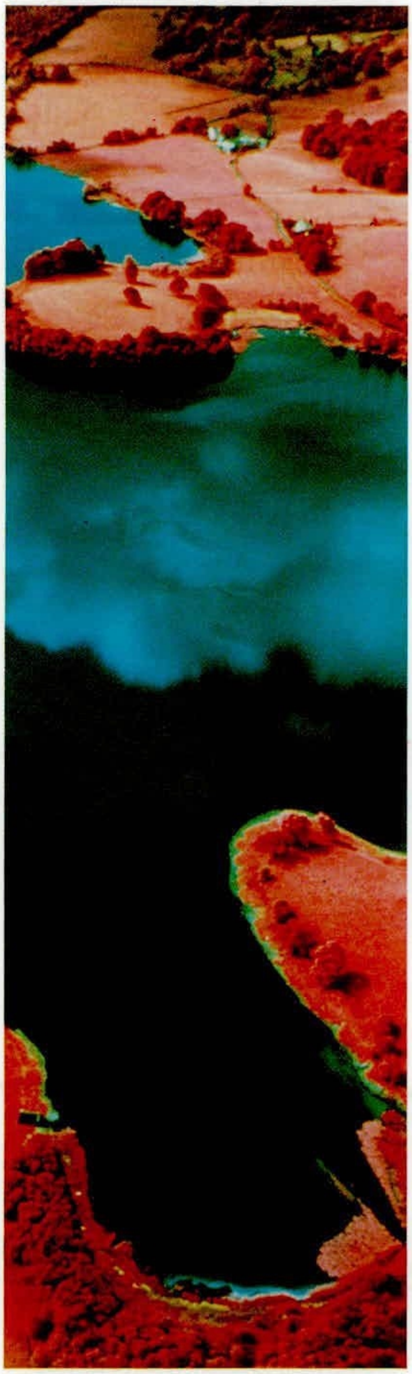
1990 — 1991
REPORT



To Scan

Institute of Freshwater Ecology

Natural Environment Research Council

Foreword

Environmental issues continue to grow in importance both nationally and internationally. These issues, whether local, regional or global, must be addressed on the basis of sound and up to date scientific knowledge. NERC's Terrestrial and Freshwater Sciences Directorate provides a focus for fundamental and applied research in land use and the development of natural resources, the maintenance of environmental quality and the principles which underline management and conservation.

Much of this research is interdisciplinary and demands the wide range of expertise in NERC establishments and higher education institutions. The Directorate's in-house capability comprises the Institute of Freshwater Ecology, the Institute of Hydrology, the Institute of Terrestrial Ecology, the Institute of Virology and Environmental Microbiology, the Unit of Comparative Plant Ecology (Sheffield University), the Interdisciplinary Research Centre for Population Biology (Imperial College, London), the Unit of Behavioural Ecology (Oxford University) and the Water Resource Systems Research Unit (Newcastle-upon-Tyne University).

The Institute of Freshwater Ecology is now fully established as the UK's leading body for research into freshwater ecology and management. As this Report shows, there is much exciting research undertaken on all aspects of freshwater biology, chemistry and physics. This research ranges from fundamental studies of microbes to environmental impact assessment, but the common thread is the relevance to issues of public concern, in particular water quality.

Dr P B Tinker
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Front Cover Illustration:
Esthwaite Water, Cumbria. False colour infra-red aerial photograph: J Hilton.

Report of the Institute of Freshwater Ecology 1990/1991

Natural Environment Research Council

Contents

Director's introduction

Professor J. Gwynfryn Jones
Director

I start this report by admitting an error of judgement. Last year I reported that the scientific output of the Institute had increased in spite of reduction in base line funding. I felt, at the time of writing, that this would be the last year in which we would maintain this productivity. The Library staff inform me that we are still maintaining an average of approximately ten papers per month. The papers currently "in press" are not included in this report, but their numbers indicate that we appear to be maintaining our output. This has occurred during a period when pressures on the staff to increase our commissioned research income were considerable, to say the least. During the same year, the scientists at this Institute produced over 70 reports to customers thus accounting for more than half of our funding.

This success has been the result of teamwork within the Institute and between Institutes. In my first report I said that I considered myself fortunate to be the Director of a body of scientists which produced research of such quality that this would be recognised both by our academic peers and our customers. The success of the past year provides further evidence of this.

All the eight major projects have produced excellent science and we have managed to maintain a balanced programme which ranges from studies on the physics and chemistry of natural waters to the population ecology of fish.

In addition to the research conducted within the major projects, the number of multidisciplinary teams which have been formed has increased. Such teams may be formed to tackle a fundamental science question or to respond to the requirements of a particular customer. A good example of such teamwork is our study of Seathwaite Tarn. The project was conceived by Dr Bill Davison, as an extension to his studies on the rehabilitation of acid waters. The aim is to stimulate natural base production in a lake by the careful addition of phosphorus. This will increase primary production which in turn will drive the microbial decomposition processes which generate base. The programme will require a thorough study of all aspects of the lake's function, including the effect on the fish population. To put such a programme together in a way that not only attracted Science Budget funding, but also the support of the National Rivers Authority, the Electricity Industry and the Chemical Industry required considerable effort and a great deal of paperwork. The result will be an excellent piece of science and the application of our knowledge to the improvement of a water body.

Bill Davison, who developed the Seathwaite project, has left IFE, having been appointed to the Chair of Environmental Chemistry at Lancaster University. Bill had received Individual Merit Promotion in recognition of his work in aquatic chemistry and, although this is a loss to the Institute, we wish him well in his

Seathwaite Tarn, Cumbria

new career, confident in the knowledge that his appointment will strengthen our collaborative links with Lancaster University. Dr Ed Tipping has assumed overall responsibility for the project devoted to Physico-Chemical Processes in Catchments and it is a particular pleasure to record that Ed was awarded the degree of DSc and received Individual Merit Promotion during the year. Two other members of staff have left the Institute. Mr Terry Gledhill retired after 35 years research at both the River and Windermere Laboratories. Terry is a recognised authority on water mites and his expertise in the analysis of freshwater invertebrate populations not only contributed substantially to the Institute's research programme in this area but also to our success in earning commissioned research. Joan Bird left us after eleven years as assistant librarian at the Windermere Laboratory. Many of us, both within the Institute and those who have used the library's information service owe a debt of gratitude to Joan for the thoroughness with which she handled the many enquiries which came her way. We wish her well on her appointment as a Librarian at the British Geological Survey.

The success of our staff in obtaining promotion, and moving to other positions over the past two years is to be welcomed, in that it reflects the quality of the individuals involved and is a reward for their scientific achievements. It does, however, pose problems when we attempt to maintain the balance of our programme. If I might cite just one area of research, invertebrate zoology, as an example of the pressures which arise from such staff changes. We are all increasingly aware of the need to assess and maintain biodiversity within ecosystems. To do this successfully, we need scientists who are adequately trained in systematic biology. Unless we can identify the organisms present and determine whether the community present is functioning properly, then we are less able to provide appropriate management advice. The demand for the services of invertebrate zoologists is now such that individuals often spend more than 90 % of their time on commissioned research. This is valuable work, but the outcome is often that little or no time is given to the research required for the future or for training new staff essential for such work.

Given our excellent working relationship with many British Universities I believe that these problems will be overcome, but I remain concerned about the erosion of the UK science base in this and other important areas.

Open Days at the River Laboratory attracted a large attendance and much discussion

Management of lakes and reservoirs

Problems associated with algal blooms

Popular interest in planktonic organisms, explicitly or by implication, has continued to increase throughout the past year. This ascendancy stemmed primarily from the concerns about the occurrence of toxic blue-green algal blooms and the threats they pose to amenity, to the health of users of recreational waters and, allegedly, to consumers of drinking water. That several significant commissions, together with numerous minor contracts, have been undertaken recently by project personnel, properly reflects these concerns. For instance, staff at Windermere and Edinburgh have provided extrapolations, options and recommendations for a diversity of water-quality management issues. These have included projections for a proposed enlargement of one pumped-storage reservoir, for the addition of a fluvial raw-water source in the case of another and, for another customer, for the delivery to a treatment works from a chain of reservoirs of stored water with a year-round, low algal content. In another instance, Institute staff are directly involved in a programme of investigations to discern the regulation of algal growth in a major storage reservoir. Meanwhile, the persisting enthusiasm to smooth off the irregularities of the British coastline with barrages and the laudable desire to regenerate redundant docks and urban watersides, bring a succession of requests to the Institute to predict future water quality and to recommend procedures for its enhancement. Moreover, as the requirements of the National Rivers Authority for ecologically-sound management principles have been progressively defined, so the recognised ability of the Institute's staff to supply reliable, quantitative models, based upon a well-researched understanding of the system, has been increasingly tapped. A significant and growing commitment to the NRA's programme on toxic blue-green algae has come from the IFE.

Pending the success of tenders outstanding at the time of writing, this project will become wholly customer-driven. Against the present criteria for judging science, this may be viewed as a notable achievement. Supposing that sentiment plays no part in the choice of contractor, the Institute is being judged as being capable of delivering the goods, satisfactorily and economically. It is naturally appreciative of this interest and support from its customers.

Nutrient control

In most instances our priority is to determine the present controlling mechanisms or, at least, those operating for predominant periods. It is not often the case that a lake - or reservoir - system which is currently causing management difficulties or producing algal populations of prejudicial sizes will prove to be "nutrient-limited". It follows that attempts to restrict the amounts of phosphorus or nitrogen will have little effect until either is actually forced to limiting concentrations. Where will these levels be? What about diffuse sources or internal loads? How responsive would the system be? Nobody has yet answered these questions in a systematic and applicable way. Gradually, however, as our understanding of individual systems improves, the general overview also becomes clearer. Our attempts to simulate realistically the response rates of algae, their growth *in situ* and the demands they place on the resources are steadily improving; once we can reproduce something close to the prototype, we can then alter factors selectively to investigate "what if...." type questions: What if we removed the effects of nutrient limitation? What if we reduced the amounts available? and so on. An example of a test run on nutrient control is illustrated in Figure 1 - a sort of computer bioassay experiment!

Other controls

In those instances where nutrient limitation is demonstrably not occurring, then it is clearly desirable to be able to determine what other factors are critical and how they operate. Again, gradually rather than systematically, we are evolving and refining models which determine how the dynamics of given species are affected by water temperature, day length, mixing intensity and depth, by flushing and by higher trophic levels. Here, there tends to be a reliance placed upon literature values

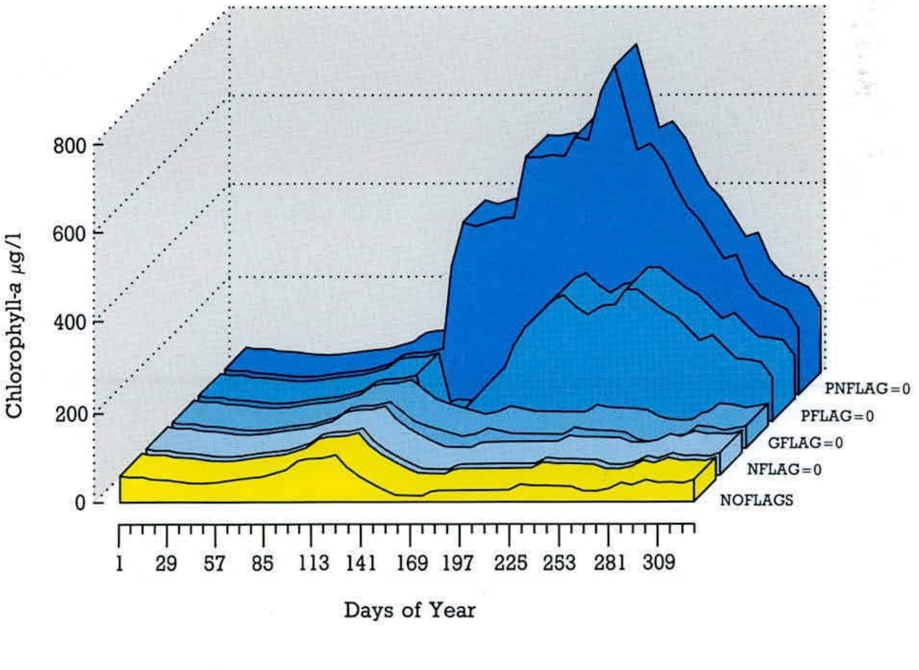


Figure 1 Diagram of PROTEC output predicting chlorophyll concentrations against physical-chemical variables. One of the features of the simulation is that potentially limiting variables may be selectively eased to determine which is the controlling factor. Thus, relieving N-limitation (NFLAG = 0) makes no difference to the basic run (NOFLAGS), nor does relieving grazing removal (GFLAG = 0) have much effect. Allowing unlimited phosphorus (PFLAG = 0) gives a much larger biomass response, to the limits of the nitrogen supply in fact. When both N and P are freed (PNFLAG = 0) the system achieves its light-limited maximum.

which are not always strictly applicable, so it is useful to be able to interpolate first-hand data wherever possible. For instance, the use of airborne remote-sensing to measure dissipative mixing processes at the surface of lakes has proved valuable in relating depths and rates of convection to wind speed. We are able to relate species, abundances and water temperatures to approximate rates of removal by grazers rather than suppose "that it must happen".

The complexity of pelagic systems

Pelagic systems are at last being recognised to be much more complex than a solution of chlorophyll looking for a few atoms of phosphorus. Their dependence upon physical forcing and biotic interactions are no less important, neither are the adaptive mechanisms that various species have evolved to cope with different parts of the spectrum of environmental variability (Figure 2). As in other branches of biology, the need to resolve the critical time and space scales of the various processes involved remains paramount.

The redeeming prospect is that the larger clients now recognise the true value of fundamental research. There would appear to be developing opportunities for the sponsoring of strategic projects, over a number of years. The groups created are likely to be small and to be directly responsible to their sponsors. The Institute is alive to these openings and the need for a more flexible structure to accommodate them.

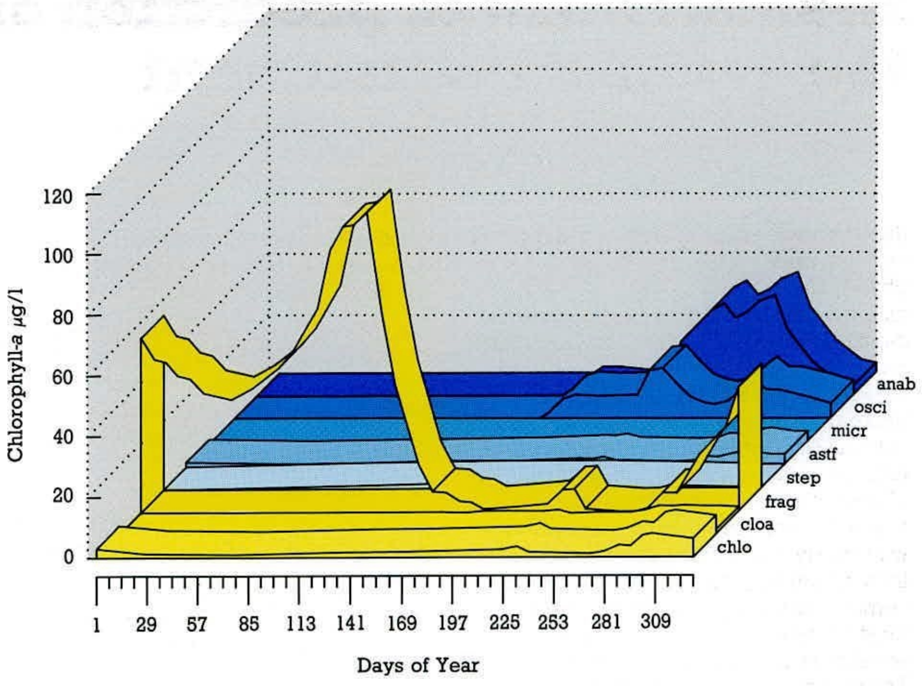


Figure 2 An example of the simultaneous simulations of eight algal species to the conditions (temperature, mixing, nutrients and grazing rates) offered through the year. Fragilaria, *a common diatom, predictably responded to the cool, well-mixed and silicon-rich conditions though, in this instance, benefitted from high initial 'seeding'.* Anabaena *replaced* Oscillatoria *and, indeed, all other species, during severe nitrogen depletion in late summer. anab*=Anabaena circinalis; *osci*=Oscillatoria agardhii; *micr*=Microcystis aeruginosa *(in 100 µm colonies); astf*=Asterionella formosa; *step*=Stephanodiscus hantzschii; *frag*=Fragilaria crotonensis; *cloa*=Closterium aciculare; *chlo*=Chlorella *sp. (assumed to be 4 µm in diameter).*

Assessment and prediction of changes in the aquatic environment

Research within this project has increased our awareness of the importance of physical factors in determining to what extent planktonic organisms, for example, capitalise on nutrients and other chemical resources. Indeed, the balance between free-living plants and species of attached micro- and macro-flora in different habitats (eg streams *cf* ponds, rivers *cf* lakes) is also largely determined by physical factors such as the water residence time, and the depth of the waterbody. The physical environment thus influences changes in a number of components of aquatic ecosystems. In most of the areas discussed below, the weather is an important consideration. The essential requirement for taxonomic expertise, to aid interpretation of biological changes, is also highlighted. The section concludes with a reference to the underpinning of tropical fisheries management with research on the physical, chemical and biotic aspects of the ecology of lower organisms.

Inter-annual differences in stream silica

The River Laboratory has been studying the chemistry and flow of southern English chalk streams for over 25 years and has built up a unique set of data on these subjects. Plant nutrients such as nitrate, phosphorus and silica, are of special interest and have been investigated in both natural and artificial re-circulating streams. Seasonal changes in silicon concentration in natural streams are often related to algal growth. It is notable that fluctuations in silicon are similar over the complete catchment of a southern river (Figure 3); indeed, seasonally similar patterns were recorded in other rivers, eg the Frome in Dorset, and the Avon in Hampshire. Figure 3 also shows that the similarity is maintained even between years exhibiting otherwise quite different patterns of change, particularly as regards the total range of values. The weather has an important influence on the observed concentrations in at least two respects. Firstly, rainfall affects runoff and flow and, secondly, temperature controls diatom activity. Uptake of silicon by, and its dissolution from, diatoms was intensively studied using the re-circulating experimental channels at Waterston. Because these channels were run as closed systems, it was possible to quantify the fluxes of silicon by measuring the inflow and outflow concentrations; the changes were related to the growth and decline of diatom populations. Results from the channel experiments were then compared to changes in silicon concentrations occurring in natural streams.

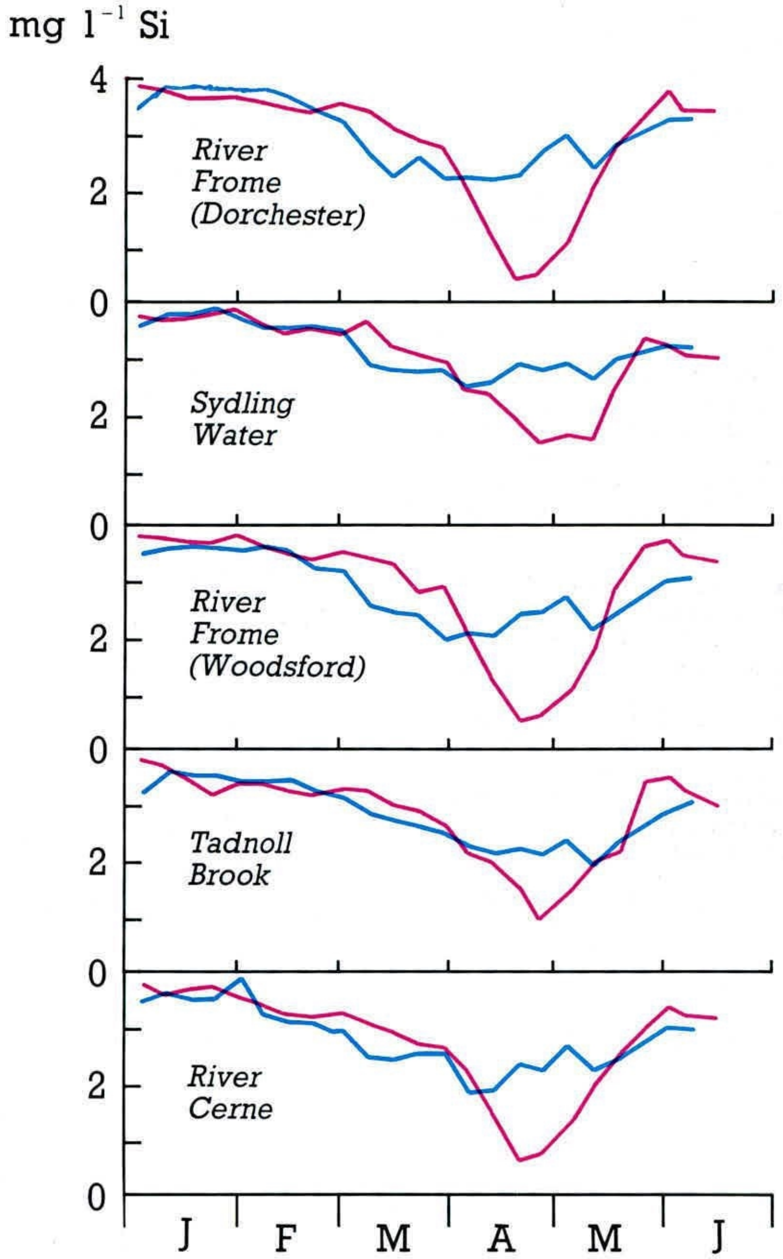
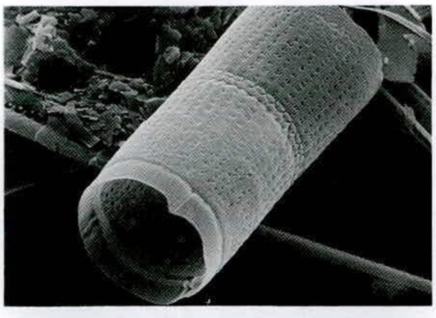


Figure 3 Silicon concentrations over the River Frome catchment for the period February to June 1983 and 1984: note the large differences between years but the similar pattern over the catchment for each year.

Long-term assessment of English Lake District waters

The spread of planktonic algae

As in previous years, the spring phytoplankton of these lakes has been dominated by diatoms. However, many of the species recorded appear to have only recently invaded these waters, but they already account for a significant proportion of the algal populations. Good examples include *Aulacoseira islandica* subsp. *helvetica* (O. Müller) Simonsen in Windermere, and *A. ambigua* Grunow in Bassenthwaite Lake. These diatoms (compared in Figure 4) may have remained unidentified but for collaboration between ecologists with taxonomic expertise, the culture facilities and the Fritsch Collection of Algal Illustrations. The situation demonstrates the necessary research arising from a long-term monitoring project. The migration of species, such as the two *Aulacoseira* species referred to above, and two *Oscillatoria* species, poses the



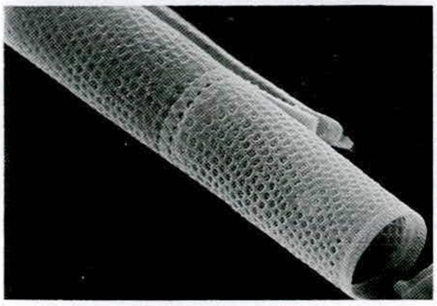


Figure 4 New diatom plankton in Windermere and Bassenthwaite Lake, English Lake District: a) Aulacoseira islandica *subsp.* helvetica *b)* A. ambigua *- scanning micrographs of sibling valves with diagnostic areolar patterns and interlocking spines (bar = 10 µm).*

question as to how new species invade, and can eventually dominate, a lake. They plainly reflect nutrient inputs but, more importantly, they may represent contamination or imports from sources many kilometres distant. This suggests that transport could be affected by a human agency, particularly in these days of increased leisure travel. It highlights the problem that harmful, as well as inocuous, organisms are now assisted in their passage between waterbodies; moreover, those monitoring them may be instrumental in the dispersal process.

Weather and algal blooms

The recent trend of mild winters followed by warm summers with an ample supply of nutrients, has resulted in the widespread establishment of bloom-forming nuisance algae - in particular, species of *Anabaena, Aphanizomenon, Microcystis* and *Oscillatoria*. The ultimate abundance of these generally slow-growing organisms is very dependent upon the length of their growing season. For instance, warm, dry spells of even a few days, let alone weeks, longer than usual, may facilitate one or two extra cell divisions, ie a doubling or quadrupling of the biomass. Indeed, a preliminary analysis of the long-term algal records for Windermere has shown - perhaps surprisingly - no consistent trend towards increased blue-green algal abundance over the last 50 years. Rather, there have been relatively good and relatively poor years for the growth of these algae.

Variation in flushing rate: effects on the restoration of Loch Leven

By virtually eradicating a source of phosphorus-rich industrial effluent, the external input of this nutrient to Loch Leven, was reduced during 1988 to 1989 by about 25% - a value based on 1985 loading figures. In 1990, however, the levels of soluble reactive phosphorus (SRP) and of particulate P (PP) in the form of phytoplankton, were considerably higher than those measured in 1985. This observation appeared to be all the more anomalous considering that, in Scotland, 1990 was slightly wetter than the previously-considered wet year of 1985. A possible explanation relates to the difference in the seasonality of rainfall between the years - as expressed in Figure 5 by the patterns of cumulative discharge of water from a major inflow to the lake. A marked contrast relates to the percentage of the annual discharges achieved between the beginning of the year and the end of April, ie 23% in 1985, and 62% in 1990. In addition the period July to September inclusive in 1985 saw an input of some 35% of the annual discharge while, during the corresponding 3 months of 1990, only 5% of the yearly amount was recorded. Thus, during the late summer-early autumn period in 1985, the loch was especially well-flushed, algal populations were moderate, and net gains of P to the water column due to release from the sediments were minor. In the same period of 1990, however, warm, rain-free conditions prevailed, and enormous releases of SRP from the sediments were recorded, ie about 18 mg P m^{-2} day^{-1}, and algae increased as a consequence.

Long timescale changes: Blelham Tarn palaeolimnology

At the time of the FBA's Golden Jubilee in 1979, the study of the diatom stratigraphy of the recently-accumulated sediments of Blelham Tarn (near Windermere) was verified by the excellent correlation found between the records of planktonic algae and the successive annual layers of sediment. Further core samples were collected in June 1990, using freezing techniques, and were studied in collaboration with Liverpool University and King's College, London. The sediment included a clearly laminated stratigraphy within the upper part - a feature not found in the earlier material - and these changes were sufficiently clear for the light and dark bands to be sampled separately.

Diatom analyses have correlated the 25 cm section with earlier studies and show

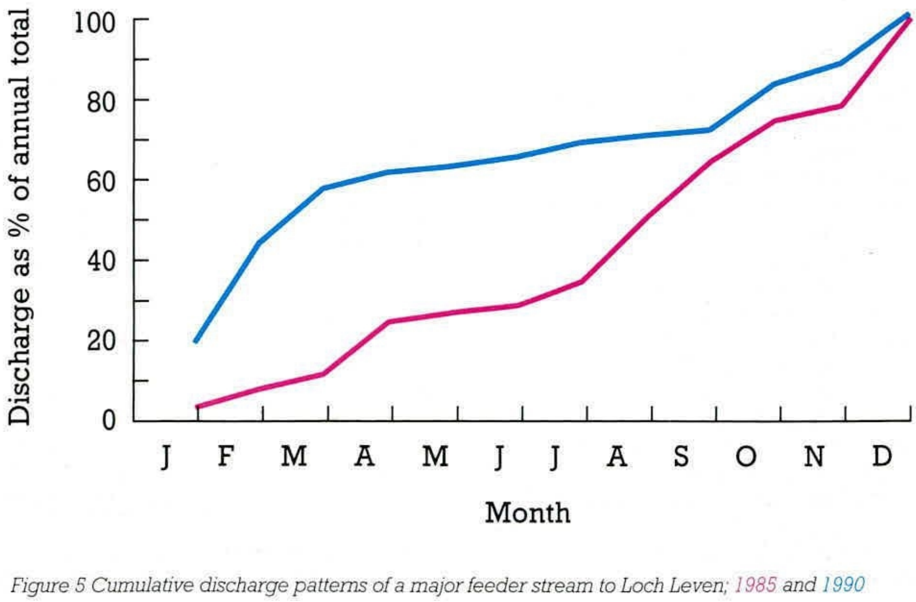


Figure 5 Cumulative discharge patterns of a major feeder stream to Loch Leven; 1985 and 1990

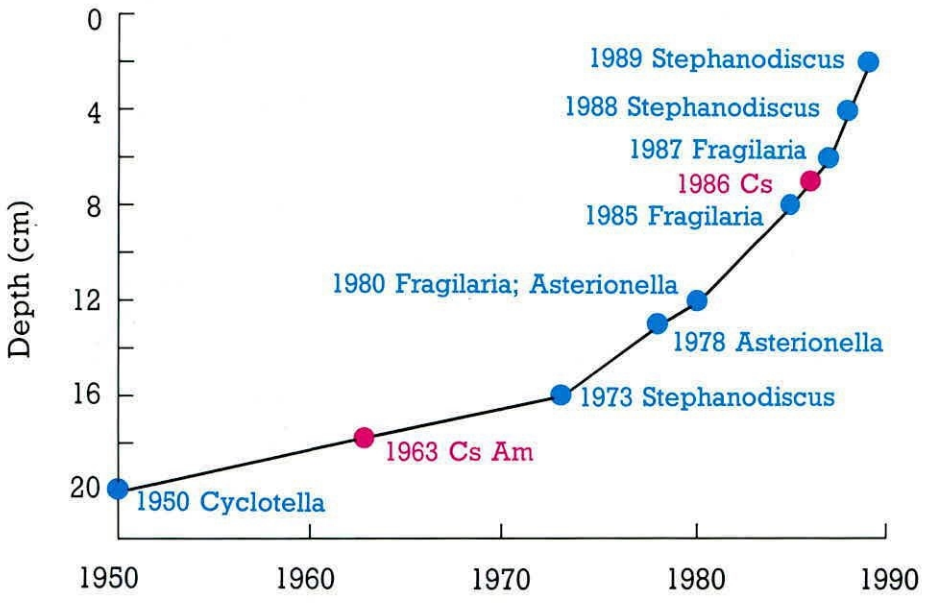


Figure 6 Time/depth curve for Blelham Tarn recent sediments: dated diatom maxima and radio-isotope analysis.

that (i) the original sediment *Cyclotella* decline of 1950 is now at 20 cm, and (ii) approximately 12 cm of sediment has accumulated since 1978. Changes in the living populations, as monitored by our algologists, were again used to construct an algal-based assessment of sediment accumulation (Figure 6). The current data highlight the considerable increase in sediment input; from 0.22 cm $year^{-1}$ between 1950 and 1973, to 0.57 cm $year^{-1}$ between 1973 and 1980, and 0.80 cm $year^{-1}$ between 1980 and 1987, with the subsequent accumulation of about 2 cm $year^{-1}$ representing uncompacted material. Maxima in the radioisotopes 134-Caesium, 137-Caesium and 241-Americium relating to the 1986 Chernobyl incident, and to the 1963 maximum of weapons testing, fit in extremely well with the algal time-scale, and substantiate the acceleration in accumulation.

With increased accumulation, differences in seasonal layers in the deposits are much more conspicuous. Black layers are the products of summer de-oxygenation between June and October, while the brown ones represent the period between autumn overturn and the spring diatom bloom. That the brown material is so visible, suggests that it is accumulating faster; this may be due to some disturbance in the catchment, since changes in nutrients and algal productivity hardly account for such an increase. The Chernobyl radio-isotope peak coincides precisely with the summer black band at 7.1 cm. The light and dark bands of 1980 to 1985 are less well-defined than those of later years. In common with the other issues discussed, it is likely that weather events are important; here it would affect, for example, the transport of sediment from the catchment.

Application of the research - a tropical focus

The previous Annual Report expressed our wish to see findings of our research applied more widely to the requirements of water managers and other custodians of the aquatic environment. It is a pleasure to report that attention to this has increased markedly; indeed, without the financial support of the National Rivers Authority, much of the Windermere programme would suffer and, were it not for funding from the Scottish Office, the surveillance of Loch Leven would have ceased. Fortunately, however, there is the need by these departments for scientifically-sound limnological programmes.

Much of the thinking behind ecological studies of the type described above could benefit programmes aimed at enhancing fish production - particularly in developing countries. Currently, we are involved in studies on the physical features, chemical composition and biotic interactions of organisms in food chains leading to fish. An example is the research highlighted by a mission to Bangladesh; one project aims to assess the impacts of proposed flood control programmes on the existing flood plain fishery of that country, and another seeks to evaluate fish stocking programmes designed to compensate for any loss of flood plain resource. For example, the ecology of water bodies of the type shown in Figure 7 will be investigated intensively even before any stocking is carried out. At present, the economics of stocking such large lakes remains unquantified, not least because the influence of 'native' fish species on the introduced fry is unknown. In another area of collaboration - with Indian scientists - it appears that the general structure of the food webs in multi-species fish culture systems is known, but the ways in which the basic properties and environmental requirements of the component organisms (population densities, physical and nutrient preferences) are assessed, can be improved.

Figure 7 Chak net fishermen on the Baluhar Beel (Oxbow lake), Jessore District, South-West Bangladesh which is the subject of a large-scale fish-stocking programme.

Ecology of large lowland rivers

Earlier work, carried out on the River Severn established the relevance of the aggregated dead-zone model of flow to the dynamics of phytoplankton populations and raised a number of important subsidiary questions. Do storage zones serve as refugia for flora and fauna during major perturbations? Are river communities more or less vulnerable to pollution incidents than hitherto thought, as a result of significant quantities of water being held "in store"? Are current discharge consents set appropriately? Does the siting of telemetric instruments give the best synoptic view of the health of a river? In order that such questions can be answered correctly it is necessary to establish how widespread is the dead zone behaviour; hence an important component of the large river research programme involves an extensive survey of the fluvial characteristics of 16 rivers.

The second component is an intensive study of the ecosystem of one such river, the Great Ouse. The Great Ouse is a highly regulated and intensively used and managed river in which the quality of the fishery, at least in the middle and lower reaches, is generally perceived to have changed from what was once an excellent and productive mixed fishery to one that is now strongly dominated by small roach. The work being done by the Eastern Rivers Laboratory is designed to be complementary to that which has been carried out by the National Rivers Authority (formerly by Anglian Water) since the early 1980s. The NRA conducts a survey of coarse fish populations in the river as part of a rolling 3 year programme, encompassing all major rivers and tributaries in the Anglian Region. However, the NRA data are restricted, by virtue of the sampling methods employed, to fish that are greater than 10 cm in length. IFE research on the river therefore concentrates upon the larval and juvenile stages and the factors that are likely to influence their growth and survival, including physical conditions and the population dynamics of their principal food organisms.

Fluvial characteristics of lowland rivers

The premise upon which this work is based is the paradoxical one that rivers do not discharge very efficiently but instead comprise numerous pockets of non-flowing water, exchanging fluid across their boundaries with the main downstream current. These dead zones are now recognised to be extremely important in fluvial ecology. They have been likened to individual ponds interlinked by a common bathing medium but isolated in so far as their internal dynamics are concerned. The longer water is detained the more its character may change, with respect to solutes (including gases), suspensoids (finer material has the opportunity to sediment), the nature of the underlying sediment, and the abundance and species composition of the phytoplankton.

Particular attention is being paid to the latter for its potential to characterise the behaviour over selected reaches, for, although the combination of flow variability amounts to an infinite progression, the sum of the processes may be judged by changes along the reach in the mainflow algal concentration.

The programme has already established that the increase in phytoplankton can be greater, sometimes by a factor of 3 or more, than can be explained by growth of algae carried between an upstream and a downstream station at what appears to be the mainstream velocity. The hypothesis, yet to be disproved, is that the greater is the exaggeration in downstream increase, then the greater is the aggregated dead-zone retentiveness of the reach as a whole.

Over 60 reaches in 16 river systems have been selected for synoptic study. The choice has as far as possible, included a cross-section of headwaters and lower basins; steep- and low-gradient reaches; differing distances from source; and differing levels of enrichment and pollution loads. Each reach has been observed under differing seasonal, flow and temperature conditions. A database has been accumulated pending evaluation of comparative reach retentiveness against the primary variables. The early indications are, not surprisingly, that retentiveness appears to be an inverse function of gradient, though the effect may be enhanced or suppressed by degree of sinuosity.

Samples have also been taken that are intended to show that the fluid exchange rates between main flow and dead zones are themselves sensitive to discharge fluctuations.

The Great Ouse Ecosystem

The previous report in this series concentrated on spatial variability in the Great Ouse. This time the emphasis will be on temporal variability and in particular on between-year differences in factors that are likely to influence the survival or growth of larval and juvenile fish to a significant extent.

Water velocity

Young cyprinids, especially during their first year, are unable to maintain station for any length of time at velocities in excess of a few centimetres per second. Newly-hatched roach, for example, require regions where velocity does not exceed about 6 cm s^{-1} (Figure 8). The predominantly uniform and more or less rectangular cross section of the Great Ouse provides few areas where shelter from periodically high current velocities can be found. Figure 9 illustrates this point with reference to an important back-channel, Lees Brook, which is similar in shape, though narrower and shallower than the main river. Even at very low discharge only the extreme margins are within the limits of tolerance of newly hatched roach and at high discharges virtually no part of the river is suitable for them. In the circumstances described

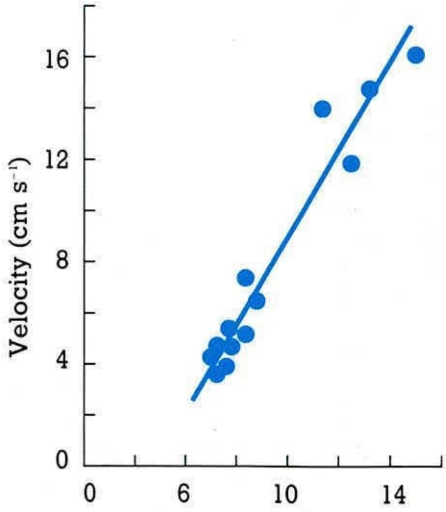


Figure 8 Critical velocities for maintenance of station by young roach.

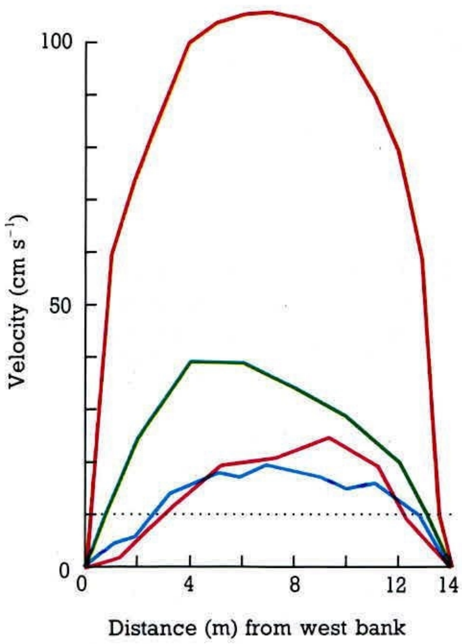


Figure 9 Current velocities measured across a fixed transect on Lees Brook, under a range of discharge conditions: 25 April 1989; 2 May 1989; 18 January 1990; 9 February 1990.

above, shelter provided by the development of submerged plants in summer is potentially very important to the survival of young fish.

Phytoplankton and turbidity

While winter turbidity (Figure 10) is mainly attributable to suspended allochthonous material, turbidity in late spring and early summer is primarily caused by phytoplankton populations. The resultant attenuation of light restricts the development of higher plants and of periphyton. The pattern of development of phytoplankton in 1988 was almost identical to that in the following year. In both years a single large peak occurred during May, but in 1990 phytoplankton began to increase early in March and, by the middle of that month, had already attained a density equivalent to the maximum for 1988 and approaching that for 1989. Phytoplankton chlorophyll levels subsequently remained relatively high until the end of June 1990 with three further peaks in April, late May and June (Figure 11). In spite of the very different pattern of abundance during the first half of the year, phytoplankton populations still declined in July and August, as in 1988 and 1989.

Phytoplankton also plays an important role in the ecology of this river as a source of food for planktonic animals, notably rotifers, which are an essential component of the diet of very young cyprinids.

Growth of submerged plants

The main channel of the Great Ouse is mostly too deep and the water too turbid to permit much primary production to take place on the river bed because there is insufficient light for growth of either macrophytes or attached algae. Higher plants and epiphytic algae are able to develop only in the shallow margins of the main river. Mapping of the distribution of higher plants was carried out by means of a series of transects on five occasions between September 1988 and September 1990, on three main river reaches and in three side-channels.

In terms of the extent of river bed occupied, and in the submerged surface area that it contributes, *Nuphar lutea*, the yellow water lily, is the most important species of macrophyte in the Great Ouse system. Since it has floating leaves as well as submerged leaves that are elevated well above the river bed, it is able to grow in water that is too deep for smaller submerged plants. The growing season of *N. lutea* extends from April to October and area of maximum cover was assessed from 1988 to 1990. These estimates indicate an increase in the area of main river occupied by *N. lutea* from about 5% in 1988 to approaching 10% in 1990. It seems likely that the severe floods of the winter of 1987/88 dislodged a proportion of the rhizomes of this plant with a gradual expansion in area resulting from the much more stable conditions that pertained during the ensuing dry years.

Wholly submerged plants, such as the pondweed, *Elodea*, are able to grow only in areas that are shallow enough for sufficient light to reach the river bed. Such areas, although very restricted in the main river, are much more common in several of the back-channels. However, one of the main river sampling sites is unusual in having an extensive shallow marginal area that occupies almost one third of the river area. This region was densely colonised by submerged species only in 1989, when up to 30% of the river area in this particular reach was occupied by *Elodea*. The absence of submerged plants in 1988 is probably attributable to the relatively high current velocities during the spring and preceding winter, which would have extensively scoured the soft marginal sediments in which this species has its roots. Conversely, the mild winter and low discharge regime of the following

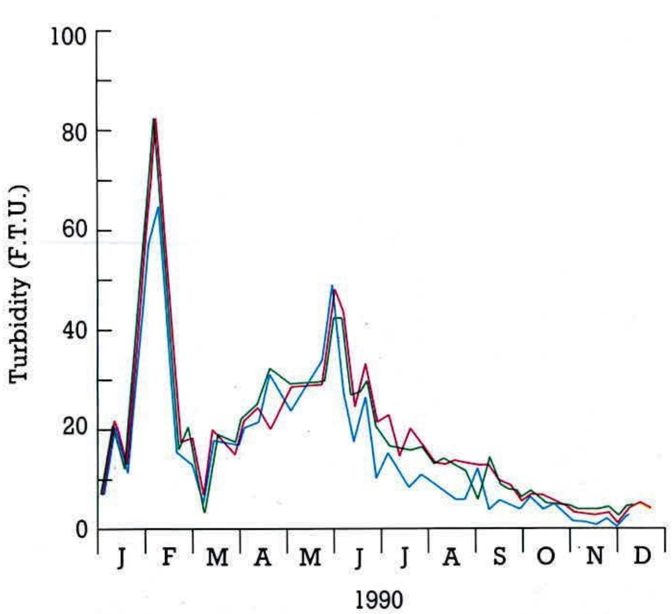


Figure 10 Seasonal variation in turbidity, expressed in Formazine Turbidity Units, in the River Great Ouse, 1990: Huntingdon, site 7; Lees Brook site 3; Cooke's Backwater, site 6.

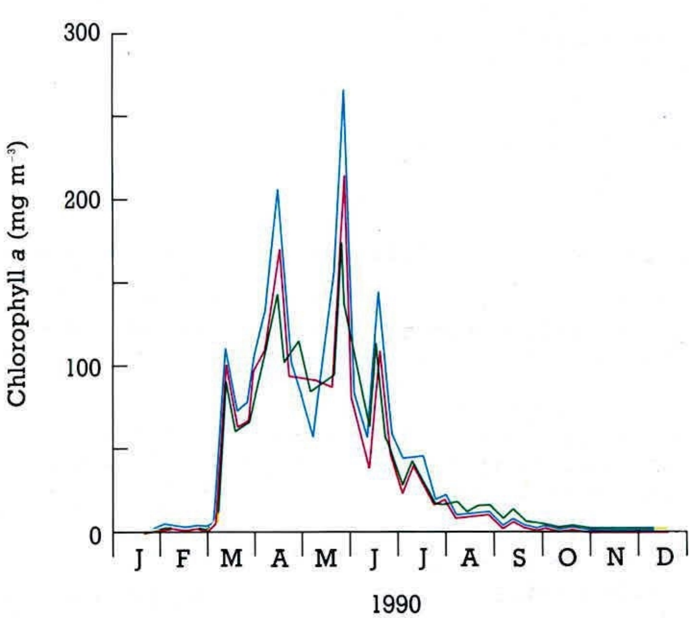


Figure 11 Seasonal variation in phytoplankton chlorophyll a *in the River Great Ouse, 1990: Huntingdon, site 7; Lees Brook, site 3; Cooke's Backwater, site 6.*

year, coupled with the relatively clear water that prevailed over much of 1989, favoured the development of submerged species. The absence of any development of submerged plants in 1990, following a winter with predominantly low current velocities, resulted from the much more turbid conditions, due to the early development and greater persistence of phytoplankton during spring and summer of that year.

Young cyprinids and their food organisms

Rotifers are the dominant items in the diet of recently hatched roach. During the early days after hatching only very small organisms can be ingested and it is possible that the availability of rotifers at this critical time is an important factor influencing their early growth and survival. Investigations on larval cyprinids, carried out in hatcheries have indicated that maximum intake of rotifers only occurs at densities greater than about 1500 l^{-1}. At lower densities consumption rapidly declines. In 1989 densities only exceeded this, apparently critical, level for a very short period, coincident with the peak in phytoplankton abundance and closely coincident with the time of hatching of roach but well before the appearance of larval bream. In 1990, in response to the greater abundance of phytoplankton, densities of rotifers were above this critical level for most of the late spring and early summer. It is interesting to note that in 1989 numbers of young bream were found with empty guts, perhaps reflecting a scarcity of suitable food items.

Dietary studies of young roach in the Great Ouse also indicate a shift in feeding behaviour later in the summer from predominantly plankton feeding to the grazing of aufwuchs from plant surfaces, with rotifers becoming less important and Cladocera, Copepoda and other invertebrates becoming correspondingly more important. The much greater abundance of Copepoda and Cladocera on *N. lutea* in 1990 (Figure 12) may also have aided survival during the transitional period between reliance on very small planktonic animals and progression to feeding on macro-invertebrates such as Chironomidae. Instantaneous growth rates of roach (Figure 13) indicate a reduction in rate of growth for a short period in 1989 that was not temperature related. This may indicate that feeding conditions were limiting, if only for a short period. On this basis it would be predicted that 1990 will be a better year for cyprinid recruitment in the Great Ouse than 1989, in spite of both being very warm years with little disruption of populations through periodically high current velocities.

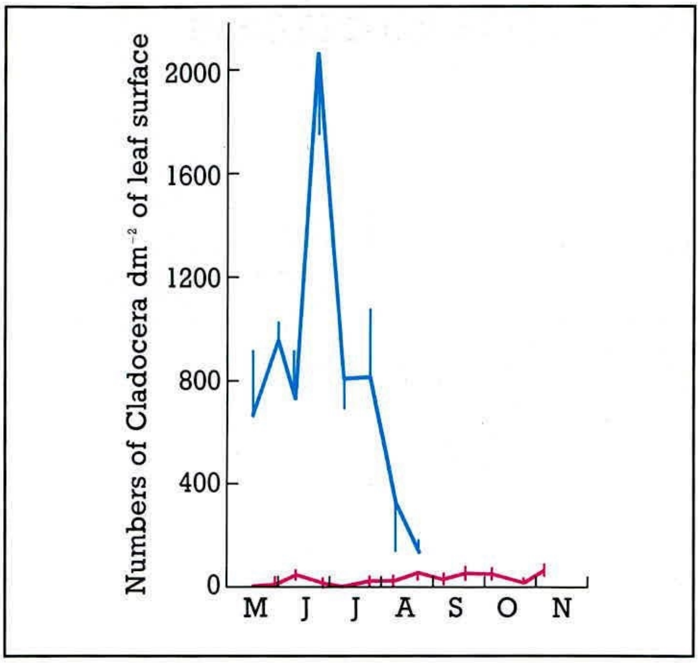


Figure 12 Densities of Cladocera on N. lutea *in the River Great Ouse in 1989 and 1990.*

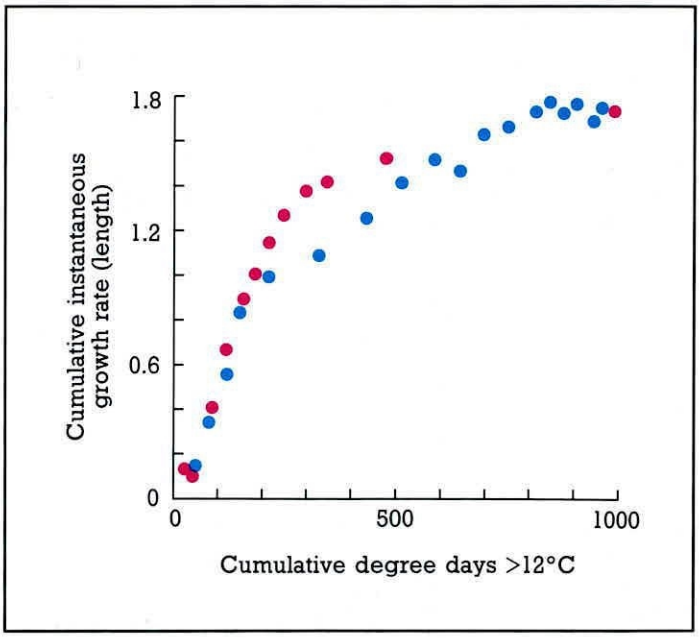


Figure 13 Cumulative instantaneous growth rates of young roach in the River Great Ouse in 1989 and 1990.

Land-river interactions

Macrophyte-invertebrate associations

Lowland river sites frequently have a complex mosaic of habitat types. These can include a range of emergent, floating and submerged macrophytes, together with non-macrophyte substrata such as gravel, sand and silt. Given the diverse assemblages of invertebrates found at many unstressed sites, there is an expectation that different species will exploit the full range of habitats, depending on their particular requirements.

Many previous studies have shown associations between species and habitats at a given site or sites within a single river. However, the extent to which generalisations are possible on the invertebrate fauna of particular habitat types across a series of lowland rivers has not been examined previously.

Detailed information on where invertebrates occur is important for their conservation and must be available if the consequences of river management practices involving habitat change are to be anticipated. The Nature Conservancy Council has been sponsoring such a study, involving 76 sites on over 30 river systems in lowland Britain. Data on the macroinvertebrates associated with a very wide range of different habitat types in summer have been obtained and are currently being prepared for analysis.

Even at this early stage it is apparent that the taxon richness of the fauna varies between the major habitat categories (Figure 14). The assemblages of invertebrates on the non-macrophyte substrata are less taxon rich than those on submerged and floating macrophytes, as anticipated. However, the richest assemblages are found on the emergent macrophytes and, in particular, in some of the widespread tall emergents, including *Phalaris, Sparganium* and *Glyceria*. These findings raise basic questions on the role of habitat structure, food availability and seasonal stability, as factors influencing both the richness and composition of the assemblages found on the major habitat types. It appears that marginal vegetation provides valuable refugia for many invertebrates and, at times of high discharge, may be critical to the survival of certain taxa.

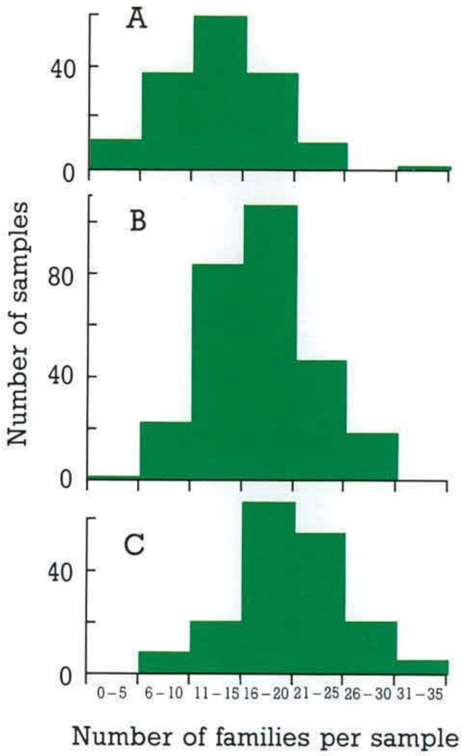


Figure 14 Number of families of macro-invertebrates per timed pond-net sample from: A - non-macrophyte substrata (n = 155); B - submerged and floating macrophytes (N = 276); C - emergent macrophytes (n = 175).

This project will generate information on the species of invertebrates associated with individual species of macrophytes and other substrata. In the future we hope to link our current approach to the prediction of the fauna at a site from environmental variables with this new information, in order to give practical guidance for the conservation of river invertebrates.

Midge communities in filter beds

Slow sand filters are used to remove particulate and dissolved material from microstrained raw reservoir water for drinking water supply. Each filter bed consists of a large concrete tank with a porous base overlain by cobbles and a thick layer of sand which forms the filter. Water flowing into the tank flows through the sand and cobbles to the porous base and thence to the water supply system after chlorination.

After only a few days the surface of the sand develops a rich organic coating which is removed by mechanical scrapers when the beds are drained. A study was carried out in collaboration with Dr R.S. Wotton, University College, London at a site where cleaning occurred on average every 30 days. The range of bed runs (the time of filter operation between cleaning) was from 16 to 77 days. Beds were cleaned as necessary but most were kept full at any one time to ensure a continuous supply of filtered water. Each bed can therefore be considered as a transient pond surrounded by other, identical ponds but with different cycles of drying and filling. All beds are identical in size, homogeneity of the substratum, and water depth (Figure 15).

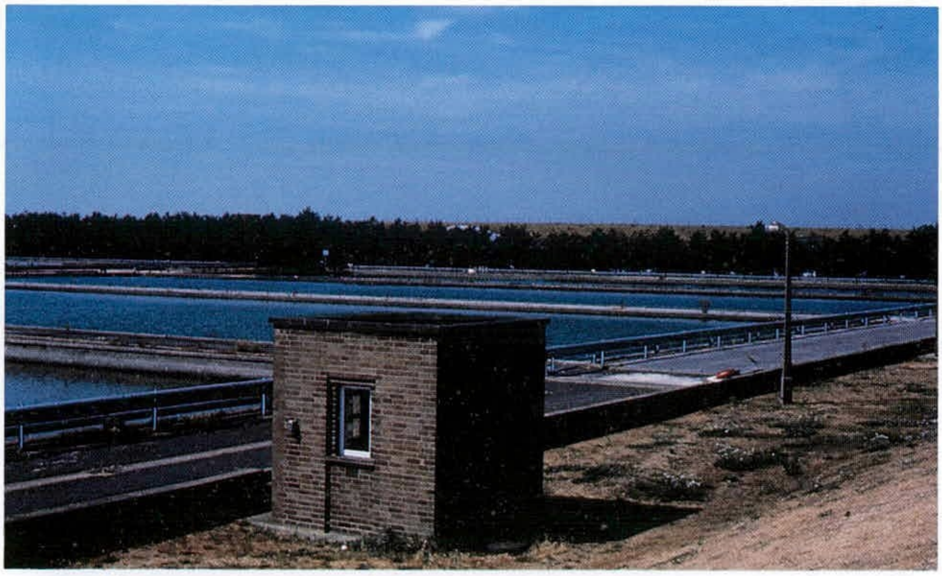


Figure 15 Slow sand filter beds.

The filter beds are colonised rapidly by non-biting midges, Chironomidae. The eggs (yellow mass) in the container shown in Figure 16 were collected from a single cord placed across the water surface of a filter bed one day after the bed was filled with water. Scale is shown by a £1 coin on the edge of the tray.

Figure 16 Chironomid egg masses.

Emergence traps were located on eight beds and the numbers of emerging midges recorded every two days while the beds were in operation (166 separate estimates throughout the study period July-December). As colonisation began from the time beds were refilled with water, the timing of the first peak of emergence of each species was used to estimate the duration of the aquatic phase of the life-cycle. In addition samples of larvae were taken from the filtered organic layer when the beds were drained (Figure 17) in order to provide data on those species which had not had time to complete their development and on population structure and food intake.

The benthic macroinvertebrate fauna of the filter beds was dominated by Oligochaeta and Chironomidae throughout the study period. The abundance of oligochaetes was noted but no further work was done on this group. A total number of 23 taxa of Chironomidae was recorded from both emergence traps and benthic samples. Of these, only four (*Cricotopus sylvestris, Psectrocladius limbatellus, Tanytarsus fimbriatus* and *Ablabesmyia phatta*) were consistently abundant during the study period.

Figure 17 Chironomid larvae in core of bed material.

When the size of all adult midge species was compared with the duration of the aquatic phase, it was clear that the first to emerge were taxa of small size. These species (namely the four above) were able to complete their development in a mean period of about 20 days and were thus well adapted to the cycle of drying and filling prevailing in the filter beds. Larger midges, mainly belonging to the sub-family Chironominae, took longer to develop and were only recorded as larvae at the end of short bed runs, although they did dominate the emergence trap collections at the end of long bed runs.

The study showed that slow sand filter beds provide excellent replicated habitats to study the interactions between colonisation processes, food supply and population densities.

Countryside Survey 1990

The 1990 Countryside Survey was the most detailed field-based study ever undertaken of the British landscape, the way it is used and the flora and fauna it supports. This ambitious study was principally funded by NERC and the Department of the Environment with additional funding from the Department of Trade and Industry and the Nature Conservancy Council.

The programme involved the collection of extensive data from a total of 508 rural and 25 urban 1 km squares. Selection of survey squares was based on a comprehensive national classification of each of approximately a quarter of a million squares into one of 32 different land classes. The research institutes participating in the programme, apart from IFE, included the Institute of Terrestrial Ecology (ITE) who coordinated and led the research, Soil Survey and Land Research Centre, Macaulay Land Use Research Institute and the University of Newcastle-upon-Tyne.

The main terrestrial studies were undertaken by ITE. Amongst the many features they recorded were the agricultural use of land, the vegetation of unfarmed land, the types and lengths of hedges, walls and fences surrounding fields and the variety of plants occurring in open fields and woodlands, along hedges, road verges and streams and within the streams themselves.

The majority of the information collected by ITE can be directly compared with similar surveys they had carried out in 1978 and 1984. In this way the changes taking place in the countryside can be quantified and the ecological implications of the changes assessed.

IFE's principal contribution was the collection of data on the macroinvertebrate fauna of streams in each of the 32 land classes. A feasibility study, conducted in 1988, showed there to be a marked difference between the types of species occurring in streams in the different land classes and strong correlations between aquatic faunal assemblages and geographical features and land usage of the streams' catchments.

In 1990 361 of the 508 rural study squares had suitable running water sites for sampling. These ranged from the Orkney and Shetland Islands in the north to the Isle of Wight and the Lizard in the south and west. At the same time two standing water sites per square, if available, were sampled for macroinvertebrates on behalf of the University of Newcastle-upon-Tyne.

Thus a detailed picture of the aquatic fauna of each 1 km square is being compiled which can act as a standard for comparison with the fauna of the same locations in subsequent national surveys. Any change in the composition of the fauna can then be compared with simultaneous changes in the use of surrounding land.

Most of the streams sampled during the survey were small headwater sites, less than 2 m wide and within 1 km of the stream's source. Initial examination of these samples has shown them to contain unusual assemblages of animals, unlike those of most of the larger sites incorporated in RIVPACS (River InVertebrate Prediction and Classification System), including a number of rarely recorded species in Britain. However, initial biological evidence also indicated that many of the streams were suffering environmental stress due to pollution.