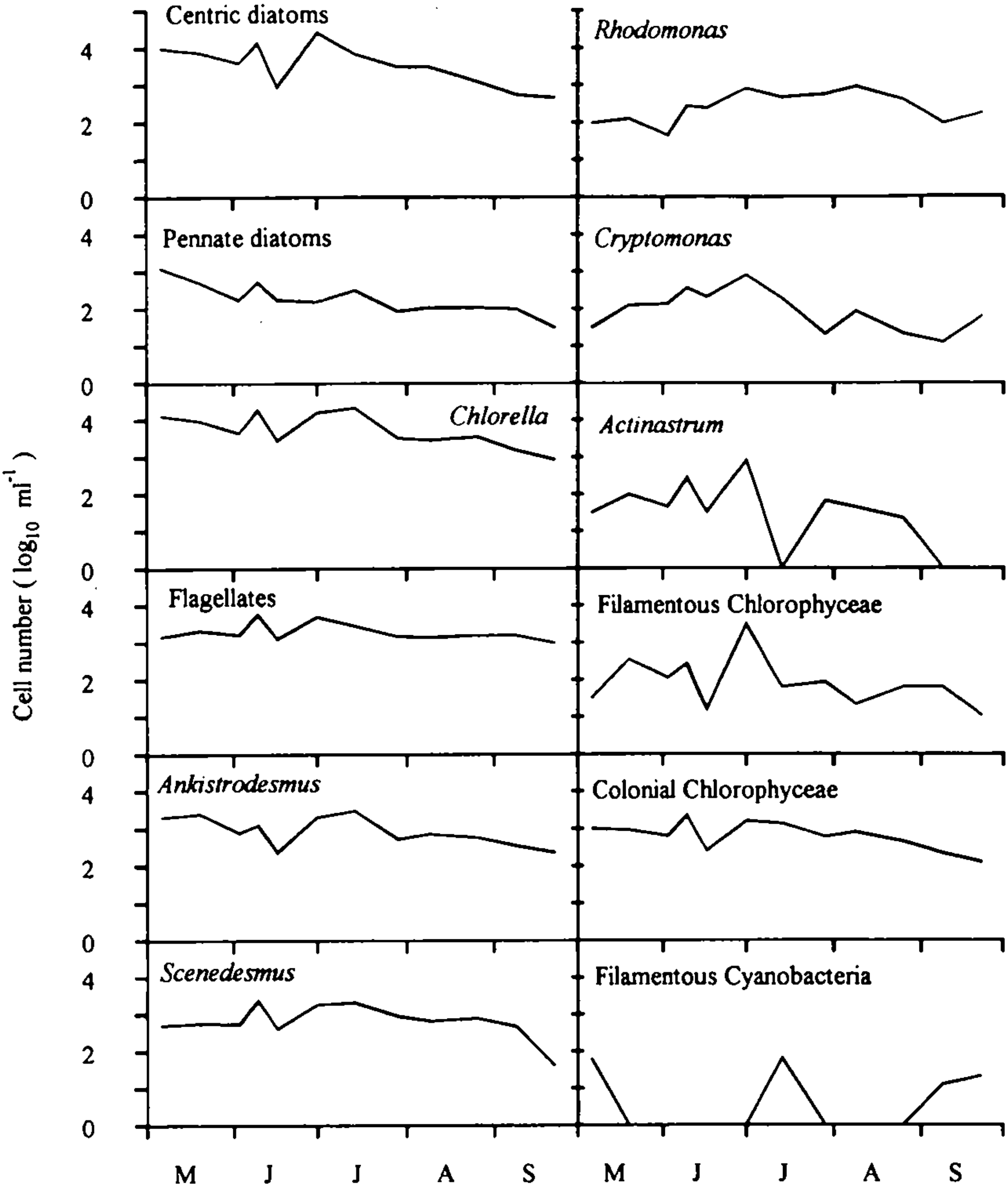

Fig. 16 Variation in phytoplankton numbers in the River Trent, during summer 1993.

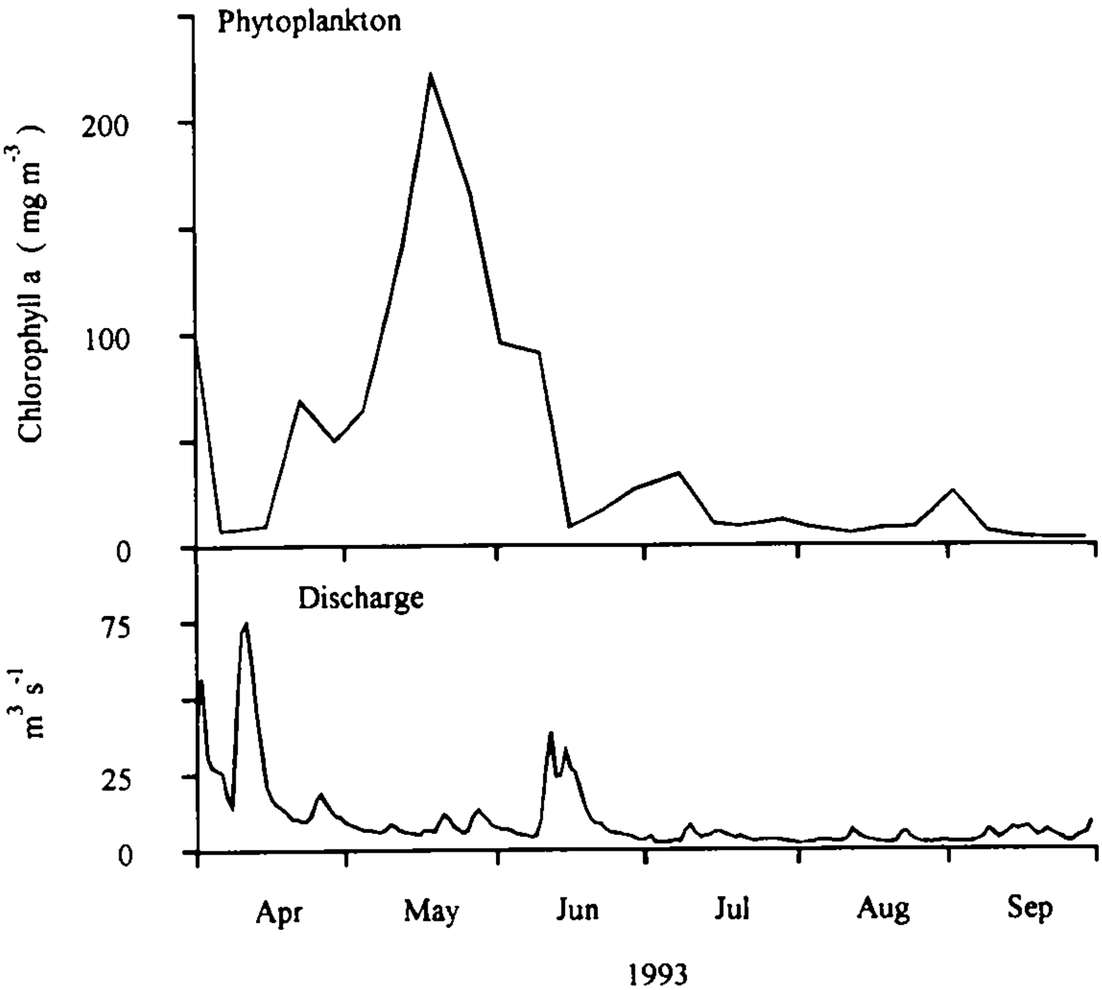

Fig. 17 Variation in phytoplankton chlorophyll *a* and discharge in the River Great Ouse, Cambridgeshire.

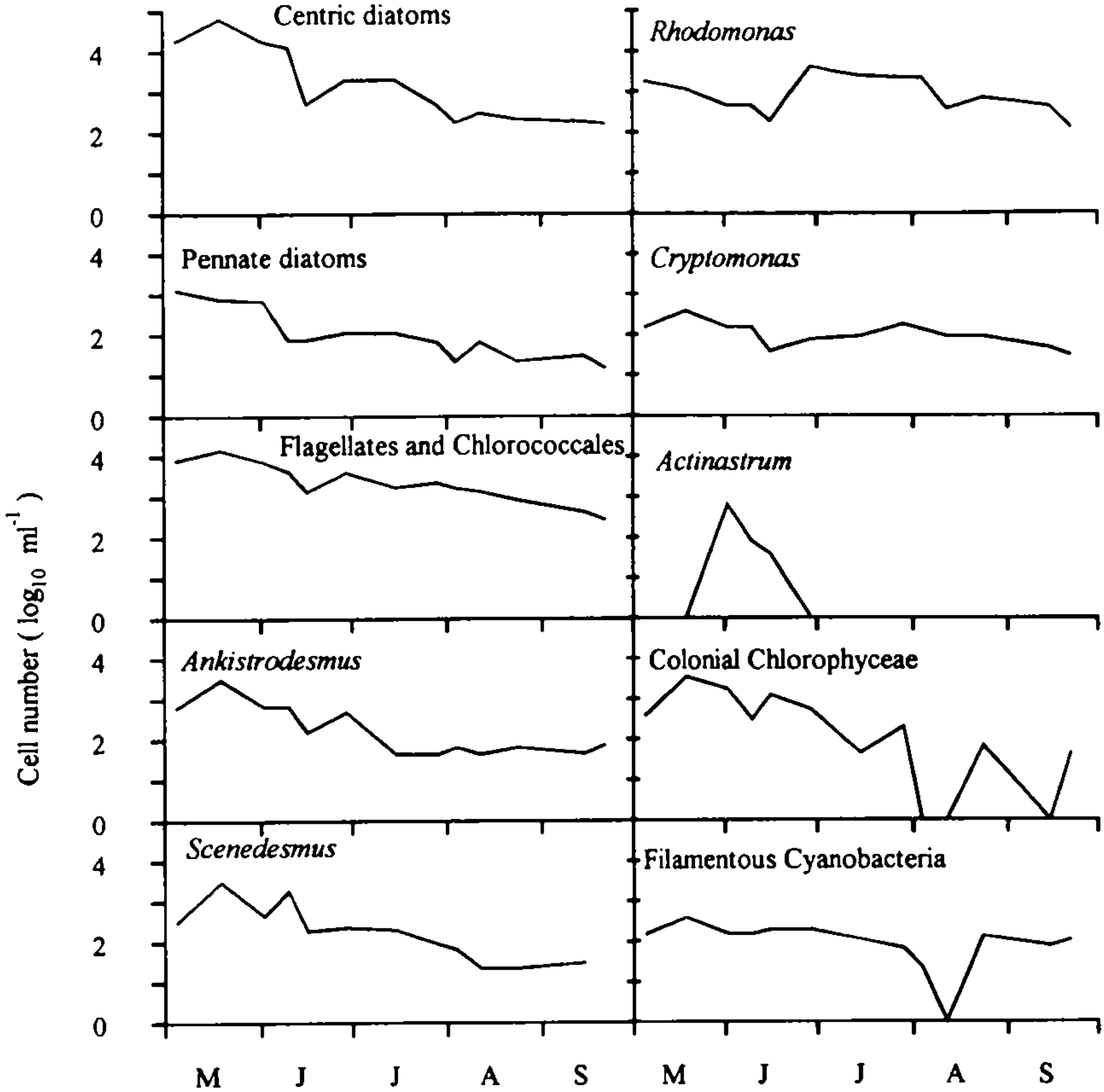

Fig. 18 Variation in phytoplankton numbers in the River Great Ouse, during summer 1993.

5. DISCUSSION and CONCLUSIONS

Phytoplankton have been studied sporadically in British rivers over many years. The River Thames has received the greatest attention dating back to the early work of Fritsch (1902, 1903). Later studies by Rice (1938a & b) together with the quantitative work of Lack (1971) and Lack and Berrie (1976) make an interesting time-series comparison. More recently Whitehead and Hornberger (1984) developed a phytoplankton model for the Thames. Elsewhere in Great Britain and Eire there have been a variety of phytoplankton studies of which those on the Wharf (Shroeder, 1930), the Shannon (Southern and Gardiner, 1938), the Severn (Swale, 1969; Reynolds; *et al.,* 1989) and the East Anglia Stour (Swale, 1964) are examples. Many more detailed studies have been carried out in continental Europe on much larger rivers (e.g. Friedrich and Viehweg, 1984; Ertl, 1985; Kiss 1987 and Steinberg, *et al.* 1987) and on more modest ones (Müller, 1984; Descy, 1987; Descy *et al.*, 1987). Detailed work on the Rhine goes back some fifty years (Peelen, 1975).

In this and preceding studies, clear patterns of phytoplankton growth were established in the River Trent and the River Great Ouse, comparable to those found in the Thames (Lack, 1971; Lack & Berrie, 1976). These are southern rivers flowing over lowland catchments. The rivers flowing into the Humber from the north and west are different in character and this was reflected in the smaller phytoplankton in 1993, a particularly wet year. The waters of the Rivers Trent and Great Ouse are generally turbid in winter due to allochthonous detritus, particularly after periods of heavy rainfall. Large phytoplankton populations take over in the spring maintaining high turbidity because, as the surrounding land dries out, detritus in the river system diminishes and discharge drops enabling the phytoplankton to develop. High turbidity restricts the penetration of light and markedly affects the depth to which plants will grow (Chambers & Prepas, 1988). During periods of high rainfall the Yorkshire Ouse and R. Aire were noticably discoloured by yellow humic substances (Kirk, 1977). This "gelbstoff" markedly attenuates blue light (400 - 480 nm), restricting the availability of photosynthetically important radiation.

The populations are largely dominated by *Stephanodiscus*, although in dry years additional Chlorophyceae and Cyanobacteria also occur, as in 1990. In the Great Ouse this late spring population generally declines during June and July and dissolved silica drops to low levels in the spring, suggesting that diatom biovolume must be near its maximum at the time of the spring chlorophyll maximum. As the diatom population collapsed the silica concentration increased but, in spite of continued silica abundance the diatoms never recurred to the same extent. Insufficient data were provided by the NRA to shed much light on the status of silica in the Humber rivers but it is unlikely to have been limiting except in the Trent in June. *Rhodomonas*, *Cryptomonas* (and other flagellates), *Scenedesmus* and *Ankistrodesmus* were common to all the rivers. High concentrations of *Oscillatoria* occurred in the Great Ouse during the late spring of 1990 but was not significant in any river in 1993 due to the hydraulic conditions. This evidence suggests that drier conditions and the restriction of discharge could increase both the size and the duration of phytoplankton populations, in particular Chlorophyceae and Cyanobacteria. The evidence for this from the Great Ouse is two fold. Firstly, in 1990, which was a particularly dry year, phytoplankton developed in late March and persisted until June (Marker & Collett, 1991). Both the marinas of the Great Ouse (Marker & Collett, 1991) and the marina on the Yorkshire Ouse, investigated in 1993, carried higher algal populations than the adjoining river. It is tempting to suggest that displacement is the primary influence since in the marinas, which are blind side arms, there is much less potential for wash out of phytoplankton than in the river. However, this does not appear to be a sufficient explanation. In the Great Ouse in spring, the large chlorophyll maximum occurred when discharge was significantly higher than in the summer. The retention time will have been greater in the late summer theoretically allowing more time for algal growth. This did not occur. It must therefore be postulated that either the specific growth rates of the phytoplankton were lower in summer than in spring or that the loss processes were greater. Little is known of *true in situ growth rates*. Of the loss processes wash-out has just been discussed, which leaves sedimentation and grazing as potential loss mechanisms. The study of these rate processes was the primary objective of the original proposal.

To summarise, 1990 and 1993 provided contrasting hydraulic condition and show that the Yorkshire Ouse and R. Derwent have the potential to develop large phytoplankton populations under dry conditions. The data also show that 1991 and 1992, which were wetter than 1990 but drier than 1993, carried significant populations. Presumably the Don and Aire would have had increased populations as well but there were no data to confirm this. Data from 1991 and 1992 are considered likely to be more typical than either 1990 or 1993. Thus the rivers feeding the Humber offer a range of types from the fast flowing rivers in the north to the large lowland Trent in the midlands to investigate the phytoplankton dynamics outlined in the original proposal. The Trent offers a "guaranteed" large phytoplankton under most spring and early summer conditions and is of strategic importance to the overall LOIS objectives because of its sheer size. The Yorkshire Ouse, on which both core and topic work will be centred is, therefore, the natural choice of contrasting river type to further our understanding of phytoplankton dynamics.

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7. ACKNOWLEDGMENTS

During the course of this work many people have been extremely helpful to the running of this programme. Staff of the National Rivers Authority in the Yorkshire and Severn Trent Regions provided data on discharge and nutrient concentrations. Yorkshire Water provided phytoplankton data for the Derwent and Yorkshire Ouse and Severn-Trent NRA made available an earlier report on the Trent.

Appendix 1

ORIGINAL PROPOSAL

TITLE The effect of environmental conditions on the phytoplankton production dynamics in feeder rivers of the Humber estuary and the flux of autochthonous carbon to the estuary.

DESCRIPTION
Changes in the environment are likely to have profound effects on our river systems. Declining rainfall, increased evapotranspiration, increased pressure on public water supplies, and an increasingly consumer orientated society will all lead to decreased river discharges and slower replenishment of underground aquifers. Changes in discharge from any of these causes will directly affect the size and seasonal pattern of phytoplankton populations in rivers, their interaction with zooplankton populations, sedimentation and hence the overall flux of carbon to the estuary. Although models have been developed to describe the behaviour of river phytoplankton (Whitehead & Hornberger, 1985; Reynolds et al., 1989), detailed and accurate knowledge of many of the rate processes is lacking.

Estimating the growth and production of undifferentiated organisms has always presented difficulties. Classical methods of measuring in situ photosynthesis(^{14}C and O_2), which have been used with varying degrees of success to measure production, only measure overall production. More time consuming methods, using track radiography (Knoechel & Kalff, 1976), give estimates on the productivity of individual species. Although these methods have been used to estimate growth rates, they are only indirect methods and production rates as such do not necessarily equate directly to growth. More simple methods of measuring growth rates, involving changes in standing crop with time, take little or no account of loss processes (sedimentation or grazing) or, when they do, such corrections are subject to large potential errors.

Recently a method of estimating species-specific growth rates of phytoplankton via the DNA synthesis cycle has been developed (Carpenter & Chang, 1988; Chang & Carpenter, 1988). The method involves frequent sampling within a 24-hour period and detailed quantitative fluorescence microscopy after staining the DNA with DAPI (4'6-diamidino-2- phenylindole). This method, giving direct estimates of growth rates, combined with direct estimates of species production is potentially far more useful than classical production studies alone in that they are species-specific and directly relevant to interpreting fluctuations in standing crop and the interactions between trophic levels. Combined with estimates of sedimentation and grazing, much more realistic stochastic modelling of the river ecosystem will be possible and will be used in interpreting the fluxes of autochthonous production to the estuary.

Work by the Institute of Freshwater Ecology under contract to the Department of the Environment and the National Rivers Authority has involved two distinct but related pieces of work on large rivers. The first piece of research is part of a major undertaking by the Institute of Freshwater Ecology into the large lowland rivers of eastern England. These studies (Marker and Collett, 1991) have involved investigations into the causes and nature of the turbidity (and hence the underwater light climate) of the River Great Ouse. This work has developed our understanding of the light climate of lowland rivers and the patterns of phytoplankton development in relation to channel morphology and type. The dynamics of rotifer populations, in particular, and to a lesser extent those of Copepoda and Cladocera, interact closely with phytoplankton dynamics in the River Great Ouse. A second study carried out in the River Great Ouse has shown that this relationship is strongly influenced by the discharge pattern. In dry years, with low summer flows, the interactions and pattern of abundance is heavily influenced by discharge levels in the late winter and early spring (Pinder et al. 1991). The work of Reynolds et al. (1989) and Reynolds and Glaister (1992) on the aggregated dead-zone model is highly relevant to this proposal. In comparable British rivers only the plankton of the Thames has been studied extensively (Fritsch 1902,1903, Rice 1938a & b, Lack 1971, Lack and Berrie 1976, Whitehead and Hornberger 1985, Botterell 1977). The author of this proposal has extensive experience in the trophic dynamics of chalk-stream ecosystems (Marker and Casey 1982, Marker et al. 1987) and combined with his recent experience in large river systems, provides a strong base from which to exploit the opportunities in the Humber provided by LOIS.

OBJECTIVES

1. To quantify the seasonal changes in the size and composition of the phytoplankton, with particular reference to the Yorkshire Ouse.

2. To estimate the in situ growth and production rates of dominant phytoplankton species at different times of the year in contrasting environments during both the waxing and waning of naturally occurring growth cycles.

3. To quantify the major loss processes in the river, involving grazing and sedimentation.

4. To develop models to predict the effect of changes in environmental conditions on the development of phytoplankton in large river systems and the output of this autochthonous production to the estuary.

METHOD

1. Methods for measuring biomass and community structure of algae are well developed (Marker, 1976; Marker & Casey, 1982) and will involve extensive use of chlorophyll analyses (including HPLC) as well as classical microscopy.

2. Methods will be developed for measuring the cell division rates and production of phytoplankton.
   (a) To test whether methods for measuring the species-specific growth rates of phytoplankton, via the DNA synthesis cycle, are applicable to lotic environments. Laboratory growth chamber experiments to validate the method for some of the chosen species. Some of this work will take place at IFE Windermere.
   (b) Select suitable species of phytoplankton for in situ growth rate studies (e.g. Stephanodiscus, Scenedesmus, Chlamydomonas, various Cryptomonads as well

as a number of the less common species for contrast).

3. Loss processes:
   (a) A substantial amount of information on the growth and feeding rates of Rotifera in response to temperature and food supply is available from the literature, for example the work of May (1987a & b). Additional laboratory studies may be necessary.
   (b) Some time will be spent comparing methods of measuring sedimentation in lakes and rivers to develop the most appropriate system for use at specific field study sites.

4. Archived NRA river data will be examined in detail before locating the most appropriate sampling sites and evaluating whether any of the environmental data they collect is available in sufficient details for this project.

5. Sampling of phytoplankton and Rotifera will be at three sites (primary NRA monitoring sites) on the main river feeding into the Humber (eg the Yorkshire Ouse).
   (a) Upland site,
   (b) Middle site,
   (c) Estuarine boundary.

   Detailed trials will take place on the River Great Ouse where background knowledge is available and in which a wide range of physically contrasting habitats is available.

6. Field studies will be particularly concerned with the spring increase in phytoplankton and the subsequent decline during the summer. Detailed studies will include:
   (a) Seasonal changes in phytoplankton biomass and population structure.
   (b) Rates of production of individual phytoplankton species.
   (c) Cell division rates of individual species.
   (d) Loss rates, including grazing by Rotifera etc and sedimentation.
   (e) Temperature, irradiance and other environmental variables will be routinely monitored.

   Analyses will be carried out in part on site and in part at Monks Wood and IFE Windermere. Extensive travelling will be required.

7. Remote sensing will be used to detect aggregated dead zones.

8. Modelling of the plankton system will incorporate phytoplankton and zooplankton growth rates, changes in biomass and population structure, grazing rates, sedimentation, the effects of discharge, temperature and irradiance (both incident and underwater attenuation. Hence estimate the primary variables controlling the flux of carbon within the river system and its export to the estuary.

Appendix 1

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Appendix 1

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Appendix 2

ANSWERS TO REFEREES QUESTIONS.

Question 1. **Although much of the growth is of indigenous forms in many instances there is a very substantial input from resevoirs and lakes draining into the rivers in the form of overspills or compensation waters. It is not clear how indigenous and reservoir-derived populations will be differentiated in this study, (perhaps using live:dead ratio.** *(refer to appended section 19)*

The significance of external input cannot be established a priore. However, three quite different methods are indicated.

1. The composition of the phytoplankton will be established by classical microscopy and this should give a broad indication of the relative contributions.
2. 6a rates of production of individual species (track radiography).
   6b cell division rates (DAPI method)
   Both these methods are species specific and the three methods taken together will reveal the most active species in the system (which is of primary importance) rather the origins of the inoculum which might have been a reservoir, backwater, dead zone or even the benthos.

Pigment ratios and a more rigorous separation by HPLC will give some indication of the proportions of live and dead material, but not necessarily the origins of the dead material. Carbon isotope ratios (which may be part of the core studies) would also reveal the proportions of allochthonous to autochthonous input.

Question 2. **The project should make clear which river(s) are to be studied, as the title indicates a number of feeder rivers to the Humber, but the summary states only the Ouse.** *(refer to appended section 19).*

Initially it is intended to centre work on the Yorkshire Ouse and this is made clear in the first objective and again in methods section 5. This follows the decision of the LOIS steering committee to concentrate efforts on the Yorkshire Ouse.

Question 3. **In view of the facts that there appear to be no published data on the occurrence of phytoplankton in the Yorkshire Ouse, that no values are included in the application, and that much of the river is highly turbid, does the applicant have any information on population densities? This is a major research programme to commence solely on phytoplankton, should the phytoplankton play only a minor role in the Ouse ecosystem.**

One of the reasons for being deliberately vague over the choice of river (other than referring to detailed work on the Yorkshire Ouse) was the apparent lack of detailed knowledge of the phytoplankton. Such information would be held by the NRA and not available until the project had started. The Trent, however, is known to carry a large phytoplankton population (like the Rivers Thames, Severn and Great Ouse). If the Yorkshire Ouse does indeed turn out to be very turbid throughout the year with low phytoplankon populations, studies will take place on the River Trent, with the advantage that it is nearer to Monks Wood and is still part of the Humber system on which LOIS is centered. However, since the core studies are going to be centered on the Great Ouse it is important that results are related directly to the Yorkshire Ouse to quantify differences and show the reasons for those differences. This, in itself, will be a valuable input into the LOIS programme as a whole.

Questions 4 & 10.

Q4 The project involves contributions from 7 Institute of Freshwater Ecology staff in addition to the requested 5-yr appointment. However no information is given about the individual roles of any of these people, nor whether the full-time assistant will be based near the river or at one of the IFE's laboratories.

Q10 Apart from the PI, 2 senior research staff, 4 technicians and 1 contract staff are to be involved and partially funded. Yet nowhere in the proposal is the role of these 8 persons explained or the requested funding justified.

These two questions are best taken together. The modified proposal (3rd November 1992) does not include senior staff and this change was made at the request of the Steering Committee, after clarification sought at Institute Director level. Were the referees supplied with the final version?

1. There are three Grade 7 involved and not funded by LOIS:
   Dr A.F.H. Marker. Principal Investigator and algologist. Responsible for the general coordination of the project and direct supervision of the algal work.
   Dr L.C.V. Pinder. Senior invertebrate zoologist and head of the Eastern Rivers Laboratory at Monks Wood. He will be responsible for advising and supervising zoological aspects of the work.
   R.T Clarke. Senior statistician based at IFE River Laboratory and ITE Furzebrook. Responsible for developing and/or advising on statistical analysis and simple modelling.
2. There are four support staff listed.
   A. Garbutt and D. Leach are respectively ASO and SO at Monks Wood and act in a support role in algology and invertebrate zoology. Both are experienced in both laboratory and field work and their support is anticipated during extensive, labour-intensive field work. A. Garbutt is on a short-term contract and is due to be replaced by G.D. Collett in early 1994 and currently on leave-of-absence in Cambodia. The latter is a very experienced assistant whose strengths include working under difficult environmental conditions (eg Antarctica and Cambodia). He is highly skilled in using boats, field logging and computing equipment as well as laboratory-based systems.
   It is also anticipated that some laboratory equipment and field monitoring equipment will have to be constructed. What precisely and how much is unknown at this stage since some (temperature and discharge) will be monitored by the NRA and other variables are likely to be measured by the IFE (& other Institutes) elsewhere in the core programme.
   A. Crompton: Engineer in the Windermere workshop.
   D. Aspinall: Electronics engineer in the Windermere workshop.
   These two specialists will construct sampling devices yet to be decided. Examples are sediment traps, logging equipment and laboratory equipment not available from laboratory suppliers. Precise details cannot be decided at this stage before preliminary surveys have been carried out, detailed methodology established and equipment on site assessed.

In addition we propose to appoint a contract HSO (post-doctoral research assistant) working full time on the project. The post requires a specialized numerically-literate algologist with strong interests in ecological physiology.

Questions 5 & 15.

Q5 A requirement for Airborne Remote Sensing is listed (Section 11), yet not mentioned in the plan. An explanation should be given of how this will contribute to this particular project *(see section 11).*

Q15 It is not sufficient to state that remote sensing will be used to detect aggregated dead zones. How frequently will remote sensing be deployed? What steps will be taken to "ground truth" the remote reults?

Remote sensing will be peripheral to the main studies in locating those areas where phytoplankton is accumulating. Much of this should be possible to predict from the hydraulic characteristics of particular reaches. It will not be used in the first year and probably only in the second or third years. It is also very unlikely that that more than two flights would be allocated by NERC and it is important to have a slot coinciding with the phytoplankton maximum. Following experience on the River Great Ouse, unless narrow-band wavelength scanning is available through CASI, it is unlikely that remote sensing would be successful. Ground truth measurements will be carried out using standard chlorophyll extraction techniqes. A large number of staff will be deployed at the time of the overflight to obtain as many phytoplankton samples as possible. At the same time notes will be taken of possible interferences, submerged macrophytes, shadows, localised turbidity etc.

Questions 6, 13 & 16.

Q6 The production of the model is presumably a key part of the programme, yet no details are included.

Q13 No details are given of the methods of acquisition of the environmental variables which are to be incorporated into the final model.

Q16 More details are required of how the results which will be obtained will enable the stated aims of the proposal to be realised. In particular, the modelling approach which will be adopted to "estimate the primary variables controlling the flux of carbon within the river system and its export to the estuary" needs to be specified and explained.

Other environmental variables will be required for the final model. Some of these will be available through the NRA (water temperature, discharge, major inorganic chemical constituents etc). Others should be made available through the core programme (certainly on the Yorkshire Ouse, but possibly not on the Trent), water velocities, flux of suspended solids and organic carbon etc. Some instrumentation will have to be constructed in Windermere workshops or purchased (eg irradiance sensors to measure incident and underwater PAR). A closely defined list cannot be given at this stage.

Appendix 2

Model variables	Method	by whom
temperature	)	)
Discharge	) NRA	) NRA
Nutrient concentrations	)	)
Irradiance	PAR sensors	IFE or near station
Turbidity	Sensors	NRA or core programme
Phytoplankton		
Phytoplankton Chl a	Standard method	IFE
" composition	Microscopy	IFE
Carbon uptake	^{14}C track radiography	IFE
Growth rates	DAPI Microscopy	IFE
Loss by grazing	In situ methods & literature	IFE
Sedimentation	In situ methods	IFE
Export	Flux through reach	IFE

Question 7 **The details of funds are unintelligible, because various amendments have been made and the columns do not tally.**

I cannot help here --- as far as I can see the columns and rows add up. Will the steering committee make sure that the correct figures are made available to the referees.

Question 8 **The title refers to flux of autochthonous carbon to the estuary from feeder rivers, but only the Yorkshire Ouse is to be studied. How will the flux from this one river be related to the total flux to the estuary?**

This is a perfectly reasonable question. The LOIS steering committee quite openly state that this is the aim of the programme but also states that not all rivers can be studied to the same degree. It therefore follows that the shortage of funds will lead to substantial extrapolation to cover the aims of the programme. A limited topic request must therefore be confined to one or at the most two rivers. Overall LOIS modelling will make use of this data and extrapolation will then be inevitable.

Question 9 and 12.

Q9 The proposed duration of the work is 5 years, yet no schedule of work is presented to justify this duration.

Q12 The field sampling programme is too vague.

I am not quite sure how to react to this question. I had assumed that since LOIS had an anticipated 5-year programme it would be useful to bid for the five years. If, however, the committee prefer a standard 3-year duration, the programme can be curtailed. I set out below a programme for five years, with a curtailed three year programme in italics. An amended costing form is appended.

First year

1. It is anticipated that a substantial part of the first year will be spent establishing the phytoplankton patterns on the Yorkshire Ouse and the River Trent.

2. Making contact with both Yorkshire and Severn-Trent NRA for base-line data. Much of this material will be in a raw, unprocessed state so it is anticipated considerable time may be spent both locating and analyzing material (the applicant had to do this in relation to the River Great Ouse in the Anglian NRA region).
3. In addition two methods are very time consuming and will require considerable preparation time. Facilities will have to be developed for track radiography. The development of techniques for utilising the 24h synchronised DNA cycle for measuring cell division rates will have to be established for key species in the phytoplankton and will involve considerable laboratory work at Monks Wood and Windermere. The River Great Ouse populations would be used for these studies.

Second Year will involve the major sampling programme (refer to section 19). This year will be devoted in its entirity to methods section 5, 6 and 7, with less emphasis on 6d. *If the programme is curtailed section 7 would be omitted, but with greater emphasis on 6d.*

[***Third year** of the curtailed programme. The emphasis would be on differences between the River Trent and the Yorkshire Ouse. The development and interpretation of the results. Costs would then be reduced by omitting years three and four from the original.*]

Third Year Due to anticipated substantial between year variation it is important to repeat the essentials of the second year programme but with much greater emphasis on the loss making processes.

Fourth Year The emphasis would switch to the Yorkshire Ouse and a curtailed version of the 2nd and 3rd year programme would be undertaken.

Fifth Year There will be three aspects to this years work. Firstly it is anticipated that there will be a substantial backlog of samples to be analyzed. Secondly certain aspects of the work are likely to prove intractible and will require further studies. But the primary purpose of the the final year will be the analysis of the results, a comparison of the two rivers chosen for the study, statistical comparison and the development of the model.

<u>Question 11.</u> **The requirements for other funds is not justified in the proposal.**

I believe that the breakdown of "other funds" is split as far as is practical at this stage.

<u>Travel and subsistance</u>. *(refer to section 9)* It is assumed that the work would be based primarily at Monks Wood and so a significant amount of travelling in connection with the field work would be essential. The facilities for microscope work and radioisotopes are at Monks Wood. It is not at all clear at this stage what facilities will be made available at Hull or in local portacabins.

<u>Consumables</u> *(refer to section 10)*

Ethanol. The standard solvent for chlorophyll and general pigment extraction.

HPLC Consumables For rigorous pigment analysis. HPLC grade methanol, acetone, ion-pairing reagents, replacement columns, wear & tear and maintenance.

Other chemicals and laboratory materials surely a detailed breakdown is not required.

Filtration equipment	)	portable equipment so that
Bench centrifuge	)	so that initial processing
pH meter	)	is mobile and self-contained.

Equipment *(refer to section 12)*

1. Inflatable boat. The Yorkshire Ouse and River Trent are not wadeable rivers.
2. Bench centrifuge.) field processing of
3. Top-pan balance.) phytoplankton samples.

Question 14. **The proposal emphasises the critical importance of the loss processes, sedimentation and grazing. However, it is not clear how sedimentation is to be evaluated. The proposal states that some time will be spent comparing methods of measuring sedimentation, but this is too vague.**

A considerable amount of experience has been gained in IFE over the years in assessing grazing and sedimentation. Sedimentation rates have been studied by Reynolds in Blelham Tarn enclosures and I have also collaborated with him in assessing particle sedimentation rates in the IFE recirculating channels in Dorset (Reynolds et al. 1990). Other work at the River Laboratory is also relevant (Marker & Casey, 1982; Ladle et al. 1985). Grazing has been studied extensively by IFE staff (Welton et al. 1991; Marker et al. 1987). Modifications of these methods will be used initially but there is also a very extensive literature illustrating a wide range of methods. It is important to approach a new river system with an open mind.

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