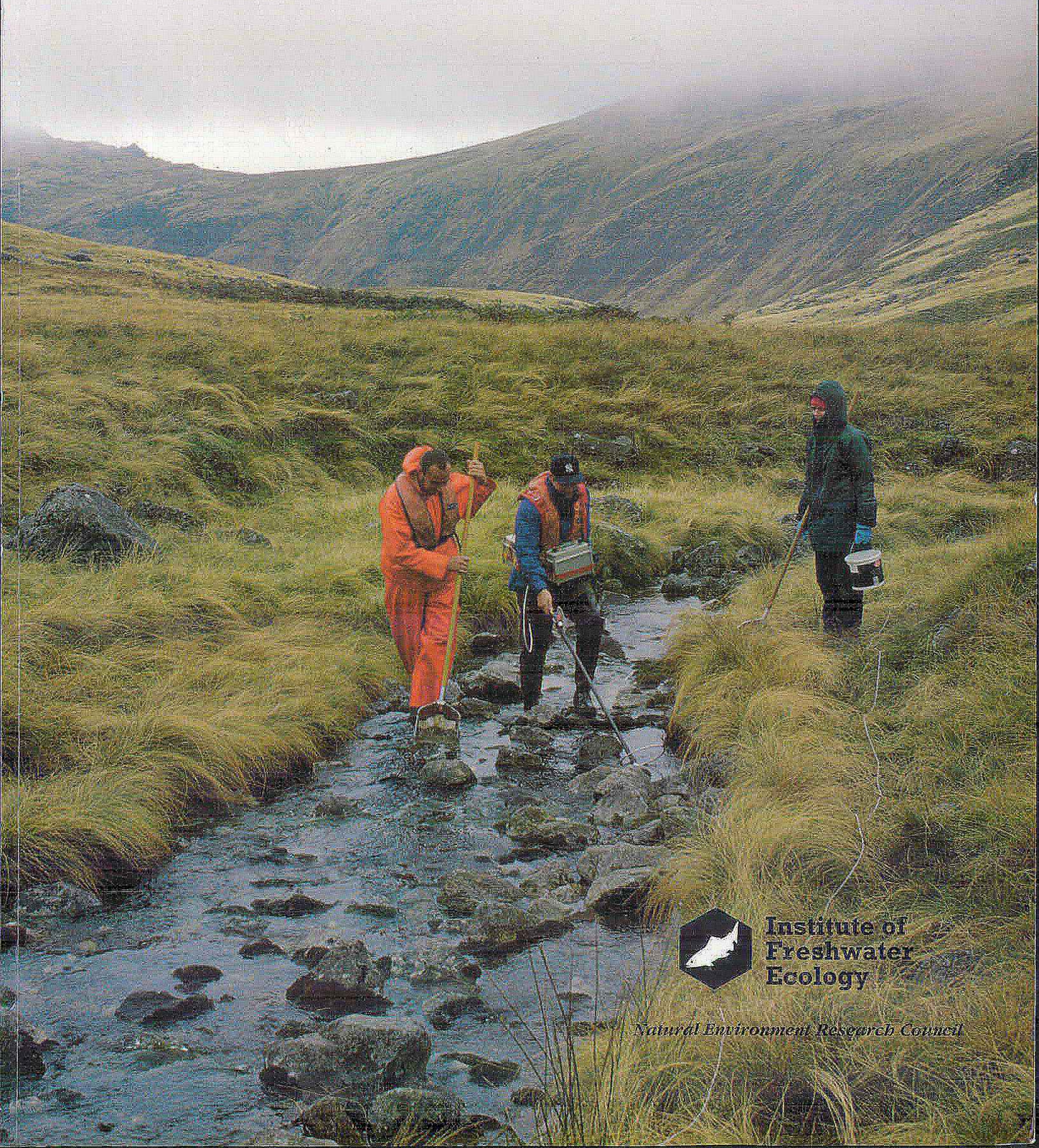
Annual Report 1993–1994



Institute of Freshwater Ecology

Natural Environment Research Council

Foreword

The past year has been one of considerable change in NERC, both in the focus of its science and in its structures. The catalyst for these changes was the publication of the White Paper *Realizing our Potential*. NERC was given a new mission for its science to embrace the concepts of meeting the needs of its user communities and contributing to wealth creation and the quality of life. We have, of course, always paid close attention to these objectives, but there is now a clear need for a sharper focus and better articulation of what we do in these areas. Basic science and long- term monitoring are also included in our mission, and due weight must also be given to these when developing our science strategies.

The science directorates will cease to exist towards the end of 1994, and new structures will be put in place. TFSD Institutes are being regrouped as the Centre for Ecology and Hydrology. However, the report of the Multi-Departmental Scrutiny of Public Sector Research Establishments is awaited, and decisions arising from this may result in further organisational changes within NERC.

An important activity during the year has been the preparation of a new science and technology strategy for the terrestrial and freshwater sciences. Publication is expected in July, and a number of research areas will be identified for priority support over the next five years.

This is my second and final foreword. During my relatively short time with NERC, I have come to appreciate and value the breadth and strength of our work in the terrestrial, freshwater and hydrological sciences. The last year has seen changes in the senior management posts at IFE. Professor J G Jones relinquished his duties as Director to concentrate on his FBA post and Professor A D Pickering is Acting Director. I would like to express my appreciation to both of them. As this Report shows, there have been exciting developments in all the main areas of IFE science, including IFE's involvement in the LOIS (Land-Ocean Interaction Study) Community Research Programme and UK Environmental Change Network.

Finally, I should like to state how much I have appreciated the friendships that I have established with so many members of our community. It is these that will be my most valued and lasting memories of NERC.

C Arme
Director of Terrestrial and Freshwater Sciences

Front Cover Illustration:
Electrofishing in the outflow stream of Scoat tarn, Wasdale, at an altitude of 1500 ft, for the national acid waters monitoring programme.

Report of the Institute of Freshwater Ecology 1993/1994

Natural Environment Research Council

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Director's introduction

Professor Alan Pickering
Acting Director

As Acting Director of the Institute of Freshwater Ecology, this is my first opportunity to review our achievements over the past year and to look forward to the future. However, to be given this opportunity at a time of major change in the way in which UK science is administered and funded increases the challenge. Indeed, during my 25 years with the IFE and the FBA, I cannot recall another period of such fundamental change.

Following on from the Government's White Paper "Realising our Potential", published in May 1993, in which the Research Councils were restructured and given new mission statements, the Office of Public Service and Science Efficiency Unit's multidepartmental scrutiny of 53 public sector research establishments was initiated in late 1993. At the time of writing this introduction, the Unit's report has been published but we are still in a 'consultation phase' with regard to the options put forward for the future structure of UK public sector research. This year has also seen the launch of the OST's Technology Foresight initiative, with its aim of identifying those areas of science which are most likely to contribute to wealth creation and the quality of life in the near, mid and distant future. To achieve this, 16 Technology Foresight Panels have been appointed, each to review a specific area of activity. During the consultation process, it has become clear that environmental matters are assuming an increasing importance, with freshwater issues at the centre of many of the discussions. In this context I hope to see a high profile for freshwater science when the final reports are published.

Focusing more closely to home, the announcement of the appointment of Prof John Krebs as the new Chief Executive of NERC, was made in January 1994. Prof Kreb's restructuring programme for NERC includes the establishment of the Centre for Ecology and Hydrology (CEH), thereby promoting even closer collaboration between its component Institutes (IFE, ITE, IH and IVEM). Prof Brian Wilkinson, as Acting Director of CEH, is overseeing the development of it's science programme, structure and administration. Within the Institute of Freshwater Ecology, Prof John Hilton has been appointed as Head of the Regional Laboratories (River Laboratory, Eastern Rivers Laboratory, Edinburgh Laboratory). John's expertise and experience in strategic research, combined with his knowledge of the water industry, will greatly strengthen the IFE management team and ensure a fully integrated research programme across the Institute.

Against this background of change, it is important to recognise that one of the strengths of Institute science is the ability to put together multidisciplinary teams for the purpose of undertaking long-term environmental research. In this way, the Institute occupies a unique role and one which cannot be adequately undertaken by other organisations. However, to make important scientific advances in this area of research requires a stability of structure and funding, a point that must be recognised by the 'user' community. With such considerations in mind, it is my pleasure to highlight the exciting progress made during the past year in the IFE's eight major research projects.

Water quality problems, in particular the development of costly (in terms of treatment), unsightly and potentially toxic algal blooms in lakes and reservoirs, are still a major concern to the 'water industry' (in its broadest sense) and to the general public. Sophisticated computer models based on a fundamental understanding of all the important factors controlling algal growth, have given the IFE an international lead in this area of science. Application of this technology to 'problem' waters allows the identification of the most suitable and cost-effective management options. The recent incorporation of a vertical, stratification component to the model now extends the range of application from fully mixed systems to deep, stratified water bodies. Moreover, application of these process- based models has changed our fundamental understanding and appreciation of the importance of nutrient recycling processes, particularly in shallow, well-mixed lakes.

The influence of changes in weather patterns on algal productivity in freshwater systems can be detected and, ultimately, modelled over timescales varying from hours (eg the photosynthetic activity of phytoplankton in Esthwaite Water) to decades (diatom sedimentation in Windermere, the phytoplankton succession in Loch Leven). Such long-term data sets are an invaluable resource, not only for the IFE, but also for UK science in general. The recent discovery that long-term, cyclical changes in zooplankton populations in the English Lake District are paralleled by changes in road-side vegetation in Oxfordshire could be seen to be nothing but an odd coincidence were it not for the fact that both observations also correlate well with cyclical fluctuations in the latitude of the Gulf Stream! Long- term data sets in the fields of limnology, terrestrial ecology, oceanography and meteorology are now helping us to understand and predict how the ocean currents can, via changes in regional weather patterns, have important impacts on terrestrial and freshwater ecosystems. Indeed, lakes are particularly responsive to relatively small environmental signals and they have the added advantage of recording these responses in their sediments.

Modelling is a major theme throughout much of the IFE's research programme.

Particular emphasis is placed on process-based models and nowhere is this better illustrated than the Institute's studies of physico-chemical processes in catchments. During a recent peer review exercise, the chemical equilibrium model WHAM (a model that allows the simultaneous interactions of many different chemical components to be calculated for waters, sediments and soils) was acknowledged to be 'the best available at this time'. Recent developments in this area have now resulted in the incorporation of WHAM into a catchment-based model (CHUM) for water chemistry prediction in upland systems. Similar quality standards are applied to our model development in related areas of science (radionuclide behaviour, silicon dynamics in rivers, soil erosion and river sediment movements) and this expertise has been applied for practical purposes ranging from the reclamation of an acid lake by controlled enrichment to the development of a management programme to ameliorate the problem of obstruction to river traffic by dune formation in the Rhine.

The Institute's work on fish population dynamics and management has always been a high-profile area in the overall research portfolio. Given the pressures on aquatic systems, it is important that we understand how fish react to the many and varied 'stresses' imposed upon them and how this response is translated into longer-term impacts at the population level. Current work highlighted in this Annual Report considers impacts such as eutrophication, water abstraction, species introductions as well as intra-specific competition. Long-term studies at Windermere, Teesdale and the River Laboratory have all highlighted the importance of mortality during the early stages of the life cycle (the 'critical period') in determining population dynamics and structure in salmonid fish. Much of this relates to the aggressive behaviour of young fish in acquiring and defending a suitable territory. A study of the endocrinology of young trout has shown that even at this early stage, the newly emerged fry are capable of developing a typical stress response and it is likely, therefore, that much of the mortality during the critical period is caused by the chronic stress (and resultant growth impairment and immunosuppression) of intra-specific competition. One of the practical aspects of work in this area is illustrated by our studies on the most effective stocking strategies for salmon fry and the potential interactions between stocked and natural fish.

World-wide developments in molecular biology and gene technology have facilitated spectacular progress in many areas of science. This is true of environmental microbiology although it is a sobering thought that although more than 90% of all living organisms are microorganisms, only a very small fraction (perhaps less than 1%) have ever been cultured. Thus, there is enormous potential for further developments in the study of microbial diversity. Microbial processes drive the major biogeochemical cycles and have impacts as local as the food conversion efficiency of a single ruminant to the methanogenic contribution of such livestock to the global warming problem! This Annual Report illustrates the breadth of environmental microbiological research, even within a relatively small organisation such as the IFE, and addresses such practical issues as bioremediation of oil spills and the detection of toxic dinoflagellates, the causative organisms of certain forms of shellfish poisoning. The creation of the CEH now offers a real opportunity to develop an integrated research strategy for environmental microbiology across the component Institutes.

Productivity in lowland rivers may be suppressed by a variety of factors and work at the IFE's Eastern Rivers Laboratory have shown the importance of discharge rate in determining the diversity of food organisms (predominantly zooplankton) available to sustain juvenile cyprinid fish such as bream and roach. Building on previous studies of temperature dependency, primary productivity and turbidity in large lowland rivers, our understanding of the constraints on coarse fish production now enables us to advise on suitable management strategies. It is clear that for the Great Ouse, the imaginative use of adjacent, disused and flooded gravel pits would provide a suitable reservoir of planktonic organisms and would also create refugia for young fish during periods of high discharge.

Assessing the quality of river sites has been a major preoccupation of the programme of research in the broad area of land-river interactions. RIVPACS, the assessment system based on macroinvertebrate diversity has been in use with the NRA for several years and an updated version is nearing a state of completion for the 1995 River Quality Survey. It is becoming evident that headwater streams make a particularly important contribution to the overall species richness of each individual river system, including species of conservation importance, but that they are extremely sensitive to agricultural impacts. The impact of variation in flow regime on habitat structure and floral and faunal abundance/diversity is also an important issue that still requires considerable fundamental research before we are likely to be able to predict, with any detail, the likely effects of water abstraction, flood alleviation or other flow control schemes on river ecology. To understand the links between hydrology, physical habitat structure and biological response requires the combination of skills now being brought together within the overall structure of CEH.

It is clear from the foregoing review that the IFE has made important advances in all areas of its research programme and that the science is also being developed for practical management purposes. This has been achieved in an atmosphere of change and uncertainty and bears testimony to the skill and dedication of the staff of this Institute. I have no doubt that these qualities will be required in the coming year as many of the proposed changes take effect. It will be essential for the Institute to maintain its unique blend of talents and to use these, perhaps in closer collaboration with our customer departments, to maintain the scientific momentum so evident in this Annual Report.

Management of lakes and reservoirs

This, the fifth annual report on this project (if one includes the one covering the period before the founding of the Institute), provides an opportunity for a wider review of the overall progress made since 1989. The declared objectives of the project, to enhance our understanding of the impact of biological changes in stored water through an increased resolution upon the dynamics of key processes and to evolve practical approaches to managing their consequences, have remained unaltered through this period. However, the work has developed along lines which were not originally anticipated: this has been attributable to our obligation to fulfil customer requirements but these have been sensitive and responsive to the new insights and capabilities that have been opened. This review begins at the first principles of water quality, its importance and the threats thereto; it outlines the new developments and applications of our researches; and, by reference to two case studies in the English Lake District, it shows how different lake systems, though faced with the analogous generic problem, require different approaches to their remediation.

Managing water quality - why it matters

The public believes it has a right to clean lakes and rivers. Whether or not it is justified after generations of misusing water resources and taking their renewal for granted, there is every case for protecting water quality for subsequent users; besides, as the Institute has argued in a report commissioned by the Department of the Environment (DoE), to do so instils more responsible attitudes to the management of terrestrial resources. The driving relationship between the biological quality of lakes and rivers and their catchments has long been recognised but has been emphasised through palaeolimnological investigation and palaeoecological interpretation. Once the forests had developed after the last glaciation, the erosion and leaching of the terrestrial soils greatly reduced, so the biologically critical nutrients, especially nitrogen and phosphorus; were increasingly retained in terrestrial biomass. Accordingly, the lakes became impoverished, mainly oligotrophic and ostensibly clear-watered systems, rather like the various forest lakes, at a range of geographical latitudes, studied by IFE staff. Clearance of forest for agriculture (assarting), followed gradually and inexorably by ploughing, urbanisation and industrialisation, accompanied by an explosive growth in the human population (25-fold in the last millenium), have led to an increased 'leakage' of nutrients from catchments to the draining rivers and lakes. Yet, remarkably, one of them - phosphorus - was sufficiently adherent to soils for it to be passed on to recipient lakes only sparingly. Even this barrier was removed with the widespread introduction of proper secondary sewage treatment which restores to drainage waters much of its potential complement of phosphorus, now in solution.

The most obvious consequence of the augmentation of plant nutrients to the drainage water is the enhanced capacity to support the growth and maintenance of planktonic algae. There is often a change in species composition in favour of the bloom-forming cyanobacteria, or blue-green algae. Their ability to float to the surface compounds the unsavoury impression of their abundance and also concentrates (as Institute research has shown), by factors of a million or so, the highly toxic chemicals that, at times, they may produce.

It is more than recreation that is impaired by algal growth, whether of blue-greens or otherwise: where it can be used again, the water must be cleaned. After abstraction from a river or being retained in a storage reservoir, the water is subject to a series of filtrations and disinfection. The cost of supplying water has been an important social issue in recent months, with the inclusion of K-, Q- and X- factors, but "the A-factor", the cost of actually removing algae and their products, can easily account for one quarter of the cost of its price at the tap. Moreover, the risk of poisoning posed by toxic populations of bloom-forming blue-greens now warrants the closure of infected recreational waters. It is little wonder that managers are now very interested in means of impairing or stopping the algae growing in the first place. If this is to be done successfully and responsibly - a few tons of copper sulphate is no longer a satisfactory answer - expert biological advice must be taken. In promoting the experience of the Institute, we are able to justify its acquisition as contributory to the protection of generated wealth (we estimate some £M15 per annum) and to the quality of life.

Modelling algal growth

The work of the project group has been about defining and quantifying the algal growth responses. Unlike other modelling approaches, our philosophy starts not with the system but with the potential of a single healthy cell to react to a favourable environment by growing in mass, dividing and thus recruiting new cells to the population. As the literature attests, these growth responses are demonstrably subject to numerous influences, ranging from the concentration of molybdenum to the presence of host-specific parasites and viral infections. It is satisfying, therefore, to have been able to show that the major share of the variability in planktonic biomass and, often, of its species composition too can be explained by just five principal components acting upon the idealised growth-rate performances of each modelled species. These are the water temperature, the daily aggregate of exposure to growth saturating irradiances (through the interaction of daylength, underwater light-attenuation and the depth of the wind- mixed layer), the rate of flushing, the availability of phosphorus (though the resources of silicon and nitrogen may influence species composition but not the supportable biomass) and the responsiveness of filter-feeding grazer populations to the availability of food. In consequence, iterations based upon these components yield credible simulations of real data.

In the model PACGAP, sponsored entirely by the National Rivers Authority, the supportive capacities of the components are compared with given performance to determine which, if any, of them is most often controlling production and the extent of adjustment necessary to invoke an appropriate control. The model PROTECH was sponsored initially by a Development Corporation to predict the dynamic responses of each of several species and their effect upon algal quality in a new impoundment. It was authenticated against a dataset for Slapton Ley and has since been used in the design of reservoir-management strategies for seven water-supply companies and two further new impoundment schemes. The simulated algal dynamics also transfer well to models of river plankton. The model PROTECH 2 is a 2-D version of Protech suitable for variably and transiently stratified systems, conceived as a stack of Protech slices which integrate or resegregate according to the thickness of the surface mixed layer. The inclusion of buoyant and sinking movements in the modelled algal responses has given improved resolution of the sharp transitions in species composition which often follow abrupt changes of weather.

The phosphorus cycle

The ability to construct sensitive simulations of the seasonal fluctuations in phytoplankton mass and its broad species composition attest first to an enhanced understanding of the key controlling processes. As well as they have been found to simulate algal dynamics in real lakes and reservoirs over periods of some months, neither PROTECH nor PROTECH 2 will generate plankton populations indefinitely on the external loads of phosphorus provided but, rather, require the simulated injection of a new resource. This is introduced either arbitrarily or as a constant increment, supposing it to represent internal loading and recycling from the sediment. Pragmatic adjustment of the simulated additions to generate the required response may not seem a proper modelling approach but the best fits to actual responses have pointed us to pulsed releases of phosphorus, usually but not exclusively led by wind-mixing events, and increases in the suspended sediment content. This important association has led us to seek explanative mechanisms involving the fractions and solubilities of phosphorus in the interstitial waters of shallow and deep sediments and in the hypolimnion of the lake. This work has again relied exclusively on outside financial support but it has produced clear results about how phosphorus enters, and is released from, the different bonding agents present. Our immediate task is now to incorporate a subroutine of phosphorus returns into PROTECH which takes more factors into account than hypolimnetic anoxia.

Local applications

Lake restoration technologies developed at the Institute have been brought to bear upon two instances of quality deterioration in the English Lake District. The water quality of Windermere, despite the well-documented background of progressive enrichment, continues to relate to its considerable depth (64m), long hydraulic residence (270 d) and its annual external phosphorus load (which reached about 16.5 tonnes in 1988, or around 1.1 g P per square meter per annum, a little over half being derived from treated sewage). The ability to support significant phytoplankton crops in summer, including of scum-forming blue-green algae, as well as the prolific growths of *Cladophora* in recent years, depends largely upon 'new' dissolved phosphorus, for we have shown that recycling of 'old' phosphorus is relatively weak in Windermere. We could predict that a rapid recovery of quality would follow the instigation of phosphorus 'stripping' in 1992 and there are already signs that this is happening.

In contrast, the biological impact upon water quality in Bassenthwaite Lake has been regulated by the shortness of the hydraulic residence: the average of 20 days does not allow sufficient time for phytoplankton to develop before it is washed out of the lake. Most of the 13.3 tonnes of phosphorus brought in annually is quickly shed from the lake. During drought-periods, however, plankton can expand within the capacity of the (albeit dilute) available phosphorus. Yet because the lake is so relatively shallow (19m) and so much is under 5m, it has frequent opportunity to recycle dissolved phosphorus from the oxic sediments but only slowly to inactivate it beneath the deeper parts of the lake. This makes restoration protracted - the best that can be achieved is a fairly sharp initial reduction in the dry-weather crop-carrying capacity of the phosphorus available, with only slow improvement thereafter, but the flow will continue to regulate production, as now, at other times of hydraulic sufficiency.

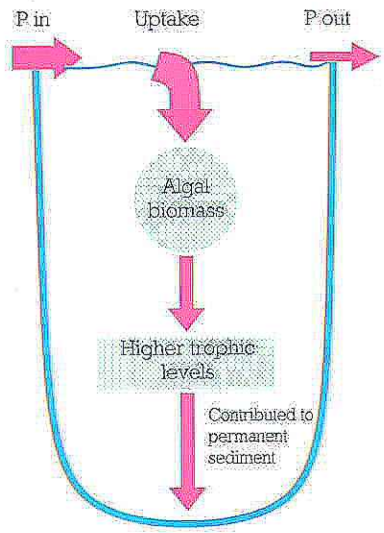


Figure 1. Idealised P processing in Windermere.

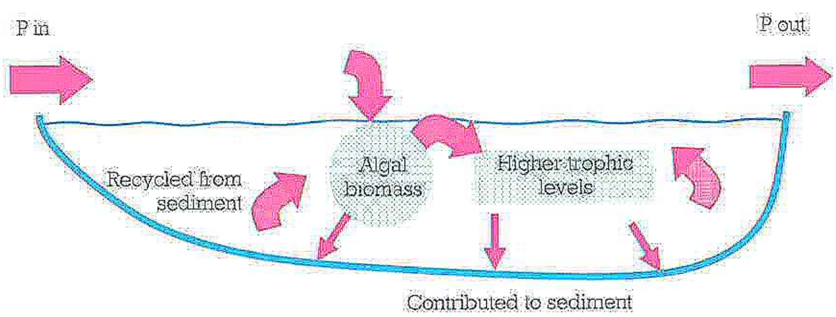


Figure 2. Idealised P processing in Bassenthwaite.

Ecology of large lowland rivers

Introduction

Strong year classes among cyprinids are generally associated with higher than average water temperatures that permit high growth rates among the newly hatched fish. However, as indicated in the Annual Report for 1992/93, inter-annual differences in temperature explain only 65% of the variation in growth-rates of dace and between 44% (chub) and 69% (dace) of the variance in year class strength. The main thrust of the work being carried out by the Eastern Rivers Laboratory is to determine the importance of additional factors, including anthropogenic influences, that affect the growth and survival of larval and juvenile cyprinids in the lowland rivers of eastern England. Those relationships currently being investigated are summarized diagrammatically in Figure 3.

The corresponding Report for 1991/92 was concerned with factors influencing the success of macrophyte and algal populations in the River Great Ouse, while last year's Report concentrated on the ecology of juvenile coarse fish in this River. The latter Report indicated that between-year variation in food supply may be one important factor influencing the growth rates and survival of cyprinids during their first year. The present Report considers aspects of temporal and spatial variability in invertebrate populations that are exploited as food by larval and juvenile fish.

The main river channels of the Great Ouse, and those of many of the back-channels, are highly canalised and regulated. Predominantly slow flows during most of the summer may be punctuated by periods of high velocity that are very disruptive to populations of young fish as well as to their food organisms. High turbidity and deepened channels allow little primary production on the river bed over much of the middle and lower reaches of the system (see Report for 1991/92) and secondary productivity on the river bed is low in consequence. Planktonic invertebrates and those associated with marginal plants are therefore very important in the nutrition of young fish. Planktonic communities in marinas also provide additional, locally important, food resources.

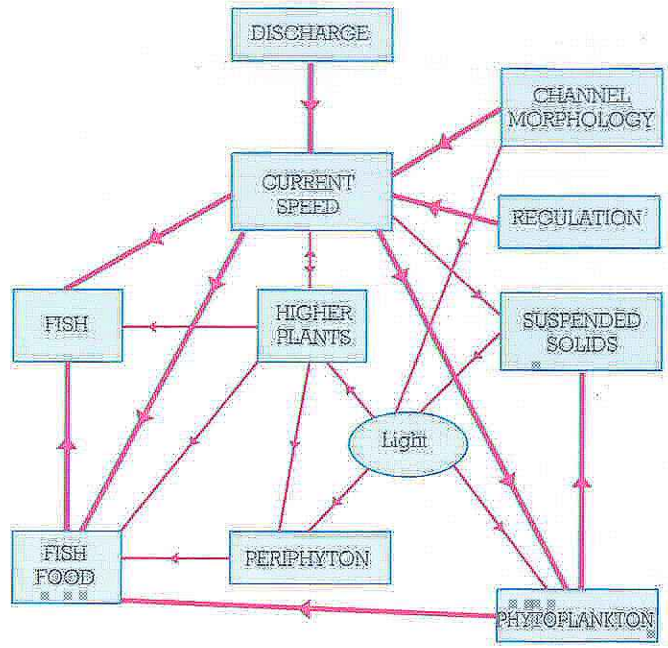


Figure 3. Major physical and biotic interactions influencing recruitment and early growth and survival of cyprinid fry in the Great Ouse.

Food resources in river channels

Zooplankton

"Zooplankton" is used loosely in this context, to include invertebrates that are derived from predominantly benthic and epiphytic communities, as well, as populations that are more strictly planktonic. During spring and early summer Rotifera dominate this community, with small numbers of Copepoda and Cladocera also present.

During the first year of the study (1989) three main river and one back-channel site were investigated. Populations at all sites followed an almost identical pattern, with low densities for much of the time and a very short period in late May when mean numbers exceeded 1500 l^{-1} (Figure 4). Whereas planktonic rotifers were fairly abundant during the period when most roach eggs were hatching in 1989, they were scarce during the hatching periods of species such as dace that spawn earlier and those such as bream that spawn later.

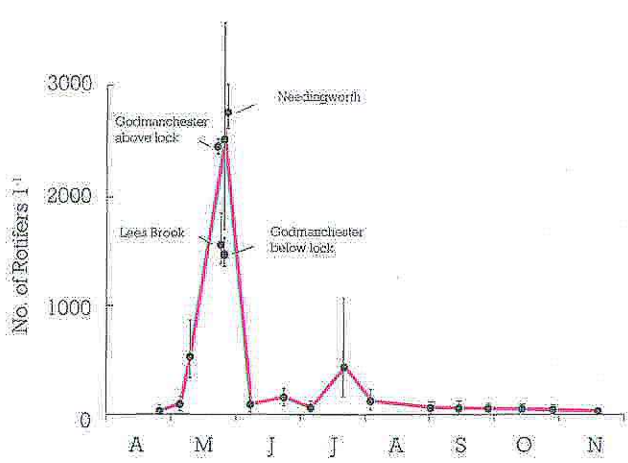


Figure 4. Densities of Rotifera in the Great Ouse in 1989 (with 95% confidence limits - data for all sites are combined except at peak density during May).

In view of the similarity between river sites in 1989 subsequent observations were confined to one main river site and an adjacent back-channel. In 1990 high densities persisted in the main river for much of the period from late April to the end of June with peaks of 15,000 l^{-1}, 16,000 l^{-1} and almost 6,000 l^{-1} in early May and early and late June respectively. A similar situation was observed in the back-channel but here, densities were generally lower, attaining maxima of 3000 to 5000 l^{-1} but with a fourth peak of about 2000 l^{-1} in mid-July (Figure 5). Thus rotifers were abundantly available to all species of cyprinid throughout the initial period of their recruitment in 1990.

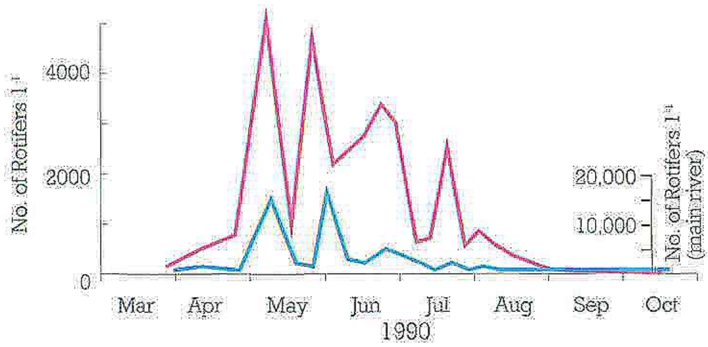


Figure 5. Densities of Rotifera in the main river and an adjacent back-channel during 1990. (note different scales)

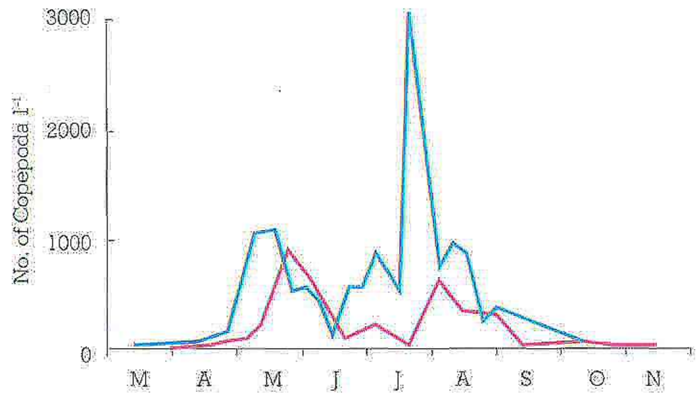


Figure 7. Densities of Copepoda in a marina on the Great Ouse in 1989 and 1990.

Similar patterns of abundance were repeated in the following two years; relatively high densities were restricted to late May in 1991 while in 1992 distinct peaks in abundance were observed early in May, mid-June, July and early August. However the very high densities that were observed in 1990 were exceptional and a maximum density of 2000 to 3000 l^{-1} appears to be more usual.

Epiphytic Invertebrates

Extensive marginal beds of the yellow water-lily *Nuphar lutea*, occur throughout the middle section of the Great Ouse and from mid-summer onwards juvenile fish feed extensively on the organisms associated with the submerged leaves of this plant, notably on Cladocera and Chironomidae. The availability of these organisms to fish varies substantially between years (see Annual Report for 1990/91) and between sites in the same year (Figure 6).

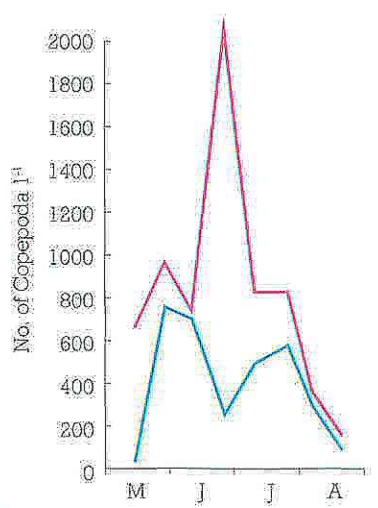


Figure 6. Densities of Cladocera on leaves of Nuphar lutea *in the main river and an adjacent backwater in 1990.*

Invertebrates in marinas

A number of marinas, some purpose built, others converted gravel pits, exist along the middle and lower reaches of the Great Ouse and in such places a more abundant and persistent zooplankton may develop, including large numbers of Cladocera and Copepoda, as well as Rotifera. During summer many juvenile fish migrate from the river into marinas, benefitting from ample supplies of food organisms (e.g. Figure 7). Whereas, in the river roach switch to feeding on epiphytic material in mid-summer, those in marinas continue to feed on plankton.

Discussion

Rotifers figure prominently in the food of young cyprinids, especially during the immediate post-hatching period when the mouths of the fish are too small to permit larger invertebrates to be ingested. Some studies in hatcheries have indicated that young roach feed with maximum efficiency only when rotifer densities exceed about 1500 l^{-1}. In some years rotifer numbers are much less than this for much of the period when cyprinids are hatching. A little later in their development the juvenile fish are able to feed on larger invertebrates, such as Copepoda and Cladocera and in late summer may switch to feeding on epiphytic populations of invertebrates; notably Cladocera and Chironomidae. At this stage the guts of roach are often filled largely with aufwuchs, indicative of unselective feeding behaviour. The guts of bream, in contrast, never contain aufwuchs; they are highly selective for invertebrates, notably Cladocera and were often observed to have empty guts when population densities of food organisms were low.

Both planktonic and epiphytic populations of invertebrates have been shown to be highly variable in the rather uniform channels of the main river and many back-channels, while in marinas, substantial populations of planktonic organisms may persist throughout the summer and continue to provide an important food resource when the abundance of food organisms in the main river is reduced. This source of food may be especially significant in the case of selective feeders - such as young bream - in years like 1989 when food resources in the river channels were apparently very limited. Many studies have shown the importance of flood-plain features, such as pools and oxbows, in maintaining a high biodiversity in rivers. As indicated also by last year's Report there is substantial potential for improving feeding conditions for fish in the Great Ouse by linking more of the adjacent, disused and flooded gravel pits to the river. In addition to providing reservoirs of planktonic organisms they would also provide additional refugia for fish during periods of high discharge and if appropriately managed would also create additional spawning habitat for a number of species.

Land-river interactions

Introduction

This project includes strategic and applied research in river management, conservation and the impact of land use on river biota. Over the last twelve months, work has been progressing towards the development of a new version of RIVPACS (River Invertebrate Prediction and Classification System) for use in the 1995 River Quality Survey. The research is continuing and developments will be reported in the next annual report.

This year's review includes two contrasting projects. The first is providing valuable information for the future protection of headwater streams. Many of these streams are highly vulnerable to adjacent land-use practices. The second article features strategic research on a running water system and offers new insights which help to link the strategic and more applied components of the project.

Faunal richness of headwater streams

The initial interest in headwater streams, that is streams within 2.5km of source, arose from the IFE input to the Countryside Survey of Great Britain. This long-term study of Britain's changing landscape, flora and fauna included a freshwater component for the first time in 1990.

Using RIVPACS, the evaluation system applied during the 1990 River Quality Survey of Britain, it was shown that almost 30% of 361 small watercourse sites failed to attain good biological quality (band A). This was despite the fact that most of these watercourses are not subject to the influences of either industrialisation or urbanisation.

Worst affected streams were in arable and pastural landscapes where 40% and 36% of sites were not of good quality. Here the impacts on streams included point source and diffuse agricultural enrichment, channelisation, dredging, re-alignment and culverting.

Higher altitude sites were generally less affected with 73% of marginal and 88% of extreme upland sites being of good quality. Additional impacts here included forestry practices, bracken-spraying and acidification.

Figure 8. Alton Common. A site on an un-named tributary of the River Stour.

The significance of these results can be put in context by the extent of the nation's headwaters. Cartographic studies at the Institute of Terrestrial Ecology (ITE) have shown that there are an estimated 146,853 first order streams, that is watercourses without tributaries, in Britain.

Against this background the National Rivers Authority (NRA) commissioned IFE to meet three overall objectives:-

- to assess the conservation value of headwater stream invertebrates and their contribution to catchment bio-diversity
- to determine agricultural impacts upon headwaters and their fauna
- to propose a headwaters conservation strategy

The first stage was to look at existing information in order to identify taxa whose distribution was specifically associated with headwaters.

This study of 141 headwater sites, reported in a previous annual report, demonstrated that 101 taxa were either exclusive to, or significantly associated with headwaters. More importantly, nearly 20% of the specialist headwater species were taxa classified as of national conservation importance, including four taxa in the most threatened conservation group, the Red Data Book.

The next stage of the work focussed on the contribution of headwaters to overall macro-invertebrate bio-diversity in specific river systems. Four systems with contrasting land usage were chosen for analyses. These were the Cam, the Lugg, the Yorkshire Derwent and the Dorset Stour. A range of headwaters was sampled in each system (Figures 8 and 9) and data on sites further downstream were acquired from existing NRA and IFE data-bases. All sites were chosen in the belief that they were not significantly stressed.

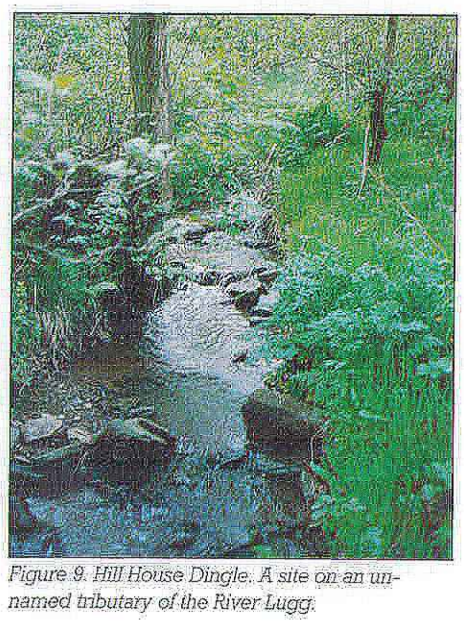


Figure 9. Hill House Dingle. A site on an un-named tributary of the River Lugg.

Results were unequivocal. Headwaters were making a significant contribution to the overall species richness of each individual river system. An average of 45 taxa per river system were exclusively found in headwaters. This represented almost 20% of the taxa found in a given system (Figure 10). Furthermore approximately 55% of all taxa found in headwaters were more frequent there than anywhere else in the river system.

Further analyses and field studies revealed other important findings. For example, the tendency for headwaters to support taxa of conservation importance was confirmed with new records including the nationally-threatened Red Data Book 1 (RDB1) caddis, *Hydropsyche saxonica*.

Analyses also showed that some headwater stream assemblages are very markedly zoned over their first kilometre with several taxa confined to less than 200m of stream length. The true faunal richness of a given headwater is thus likely to be considerably greater than that recorded at one site along its length.

These results are of major significance, given:-

- the current global awareness of the need to understand and maintain bio-diversity at all levels of geographic resolution
- the new Council of European Communities Directive on the Conservation of Natural Habitats and Wild Fauna and Flora
- NRA's statutory obligations to further conservation as set out in the Water Resources Act of 1991.

IFE's study is now centred on the relationship between the biological quality of headwaters and the land use in their catchments. A total of 132 randomly selected sites, of all qualities, have been sampled in the same four river systems and the catchment of each site has also been surveyed for land cover.

Through utilization of these data, in association with other morphological and geological information, it is hoped to produce vulnerability maps of the susceptibility of headwaters to environmental stress, to identify indicator taxa of stress in different landscapes and, through this, to help NRA to formulate a conservation strategy to manage the biological resources of these small but important watercourses.

Figure 11 The patchwork of mesohabitats in the Mill Stream

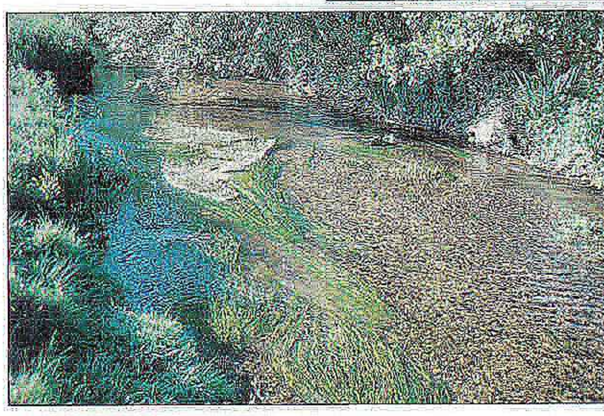


Figure 12 Gravel 'fast' and Ranunculus 'fast' in the Mill Stream

Habitat/Fauna relationships - application to management

A side-arm of the River Frome in Dorset, the Mill Stream, has recently been the subject of a multidisciplinary study examining biological and hydrological aspects of stream ecology. The water course has chalkstream characteristics with a relatively stable flow regime and hard water. Such a combination favours the development of a variety of instream macrophytes which have a major effect on stream hydraulics resulting in a mosaic of different habitat types (Figure 11). An observer walking on the bank finds these areas easy to distinguish and we have used these as our basic ecological unit. Essentially the unit is visually distinct from the bank and we have called it a **mesohabitat** (Figure 12) to introduce a measure of scale which the term biotope does not have and to distinguish it from microhabitats such as a leaf tip or stone surface and macrohabitats which might include the whole of a reach of river. We wished to see if these mesohabitats support specific faunal assemblages and whether these assemblages remain distinct throughout the year. If this was the case how could this information be used in environmental management?

Inspection of the Mill Stream early in April 1992 revealed 8 mesohabitats which could be distinguished from the bank. 1, '*Ranunculus* fast' - patches of *Ranunculus* in fast flowing shallow water; 2, '*Ranunculus* slow' - patches of *Ranunculus* in slow flowing deep water; 3, 'Silt' - areas marginal to the bank of silty sand; 4, beds of '*Nasturtium*'; 5, marginal beds of '*Phragmites*'; 6, patches of 'sand' in deep water; 7, 'Gravel fast' - patches of sandy gravel in fast shallow water; and 8, 'Gravel slow' - patches of sandy gravel in slow flowing water. When selecting the mesohabitats no attempt was made to

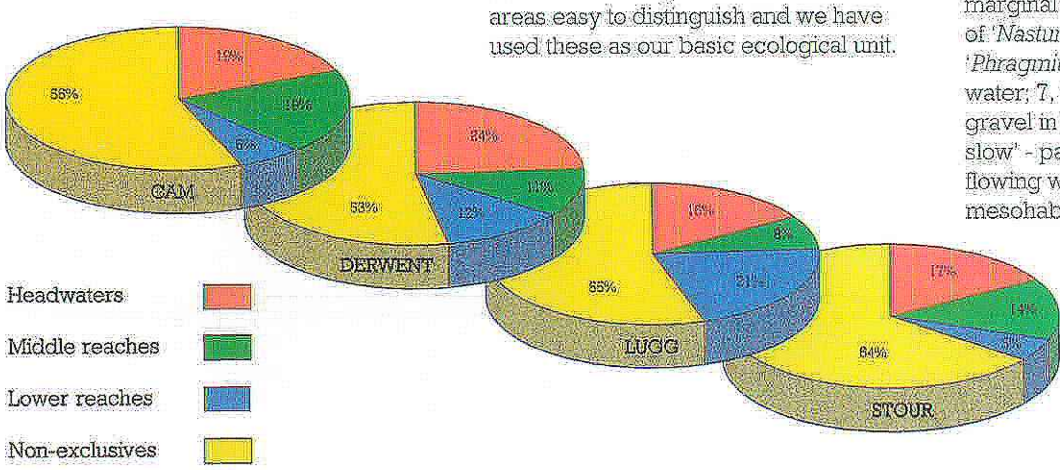


Figure 10. The proportions of species which are exclusive to headwaters (0 - 2.5km from source), middle (2.6 - 20km) and lower (>20km) reaches of four river systems. The proportions of non-exclusive taxa, which occur in two or more reaches, are also shown.

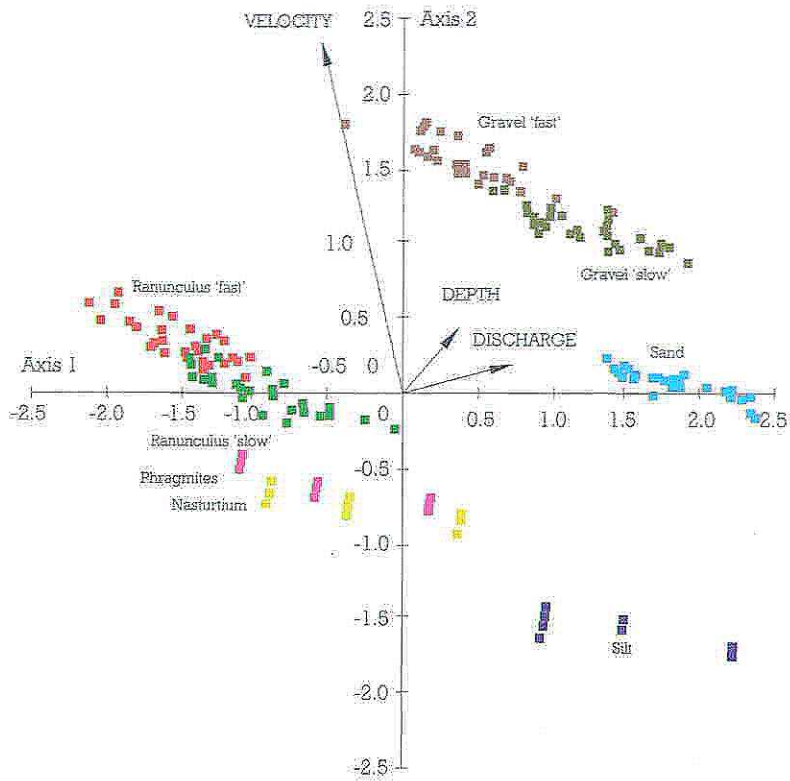


Figure 13 Ordination (Canonical Correspondence Analysis) diagram based on quantitative data from all mesohabitats. The samples taken within each mesohabitat in all seasons are shown in the same colour.

measure depth or velocity (which were judged by eye) but as noted from subsequent measures of velocity and depth, slow mesohabitats ('*Ranunculus* slow' and 'Gravel slow') were always over 45 cm deep. Velocity was not as useful as depth in visual selection because the differences between mesohabitats in summer and autumn were slight.

Ten replicate samples were taken from most mesohabitats in spring (21-22 April), summer (6-7 July) and autumn (28-29 September). Exceptions were '*Nasturtium*' and 'silt margin' which were not well represented in the Spring data set. Five replicates were taken from these mesohabitats at that time. To avoid the problems of pseudoreplication samples were taken from different areas of mesohabitat along the 400 m section of river. All analyses of data were carried out on samples identified to family level.

A multivariate technique, canonical correspondence analysis, which utilises information on the composition and abundance of the total faunal community, in conjunction with environmental data, showed that in general the mesohabitats selected for study remained distinct from one another (Figure 13) but that the degree of separation varied markedly with season. Seasonal trends are particularly marked in the marginal mesohabitats (*Phragmites*, *Nasturtium* and Silt). In spring when discharge was high, mesohabitats showed considerable overlap on the basis of their faunal communities. As the year progressed and discharge declined so mesohabitats became more distinct. There was a continual expansion and contraction of available mesohabitat. Thus instream macrophyte beds increased at the expense of open water habitat, and marginal vegetation encroached into the main flow. The stream therefore consisted of a dynamic system of mesohabitats whose borders were best defined in low flow periods.

The 'distinctness' of these mesohabitats has meant that the contribution of each one along a reach can been calculated. Long reaches can be described in terms of the proportions of the various mesohabitats which are found there (Figure 14). This information together with data on the 'quality' (species richness, faunal abundance, rarity) can be used to categorise a stream at reach level and assess the effect of management (flow changes, dredging, bank clearance and weed-cutting) on the distribution of mesohabitats and hence on the faunal assemblages associated with them. If a particular management regime results in deeper slower conditions it would be possible to demonstrate the likely effects on the distribution of mesohabitats. Some of these may support preferred assemblages of macroinvertebrates (as fish food for example) and the mesohabitat data will provide information on which assemblages are likely to be affected. This may be a more useful scale of assessment than point sampling when considering the total instream environment including fish and macrophytes as well as invertebrates. This technique is currently being applied to determine the effects of the regulation of the upper reaches of the Mill Stream by sluice gates and could be applied to assess the impact of any scheme which is likely to affect the distribution of mesohabitats.

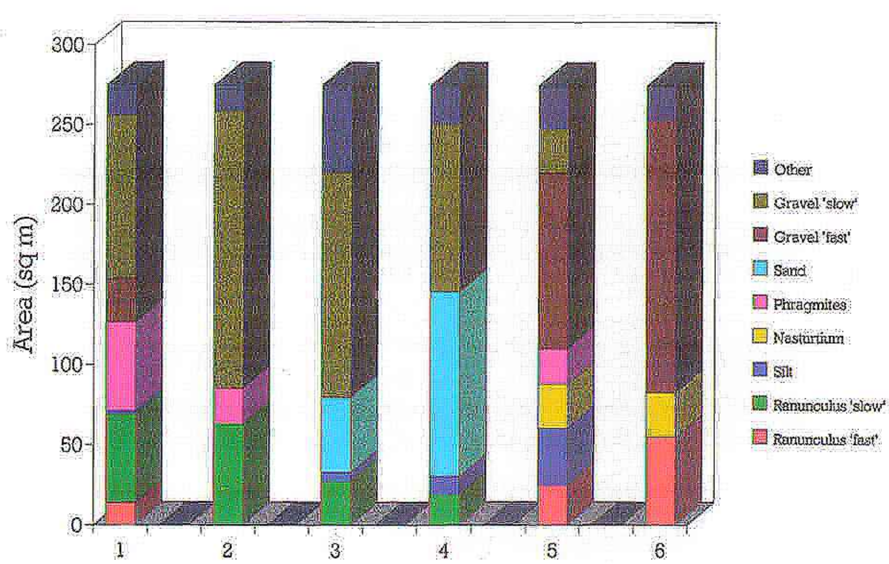


Figure 14 The distribution of mesohabitats in 50m sections of the Mill Stream.

Microbes in the aquatic environment

Methanogens in ciliates

Methane is one of the more important greenhouse gases, and much effort is devoted to identifying and quantifying the principal sinks and sources. We have established that most free-living anaerobic ciliated protozoa act as hosts for methanogenic bacteria, and that these bacteria produce methane which diffuses out of the ciliates and into the surrounding water. We recently turned our attention towards the large numbers of anaerobic ciliated protozoa living in the rumen of herbivorous mammals. The emission of methane from ruminants, especially cattle and sheep, is one of the largest biogenic sources; it is also economically important as it can represent up to 15% of the animals' total energy intake. It is important to identify exactly where this methane comes from.

The rumen contains large numbers of anaerobic micro-organisms, especially bacteria and ciliated protozoa (~10^{10} and 10^{6}/ml respectively) which degrade ingested plant material. One of the products of this digestion is hydrogen (H_2) gas which is converted into methane (CH_4) by methanogenic bacteria. The methane, which is useless to the ruminant, is lost to the atmosphere. It has long been assumed that the methanogens live freely in the rumen, but we have recently shown that they also live inside the rumen ciliates (Figure 15) and that these "endosymbionts" may be quantitatively important.

The methanogenic endosymbionts were detected using three independent methods: (1) microscopically, from coenzyme F_{420} autofluorescence, (2) using a rhodamine-labelled *Archaea*-specific oligonucleotide probe (in collaboration with the Natural History Museum, London), and (3) by transmission electron microscopy. Stereological methods confirmed that the same particles were being examined with each method. The most abundant ciliate species (accounting for >90% of all rumen ciliates) each contained a few hundred endosymbiotic methanogens, and they accounted for approximately 1 - 2% of host ciliate volume. Roughly the same volume fraction is known for the methanogens living inside a variety of free- living ciliates, so it is possible that the endosymbioses are functionally equivalent (i.e. intracellular H_2 sinks) in free-living and in rumen ciliates. It is surprising that there is no other published reference to methanogens living inside rumen ciliates.

How important could these endosymbiotic methanogens be? For a typical sheep with 5 liters of rumen liquor producing 19 liters CH_4 per day, methanogenic ciliates could account for up to 37% of total methane production. Methane emission from ruminants reduces their productivity and contributes to the rising level of methane in the atmosphere. The elimination of ciliated protozoa from the rumen may increase the productivity of ruminants. It is known that defaunation also reduces ruminal methanogenesis, so the treatment may have the additional benefit of reducing the adverse environmental impact of farmed ruminants.

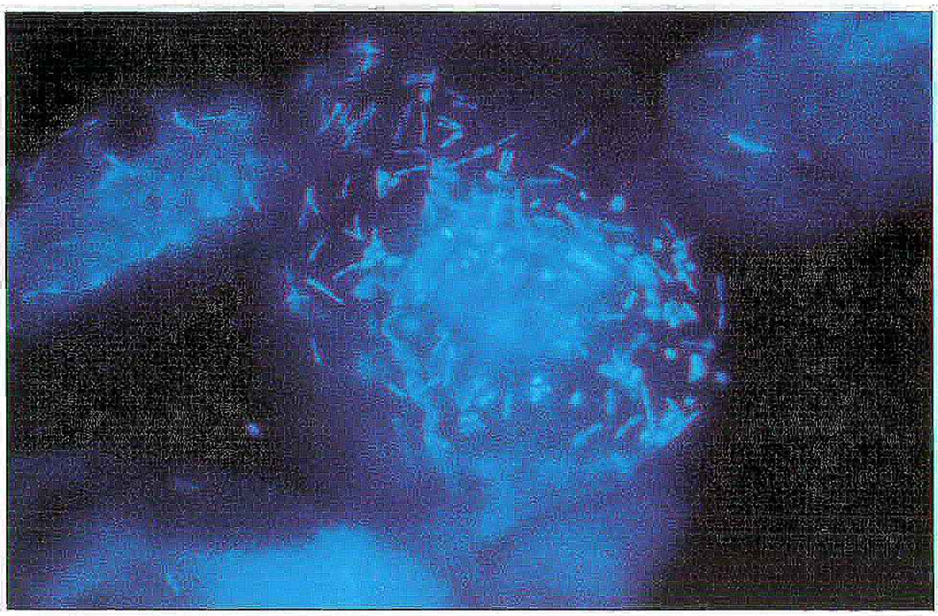


Figure 15. Autofluorescence of two types of symbiotic methanogens living inside the rumen ciliate Dasytricha ruminantium. *The ciliate is approximately 70 µm in length.*

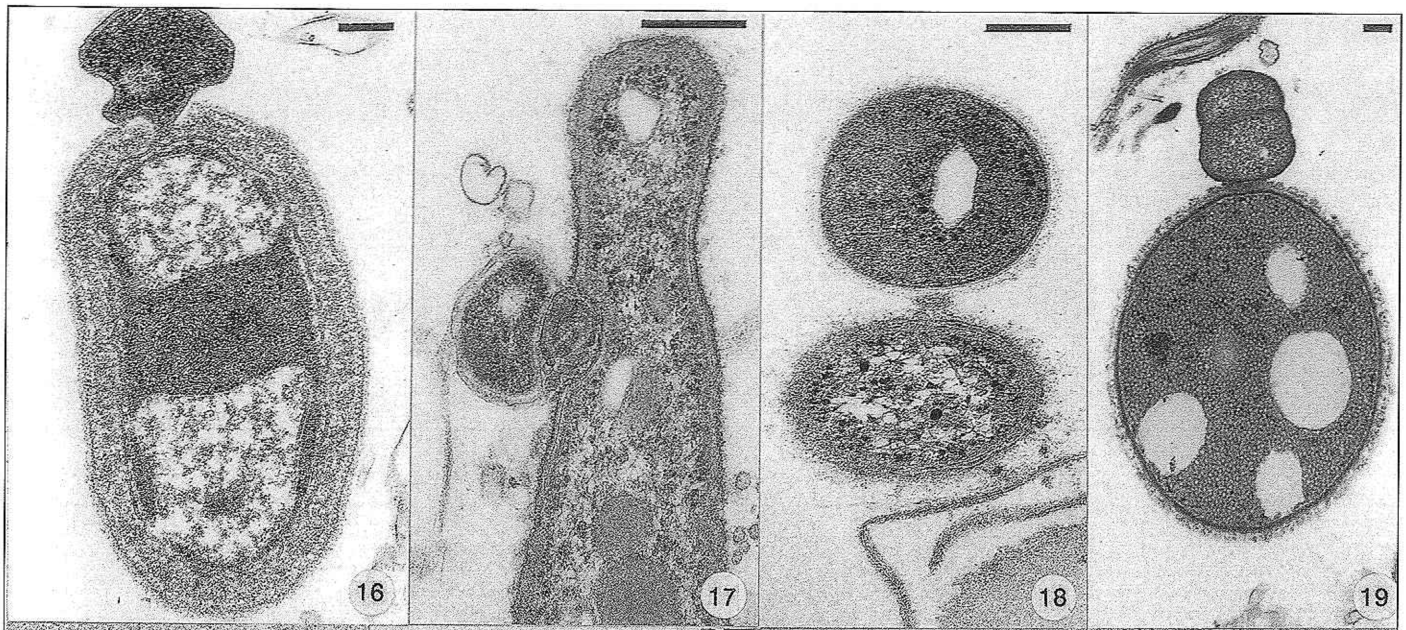
Electron microscopy

We continue to explore the potential of electron microscopy (EM) in studies of microbial diversity in fresh waters. Samples collected from the anaerobic hypolimnion of a sulphide-rich pond in Spain have revealed a variety of new types of associations between prokaryotes. Many of these appear to represent "host- parasite" relations: in others, the physical attachment connects apparently healthy but dissimilar cell types, which may be syntrophic consortia (Figures 16 - 19). Other target groups of freshwater organisms include the scale-bearing chrysomonads and heliozoons (Figures 20 - 23; we recently recorded 40 different morphological species living in a drop of pond water), the scale-bearing and testate amoebae, diatoms and dinoflagellates.

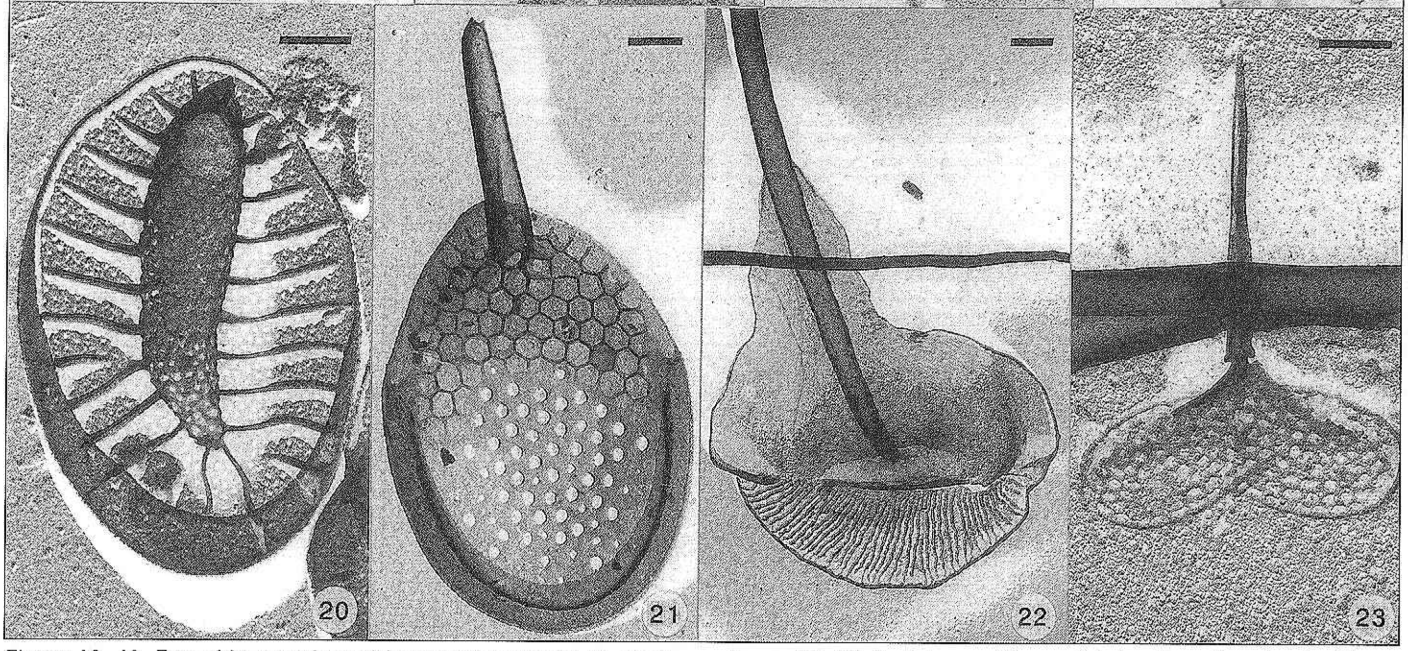
New techniques for studying natural microbial communities are continually being developed. These include methods for rapid fixation and shadow-cast specimen preparation for transmission EM, and volatilising-agent methods for scanning EM. The time required from cell fixation to EM examination can be reduced to less than one hour, and procedures involving thin sectioning can now be completed in three hours using specially formulated resin.

Culture Collection of Algae and Protozoa

The primary remit of the Culture Collection of Algae and Protozoa (CCAP) is to act as a depository for microalgal and



Figures 16 - 19. Four of the many bacterial associations found in an anoxic Spanish pond. Bar = 0.25 µm.
16 & 17. 'Host-parasite' relationships
18 & 19. Possible syntrophic consortia.



Figures 20 - 23. Scale types of four protists in a drop of pond water. The scale features are species-specific. Bar = 0.5 µm.
20. Scale from the chrysomonad Synura petersenii
21. Scale from the chrysomonad Synura spinosa
22. Scale from the heliozoon Acanthocystis pantopodeoides
23. Scale from the chrysomonad Paraphysomonas takahashii

free-living protozoan biodiversity. It is used extensively by the scientific community in the UK, Europe, and world-wide, for a wide range of applications including taxonomic research. CCAP also acts as a research centre for visiting taxonomists who also have access to the Fritsch Collection of Algal Illustrations. Currently, CCAP is engaged in a major taxonomic research project in collaboration with the National Institute for Environmental Research (NIES) Tsukuba, Japan. The primary focus is the taxonomy of the Cyanobacteria, which is being pursued using both traditional and modern molecular methods. The diversity of unique cyanobacterial strains in CCAP, many of them economically important, is making an invaluable contribution to this joint research programme.

"In house" expertise in molecular taxonomy is also becoming well-established in the case of the naked amoebae. The different species of the ubiquitous freshwater genus *Naegleria* have been subject to detailed study for many years, principally because at least one of them can be a human pathogen. Differentiation between the species is very difficult using morphological and ultrastructural characters, so biochemical and molecular biology techniques are now being applied. In collaboration with the Institute of Hygiene and Epidemiology (Brussels) and the Australian Centre for Water Treatment and Water Quality Research (Adelaide) these techniques are currently being used to analyze a large number of the known non-pathogenic strains. Isoenzyme analysis by the Australian workers has grouped them into 35 allozyme clusters, each of which may represent one species. Within CCAP the aim was to determine whether riboprinting of small sub-unit ribosomal DNA from strains taken from each of the clusters would reveal sufficient variation to identify each cluster as a distinct species. Insufficient restriction sites were detected within the small sub-unit rDNA, and now the large sub-unit rDNA is being analysed. Other genera within the amoeba family Vahlkampfiidae are also being investigated using the riboprinting technique. This will certainly result in the translocation of strains between the genera established using classical methods of taxonomy.

Bioremediation

In collaboration with ITE, British Geological Survey and W. Halcrow and partners, a multi-disciplinary investigation into the bioremediation of hydrocarbon pollution in the marine and freshwater environment is now underway. This work, funded by the Department of Transport, is being pursued as separate experimental approaches to the problem of hydrocarbon degradation, each existing as a separate module within the overall project. The modules range from controlled laboratory experiments to the clean-up of real pollution events. A lysimeter test of the effects of different oil types and weathering on the rate of oil degradation in sandy soils commenced this year. One useful advantage of this approach was the inclusion of control plots which would not be possible in real pollution events.

In January 1994, heavy fuel oil was beached in South Wales, and subsequently buried in nearby sand dunes. The project team was called upon to monitor the behaviour and breakdown of the oil within the dump. Preliminary results showed that the natural bacterial flora of the sand dunes rapidly adapted to degrade petroleum hydrocarbons. Moreover, changes in the microbial community were associated with increased emissions of carbon dioxide from the surface of the oil dump.

TIGER

In collaboration with the Universities of Liverpool and Warwick our research within the TIGER community program has combined the use of ecological techniques with molecular methods to examine the diversity of methanogenic and methane oxidising bacteria in blanket bog peat. The molecular approach has been to amplify 16S ribosomal RNA extracted directly from peat, using primers specific for archaebacteria (methanogens) and methane oxidizing bacteria. Sequence analysis has provided an insight into potential diversity and permitted the development of highly specific probes to individual members of each community. We are now in a position to begin to enumerate these organisms using fluorescently-labelled oligonucleotides, microscopy and flow cytometry.

Immunodetection of toxic dinoflagellates

One of the more promising methods for the immunodetection of specific algae and cyanobacteria utilises antibody molecules produced by a mammalian immune system. These antibodies can be tagged with a fluorochrome, then presented to potentially similar test antigens (other algal strains), and any recognition between the two, visualised with a fluorochrome marker.

Toxic dinoflagellates and diatoms affect fish, shellfish and humans. With respect to humans they are often grouped according to the medical symptoms they cause. The paralytic shellfish poisoning organisms (PSP) include *Alexandrium tamarense* and *Alexandrium catanella*. The diarrhetic shellfish poisoning organisms (DSP) include *Dinophysis acuta*, *Dinophysis acuminata*, *Prorocentrum micans* and *Prorocentrum lima*; and the amnesic shellfish poisoning organisms (ASP) include *Nitzschia* pungens *f.multiseries*. The impact of these organisms on human health makes their rapid identification important.

We have recently raised polyclonal antisera to a range of dinoflagellates and assessed their specificity in recognising other algal cells. We have also studied the effects of preservation methods and mixtures of various organisms on the antigenicity of dinoflagellate cultures. Finally we have assessed the ability of antisera to detect target organisms within preserved natural phytoplankton samples.

Polyclonal antisera raised to *Alexandrium tamarense*, *Prorocentrum lima*, and *Amphidinium* spp. appeared to specifically recognise the genus of algae to which they were raised. The intensity of the immunolabelling reaction between algal cell and antibody indicated the avidity of the recognition; homologous antisera and algal strains gave the most intense reactions. The reactivity of anti-*Alexandrium tamarense* antibodies (raised against a strain from the Tamar) were assessed against four newly cultured British *Alexandrium* cultures from the West coast of Scotland. This antiserum and others were tested with algal material which had been preserved in Lugol's Iodine. This preservation method did not appear to affect antibody reactivity over a short time period (Figure 24).

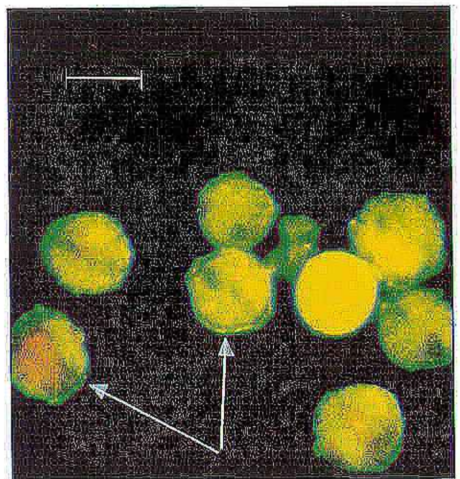


Figure 24. A culture of Alexandrium tamarense *(PCC 173a) which has been preserved in Lugol's Iodine before immunolabelling with anti-*Alexandrium tamarense *antiserum and observed by fluorescence microscopy. Cells appear edged with fluorochrome dye (arrows). Scale bar represents 40 μm.*

Experiments involving mixed genus algal samples showed that the specificity of the antisera was not affected by the presence of more than one algal genus within the test sample (Figure 25).

Preserved natural samples from Scapa Flow, Orkney, yielded cells which were cross-reactive with antiserum raised against *Alexandrium tamarense* strain PCC 173a and *Scrippsiella trochoidea* PCC 104. Their presence was determined by both fluorescence microscopy and continuous flow cytometry. Preserved samples from Berwick harbour and the Firth of Forth also contained cells which were positive with anti-*Alexandrium* antiserum.

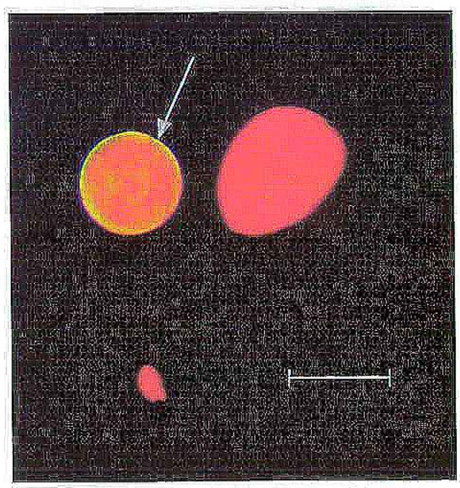


Figure 25. A mixed culture of Alexandrium tamarense *(PCC 173a),* Amphidinium *spp. and* Prorocentrum micans, *immunolabelled with anti-*Alexandrium tamarense *antiserum and observed by fluorescence microscopy. Only the* Alexandrium *cell appears edged with fluorochrome dye. Scale bar represents 40 μm.*

Fish population dynamics and management

Post-Chernobyl radiocaesium in brown trout and Arctic charr from six Cumbrian lakes

Following the reactor accident on 26 April 1986, the Chernobyl plume passed over England during 2-3 May 1986. Much of the remaining activity continued northwards over Scotland, but some moved westwards and then returned to traverse Wales and northern England during the 7-8 May. Limited deposition occurred throughout the UK and the highest values were recorded in Cumbria, North Wales and parts of Scotland. Early monitoring of fish showed that, whilst the radiological significance of the fallout on marine fish was negligible, radionuclide accumulation by freshwater fish was significant, especially in high deposition areas such as the Cumbrian Lake District. It was soon found that there were wide variations between lakes, fish species and individuals of the same species in the same lake. This work was performed in conjunction with staff from the Ministry of Agriculture, Fisheries and Food (MAFF) and was supported financially by NERC and the Commission of the European Communities.

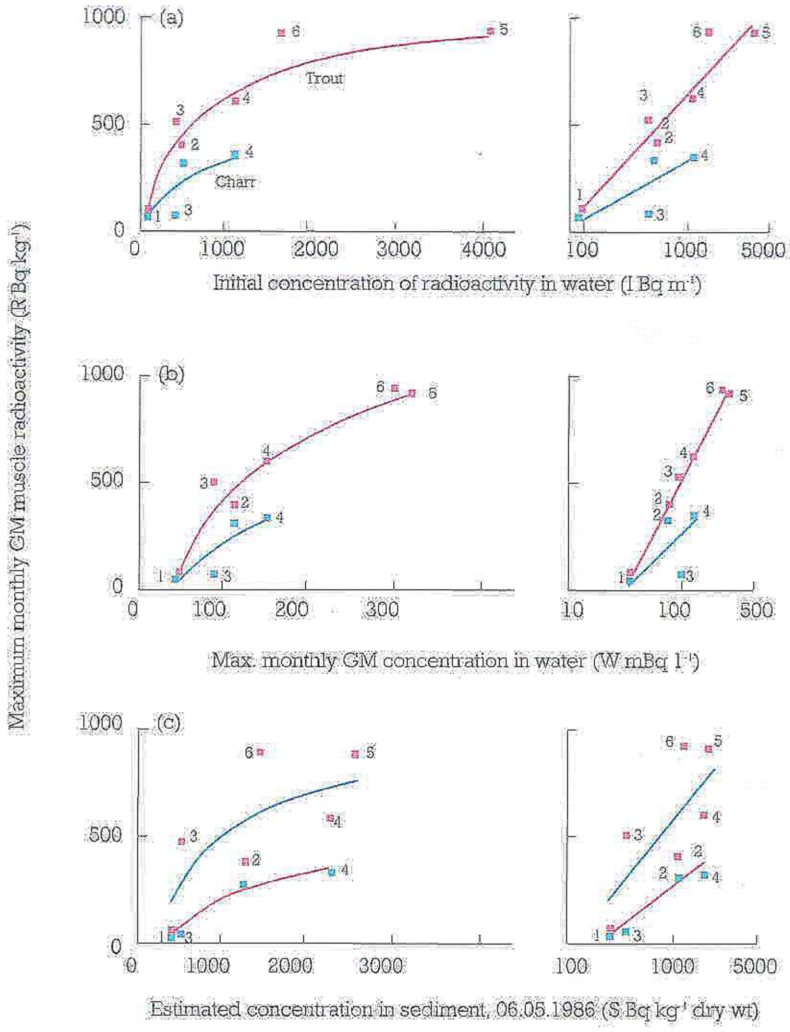


Figure 27. Relationship between maximum monthly geometric mean (GM) muscle radioactivity (R Bq kg⁻¹) for trout and charr in different lakes and : (a) initial concentration of ¹³⁷Cs in the water (I Bq m⁻³); (b) maximum monthly GM ¹³⁷Cs concentration obtained from the routine water samples (W mBq l⁻¹); (c) concentration of ¹³⁷Cs in sediment (S Bq kg⁻¹ dry weight). (Lakes : 1. Windermere (north basin), 2. Crummock Water, 3. Wastwater, 4. Ennerdale Water, 5. Devoke Water, 6. Loweswater). Relationships are indicated as significant (P<0.05) or not significant (P>0.05).

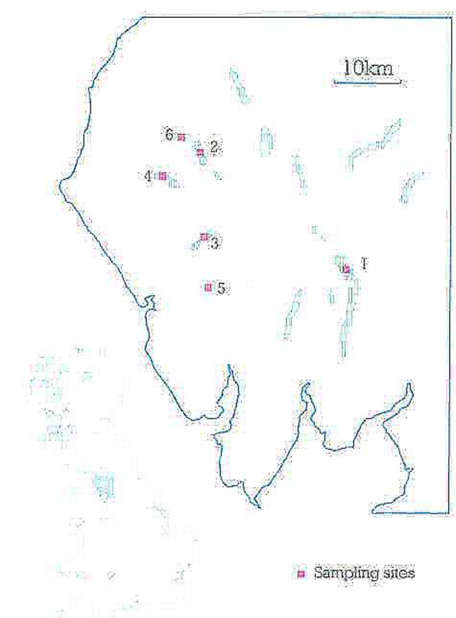


Figure 26. Location of the sampling sites. 1) Windermere (north basin); 2) Crummock Water; 3) Wastwater; 4) Ennerdale Water; 5) Devoke Water; 6) Loweswater. Trout were found in all six lakes and charr in lakes 1-4.

The objectives were to evaluate temporal variation in ^{137}Cs in trout and charr from three lakes, and to compare levels in trout from six lakes and charr from four lakes (see Figure 26). Fish were caught between June 1986 and October 1988, chiefly with fyke nets and gill nets. Overall means for ^{137}Cs in trout were markedly higher than those for charr. Values for individual trout exceeded 1000 Bq kg^{-1} in Ennerdale and 500 Bq kg^{-1} in Wastwater and Crummock Water, but values for charr never exceeded 350 Bq kg^{-1}. Monthly mean values for ^{137}Cs in trout followed similar temporal patterns in the three lakes and a parabola provided a simple model for these changes. Chernobyl deposition occurred early in May 1986 and maximum values in trout were in December 1986 in Wastwater, January/February 1987 in Ennerdale Water and March 1987 in Crummock

Water. The exponential rate of decrease from these maxima did not differ significantly between the three lakes and ecological half-lives of ^{137}Cs in the trout differed slightly, but not significantly, between lakes: 180 days for Wastwater, 194 days for Crummock Water and 249 days for Ennerdale Water. The equivalent value for Ennerdale charr was lower at 132 days, and it was impossible to fit models or calculate half-lives for Wastwater and Crummock charr.

Maximum monthly geometric mean ^{137}Cs values in trout from six lakes and charr from four lakes were related to the initial concentration of ^{137}Cs in both water and sediment, and the maximum monthly geometric mean ^{137}Cs values obtained from the routine water samples. The relationship was curvilinear and approximated, but was not identical to, an asymptotic curve (see Figure 27). No similar relationships were found with mean Ca or K levels in the lake water. Metabolic and diet differences probably explain the lower ^{137}Cs levels in charr compared with trout. Differences for the same species from different lakes may be due to limnological variations and differences between lakes in the nature of their sediments and catchment soils. This project serves as a useful guide to the complexities of studying contaminants that are introduced accidentally or deliberately into the food chains of lakes.

The relative benefits of "Point-stocking" and "Scatter-stocking" with unfed Atlantic salmon (*Salmo salar* L.) fry

These studies form part of a wider contract with MAFF, which was completed on 31 March, 1994.

In each of the years 1989, 1990 and 1991 a batch of unfed salmon fry was released at a point in Bollihope Burn, a small stony tributary of the River Wear in County Durham. This stream is inaccessible to adult wild salmon. In September of each year a series of stations, upstream and downstream of the release point, was electrofished. Information was obtained on the population density and size of the surviving salmon parr at each station. In 1993 the process was repeated, except that the fish were scattered as evenly as possible over 453 m of stream length. The main conclusions were:

a) By September some fish from point-stocking had dispersed up to 50 m upstream and c.500 m downstream of the stocking point, but most remained within 20 m of the stocking point.
b) This led to considerable spatial variation in September population density and fish weight which could be modelled by semi-logarithmic curves (Figure 28).
c) Survival to September from point-stocking was 15% to 20% and 20% to 25% of the survivors were found upstream of the release point.
d) Scatter-stocking gave estimated survival to September of c.27% and much less spatial variation in population density or fish weight.

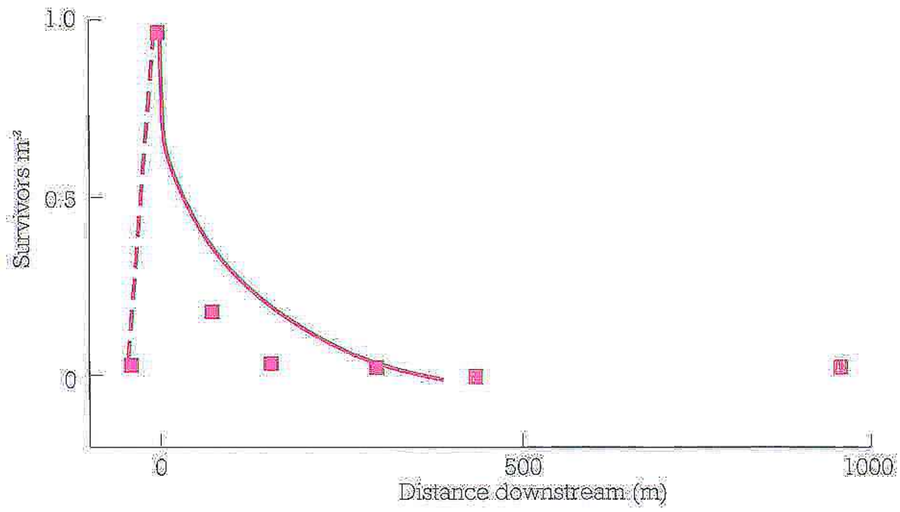


Figure 28. Plot of estimated numbers of 0-group salmon m^{-2} in September 1989 (y) against distance downstream from the release point (x m): the fitted curve is also shown.

These findings are relevant to our understanding of what happens when fry emerge from a natural redd and also to the practicalities of stocking with hatchery reared salmon.

Ecology of schelly in Haweswater

The ecology of the rare fish *Coregonus lavaretus* has been investigated with the aim of providing conservation advice to the public and private components of the water industry. This species, which is protected under the Wildlife and Countryside Act of 1981, is found at only seven sites in the U.K. It occurs in one lake (Llyn Tegid) in Wales where it is known as the gwyniad, in two lochs (Lomond and Eck) in Scotland where it is known as the powan, and at four sites (Brotherswater, Haweswater, Red Tarn and Ullswater) in the Lake District where it is known as the schelly. Particular attention has recently been paid to the population in Haweswater because an earlier extensive study of the *Coregonus* populations of England and Wales suggested that the status of this population was poor.

During January, February and March of each year, schelly are accidentally entrapped into the water abstraction system of Haweswater, counts of which have been maintained since 1973. The absolute numbers of fish killed in this way are small when compared with the population size estimated by quantitative echo sounding (see below). Furthermore, these entrapment data provide an invaluable long-term index of schelly abundance in the lake. The numbers entrapped declined considerably in the early 1980s and have remained low in recent years (Figure 29), suggesting a decreased abundance in the lake itself. Although recent quantitative echo sounding has confirmed the present low abundance of adult schelly in the main body of the lake with densities typically below 60 individuals ha^{-1}, this still amounts to an adult population size of c. 23,000 fish. Denser aggregations occur near the water abstraction intake during the spawning season (Figure 29), when fish from other parts of the lake converge on this area.

The Haweswater population of *C. lavaretus* is the only one outside Scotland for which an earlier population biology study has been published, which was based on the examination of fish entrapped during the mid 1960s. A similar examination of fish entrapped during the last three years has allowed the detection of several fundamental shifts in the biology of this population, all of which give cause for concern on conservation grounds (Figure 30). Firstly, small schelly are no longer entrapped, even though small charr (*Salvelinus alpinus*) are frequently taken. Secondly, the age structure of the schelly population currently shows a dominance by only two

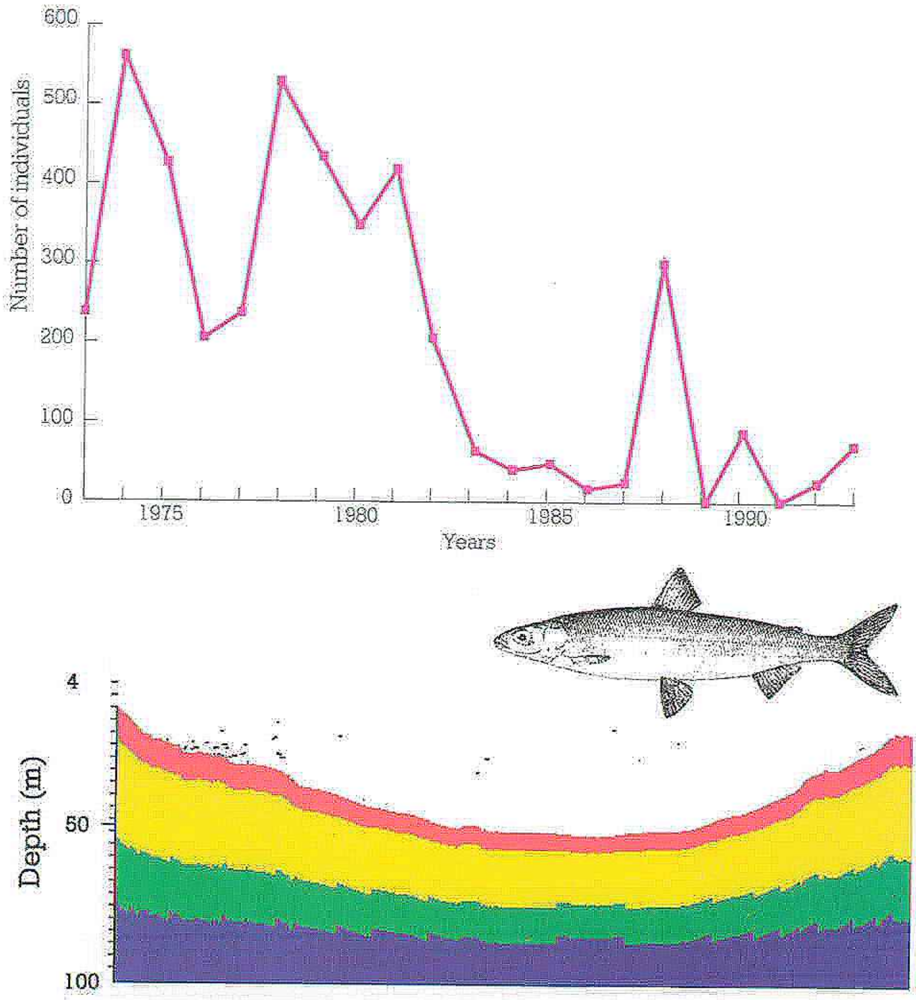


Figure 29. Echogram taken across Haweswater beginning near the abstraction point of the east shore (left side of echogram) at 17.45 hours on 10 February 1993 showing an aggregation of spawning schelly (lower part of figure), and the long-term trend in the entrapment of schelly over the last 20 years (upper part of figure).

year classes, which contrasts with that of the mid 1960s when the age structure was more equitable. Both of these features indicate inconsistent recruitment in the late 1980s and early 1990s. Thirdly, the growth rate and maximum individual size of this population have decreased since the mid 1960s.

In the absence of both eutrophication and species introductions, agencies which threaten *Coregonus* populations elsewhere in the U.K., it is likely that the observed deterioration in the status of the Haweswater schelly is a result of water level fluctuations arising from the operation of this lake as a reservoir. Detailed analysis of long-term records of such fluctuations, which may be in excess of 10 m during the course of a single year, have shown that they have become more extreme in recent years.

On the basis of the above observations, practical recommendations for the sympathetic management of the water level regime of Haweswater have been made to its operators. Although the schelly population is currently in a poor condition, the absence of any other threats at this location suggest that a future recovery is possible.

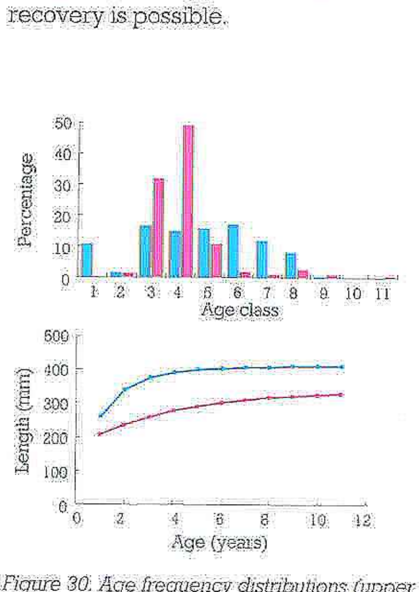


Figure 30. Age frequency distributions (upper part of figure) and growth curves (lower part of figure) for schelly entrapped during 1965-1967 and 1992-1994.

The endocrine response of trout alevins and fry to environmental stress during a "critical period"

It is well-established that exposure to environmental perturbations evokes a neuroendocrine response in teleost fish, similar to the stress response observed in mammals, a response which is believed to have adaptive value in the short-term but which may become profoundly maladaptive if prolonged. Deleterious effects of chronic or repeated stress on growth, reproductive function and immunocompetence are demonstrably linked to the activity of the pituitary-interrenal axis and in particular to circulating levels of the steroid hormone cortisol. Although a comprehensive assessment of the consequences for fish of exposure to stressful conditions is now possible, most, if not all, previous studies on the endocrine response of fish to stress have been carried out on the late juvenile through to sexually mature adult stages. Thus it is not yet established whether the immediate post-hatch and early developmental stages of fish display an integrated physiological response to stress, with the attendant advantages and disadvantages such a response would confer.

Young salmonids are particularly vulnerable to changes in the environment. Immediately post-hatch, and for several weeks following (the exact period being temperature dependent), the alevins are confined to the gravel stream bed within which the eggs were deposited. On emergence from the gravel, after resorption of the yolk sac and the onset of exogenous feeding, the fry enter what is commonly termed a "critical period", during which a high mortality rate may occur, and the long-term success of the year-class is determined. Whether fish during these early stages of life possess a functional and stress-responsive pituitary-interrenal axis is clearly of some relevance to understanding changes in abundance occurring as a result of factors both external and internal to the population. It might be argued that for the larval trout, confined within the gravel, a stress-response which optimises respiratory function and mobilises energy resources would be of no adaptive value since escape from, or avoidance of, stressful stimuli would not be options available to the fish. However, there is evidence for within-gravel movements of pre-emergent salmonid fry and a recent study which examined the metabolic,

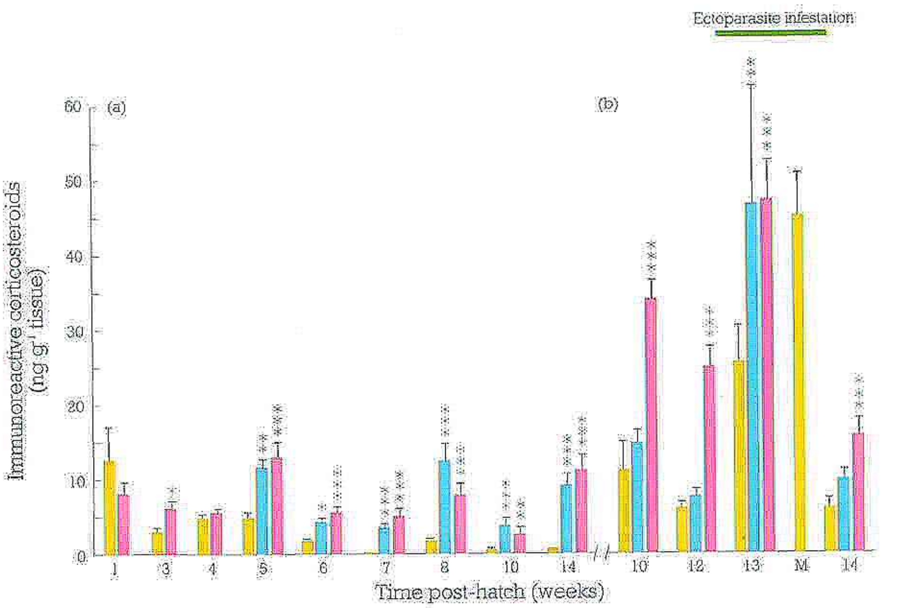


*Figure 31. Whole-body immunoreactive corticosteroid levels in two groups of rainbow trout (a) from 1 week post-hatch to 14 weeks post-hatch and (b) from 10 to 14 weeks post-hatch. The period during which an ectoparasite infestation was observed is denoted by the horizontal bar. Corticosteroid levels in fish identified as moribund are given by the bar (M). Levels in undisturbed fish (0 min); levels in fish after 30 min disturbance; levels in fish after 60 min disturbance. Each bar represents the mean ± SE (n = 10). Asterisks indicate significant differences from values at time 0 for each sample time. * $P<0.05$, ** $p<0.01$, *** $p<0.0001$.*

rather than endocrine, responses of rainbow trout alevins to physical and anoxic stress demonstrated that the adaptive physiological changes elicited by such stressors are comparable to those observed in adult fish.

This study sought to establish at what point in their development, post-hatch, salmonids become stress-responsive in terms of activation of the hypothalamic-pituitary-interrenal (HPI) axis. Immunoreactive corticosteroids were measured in tissue extracts of rainbow trout (*Oncorhynchus mykiss*) at intervals from 4 weeks pre-hatch to 27 weeks post-hatch and in brown trout (*Salmo trutta*) from 5 to 22 weeks post-hatch, encompassing a body weight range of 0.05 - 2.0 g. Corticosteroids were detectable throughout this period in both species. Simultaneous determination of whole-body corticosteroid levels, and plasma steroid levels in fingerling trout validated the use of whole-body levels to provide an indication of stress-induced elevation of corticosteroid levels. However, the dynamics of the circulating cortisol response to stress were not accurately conveyed by whole-body measurements. From 5 weeks post-hatch, whole-body levels of immunoreactive corticosteroids (IRC) increased significantly within 30 - 60 min following mechanical disturbance and confinement, indicative of the presence of a functional HPI axis (Figure 31). An ectoparasite (*Ichthyobodo*) infestation during this period caused a substantial elevation of baseline IRC levels in both species indicating that the HPI axis in these fish was sensitive to naturally occurring stressors. The response of fry to acute (Figure 32) and chronic stress broadly resembled that of adult fish in terms of duration.

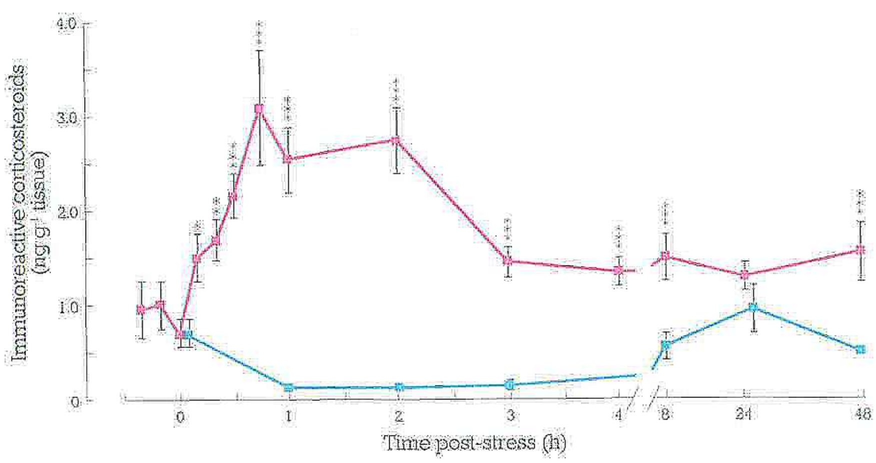


*Figure 32. The time-course of changes in whole body immunoreactive corticosteroids over a 48 h period in rainbow trout fry subjected to a brief period of emersion at time 0 and in undisturbed rainbow trout fry. Each point is the mean ±SE (n=10). For the period 0 - 45 min, asterisks denote significant differences from time 0. From 1 h to 48 h, comparisons are between stressed fish and unstressed controls. *$p<0.05$, **$p<0.01$, *** $p<0.001$.*

The results of this study indicate that both brown trout and rainbow trout display a corticosteroidogenic response to external stressors within 5 weeks of hatching. Thus, while presumably able to benefit from the adaptive advantage of HPI axis activation during episodes of acute stress, the fish are also susceptible to the deleterious consequences of prolonged activation of the HPI axis under conditions of chronic stress. Indeed, some of these deleterious consequences might be more pronounced in the early life stages. The catabolic action of cortisol may be more rapidly debilitating in early juveniles which do not have extensive energy depots to sustain them, and the effect of cortisol on the still-differentiating reproductive system could have ramifications when the fish reaches maturity. Furthermore, although salmonids are not fully immunocompetent in the weeks post-hatch, there is no reason to suppose that the juvenile immune system is not cortisol-sensitive.

The appearance of stress-sensitivity within 5 weeks of hatch will result in free-swimming newly-emerged fry being sensitive and susceptible to environmental stress during the "critical period" for salmonid fish. Moreover, because the pituitary-interrenal axis is activated by social or behavioural, as well as physicochemical, stimuli possession of a functional HPI axis may have implications for the processes involved in the establishment of territories by post-emergent fry.

Physico-chemical processes in catchments

This project is concerned with the understanding, quantification and prediction of the physics and chemistry of water bodies and their catchments. The studies provide information on the media in which aquatic biological processes take place, and on the retention and transport of chemicals and sediments.

Chemical modelling

To understand chemical processes in the environment, it is often necessary to make calculations of the extents of relevant chemical reactions under a range of conditions. Such calculations need to be based on fundamental chemical knowledge. At IFE, work is being done to exploit the large amounts of published data, mostly obtained from laboratory studies with well-defined systems. The focus at present is on natural organic matter, which often exerts a powerful control on the chemistry of waters, sediments and soils. A chemical equilibrium model (WHAM) has been developed that allows the simultaneous interactions of many different chemical components to be calculated. Studies are in progress to test how well the model can account for observations made on natural samples.

An example arises from work funded by the Ministry of Agriculture, Fisheries and Food aimed at understanding the transfer of radionuclides from soil to water in upland catchments. As part of this study, which was carried out in collaboration with the University of Lancaster, it was required to calculate the interactions of a number of radionuclide elements with soil solids under different conditions. Soils from the summit of Great Dun Fell in Cumbria were sampled, and WHAM was calibrated on the basis of solid-solution distributions of major chemical species (hydrogen ions, aluminium, sodium, magnesium and calcium). The calibrated model was then used to predict how trace amounts of radionuclides interact with the soils under different conditions, and these were compared with measurements. Conventionally, radionuclide uptake by soil solids is expressed in terms of K_D, defined by:

$$K_D = \frac{\text{amount of radionuclide bound per gram of soil solids}}{\text{concentration of dissolved radionuclide}}$$

Figure 33 shows that good agreement was obtained between observed and predicted values of K_D for three radionuclide elements, cobalt, strontium and americium. This result increases our confidence in WHAM as a means to predict environmental chemistry.

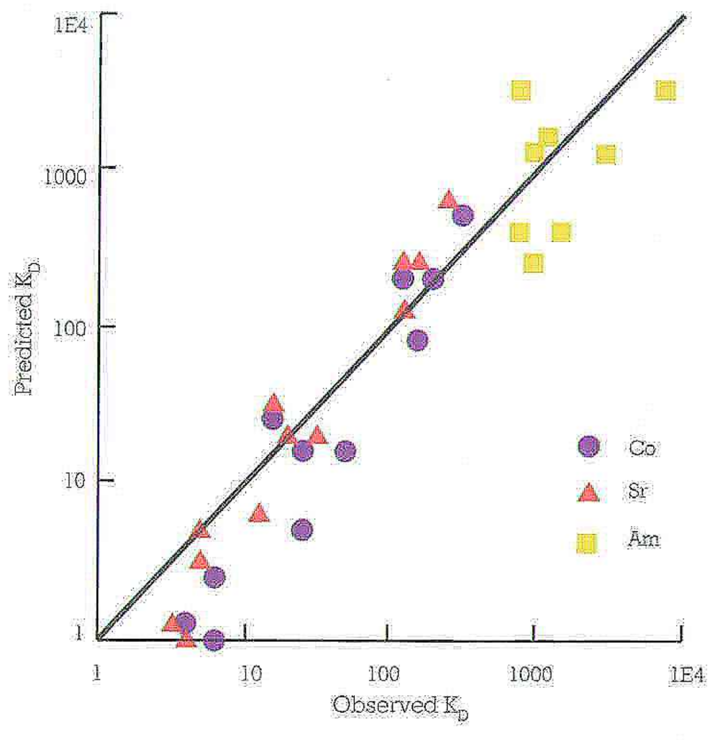


Figure 33. The uptake of radionuclides by upland organic soils; observed and predicted values of the solid-solution distribution coefficient, K_D, for cobalt, strontium and americium. The different values of K_D arise because of differences in soil type, pH and calcium level. The 1:1 line is shown for guidance.

The WHAM model is also being employed to describe soil chemistry as part of a project in the NERC TIGER programme. In collaboration with researchers from the Institute of Terrestrial Ecology, the NERC Radiocarbon Laboratory, and the Universities of Bristol and Reading, a study is being made of the effects of climatic warming on soil carbon turnover at Great Dun Fell in the Pennines. The results are expected to contribute to our understanding of upland water quality.

Radiocaesium in aquatic systems

Staff at the IFE are coordinating an international study, funded by the European Community, on the after-effects of the Chernobyl accident. In conjunction with colleagues from the Netherlands, Russia, the Ukraine and Belorus, sediment samples were collected from lakes located in contaminated areas of the UK, Russia and the Ukraine. A comparison of methods from the different laboratories showed that much of the radiocaesium was locked into the lattice of clay minerals and that in many lakes only a small amount remains mobile and potentially dangerous. The mobile fraction is mostly attached to special sites on illitic clay minerals, from where it can be displaced only by a few other compounds, one of which is the ammonium ion. In lakes with organic-rich sediments, bacterial action can give rise to high ammonium concentrations, and as a result significant mobilisation of radiocaesium occurs.

Silicon dynamics in rivers

Silicon is an essential element for the growth of diatoms, and its role in aquatic eutrophication has come under scrutiny because of the possibility of silicon limitation in lowland rivers. It is normally considered that there are essentially infinite sources of soluble silicon because of the dissolution and leaching of sedimentary minerals. However, in some eutrophic rivers abundant supplies of biologically available phosphorus and nitrogen have led to such increased diatom growth that the net flux of soluble silicon from mineral dissolution is unable to compensate for the depletion caused by planktonic uptake. This has important consequences for the growth of algae and species diversity in receiving waters.

Recent research at IFE has examined the influence of selected inorganic ions on the dissolution rate of silica (silicon dioxide). Experiments were conducted with an automated system and titrimetric procedure and the results were interpreted using an electrical-double-layer model for 1:1, 2:1 and 1:2 electrolytes, with the possibility of including sodium or calcium bidentate surface complexation and ion-pair formation in the bulk solution. The model has provided an improved understanding of the pH and ionic strength dependence of the dissolution reactions. The modelling results show that complexation of sodium with the surface is not an important influence on the dissolution reaction, but they suggest that the ionic strength dependence of the dissolution rate changes dramatically with pH. The surface complexation of calcium ions accounts for the observed increase in the dissolution rate at high calcium concentrations. Dissolution rates of silica in calcium-rich laboratory solutions are similar to those measured for a natural hardwater.

Biological response to the remediation of an acid lake

In last year's report, chemical results were presented from a study that examines the feasibility of combatting water acidity by fertilisation with phosphorus. The phosphorus stimulates phytoplankton growth, and the accompanying increased demand for nitrogen is met by the uptake of nitric acid from the lakewater. As a result, the pH increases.

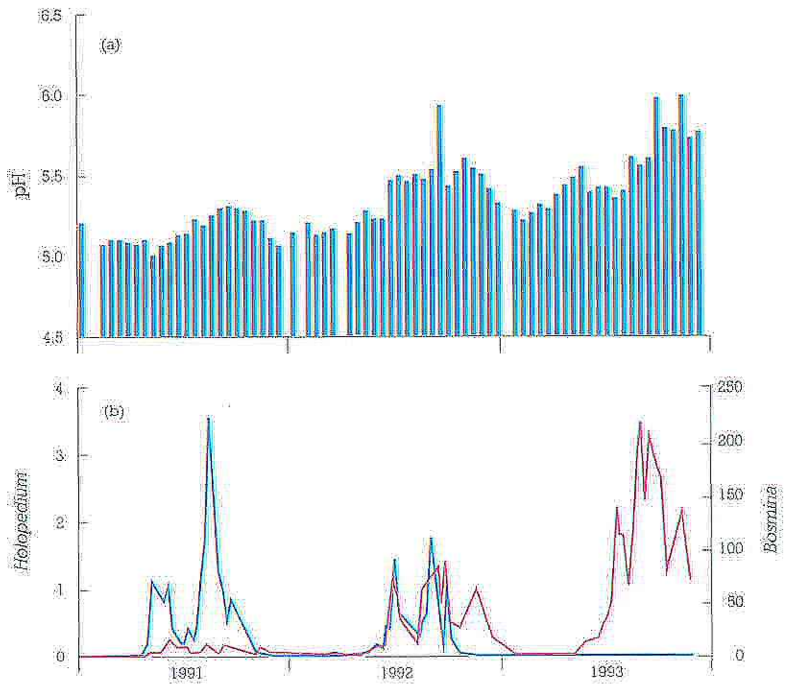


Figure 34. Seathwaite Tarn a) pH b) number of Holopedium L^{-1} and Bosmina l^{-1}.

Figure 34a shows the variation in pH of the study lake, Seathwaite Tarn, for the years 1991-3. Since fertilisation there has been a marked increase in pH, from an average of 5.1 in 1991 to 5.6 in 1993. The most dramatic biological change recorded in the lake was in the nature of the microcrustacean grazing community. Results for two filter-feeding cladocerans are shown in Figure 34b. *Holopedium gibberum* is a relatively rare species that is usually found in nutrient-poor waters, and its numbers have therefore declined as a result of fertilisation. In contrast, the numbers of *Bosmina coregoni*, which is commonly found in lakes that sustain modest growths of phytoplankton, have increased by a factor of ten, so that these animals now play a major part in the recycling of phosphorus and the sedimentary accumulation of organic matter. In functional terms, *Bosmina* is a relatively inefficient filter feeder; large cladocera, like *Daphnia*, can filter much larger volumes of water but they have a higher minimum food requirement and cannot survive periods of low phytoplankton productivity. The concentration of phytoplankton in Seathwaite Tarn is now high enough to support a flourishing population of *Daphnia*, but the species has not yet appeared in this rather isolated lake.

Sediment studies

The movements of coarse sediment, and associated changes in channel bed properties, influence riverine habitats in both the short and long term. In addition, coarse sediment behaviour needs to be understood for civil engineering and navigational purposes.

IFE staff are conducting a study of sedimentation in a river bend, with the aim of obtaining a comprehensive set of field data with which to test available models of gravel transport. Flow in bends is essentially three-dimensional, exhibiting a helical pattern which strongly affects the velocity structure and distribution of stresses on the river bed. The use of electromagnetic current meters which allow the measurement of cross- and down-stream components of velocity, has enabled accurate determination of the stresses operating in the study reach. It is anticipated that the results will allow modelling improvements to be made, by defining more clearly the relationships among local bed shear stress, sediment transport and the local bed configuration.

The hydraulic erosion of upland forestry soils is an important issue in environmental management. To expand the baseline data available for designing drainage networks, the IFE, in conjunction with the Forestry Authority, is currently engaged in research on 14 Scottish upland soils representing types commonly cultivated for afforestation. The research programme is concerned with the determination of the erodibility of the individual soils by laboratory testing in a flume which simulates erosion threshold conditions in a drain furrow. The data will be used to calibrate a hydraulic model which predicts acceptable furrow lengths and gradients for different soil types. In addition, the hydraulic criteria are being related to soil properties, in particular unconfined compressive strength and penetrometer loading.

On some reaches of the River Rhine, gravel dunes form on the river bed at high flows. At lower flows the remnants of these dunes cause obstructions to shipping which have to be removed to ensure free passage for ships. In the short term this can be achieved by dredging, but the process has to be repeated when the dunes reform. In the longer term another solution, possibly involving engineering works, is required to stop the formation of dunes. Before carrying out such work an understanding of the effects of such work on dune formation, growth and decay is required. Fieldwork has been carried out in order to make detailed measurements of flow, sediment transport and dune form and structure. In addition, regular observations of dune profiles and river stage have been made. This information has enabled the dunes formed on the River Rhine to be compared with other observations of dunes, allowing an initial analysis of likely behaviour and response to altered flows. A deterministic model of fluvial dune formation is being developed, with the aim of predicting the effects of engineering works, and thereby enabling rational management of affected reaches of the river.

Chemical analysis

Staff working on this project contribute significantly to other IFE research activities, by providing a specialised analytical service at the Windermere Laboratory. They also maintain a programme to follow long-term changes in rain and surface water chemistry in Cumbria. They participate in the NERC-wide LOIS project, carrying out analyses to determine riverine chemical fluxes, anc liaising with staff in other NERC Institutes, and with University colleagues. The laboratory has recently taken delivery of an Inductively-Coupled Plasma Mass Spectrometer, which will be used for studies of metals in lakes and rivers and soils; the instrument will be especially useful in the testing of multi-element chemical models described above.

River ecosystem processes

The sub-projects within this project have now been rearranged. This final report summarises the essence of the ongoing studies involved.

Control of *Simulium posticatum* in the River Stour

A version of this project has been in existence for almost thirty years. Over this time there have been a number of scientific advances, for example:-
A simple methodology for assessing the life history patterns of Simuliidae.
Production/Food consumption budgets for simuliid larvae. Development of the first (and still the most effective) methodology for determination of natural feeding rates of invertebrates in the field. Currently, the use of *Bti* technology (for the first time in running waters in this country) has permitted effective, environmentally friendly control of a biting simuliid.
Manipulation of natural communities of invertebrates by selective removal of single species could prove to be a major advance in the capability of testing ecological interactions in running waters.

Ecological characteristics of coarse fish in rivers

A form of this project was initiated by David LeCren at the inception of the River Laboratory. Most of the early work was carried out by Richard Mann and subsequently by the late Chris Mills. Over the years there have been a number of scientific advances. The life histories and production ecology of many chalk stream species were evaluated. A start was made on studying the early stages (eggs/larvae) of various coarse fishes. Recently this project has been investigating several new avenues. From a commissioned viewpoint the use of the models PHABSIM and IFIM on British rivers has been evaluated. A substantial part of the River Laboratory coarse fish commissioned effort is devoted to the study of the River Tees and potential shifts in fish community structure following construction of a barrage. Recent scientific studies associated with this work have involved investigations of population composition using isoenzymes, habitat modelling of populations and radio tracking of small fish.

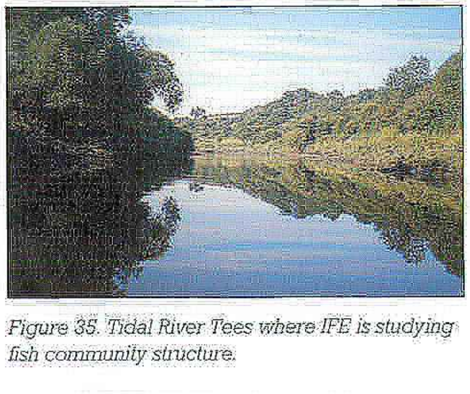


Figure 35. Tidal River Tees where IFE is studying fish community structure.

Conservation Classification of Rivers - River Habitat Surveys

Assessment and quantification of river habitats is currently undertaken particularly by the National Rivers Authority (NRA) for England and Wales. IFE, together with other external specialists, continues to assist the NRA in the formulation, development and testing of a new rapid survey technique called River Habitat Survey (RHS) which is substantially compatible with the data collection of previous techniques. In contrast to some previous, but often more detailed techniques, the aim of RHS is to be fully computer compatible. It will also allow surveys to be representative by the judicious use of 'spot' sampling at 50 m intervals within sample reaches of 0.5 km combined with an overall assessment.

Currently a backdrop of detailed data with good or full geographic coverage ie map-based, including altitude, bed slope, geology, size, distance from source, etc., is being investigated to group river segments of similar basic character, and to define a typical set of natural or bench-mark features. Each river 'type' is being associated with a set of 'predictable' geomorphological and habitat features. The relationship of the prediction is confirmed by site investigation of a data set of 1523 sites derived by selection of the stream or river (preferably classified according to water quality) nearest to the centre of each 10 by 10 km square in England and Wales. IFE undertook some 400 RHS surveys for NRA but has supplemented these data by the addition of chemical analysis and plant survey. The study continues with the assembly of an inventory of physical and biotic features of stream and rivers. These are used to develop methods to associate or order the effects of human interference, maintenance or degradation of watercourses in order to be able to prioritize the options to fulfil NRAs statutory duty of maintenance and improvement from the local to the national level.

Aggressive invasive water plants

Australian Swamp Stonecrop, *Crassula helmsii*, continues to expand its distribution. Since it recently passed 500 sites, the distribution is likely to exceed the 1000 sites predicted to be colonised even before the end of the century.
More disturbingly, the plant has invaded at least one northern English lake in which control is unlikely to be feasible and is increasing at sites in Ireland and probably on mainland Europe. Analysis of survey data from Australia confirms the impression that Britain lies well within its environmental range of temperature including frost, altitude, rainfall, water chemistry including partial salinity effects.
Further studies on herbicide control highlight two major problems. Firstly that the very dense biomasses that can accumulate over a few years would require much more than the allowed levels of approved herbicides for control because elimination is the real target.
Secondly the enormous numbers of viable nodes that develop, thus for example, whilst a submerged stand growing in 2 m of water can achieve 6-50,000 nodes m^{-2}, a marginal-emergent stand can produce a biomass of up to 60 kg m^{-2} fresh weight with up to 3,600,000 nodes. It is currently estimated that attempts at elimination of this plant, which may not be successful, could cost up to £10M and take up to 5 years without even allowing for required monitoring procedures.

Assessment and prediction of changes in the aquatic environment

Introduction

The impact of the weather over various time scales on physical, chemical and biological processes in freshwaters continues to be a major focus of this project. The interest is certainly heightened as a result of the highly vagarious weather regime of Northern Britain (where most of our long-term lake studies are based). The three areas of work illustrated here concern aspects of phytoplankton dynamics that ultimately reflect weather conditions. The main accent is on features which alter over short time scales but, because we have maintained basic surveillance programmes over decades, these can be interpreted in longer term contexts.

Changes over hours to seasons - pH fluctuations in Esthwaite Water

The technology available at a given time will determine the quality and quantity of data that can be collected. This is well illustrated in measurements of environmental conditions; advances in the performance of sensors - and of loggers and computers for data acquisition and analysis - have facilitated radically increased sampling frequencies. A good example is provided by the measurement of pH. This plays a key role in controlling the availability of, among other factors, CO_2 for phytoplankton.

In Esthwaite Water where traditionally, as in many other waters, pH has been measured only weekly, a study partly funded by the TIGER programme includes pH measurement in the surface water every 15 minutes. The increase of nearly 700-fold in sampling frequency has allowed the fine-scale of pH change to be resolved (Figure 36a). The photosynthetic activity of phytoplankton causes diurnal changes which sometimes exceed 1 pH unit. Superimposed on this diurnal pattern is an episodic one, particularly during the summer. This is correlated with, and probably caused by weather features, particularly wind velocity which controls the rate of transfer of water between the hypolimnion and epilimnion. In addition, seasonal changes in pH are seen with extreme values exceeding 10.0 for short periods.

By combining measurements of pH with other variables such as temperature and alkalinity, concentrations of CO_2 and other forms of inorganic carbon can be calculated (Figure 36b). This allows us to assess whether the lake is a source of, or sink for atmospheric CO_2 and whether $CaCO_3$ is likely to precipitate. Esthwaite loses CO_2 to the atmosphere for much of the year. Only for periods in the summer is CO_2 taken up from the atmosphere. The additional removal of inorganic carbon from water by the phytoplankton, which is the cause of the high pH values in summer, has implications for the availability of CO_2 and for phytoplankton periodicity and productivity.

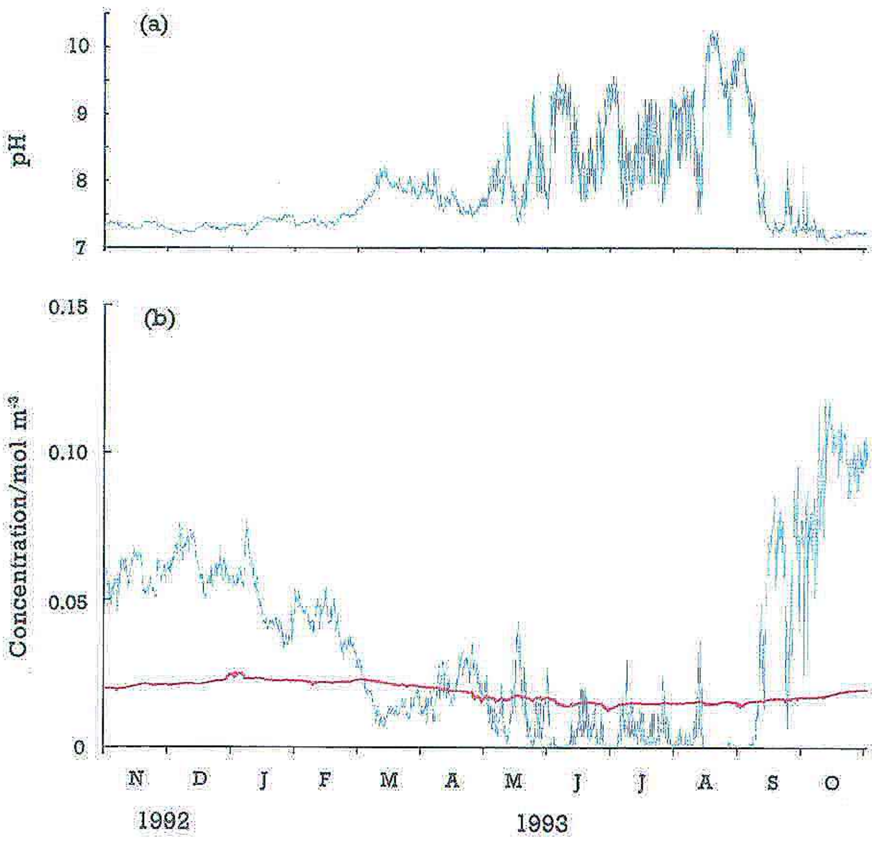


Figure 36. Changes in the surface of Esthwaite Water between November 1992 and October 1993. a) pH. b) the calculated concentration of CO_2 and the air-equilibrium concentration of CO_2.

Slot sequencing demonstrates a close relationship for Windermere between sediment accumulation and the weekly/fortnightly plankton records over the last 50 years

Detailed analysis of the planktonic diatom component in the recent sediments of Windermere can be closely compared with the long-term phytoplankton records. Quarter-centimetre sediment slices approximate to yearly accumulations and analysis shows that approximately 10 taxa account for up to 90% of the assemblage by numbers; most of the species are planktonic forms, as may be expected in a deep water core from a lake of 63m depth. Weekly or fortnightly algal counts in the Algal Data Base date from 1945 AD and the annual maxima of 5 diatoms recognized routinely provides a profile of yearly population changes. Although visual agreement between the two data sets is good, we, in collaboration with Dr Roy Thompson (Edinburgh University), had the opportunity to match percentaged data by means of a formalised sequence

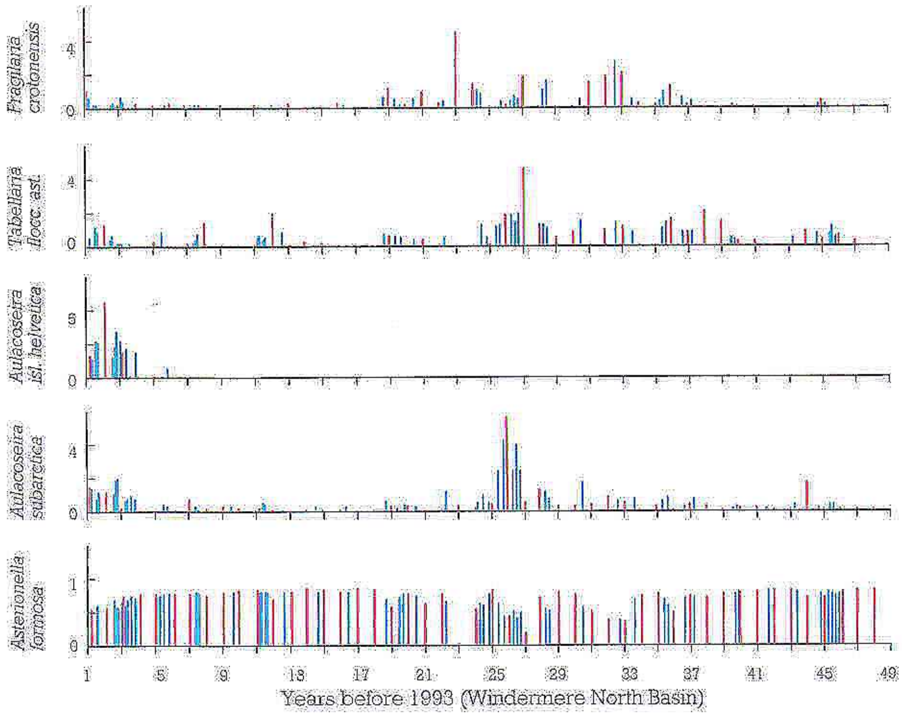


Figure 37. The sequence slotting match of a) the annual maxima and b) the percentages in 0.25 cm sections of a sediment core of 5 planktonic diatom taxa occurring in the north basin of Windermere over the period 1945-1992.

slotting algorithm. This uses a dynamic programming technique to adjust the sediment accumulation in the core to maximize the fit between the two data sets, while retaining the stratigraphic integrity of the core.

A good fit is found for all 5 taxa (Figure 37). Specific seasonal peaks are clearly seen in the sediment record, with the *Aulacoseira subarctica* and *Fragilaria crotonensis* blooms of 1967 and 1968-1970 being preserved very distinctly. The Windermere sediment is thus seen to preserve the fluctuating algal record with the remarkably high resolution of 3 years or less.

^{210}Pb provides a completely independent check on the slotting procedure. Figure 38 compares sediment ages derived from (i) the sequence slotting algorithm and (ii) the radioactive decay of ^{210}Pb. The two approaches are in excellent agreement. Sediment deposition is found to be continuous and there is no evidence of any hiatus in the Windermere record. The small inflections in the sequence slotting time-depth relationship point to several short-term changes in sediment accumulation during the last 50 years. For example, there is a period between 1966 and 1969 where accumulation rises to 5 mm y^{-1}, compared to the pre-1966 rate of 2 mm y^{-1}. This clearly relates to a weather episode - the storm event in Langdale in 1966, as confirmed by a haematite peak in magnetic studies. Subsequent increases can be related to the dredging activities associated with the sand and gravel assessments in the early 1970s, when redeposited material was seen on the surface of sediment cores.

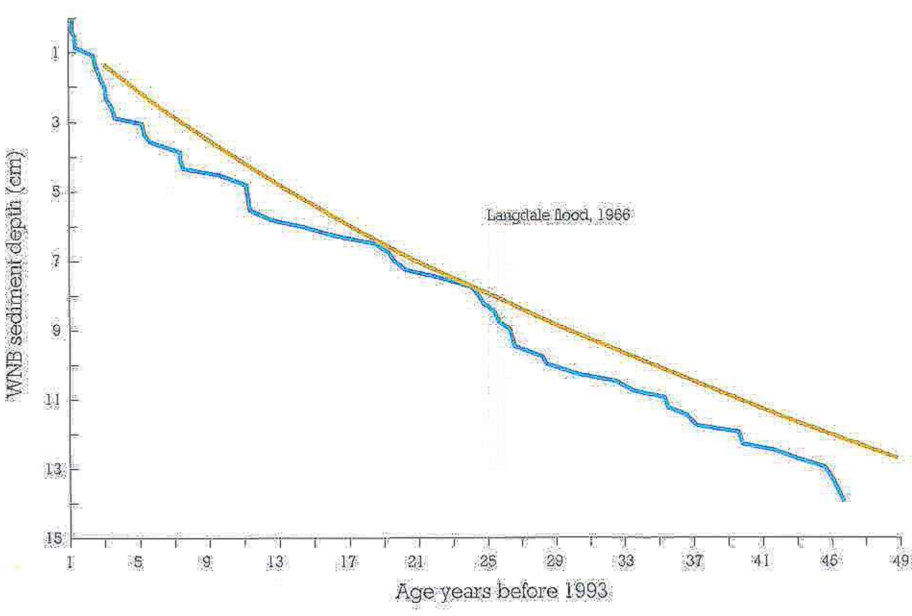


Figure 38. Comparison of the stepwise dating based on algal sequence slotting and the smoother timecurve based on ^{210} lead analysis

The impact of daily weather changes on our perception of algal blooms at Loch Leven

Loch Leven has proved to be a very useful site for studying the impacts of the weather on phytoplankton populations. Firstly, in covering 13.3km² but having a mean depth of only 4m, it is very responsive to changes in the weather. Secondly, the time taken to obtain good estimates of its often dense phytoplankton populations is less compared to the situation with oligotrophic waters with their much sparser crops.

Our records for Loch Leven show that the timing of phytoplankton maxima and minima (as indicated by chlorophyll *a* concentration), and the species composition and diversity of these crops, can differ considerably between years, seasons and shorter periods. Data for 1992-1993 illustrate these features particularly well (Figure 39). The contrast between the prominence of large (gas-vacuolate) blue-green algae in summer 1992 and the poor showing of the same species in summer 1993, reflects the higher temperatures and greater incidence of calm days (resulting in a more stable water column), and lower rainfall (smaller losses due to flushing) in the earlier year.

As sampling from late June alternated each week between 3 and 10 sites, changes in the spatial distribution of the different algal populations can be seen. Over the period of cyanobacterial dominance, late June to late August 1992, the distribution varied from extreme patchiness to more or less complete homogeneity. Changes between these distribution states can be attributed to daily shifts in wind strength; indeed, a wind of Beaufort scale 4-5 can mix a very

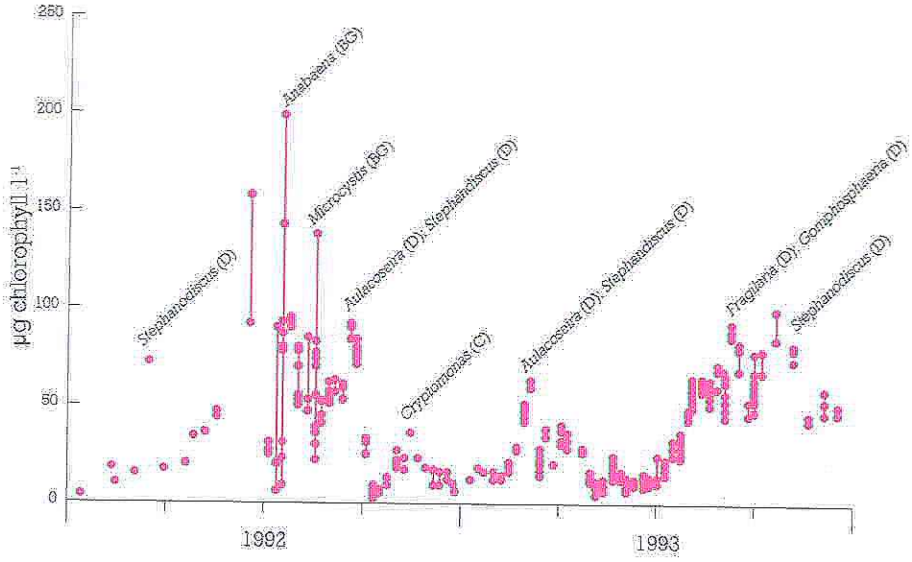


Figure 39: Changes at Loch Leven during 1992 and 1993 in the overall abundance of phytoplankton measured as chlorophyll a, with indications of the main types of algae at various crop peaks; BG - blue-green algae; D - diatoms; C - cryptomonads. Vertical lines connect the dat points for different sites sampled on the same day.

patchily distributed crop relatively thoroughly within a few hours here. Equally, a few hours of calm weather can see 100-fold accumulations of cells at the surface, and even greater concentrations of the material by a gentle breeze onto a section of shoreline. While no less potentially toxic than a surface scum, the same population when mixed throughout the breadth and depth of a lake, is far less noticeable than the often unsightly and smelly material that accumulates at the surface or in-shore.

The fact that changes in the distribution of these organisms can take place so rapidly, may have important consequences. Perhaps media attention to, and the subsequent elevation of the 'algal bloom problem' to in-vogue status, rest on the 'right' (or 'wrong'!) weather conditions persisting for as little as a few days longer in one year than another.

Another feature illustrated by the Loch Leven data for 1992 and 1993, and governing our perception of a bloom, relates to the populations of diatoms and small cyanobacteria. Although recent work suggests that the very small (i.e. ≤ 5µm) unicellular centric diatoms can be patchily distributed, samples are usually very uniform in the population densities of diatoms, green algae and the small cyanobacteria. Hence, the 'bunching' of chlorophyll data points when e.g. *Fragilaria crotonensis*, *Stephanodiscus* spp, *Aulacoseira subarctica* and *Gomphosphaeria lacustris* were dominant. On a lake-wide basis, some of these crops are denser than those of the more troublesome scum-forming cyanobacteria. Also, under mixed conditions, smaller algae in particular, tend to cloud the water more - per unit of overall biomass - than the large cyanobacteria. Still, they receive far less attention than the latter.

Laboratory services

The library and information service

Libraries in research institutes are user-centred organizations. The needs of the Institutes scientific researchers, students and managers continue to change. These changes include the need for a wider range of information types (e.g. marketing information, management information, re-formatted/predigested information) provided with faster access and response times over a wider geographical spread of sites. Despite the harsh economic climate, the Library and Information Service has managed to continue its existing services and to lay the basic foundations for the improvements required to respond to the changes in our users needs.

The library

The number of items catalogued for the Library rose by 8% during the reporting period to 10,800. All of these were added to our computerised catalogue database together with the existing digital records back to January 1987. The database now contains over 60,000 records. At this time, access to the database is only available on one library PC. In 1994/95 we hope to make the information available over the local area network being installed at Ferry House and explore the possibilities of access from other sites.

In September Sheila Scobie was appointed as Assistant Librarian for one day a week at the River Laboratory library. We thank the secretarial staff at Wareham for their co-operation in providing the essential services for this library over the last five years. We also thank once more the staff of the Institute of Terrestrial Ecology libraries for their help and co-operation in providing services to IFE scientific staff at Edinburgh and Monkswood.

The information services

The full range of information services from selective dissemination of information through to retrospective retrieval were provided as normal. We also became founder members of the UK Pro-Cite and the UK CDS/ISIS user groups.

Networks

The provision of input to the Aquatic Sciences and Fisheries Abstracts (ASFA) was improved this year and 350 entries were submitted. This still leaves a large backlog which will be tackled next year.

Contact and collaboration with the various associations of aquatic sciences libraries and information centres was maintained as was contact with the Cumbria Environmental Information Network and the network of educational organisations in the North West.

Helen Poulin, a student with the Department of Foreign Languages, Universite de Haute Alsace, joined the library team for a two month practical training period. She undertook a range of translations with an emphasis on French fish-pass papers. This is the fourth consecutive year that the library has cooperated with a French University in providing such placements.

The Freshwater Biological Association

Although many members continue to visit and use the libraries at Windermere and Wareham, the provision of the Document Delivery service has enabled many more to utilise our collection. The service has continued to expand and has been the most used of the Members services this year.

Members will be sad to learn that Vera Collins (Head of Microbiology Department, FBA until 1976) died in February 1994. She left her collection of scientific books, journals and reprints to the Association's library. The material was collected at the end of March and will be sorted and added to the library during the 1994/95 period.

Electronics and instrumentation

The development of an automated network of water quality monitoring stations in a series of European lakes.

This major three-year project (part-funded by the European Union under its 'LIFE' programme : the Community Initiative for the Environment) is now under way. The electronics section is responsible for the design and construction of the monitoring stations. Each station will be located on a buoy, moored to the lake bed and will monitor and record a variety of meteorological and water quality parameters fully automatically. A remote operator will be able to specify the recording frequency of each parameter and will be able to retrieve recorded data via the telephone network. The system will only require servicing once a month. An additional electronics engineer has been recruited to help with the design of this system.

Deployment of data loggers

A 'thermistor chain' and associated data logger will shortly be deployed in Bassenthwaite Lake. A radio telemetry system will link the data logger to a shore station connected to the telephone network. It will be possible to check the thermal structure of the lake in real-time and to retrieve stored measurements without visiting the site.

External sales

A 'multi-spectral' optical sensor (which measures incident light at five specified wavelengths) was sold to the Department of Agriculture in Belfast for research in the Irish Sea. A high accuracy temperature sensor and recording instrument was sold to the University of Edinburgh for the study of glacial meltwater lakes.

Major installations

A large amount of electrical installation work has resulted from both the refit of large sections of the River Laboratory and the renewal of the Ferry House roof.

Property, buildings and equipment

Changes to laboratories and offices have been minimal during this period. The improving of security, fire and safety standards continued with further upgrading of fire doors and the fitting of viewing panels to others. Certain measures have been put into place to improve our security cover, particularly at weekends and 'out of hours'.

The major work for this period has been the reslating of the entire Ferry House building. With the increase in insulation new ceilings had to be installed in all the top floor rooms and corridors.

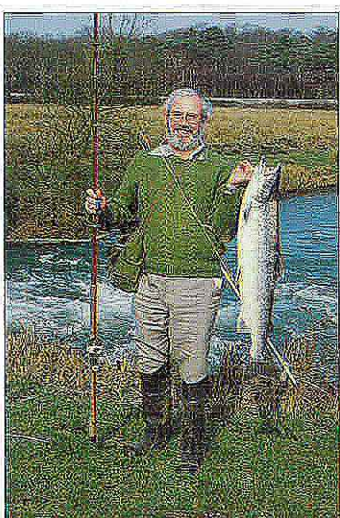
This required the entire top floor to be cleared of all staff, furniture, fixtures and fittings. Eight portacabins were located on the various lawns around Ferry House to take the displaced staff; electricity supply, telephones and computers links were all re-routed to these cabins. To accommodate the scaffolding required, the ferry road was re-aligned (this will stay after the contract to provide a degree of safety for staff leaving the rear of the building).

The contract started at the beginning of July and finished in early December with everybody back in their offices. Certain room moves were also accomplished at this time with the removal of the office built on the top floor landing and the photocopier housed on the first floor. A number of replacement windows were also fitted.

Staff and external activities

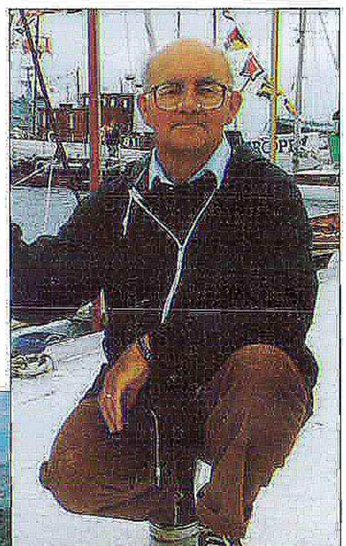
Staff changes

Mr H Casey retired in September after 30 years at the River Laboratory. Harry was appointed as analyst in 1963 when the River Laboratory was first established and after a period of working in Zambia on secondment to FAO he returned as Head of Analytical chemistry. Harry has taken an active part in all aspects of laboratory life - as safety adviser, union representative, and angler extraordinaire. Harry was awarded an MBE for services to science in the New Year's Honours List.



Harry Casey

George Jaworski



Ray Ohnstad

In September Professor J G Jones ceased to be Director of the Institute of Freshwater Ecology after holding the position since 1987 but Gwyn has continued as Director of the Freshwater Biological Association. Mr G H M Jaworski and Mr F R Ohnstad took early retirement on 31 March.

George Jaworski joined the Ferry House staff from school as a laboratory assistant in 1959. He soon moved into the algology section as an assistant to Dr Lund and the regular weekly sampling on Esthwaite and Blelham was his responsibility for many years. George's particular talent for culturing algae earned him a world wide reputation and many overseas visitors came to Ferry House to learn culture techniques from George.

Ray Ohnstad came to the Ferry House in 1975 as instrument maker and took over the position of Laboratory Steward in 1981 following the retirement of Mr W H Moore. Ray was responsible for the smooth running of all aspects of Ferry House life and for major changes in laboratory design, the introduction of the security system and finally last year the reroofing of the Ferry House.

During the year Miss S Scobie, previously at Windermere laboratory until she joined VSO in 1991, was appointed as Assistant Librarian at the River Laboratory. At Windermere Mrs G Devlin and Mrs E Monaghan having assisted with the Fritsch Collection for some years were appointed as Assistant Scientific Officers, Mr M Lee joined the electronics team and Mrs P Tullett retired. At Eastern Rivers Laboratory Mr G Collett returned in November after two years unpaid leave working as project director on an aquaculture development project in Cambodia and Mr R A Garbutt left to take a post with ITE.

The number of staff in post at 31 March 1944 was 103

Honours and Promotions

Dr J Hilton was appointed as Head of Regional Laboratories in June and Professor Pickering was appointed Acting Director IFE following the retiral of Professor Jones in September. On the retirement of Mr Ohnstad, Mr P V Allen was appointed Laboratory Steward.

Mr Mann was awarded the degree of Doctor of Science of University of Leicester and also awarded a Fellowship of Institute of Biology. (FIBiol)

Mr W R C Beaumont was promoted from Higher Scientific Officer to Senior Scientific Officer and Miss S Brown from Scientific Officer to Higher Scientific Officer. Following the setting up of the LOIS laboratory at York temporary promotions were awarded to Mr D V Leach to Higher Scientific Officer and Mr A C Pinder to Scientific Officer.

Mrs M Hurley was awarded the status of Chartered Statistician by the Royal Statistical Society.

Mr I D M Gunn was awarded a CBiol and MIBiol by the Institute of Biology. Mr R J M Gunn and Mr J H Blackburn were awarded (IDQ) Certificates of Qualification by the Natural Hisory Museum (for Freshwater Macro-invertebrates species level)

NERC activities

Mr Beaumont and Mr Glaister were members of the Executive Committee of the NERC Branch of the Institution of Professionals, Managers and Specialists with Mr Glaister Assistant Secretary and

Mr Beaumont a member of the NERC Health and Safety Committee and of the NERC Whitley Committee.

Professor Pickering and Dr Pinder served on the Environmental Change Network (ECN) Freshwater Working Group and Professor Pickering also on the Biopoles Research Working Group and the steering group of the Catchment Based Ecosystem Research Group. Professor Jones, Dr House and Dr Tipping served as members of committees or Working Groups of LOIS (Land Ocean Interaction Study) and Professor Jones also as a member of TIGER 11 (Terrestrial Initiative in Global Environment Research) committee.

Dr Elliott and Mr Pettman were members of the Terrestrial and Freshwater Sciences Directorate (TFSD) Core Groups and Dr Elliott also a member of the Aquatic and Life Sciences Grants Committee and of the NERC Visiting Group which inspected MSc courses. Dr Maberly and Dr Pottinger acted as secretaries to NERC Special Topics Working Groups and Dr Cranwell and Dr Reynolds as Working Group Members.

Collaboration with other NERC Institutes

Collaboration with Institute of Hydrology (IH) and Institute of Terrestrial Ecology (ITE) on the LOIS and TIGER research programmes continued with Dr House and Dr Tipping involved with the LOIS Core programmes, Dr House, Mr Leach and Mr Pinder with the LOIS York Laboratory and Dr Tipping and Mr Woof with TIGER 1 programme.

Dr Armitage collaborated with IH in the development of ecologically acceptable flows with reference to the effects of weed growth on discharge relationships and Mr Welton with IH on a joint consultancy. Mr Beaumont and Dr Crisp continued collaboration with IH at Plynlimon. Dr Carling had a joint project with IH and another with the Institute of Oceanographic Sciences at Bidston.

Dr Bailey-Watts and Mr I Gunn have been involved with ITE Banchory on the ecology of the Dinnet Lochs and on interactions between fish and their predators. Professor Jones collaborated with the microbiology group at ITE Merlewood and Dr Wright with ITE Monks Wood regarding RIVPACS developments.

Direct links between the Culture Collection of Algae and Protozoa (CCAP) Windermere and CCAP (Oban) at Dunstaffnage Marine Laboratory continued.

Scientific Societies

Dr Dawson was Council member of the Institute of Biology and a member of the Alien Plants committee of the Botanical Society of the British Isles. Dr Day was Newsletter editor for the UK Federation of Culture Collections. Mrs Hurley was a committee member of the Lancashire and Cumbria Group of the Royal Statistical Society. Dr Maberly was a Council member of the British Phycological Society. Dr Mann was a Council member of the British Ecological Society, the Institute of Fisheries and the Fisheries Society of the British Isles. Mr Pettman was chairman of the Britain and Ireland Association of Aquatic Sciences Libraries and Information Centres and national representative on the European Association of Aquatic Sciences Libraries and Information Centres. Dr Pickup was Convener of Environmental Microbiology Group of the Society for General Microbiology. Dr Tipping continued as member of the Board of Directors of the International Humic Substances Society. Dr Winfield was a Council member of the Fisheries Society of British Isles and a member of the organising committee for the Annual Study Course of the Institute of Fisheries Management.

Other organisations

Dr Bailey-Watts was a member of the Scottish Office Working Party on Blue-green algae and Dr Reynolds of NRA toxic Algae Task Force and also a Board member of the Centre for Water Research, University of Western Australia.

Dr Elliott was a member of the Department of Environment (DoE) Advisory committee on Releases to the Environment, and Biological Methods Panel of the DoE Standing Committee of Analysts and a member of the International Committee for the Scientific Evaluation of the Norwegian Institute for Nature Research. Dr House was a member of the DoE Technical Committee on Detergents and the Environment and on the Phosphorus Working group of ADAS. Professor Jones was a member of the Department of Trade and Industry LINK Biological Treatment of Soil and Water Management Committee and was Scientific Director of Project Urquhart.

Dr Carling was a member of the American Society of Civil Engineers Task Force on Mechanics of Non-Newtonian Fluids and of the British Standards Institute Sedimentation sub-committee and Professor Pickering of a NRA Euro Workshop. Mr Beaumont served on the steering group of the Acid Waters Monitoring Network. Dr Wright was a member of the Natural History Museum Identification Qualification Advisory Board (IDQ) and served on the Moors River Standing committee. Dr Winfield was a member of the Bassenthwaite Lake Forum.

Mr McCulloch was secretary of the Association for Information Management (ASLIB) Northern Branch. Miss Atkinson continued to serve as a Secretary of State Appointed Member of the Lake District National Park Authority and was Chairman of its Planning Policy Committee. Dr Reynolds continued to serve as an elected member of South Lakeland District Council and of Kendal Town Council and as a member of the Office of Water Services (OFWAT) committee for the North West.

Editorial commitments

Dr Finlay continued to serve as editor of *Archiv fur Protisenkunde*, Professor Jones as editor of *Advances in Microbial Ecology* and *Freshwater Forum* and Mr Pettman as editor of *New Library World* and *Librarians World*. Dr Elliott was series editor of the *FBA Scientific Publications* and editor for *International Charr Symposium : Proceedings*. Dr Cranwell was Associate editor of *Organic Chemistry* and Dr Carling joint editor of *International Geomorphology*. Dr Mann, Dr Pottinger and Dr Winfield were Assistant Editors of the *Journal of Fish Biology*. Dr Reynolds was Sub-Editor for *Archiv fur Hydrobiologie* and joint editor of a book for *Developments in Hydrobiology* series.

Staff served on the Editorial or Advisory Board of the following journals:
Dr Armitage *Regulated River* and *Netherlands Journal of Aquatic Ecology*, Dr Crisp *Hydrobiologia*, Dr Elliott *Annales de Limnologie* and *Wasser und Abwasser*, Dr Finlay *FEMS Microbial Ecology*, *European Journal of Protistology*, *Microbial Ecology* and *Microbiology*, Dr Haworth *Journal of Palaeolimnology*, Dr House, Dr Maberly and Dr May *Internationale Revue der Gesamten Hydrobiologie* and Dr Maberly also *Aquatic Biology*, Dr Mann *Ecology of Freshwater Fish*, Professor Pickering *Disease of Aquatic Organisms*, Dr Pickup *Microbiology*, Dr Reynolds *Aquatic Sciences*, *Journal of Plankton Research* and *Limnologica*, and Dr Tipping *Environmental Technology*.

Collaboration with Universities

Teaching

Dr Hilton was a Visiting Professor at the University of Reading, Professor Jones a Visiting Professor at the University of Liverpool, Professor Pickering a Professor Associate at Brunel University and Dr Tipping a Visiting Reader at the University of Lancaster. Dr Crisp, Dr Pickup, Dr Reynolds, Dr Winfield were Visiting Lecturers at the University of Lancaster and Dr Crisp also at the University of Durham. Dr House, Dr Pinder and Dr Wright were Honorary Lecturers at the University of Reading and Dr Bailey-Watts at the University of Edinburgh. Dr Dawson was a Visiting Fellow at the University of Southampton and Dr Pickup an Honorary Research Fellow at the University of Liverpool.

Seminars were given at the Universities of Leeds and Reading by Dr Carling, at Napier University and University of Edinburgh by Dr Bailey-Watts, and at the Universities of Exeter by Professor Pickering, and Reading by Dr Wright. Mr Clarke taught EM techniques to a student at Girona University, Spain.

Staff acted as external examiners for PhD degrees at the following universities:- University of Hull (Dr Winfield), University of London (Dr Bailey-Watts, Dr Winfield, Dr Wright) and University of Leuvan (Dr Hilton) and Dr Elliott was an external examiner for a Doctorat thesis at Trondheim University.

Research

Dr Armitage collaborated with the University of Natal on modelling the effects of weed growth. Dr Bailey-Watts continued studies on heavy metals and phosphorus chemistry of lake sediments with the University of Edinburgh and on Loch Ness phytoplankton with Lancaster University. Dr Carling continued a project with the University of Coblenz on hydraulics of the River Rhine. Dr Day collaborated on algal taxonomy and protist preservation with the University of Tsukuba and Dr Finlay with the Natural History Museum and with the Universities of Madrid and Copenhagen. Dr Hall collaborated with the University of Warwick on methane oxidation in peat. As part of the Terrestrial Initative in Geological Global Environmental Research (TIGGER 2) programme Dr Haworth collaboraterd with the University of London. Dr House continued joint research with the University of Reading on pesticide interaction with minerals. Professor Jones and Dr Pickup continued projects with the Universities of Liverpool and Newcastle and Dr Maberly with the University of Bristol on carbon limitation in blooms of blue-green algae. Dr Pinder collaborated with the University of Birmingham on research on large river ecosystems. Dr Pottinger continued his collaboration with Brunel University on physiological mechanisms controlling fecundity in fish, with the University of Liverpool on red blood cells of trout and with the Universities of Nijmegen and Oslo also on trout. Dr Reynolds had joint research projects with the University of Manchester on mass spectrometry, with the University of Western Australia on the impacts of fluid dynamics and with the University of Sao Paulo on plankton ecology of lakes in Brazil. Dr Tipping undertook joint projects with the University of Lancaster on radionuclide complexation by natural organic matter, with the University of Plymouth on a LOIS project, with the University of Newcastle on a soil liming study, with University of Illinois on organic complexation modelling and with Wageningen Agricultural University on acid soil chemistry. Dr Winfield collaborated on projects relating to *Coregonus* with the Universities of Wales and Stirling and with the University of London on population modelling of pike and perch.

Members of staff acted as supervisors for students registered for PhD degrees at the following universities:

Miss D Bunker (Manchester) Irreversible sorption of radionuclides onto freshwater sediments, with Dr Hilton.

Miss S Brown (Liverpool) The molecular systematics of naked amoebae, with Dr Finlay.

Mr F Charlton (Wolverhampton - CASE student) Remote sensing of freshwater algae, with Dr George.

Miss P S Davies (Leeds) Phosphorus dynamics in limnetic ecosystems, with Dr Reynolds.

Mr D Deere (Liverpool - CASE student) Identification of bacteria by flow cytometry, with Dr Pickup.

Miss N Fielding (Liverpool) Biomanipulation control strategies of eutrophication in the Merseyside disused docks, with Dr Maberly.

Miss A Fulcher (Lancaster) The physiological ecology of the rotifer community in the plankton of Loch Ness and the Cumbrian lakes, with Dr May.

Miss A Hartley (Birmingham - CASE student) Microelectrode studies of calcification and gas exchanges within hardwater algal biofilms, with Dr House.

Mr P Garner (Birmingham) Habitat use by O-group cyprinid fish, with Dr Mann.

Mr R Hastings (Liverpool) Distribution of nitrifying bacteria in lakewater and sediments, with Dr Pickup.

Mr R Head (Lancaster - CASE student) The role of sediments in blue-green algal blooms, with Dr Bailey-Watts.

Mr N Hesketh (Manchester - CASE student) The binding of hydrophobic organic molecules by humic substances, with Dr Tipping.

Miss L Jones (Brunel) Effects of alkylphenols and related chemicals on gonad development and sex determination of trout, with Dr Pottinger.

Miss S McGowan (Liverpool - CASE student) Palaeolimnology of blue-green algal bloom formation, with Dr Haworth.

Miss S Marshall (Cardiff - CASE student) Roles of natural surfactants in pollutant biodegradation in biofilms in river sediments, with Dr House.

Mr I Miskin (Liverpool - CASE student) Identification and distribution of bacteria and their plasmids in sediments, with Dr Pickup.

Miss S Owen (Cardiff - CASE student) Sorption and biodegradation of pesticide/surfactant formulations in biofilms on river sediments, with Dr House.

Miss J Reeve (Canterbury) with Dr Dawson.

Mr G Rhodes (Liverpool - CASE student) Molecular evolution of plasmids in deep sediments, with Dr Pickup

Miss V Wanstall (Liverpool) Managing semi-enclosed eutrophic coastal ecosystems: the roll of bottom-up processes in the Merseyside disused docks, with Dr Maberly.

MSc students from Napier University, Universities of Edinburgh, Central Lancashire, Lancaster, London and Reading were supervised by Dr Armitage, Dr Bailey-Watts, Dr Dawson, Dr Maberly, Dr Pickup and Dr Pottinger.

During the year five research students were awarded PhD degrees:
Miss E Baroudy (Lancaster), Miss B Ghul (Konstanz, Germany) Mr A Kelsey (Lancaster), Mr J Porter (Liverpool), Miss J Taylor (Dundee).

International meetings and visits

Dr Armitage presented two papers at the 12th International Symposium on Chironomidae held in Canberra. Dr Bailey-Watts presented a paper at a seminar in Ankara on Wetlands Management. Dr Crisp attended a meeting in Lyon of the European Inland Fisheries Advisory Commission Working Group on Fish Habitat Restoration. Dr Dawson attended an International Workshop on Plant Invaders held in Czechoslovakia. Dr Elliott was keynote speaker at the International Charr Symposium in Trondheim and attended a Workshop organised by Dr Hilton held in Moscow relating to Chernobyl radionuclides in fish which Mr Nolan also attended.

Dr Finlay was chairman and speaker in two symposia at the International Congress of Protozoology held in Berlin which Miss Brown also attended. Dr Haworth attended the 6th International Symposium on Palaeolimnology held in Canberra and presented a paper and also gave lectures at Deakin University (Victoria) and Townsville University (Queensland).

Dr Hilton was organiser and keynote speaker at a meeting in Lisbon on Radioecology of Freshwaters and Estuaries and visited Brussels and Jordan relating to contracts.

Dr House was keynote speaker at Workshops on Trends in Surface Water Analysis held in Lisbon and at Reading on Water, Sediment and Waste. Professor Jones attended a seminar at Tihany Research Institute, Hungary and visited Paris and Belgium for discussions on research collaboration. Dr Mann and Dr Welton attended a meeting in Hull on Fish Stock Assessment. Professor Pickering was Symposium organiser on Hormones and Stress at the 12th International Congress on Comparative Endocrinology held in Toronto and attended a meeting in The Netherlands of the an ESF working group. Dr Pinder was session chairman and speaker at Royal Entomological Society Symposia on the Ecology of Aquatic Insects and Insects as Environmental Indicators. Dr Reynolds was coorganiser and keynote speaker at a Workshop on Turbid Lakes and Rivers held in Belgium, presented a paper at a NATO symposium in Italy and was speaker at seminars at the Universities of Western Australia, Uppsala and Namur and attended a SCOPE (Scientific Committee on Phosphates in Europe) meeting in The Netherlands. Dr Tipping was an invited speaker at a meeting in Strasbourg on Chemodynamics of Groundwaters and presented lectures to the Swiss Federal Institute of Environmental Science and Technology and to the Swiss Federal Institute of Technology and spent two weeks at Wageningen Agricultural University undertaking collaborative research on acid soil chemistry. Dr Winfield presented two poster papers at a meeting on Factors Affecting the Distribution of Fish. Dr Wright was a keynote speaker at the 7th Congress of the Spanish Association of Limnology held in Bilbao, an invited speaker at a meeting held in Canberra on the Use of Biota to Assess Water Quality, presented a talk on RIVPACS at the Museum of Darwin prior to visiting the Alligator Rivers Region Research Institute in Northern Territory and also gave an invited lecture on RIVPACS at the University of Braunschweig, Germany. IFE Staff carried out overseas visits for collaboration on joint research projects - Miss Brown to Belgium, Dr Carling to Poland, Germany and Russia, Dr Maberly to Florida, Dr Finlay to Denmark and Germany, Dr Pickup to Japan and Dr Hilton and Mr Nolan for fieldwork in Russia.

Dr Bailey-Watts received Yuwadee Peerapornpisal from Chiang Mai University for training in algal identification and enumeration.

The Freshwater Biological Association

The Freshwater Biological Association is an independent body that conducts research into all aspects of freshwater science. The programme is maintained by awarding grants and studentships, usually to young scientists. The Association works in close collaboration with the Natural Environment Research Council's Institute of Freshwater Ecology.

By agreement with the NERC, the FBA conducts its research programme in the Laboratories now managed by the Institute of Freshwater Ecology. The Windermere Laboratory (The Ferry House) is the Head Office of the Association and the other laboratories are:

The River Laboratory, East Stoke, Dorset
The Eastern Rivers Laboratory, Huntingdon, Cambridgeshire
The Teesdale Laboratory, Barnard Castle, Co Durham
The Edinburgh Laboratory, Penicuik, Midlothian

Membership is open to individuals and organisations that wish to support the Association. Members receive copies of the Association's Freshwater Forum, and may obtain other publications at a discount; they may also visit the Laboratories, and use the Library by agreement with the Director.

The Library provides a suite of services including the following:

Current Awareness Service. A monthly publication listing recent articles, reports and books covering all aspects of freshwater science is available from the Library and Information service for an annual subscription.
The British List of Hydrobiological Papers is published annually, listing papers on British fresh waters, arranged geographically.
A Document Delivery Service supplies photocopies of articles and papers from the extensive range held in the library.
Literature Searches will be undertaken by the library staff.

All of these services are available at reduced rates to members of the Association. Further details are available from THE LIBRARIAN, THE FERRY HOUSE, FAR SAWREY, AMBLESIDE, CUMBRIA LA22 0LP.

In addition to its programme of research and publication, and the maintenance of International Archives such as the FBA Library and Fritsch Collection, the Association organises a range of meetings. These include conventional scientific symposia and major international seminars. It is also envisaged that smaller workshops and training courses will play a larger part in the future programme.

All enquiries concerning Membership and the Association's acitivities should be addressed to:

The Director
Professor J Gwynfryn Jones
Freshwater Biological Association
The Ferry House
Far Sawrey
Ambleside
Cumbria LA22 0LP
Telephone:
Windermere (STD Code 015394) 42468;
International (4415394) 42468
Fax: (015394) 46914

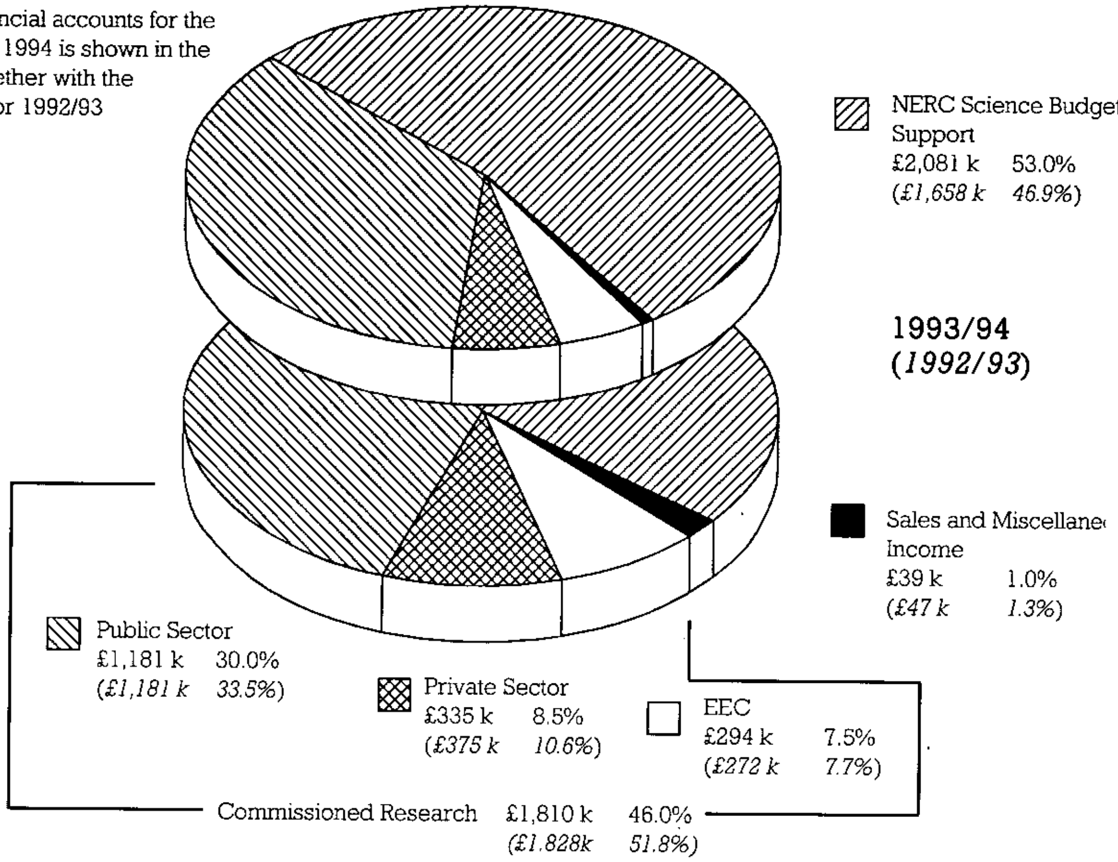
FRESHWATER BIOLOGICAL ASSOCIATION

Appendix 1

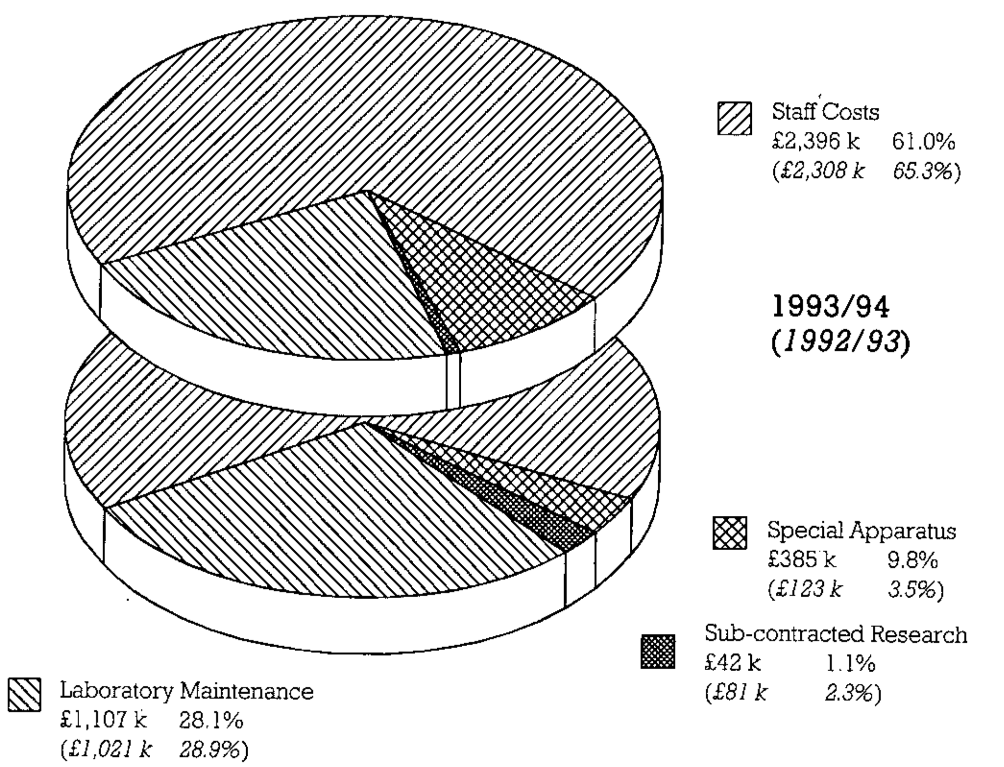
Finance

A summary of the financial accounts for the year ended 31 March 1994 is shown in the pie-charts below, together with the comparative figures for 1992/93

INCOME



EXPENDITURE



Appendix 2
Staff list

Management/Administration

Acting Director and Head of Windermere Laboratory	Prof A D Pickering	Grade 5
Head of Regional Laboratories	Dr J Hilton	Grade 6
Management assistance	Miss K M Atkinson	HSO
Secretary to Director	Mrs M Thompson	EO
Secretarial services (Windermere)	Mrs V Muzalewski	PSec
	Mrs Y Dickens	Ty Pt
	Miss K Ross	Ty
	Mrs G Machin	SB1
(River Laboratory)	Mrs D M Morton	EO
	Mrs V B Palmer	AO Pt
Finance Officer	Mr C J Moakes	SEO
Finance and establishments	Miss P Parry	EO
	Miss S Taylor	AO

Management of lakes and reservoirs

Project Leader	Dr C S Reynolds	Grade 6
	Dr D G George	Grade 7
	Dr S C Maberly	SSO
	Dr L May	SSO
	Miss C Butterwick	HSO
	Mr I D M Gunn	HSO
	Ms D P Hewitt	HSO
	Dr A E Irish	HSO
	Mr A Kirika	HSO
	Mr A A Lyle	HSO
	Miss P S Davies*	RS
	Miss A Fulcher	RS

Assessment and prediction of changes in the aquatic environment

Project Leader	Dr A E Bailey-Watts	Grade 7
	Dr E Y Haworth	Grade 7
	Mrs M A Hurley	SSO Pt
	Mr G H M Jaworski	SSO
	Mrs J E Parker	HSO
	Mrs J V Roscoe	SO Pt
	Miss J A Taylor	RF

Ecology of large lowland rivers

Project Leader	Dr L C V Pinder		Grade 7
	Mr R H K Mann		Grade 7
	Dr A F H Marker		Grade 7
	Mr J A B Bass		SSO
	Mr D V Leach	Temp	HSO
	Mr G D Collett		SO
	Mr A C Pinder	Temp	SO
	Mr P Garner*		RS

Land-river interactions

Project Leader	Dr J F Wright	Grade 7
	Dr P D Armitage	Grade 7
	Mr M T Furse	Grade 7
	Mr J H Blackburn	HSO
	Mr R J M Gunn	SSO
	Mr N J Grieve	SO
	Mrs J M Winder	SO
	Mrs K L Symes	ASO
	Miss A Brookes*	RS

Fish population dynamics and management

Project Leader	Dr J M Elliott	Grade 6
	Dr D T Crisp	Grade 7
	Dr T G Pottinger	SSO
	Dr I J Winfield	SSO
	Mr T R Carrick	SSO
	Mr P R Cubby	HSO
	Miss J M Fletcher	SO
	Miss L A Jones	RS

Microbes in the aquatic environment

Project Leader	Dr B J Finlay	Grade 6
	Dr R W Pickup	Grade 7
	Mr K J Clarke	SSO
	Dr G H Hall	SSO
	Mr B M Simon	SSO
	Mrs R M Hindle	SO Pt
	Mrs H E H Mallinson	ASO
	Miss K Lawlor	RS
	Dr G Esteban	RF
	Mr J Porter	RS
Culture Collection for Algae and Protozoa	Dr J G Day	SSO
	Miss S Brown	HSO
	Miss M M Deville	SO
	Mrs J Tompkins	AO Pt
	Mrs A Cook	ASO Pt

Physico-chemical processes in catchments

Project Leader	Dr E W Tipping	Grade 6
	Dr P A Carling	Grade 7
	Dr P A Cranwell	Grade 7
	Mr C P Woof	SSO
	Mr M S Glaister	HSO
	Mrs J P Lishman	HSO
	Mr E Rigg	HSO
	Mr L Nolan	SO
	Miss H G Orr	SO
	Mr J B James	ASO
	Mr N Hesketh	RS
	Mr A Kelsey	RS
	Mr J T Smith	RS

River ecosystem processes

Project Leader	Dr M Ladle	Grade 7
	Mr R T Clarke	Grade 7
	Dr F H Dawson	Grade 7
	Dr W A House	Grade 7
	Dr J S Welton	Grade 7
	Mr I S Farr	SSO
	Mr W R C Beaumont	SSO
	Mr P Henville	HSO
	Mrs S M Smith	HSO
	Mr D R Orr	SO

Laboratory services

Windermere Laboratory	Mr F R Ohnstad	SPTO
	Mr M A Rouen	SSO
	Mr P V Allen	HPTO
	Mr M Lee	HSO
	Mr T I Furnass	GO
	Mr B M Godfrey	PTO
	Mr D I Aspinall	PTO
	Mr J Crompton	PTO
	Mr P M Hodgson	PTO
	Mr G Gregson	Ind
	Mrs J Gregson	Ind
	Miss R J Bainbridge	Ind
Library	Mr I Pettman	SLib
	Mr I D McCulloch	ALib
	Miss C M Williams	ALib
	Mrs K Crompton	AO
	Mrs K J Pearson	AO Pt
	Mrs O Jolly	AO Pt

Fritsch Collection of Algal Illustrations

Honorary Curator	Dr J W G Lund*	
	Mrs E G Devlin	ASO Pt
	Mrs E Monaghan	ASO Pt
River Laboratory	Mr D S Cordwell	PTO
	Mr B E Dear	SO
	Miss S Scobie	ALib Pt
	Mr S C Shinn	PGSE
	Mr G A Richards	Ind
	Mrs J Whitmarsh	Ind

Abbreviations:

ALib	Assistant Librarian
AO	Administrative Officer
ASO	Assistant Scientific Officer
EO	Executive Officer
GO	Graphics Officer
HPTO	Higher Professional & Technical Officer
HSO	Higher Scientific Officer
Ind	Industrial
PGSE	Process & General Supervisory E
PSec	Personal Secretary
Pt	Part-time
PTO	Professional & Technical Officer
RF	Research Fellow
RS	Research Student
SB1	Support Band 1
SEO	Senior Executive Officer
SLib	Senior Librarian
SO	Scientific Officer
SPTO	Senior Professional & Technical Officer
SSO	Senior Scientific Officer
Ty	Typist
*	FBA - not IFE establishment

Appendix 3
Project list

Management of lakes and reservoirs

Project T04050-5 at Windermere and Edinburgh Laboratories

Programme TFS4 Water management and hydrological extremes

Leader C S Reynolds

Funding Science budget/commission/miscellaneous consultancies

Objectives To obtain greater resolution and experience in all biological aspects of stored-water quality, including methodology development, tracing physical water movements, chemical recycles and pelagic population dynamics. To develop computational methods for predicting and applying state-of-the-art knowledge to practical problems.

Ecology of large lowland rivers

Project T04052-5 at Eastern Rivers Laboratory

Programme TFS4 Water management and hydrological extremes

Leader L C V Pinder

Funding Science budget/commission

Objectives The broad objectives are to quantify the physical, chemical and biological interactions within large lowland river systems and to develop models that describe these interactions and are capable of predicting the effects of changes in factors such as management and levels of pollution.
Immediate, specific objectives include:-
a) Development of a model of flow relating hydrological and morphological properties of channels in order to predict sedimentation and transport of particulates, dissolved pollutants and dynamics of phytoplankton.
b) Determination of seasonal and spatial patterns of abundance of invertebrates and larval and juvenile cyprinid fish in the Great Ouse and relating these to factors such as channel morphology, vegetation, water velocity, management, recreational pressures and pesticides.
c) Examination of the effects of changes in light climate, due to turbidity, on the growth and development of macrophytes and phytoplankton in the Great Ouse.

Land-river interactions

Project T04053-5 and T04071-5 at River and Windermere Laboratories and ITE

Programme TFS4 Water management and hydrological extremes

Leader J F Wright

Funding Science budget/commission

Objectives This project, which is heavily commissioned, includes strategic and applied research in river management, conservation, the impact of land-use on river biota and environmental impact assessment. The relationship between catchment features/land use and the river biota is being addressed through collaborative work with the Institute of Terrestrial Ecology (ITE) and also through a commission on headwater streams. Current objectives include i) research on river management and pollution assessment which is responsive to the requirements of the National Rivers Authority; ii) studies to provide the statutory nature conservation organisations in Great Britain with information on river biota and techniques for site appraisal; iii) research on the macro-invertebrate assemblages of headwater streams, their contribution to catchment biodiversity and the impact of agricultural inputs; iv) studies on the response of the fauna and flora to reduced flows and habitat loss in a river; v) development of a data-base on the biota and environmental conditions in British rivers to service strategic research and ensure the availability of the data for environmental impact assessments, long- term monitoring, climate change studies.

Microbes in the aquatic environment

Project T10062-5 at Windermere Laboratory

Programme TFS10 Environmental microbiology

Leader B J Finlay

Funding Science budget/commission

Objectives a) To investigate the identity, diversity, distribution and functional role of microbes and microbial processes in aquatic (especially freshwater) environments.
b) The innovative exploitation of aquatic microbes with biotechnological potential, especially algae, protozoa and free-living prokaryotes.

Fish population dynamics and management

Project T11050-5 and T11063-5 at Windermere, Eastern Rivers, Teesdale and River Laboratories

Programme TFS11 Freshwater biology and water quality

Leader J M Elliott

Funding Science budget/commission

Objectives a) To obtain quantitative information on variations in numbers, biomass, growth rates, mortality rates, production rates, movements and feeding of fish and their food organisms in streams, rivers, lakes and reservoirs. To identify the extrinsic and intrinsic factors affecting these variables and to develop mathematical models that can be used to predict quantitative changes in these variables. Particular emphasis is placed on populations of brown trout, pike, perch, charr and the rare coregonids (schelly, vendace).
b) To elucidate the basic physiological and endocrinological changes that occur when fish are subjected to acute and chronic environmental stress, with special emphasis on survival, disease resistance, growth and reproduction. To investigate methods for controlling the stress response by modifying the fish's environment or by selecting, for breeding purposes, fish with low sensitivities to environmental stress.
c) To interpret and apply the results of the above work so that they can be used for the scientific management and conservation of stocks of freshwater fish and their environments, especially in relation to human perturbations such as eutrophication, acidification, changes in land use and changes in climate.

Physico-chemical processes in catchments

Project T11052-5 and 11059-5 at Windermere and River Laboratories

Programme TFS11 Freshwater biology and water quality

Leader E W Tipping

Funding Science budget/commission

Objectives a) To investigate the pathways and transformations of particulate and soluble chemical components in catchments.
b) To improve understanding of the fundamental physical, chemical and biological processes operating in soil waters, rivers and lakes.
c) To develop quantitative models of individual and combined processes.

River ecosystem processes

Project T11053-5 at River and Windermere Laboratories

Programme TFS11 Freshwater biology and water quality

Leader M Ladle

Funding Science budget/commission

Objectives This project includes strategic and applied research into river ecosystem processes. The study area ranges from procedures designed to measure the kinetics of chemical transport processes at the particle/water interface; through physical, chemical and biological investigations designed to improve management and understanding of plant communities in running waters; studies of the environmental impact of management activities including control measures for insect pests such as the Blandford Fly; development of techniques for the determination of runs of migratory salmonid fishes and for the validation of fish counting installations; establishment of the natural patterns of recruitment and resource utilisation by coarse fishes and the solution of problems of classification, identity,distribution and population genetics in a wide range of aquatic organisms.

Assessment and prediction of changes in the aquatic environment

Project T11055-5 and 11060-5 at Windermere, Edinburgh and River Laboratories

Programme TFS11 Freshwater biology and water quality

Leaders A E Bailey-Watts

Funding Science budget/commission

Objectives a) The acquisition of physical, chemical and biological data from diverse aquatic ecosystems with the primary purpose of identifying and quantifying environmental changes associated with man's activities, distinguishing man-made change from natural variations and trends and giving early warning of undesirable effects.
b) To seek a better understanding of organisms and fundamental processes within the aquatic environment and to identify particular variables, processes and aquatic environments which are sensitive to change.
c) To develop qualitative and quantitative models for the assessment and prediction of change in aquatic ecosystems as influenced by catchment perturbation.
d) To apply the knowledge to the mitigation and preferably prevention of problems attributed to cultural eutrophication, acidification and other results of human pressures.

Appendix 4
Publications

Scientific Papers

Bailey-Watts A.E. & Kirika A. 1993
Phytoplankton and controlling factors in the rapidly flushed, upland Loch Dee (Galloway, Scotland). *The Loch Dee Symposium.* (ed. D.J. Tervet & F.M. Lees) p83-96 Foundation for Water Research, Medmenham,

Baroudy E. 1991
Current research on Lake Windermere charr. *Inf.Ser.int.Soc.Arctic Char Fanatics* **No.5** 19-20

Beakes G.W., Canter H.M. & Jaworski G.H.M. 1993
Sporangium differentiation and zoospore fine-structure of the chytrid *Rhizophydium planktonicum*, a fungal parasite of *Asterionella formosa. Mycol.Res.* **97** 1059-1074

Bean C.W. & Winfield I.J. 1992
Influences of the tapeworm *Ligula intestinalis* (L.) on the spatial distributions of juvenile roach *Rutilus rutilus* (L.) and gudgeon *Gobio gobio* (L.) in Lough Neagh, Northern Ireland. *Neth.J.Zool.* **42** 416-429

Berninger U.-G., Wickham S.A. & Finlay B.J. 1993
Trophic coupling within the microbial food web: a study with fine temporal resolution in a eutrophic freshwater ecosystem. *Freshwat.Biol.* **30** 419-432

Beven P. & Carling P. 1992
Velocities, roughness and dispersion in the lowland River Severn. In: *Lowland floodplain rivers: geomorphological perspectives* (ed. P.A.Carling & G.E.Petts) p71-93. Chichester. J.Wiley.

Bickerton M., Petts G., Armitage P. & Castella E. 1993
Assessing the ecological effects of groundwater abstraction on chalk streams: three examples from eastern England. *Regul.Rivers Res.Mgmt* **8** 121-134

Brown S. & De Jonckheere J.F. 1994
Identification and phylogenetic relationships of *Vahlkampfia* spp. (free-living amoebae) by riboprinting. *FEMS Microbiol.Letts* **115** 241-246

Brown S. & Day J.G. 1993
An improved method for the long-term preservation of *Naegleria gruberi. Cryo-Letters* **14** 349-354

Bryant C.L., Farmer J.G., MacKenzie A.B., Bailey-Watts A.E. & Kirika A. 1993.
Distribution and behaviour of radiocaesium in Scottish freshwater loch sediments. *Environmental Geochemistry and Health,* **15** 153-161

Canter H.M. & Dick M.W. 1994
Eurychasmopsis multisecunda gen. et sp.nov., a parasite of the suctorian ciliate *Podophrya. Mycol.Res.* **98** 105-117

Carling P.A., Glaister M.S. & Flintham T.P. 1993
Soil erosion and conservation on land cultivated and drained for afforestation. *Hydrol.Processes* **7** 317-333

Carling P.A. & Petts G.E. (ED.) 1992
Lowland floodplain rivers: geomorphological perspectives. Chichester. John Wiley, 317p.

Casey H., Clarke R.T. & Smith S.M. 1993
Increases in nitrate concentrations in the River Frome (Dorset) catchment related to changes in land use, fertiliser applications and sewage input. *Chemy Ecol.* **8** 105-117

Clarke K.J., Finlay B.J., Vicente E., Llorens H. & Miracle M.R. 1993
The complex life-cycle of a polymorphic prokaryote epibiont of the phytosynthetic bacterium *Chromatium weissei. Archs Microbiol.* **159** 498-505

Copp G.H. & Mann R.H.K. 1993
Comparative growth and diet of tench *Tinca tinca* (L.) larvae and juveniles from river floodplain biotopes in France and England. *Ecol.freshwat.Fish* **2** 58-66

Crisp D.T. 1993
Population densities of juvenile trout (*Salmo trutta*) in five upland streams and their effects upon growth, survival and dispersal. *J.appl.Ecol.* **30** 759-771

Crisp D.T. 1993
The environmental requirements of salmon and trout in fresh water. *Freshwat.Forum* **3** 176-202

Crisp D.T. 1993
The ability of U.K. salmonid alevins to emerge through a sand layer. *J.Fish Biol.* **43** 656-658

Davison W., Hill M., Woof C., Rouen M. & Aspinall D. 1994
Continuous measurement of stream pH. Evaluation of procedures and comparison of resulting hydrogen ion budgets with those from flow-weighted integrating samplers. *Wat.Res.* **28** 161-170

Davison W., Hilton J., Hamilton-Taylor J., Kelly M., Livens F., Rigg E., Carrick T.R. & Singleton D.L. 1993
The transport of Chernobyl-derived radiocaesium through two freshwater lakes in Cumbria, UK. *J.Envir.Radioactivity* **19** 125-153

Day J.G. & Turner M.F. 1992
Algal culture collection and biotechnology. In: *Proceedings of the symposium on culture collection of algae. Tsukuba Feb.15, 1991* (ed. M.Watanabe) p11-27. Tsukuba. National Institute for Environmental Studies.

Elliott J.M. 1993
The pattern of natural mortality throughout the life cycle in contrasting populations of brown trout, *Salmo trutta* L. *Fish.Res.* **17** 123-136

Elliott J.M. 1993
The living stream. *Sherkin Comment* **No.15** p11

Elliott J.M. 1993
The pattern of natural mortality throughout the life cycle in contrasting populations of brown trout, *Salmo trutta* L. *Fish.Res.* **17** 123-136

Elliott J.M. 1993
A 25-year study of production of juvenile sea-trout, *Salmo trutta,* in an English Lake District stream. *Can.spec.Publs Fish aquat.Sci.* **No.118** 109-122

Elliott J.M. 1993
The self-thinning rule applied to juvenile sea-trout *Salmo trutta.* *J.Anim.Ecol.* 62 371-379

Elliott J.M. 1994
Quantitative ecology and the brown trout. Oxford. Oxford Univ.Press, xi + 286pp

Elliott J.M. 1991
Dr.T.T.Macan and his work on Ephemeroptera. **[Obituary]**. In: *Overview and strategies of Ephemeroptera and Plecoptera (Proc. 6th Int.Ephemeroptera Conf. & 10th Int.Symp. Plecoptera, Granada, Spain, July 1989)* (ed. J.Alba- Tercedor & A.Sanchey-Ortega) p585-588. Gainesville. Sandhill Crane Press.

Elliott J.M., Elliott J.A. & Hilton J. 1993
Sources of variation in post-Chernobyl radiocaesium in brown trout, *Salmo trutta* L., and Arctic charr, *Salvelinus alpinus* (L.), from six Cumbrian lakes (northwest England). *Annls.Limnol.* **29** 79-98

Elliott J.M., Tullett P.A. & Elliott J.A. 1993
A new bibliography of samplers for freshwater benthic invertebrates. *Occ.Publs Freshwat.biol.Ass.* **No.30** 92p.

Embley T.M. & Finlay B.J. 1994
The use of small subunit rRNA sequences to unravel the relationships between anaerobic ciliates and their methanogen endosymbionts. *Microbiology* **140** 225-235

Esteban G., Finlay B.J. & Embley T.M. 1993
New species double the diversity of anaerobic ciliates in a Spanish lake. *FEMS Microbiol.Letts* **109** 93-100

Esteban G., Guhl B.E., Clarke K.J., Embley T.M. & Finlay B.J. 1993
Cyclidium porcatum n.sp.: a free-living anaerobic scuticociliate containing a stable complex of hydrogenosomes, eubacteria and archaeobacteria. *Eur.J.Protistol.* **29** 262-270

Finlay B.J. 1993
Behavior and bioenergetics of anaerobic and microaerobic protists. In: *Handbook of methods in aquatic microbial ecology* (ed. P.F.Kemp, B.F. Sherr, E.B.Sherr & J.J.Cole) p59-66. Boca Raton. Lewis.

Finlay B.J., Esteban G. & Embley M. 1993
The hidden diversity of anaerobic microbes. *NERC News* **No.25** 4-6

Finlay B.J., Tellez C. & Esteban G. 1993
Diversity of free-living ciliates in the sandy sediment of a Spanish stream in winter. *J.gen.Microbiol.* **139** 2855-2863

Flintham T.P. & Carling P.A. 1993
Design of stable drainage networks in upland forestry plantations. *Hydrol.Processes* **7** 335-347

George D.G. 1993
Impacts of the mild winters of 1988/89 and 1989/90. Impacts on freshwater systems. In: *Impacts of the mild winters and hot summers in the United Kingdom in 1988-1990* (ed. M.G.R.Cannell & C.E.R.Pitcairn) p47-53. London. H.M.S.O.

George D.G. 1993
Physical and chemical scales of pattern in freshwater lakes and reservoirs. *Sci.Total Envir.* **135** 1-15

George D.G., Emmett B.A. & Reynolds N. 1993
Impacts of the hot summers of 1989 and 1990. Impacts on freshwater ecosystems. In: *Impacts of the mild winters and hot summers in the United Kingdom in 1988-1990* (ed. M.G.R.Cannell & C.E.R.Pitcairn) p119-126. London. H.M.S.O.

George D.G. & Winfield I.J. 1993
Factors influencing the vertical and horizontal distribution of fish in Loch Ness. **[Abstract]** *J.Fish Biol.* **43** 330-331

Gledhill T., Sutcliffe D.W. & Williams W.D. 1993
British freshwater Crustacea Malacostraca: a key with ecological notes. *Scient.Publs freshwat.biol.Ass.* **No.52** 176p

Golterman H.L., Burgis M.J., Lemoalle J. & Talling J.F. 1993
Ecological characteristics of tropical fresh waters: an outline. In: *Hydrology and water management in the humid tropics* (ed. M.Bonell, M.M.Hufschmidt & J.S.Gladwell) p367-391. Cambridge. University Press & UNESCO.

Gray A.J., Moy I.L., Warman E.A., Dawson F.H. & Henville P. 1993
Tidal regimes and salt marshes - the River Hamble analogue. *Report, ETSU* **T/04/00195/Rep** 27p

Hammar J., Chernitsky A.G., Baroudy E., DeCiccio A.L., Greer R.B., Johnson L., Kircheis F.W., Maximov V.A., Nyman L., *et al* 1991
Collective sampling the ISACF way: biological, genetic and environmental observations of a landlocked population of Arctic char sampled with style in north-east Kola Peninsula, Soviet Union. *Inf.Ser.int.Soc.Arctic Char Fanatics* **No.5** 7-12

Haworth E.Y. 1993
The responses of aquatic biota and their use as indicator organisms. In: *Biological indicators of global change* (ed., J.J.Symoens, P.Devos, J.Rammeloo & C.Verstraeten) P115-127. Brussels. Royal Academy of Overseas Sciences.

Haworth E.Y. & Sabater S. 1993
A new Miocene *Aulacoseira* species in diatomite from the ancient lake in La Cerdanya (NE Spain). In: *Progress in diatom studies - contributions to taxonomy, ecology and nomenclature* (ed. P.A.Sims) p227-242. Berlin. J.Cramer.

Haworth E.Y. & Tyler P.A. 1993
Morphology and taxonomy of *Cyclotella tasmanica* spec.nov., a newly described diatom from Tasmanian lakes. *Hydrobiologia* **269/270** 49-56

Hearne J.W. & Armitage P.D. 1993
Implications of the annual macrophyte growth cycle on habitat in rivers. *Regul.Rivers Res.Mgmt* **8** 313-322

Jakubowski H., Mann R.H.K. & Penczak T. 1988
Changes in the ichthyofauna of the Widawka River from 1963 to 1982. **[Pl.e.]** *Acta Univ.Lodz.Folia limnol.* **No.3** 67-83

Jones J.G. 1993
Recent advances in freshwater ecology. In: *Conferencias de Limnologia* (ed. A.Boltovskoy & H.L.Lopez) p159-169. La Plata. Instituto de Limnologia "Dr.Raul A.Ringuelet".

Jones J.G. 1993
The Freshwater Biological Association (FBA) and the Institute of Freshwater Ecology (IFE). *Eur.Wat.Pollut.Control* **3** 45-49

Kadiri M.O. & Reynolds C.S. 1993
Long-term monitoring of the conditions of lakes: the example of the English Lake District. *Arch.Hydrobiol.* **129** 157-178

Kipling C. 1991
The chars in English books. *Inf.Ser.int.Soc.Arctic Char Fanatics* **No.5** 95-96

Le Cren E.D. 1993
The FBA 1943-1983: a personal commentary. *Freshwat.Forum* **3** 85-96

Maberly S.C., Hurley M.A., Butterwick C., Corry J.E., Heaney S.I., Irish A.E., Jaworski G.H.M., Lund J.W.G., Reynolds C.S. & Roscoe J.V. 1994
The rise and fall of *Asterionella formosa* in the south basin of Windermere: analysis of a 45-year series of data. *Freshwat.Biol.* **31** 19-34

Maitland P.S. & Lyle A.A. 1993
Freshwater fish conservation in the British Isles. *Br.Wildl.* **5** 8-15

Malmqvist B., Nilsson A.N., Baez M., Armitage P.D. & Blackburn J. 1993
Stream macroinvertebrate communities in the island of Tenerife. *Arch.Hydrobiol.* **128** 209-235

Marker A.F.H., Butterwick C. & Garbutt R.A. 1994
Special topic focus - a pilot study of the phytoplankton of rivers in the Humber catchment. *LOIS* **No.1** p9

May L., Bailey-Watts A.E. & Kirika A. 1993
The ecology of *Synchaeta kitina* Rousselet in Loch Leven, Scotland. *Hydrobiologia* **255/256** 305-315

Morgan J.A.W. & Pickup R.W. 1993
Activity of microbial peptidases, oxidases, and esterases in lake waters of varying trophic status. *Can.J.Microbiol.* **39** 795-803

Morgan J.A.W., Rhodes G. & Pickup R.W. 1993
Survival of nonculturable *Aeromonas salmonicida* in lake water. *Appl.envir.Microbiol.* **59** 874-880

Ojala A. 1993
In situ diel DNA synthesis of a *Cryptomonas* sp. in a hypereutrophic tarn. *Annls bot.fenn.* **30** 119-129

Penczak T. & Mann R.H.K. 1993
A preliminary evaluation of the effect of human activity on the fish populations of the Pilica River, central Poland. *Polskie Archwm Hydrobiol.* **40** 101-115

Petts G., Armitage P. & Castella E. 1993
Physical habitat changes and macroinvertebrate response to river regulation: the River Rede, UK. *Regul.Rivers Res.Mgmt* **8** 167-178

Pickering A.D. 1993
Growth and stress in fish production. *Aquaculture* **111** 51-63

Pickering A.D. 1993
Endocrine-induced pathology in stressed salmonid fish. *Fish.Res.* **17** 35-50

Pickup R.W. 1991
Detection and study of microorganisms in the environment - new approaches. *Biotech.Forum Eur.* **8** 499-503

Pickup R.W. 1991
Diversity and distribution of hydrocarbon degrading bacteria in the aquatic environment: a genetical approach. In: *International symposium: environmental biotechnology 22-25 April 1991 Oostende* p11-20. Belgium. Royal Flemish Society of Engineers.

Porter J., Edwards C., Morgan J.A.W. & Pickup R.W. 1993
Rapid, automated separation of specific bacteria from lake water and sewage by flow cytometry and cell sorting. *Appl.envir.Microbiol.* **59** 3327- 3333

Pottinger T.G. & Moran T.A. 1993
Differences in plasma cortisol and cortisone dynamics during stress in two strains of rainbow trout (*Oncorhynchus mykiss*). *J.Fish Biol.* **43** 121-130

Pottinger T.G., Moran T.A. & Morgan J.A.W. 1994
Primary and secondary indices of stress in the progeny of rainbow trout (*Oncorhynchus mykiss*) selected for high and low responsiveness to stress. *J.Fish Biol.* **44** 149-163

Rand-Weaver M., Pottinger T.G. & Sumpter J.P. 1993
Plasma somatolactin concentrations in salmonid fish are elevated by stress. *J.Endocr.* **138** 509-515

Reynolds C.S. 1993
Swings and roundabouts: engineering the environment of algal growth. In: *Urban waterside regeneration: problems and prospects* (ed. K.N.White, E.G.Bellinger, A.J.Saul, M.Symes & K.Hendry) p330-349. Chichester. Ellis Horwood Ltd.

Reynolds C.S. 1993
The ecosystems approach to water management. The main features of the ecosystems concept. *J.aquat.Ecosyst.Hlth* **2** 3-8

Reynolds C.S. & Glaister M.S. 1993
Spatial and temporal changes in phytoplankton abundance in the upper and middle reaches of the River Severn. *Arch.Hydrobiol.Suppl.* **101** 1-22

Roberts R.J., Willoughby L.G. & Chinabut S. 1993
Mycotic aspects of epizootic ulcerative syndrome (EUS) of Asian fishes. *J.Fish Dis.* **16** 169-183

Spezzano P., Hilton J., Lishman J.P. & Carrick T.R. 1993
The variability of Chernobyl Cs retention in the water column of lakes in the English Lake District, two years and four years after deposition. *J.envir.Radioact.* **19** 213-232

Sutcliffe D.W. 1993
Reproduction in Gammarus (Crustacea, Amphipoda): male strategies. *Freshwat.Forum* **3** 97-109

Sutcliffe D.W. 1992
Reproduction in Gammarus (Crustacea, Amphipoda): basic processes. *Freshwat.Forum* **2** 102-128

Sutcliffe D.W. 1993
Reproduction in Gammarus (Crustacea, Amphipoda): female strategies. *Freshwat.Forum* **3** 26-64

Talling J.F. 1993
Comparative seasonal changes, and inter-annual variability and stability, in a 26-year record of total phytoplankton biomass in four English lake basins. *Hydrobiologia* **268** 65-98

Talling J.F. 1993
Environmental regulation in African shallow lakes and wetlands. *Revue Hydrobiol.trop.* **25** 87-144

Tipping E. 1993
Modelling the binding of europium and the actinides by humic substances. *Radiochim.Acta* **62** 141-152

Tipping E. 1993
Modelling of cation binding by natural organic matter in soils and waters. *Analyt.Proc.* **30** 186-189

Tipping E. 1993
Modelling ion binding by humic acids. *Colloid.Surf.(A)* **73** 117-131

Tipping E., Thompson D.W., Woof C. & Longworth G. 1993
Transport of haematite and silica colloids through sand columns eluted with artificial groundwaters. *Envir.Technol.* 14 367-372

Tipping E., Woof C. & Clarke K. 1993
Deposition and resuspension of fine particles in a riverine 'dead zone'. *Hydrol.Processes* **7** 263-277

Valairatana W. & Willoughby L.G. 1993
Spore assay of *Achlya* (Fungi, Phycomycetes) from a fish pond; apparently demonstrating strains of the genus with widely differing growth rates. *AAHRI Newsl.* **2** 1-2

Venugopal M.N. & Winfield I.J. 1993
The distribution of juvenile fishes in a hypereutrophic pond: can macrophytes offer a refuge for zooplankton? **[Abstract]** *J.Fish Biol.* **43** 329- 330

Venugopal M.N. & Winfield I.J. 1993
The distribution of juvenile fishes in a hypereutrophic pond: can macrophytes potentially offer a refuge for zooplankton? *J.freshwat.Ecol.* **8** 389-396

Welton J.S. & Ladle M. 1993
The experimental treatment of the blackfly, *Simulium posticatum* in the Dorset Stour using the biologically produced insecticide *Bacillus thuringiensis* var.*israelensis. J.appl.Ecol.* **30** 772-782

Willoughby L.G. 1993
A new destructive disease (Epizootic Ulcerative Syndrome) of freshwater fishes in southeast Asia. *Freshwat.Forum* **3** 110-121

Winfield I. 1993
Desperately seeking schelly. *Aquarist Pondkpr.* **58** 96-98

Winfield I.J., Fletcher J.M. & Cubby P.R. 1993
Confirmation of the presence of schelly, *Coregonus lavaretus*, in Brotherswater, U.K. *J.Fish Biol.* **42** 621-622

Winfield I.J., Tobin C.M. & Montgomery C.R. 1993
The fish of Lough Neagh, part E: ecological studies of the fish community. In: *Lough Neagh: the ecology of a multipurpose water resource* (ed. R.B.Wood and R.V.Smith) p451-471. Dordrecht. Kluwer.

Winstanley C., Carter J.P., Seasman M., Morgan J.A.W., Pickup R.W. & Saunders J.R. 1993
A comparison of the survival of stable and unstable chromosomally located xylE marker cassettes as an indicator of cell division within populations of *Pseudomonas putida* released into lake water and soil. *Microb.Releases* **2** 97-107

Wotton R.S., Armitage P.D., Aston K., Blackburn J.H., Hamburger M. & Woodward C.A. 1993
Colonization and emergence of midges (Chironomidae: Diptera) in slow sand filter beds. *Neth.J.aquat.Ecol.* **26** 331-339

Wright J.F., Furse M.T. & Armitage P.D. 1993
RIVPACS - a technique for evaluating the biological quality of rivers in the U.K. *Eur.Wat.Pollut.Control.* **3** 15-25

Wright J.F., Furse M.T., Armitage P.D. & Moss D. 1993
New procedures for identifying running-water sites subject to environmetnal stress and for evaluating sites for conservation, based on the macroinvertebrate fauna. *Arch.Hydrobiol.* **127** 319-326

Young J.M., Jones R.I. & Bailey-Watts A.E. 1993
Studies of the plankton of Loch Ness, Scotland. 1. Phytoplankton. **[Abstract]** *Verh.int.Verein.theor.angew.Limnol.* **25** p458

Contract reports

Armitage, PD and Gunn, RJM. 1993. *Channel Tunnel. Stream survey and assessment in the Folkestone area - Spring 1993.* 22p. Transmanche Link.

Armitage, PD, Pardo, I, Dawson, FH, Henville, P and Smith, SM. 1993. *Freshwater biological monitoring of the Furzebrook Stream.* 27p. BP Exploration Operating Ltd.

Bailey-Watts, AE, Gunn, IDM, and Kirika, A. 1993. *Loch Levan: past and current water quality and options for change. Final Report.* 24 p, 10 figures. Forth River Purification Board.

Bailey-Watts, AE, Lyle, AA, Kirika, A and Gunn, IDM. 1993. *Sensitivity of lentic waters. Final report.* ii + 24p., 8 figures, 3 tables. Scottish Office, Environment Department.

Bass, JAB and Leach, DV. 1993. *Water quality monitoring on the Rivacre Brook. Final report.* 64p. British Nuclear Fuels plc, Capenhurst.

Beaumont, WRC, Dear, BE and Ladle, M. 1993. *The efficacy of manual gravel cleaning as a means of improving salmonid spawning gravels. Report on year 2 (1992/93).* 9p + 7 tables, 20 figures, 1 appendix. Ministry of Agriculture, Fisheries and Food.

Beaumont, WRC, Ladle, M and Dear, BE. 1993. *An investigation of salmon spawning gravels in the Wessex region.* 21p, maps, photographs, figures, appendix. National Rivers Authority Wessex Region.

Carling, PA and Glaister, MS. 1994. *Conservation of Scottish forestry soil (first interim report).* 9p. Scottish Forestry Trust.

Cranwell, PA, Jones, JG and Simon, BM. 1993. *Studies on Villa Farm liquid waste disposal site. Final report for the period 1 January 1993 to 30 September 1993.* 29p. BOC Foundation.

Crisp, DT. 1994. *The ecology of young stages of salmonid fish and the implications for practical river management. Final report for the period 1 April 1991 to 31 March 1994.* 24p. Ministry of Agriculture, Fisheries and Food.

Crisp, DT. 1994. *Llyn Brianne hydro power scheme - possible effects of predicted water temperature changes upon salmonid fishes.* 15p, 8 tables, 2 appendices. Wallace Evans.

Crisp, DT and Beaumont, WRC. 1994. *Observations on the size and sex ratios of spawning trout in the Afon Cwm, mid-Wales, in November 1993.* 8p, 4 tables, 1 figure. Ministry of Agriculture, Fisheries and Food.

Dawson, FH. 1992. *Aquatic plant control in Egypt: report of visit to assess the potential for environmentally-sound weed management regimes for irrigation and drainage channels, Sept 26 - Oct 11 1991.* 156p. Hydraulics Research Ltd.

Dawson, FH. 1993. *A meeting on the future of EC R&D policy.* ca. 300p. Dr D.Coates, TFSD Marketing Manager.

Dawson, FH. 1993. *Visit to the Czech Republic. EWRS International workshop on plant invasions at Kostelec nad Cernymi lesy, field trip to the north of the Czech Republic and visit to the AS CR Institute of Botany at Trebon, south Bohemia.* 89p. British Council, Prague.

Dawson, FH, Ladle, M and Smith, SM. 1993. *A1(M) widening junctions 6 to 8 - River Mimram aquatic survey.* 29p. Travers Morgan Environment.

Dawson, FH, Welton, JS, Smith, SM and Henville, P. 1993. *M25 improvements junctions 12-15: freshwater ecological reconnaissance surveys.* 60p. Chris Blandford Associates for Department of Transport.

Day, JG. 1994. *Production of Pythium oligandrum using an optimised single-phase protocol.* 14p. W.H.Knights and Sons (Dr M.R. Groom).

Dobson, JH, Noble, L and Pettman, I. 1993. *Study of the enviromental fate of chemical substances which have a major application as active ingredients in pharmaceutical preperations. (Final report).* 33p. Joint Research Centre.

Elliott, JM. 1994. *Management and ecology of Arctic charr populations in Windermere.* 28p, 6 figures. National Rivers Authority North West Region.

Furse, MT, Grieve, NJ, Gunn, RJM, Symes, KL, Winder, JM and Blackburn, JH. 1993. *The faunal richness of headwater streams. Progress report for the period October 1993 - December 1993.* 5p. National Rivers Authority.

Furse, MT, Winder, JM, Symes, KL, Grieve, NJ and Gunn, RJM. 1993. *The faunal richness of headwater streams. Progress report for the period July 1993 - September 1993.* 15p. National Rivers Authority.

Furse, MT, Winder, JM, Symes, KL, Grieve, NJ, Gunn, RJM and Clarke, RT. 1993. *The faunal richness of headwater streams. Progress report for the period April 1993 - June 1993.* 12p. National Rivers Authority.

Furse, MT, Winder, JM, Symes, KL, Clarke, RT, Gunn, RJM, Blackburn, JH and Fuller, RM. 1993. *The faunal richness of headwater streams. Stage 2 - catchment studies. Volume 1. Main report.* 126p. National Rivers Authority.

Furse, MT, Winder, JM, Symes, KL, Clarke, RT, Gunn, RJM, Blackburn, JH and Fuller, RM. 1993. *The faunal richness of headwater streams. Stage 2 - catchment studies. Volume 2. Appendices.* 184p. National Rivers Authority.

George, DG, Winfield, IJ and Jones, JG. 1994. *A preliminary study of the vertical and horizontal distributions of zooplankton and fish in Loch Ness, U.K.* 16p, 6 figures. Scottish Natural Heritage.

Glaister, MS, Carling, PA and Orr, HG. 1992. *Gravel bed composition and structure: River Leven, Strathclyde, Scotland.* Crouch, Hogg, Waterman, Consulting Civil Engineers.

Gunn, IDM, May, L and Bailey-Watts, AE. 1994. *Analysis of 1993 Loch Leven crustacean zooplankton samples.* 13p, 6 figures. Scottish Natural Heritage.

Hartley, SE and Pickering, AD. 1994. *Genetic differentiation between Atlantic salmon populations in the Windermere catchment.* 28p, 1 appendix. National Rivers Authority North West Region.

Haworth, EY, Gunn, IDM, Cubby, PR and Carlos, R. 1994. *Survey and management proposals for the "lawn pool", Moccas Park National Nature Reserve in Herefordshire.* 28p, 6 appendices. English Nature.

Hilton, J, May, L and Bailey-Watts, AE. 1993. *Bassenthwaite Lake: an assessment of the effects of phosphorus reduction at the Keswick STW on the seasonal changes in nutrients and phytoplankton, using a dynamic model.* 42p 6 tables, 17 figures. National Rivers Authority North West Region.

Jaworski, GHM, Reynolds, CS, Hall, GH, Butterwick, C, Cranwell, PA, Cubby, PR, James, B, Lishman, JP, Maberly, SC, Parker, JE, Rigg, E and Roscoe, JV. 1994. *Water quality of the lakes of the Windermere catchment. Interim report.* 14p, 7 figures. National Rivers Authority North West Region.

Kelsey, A and Carling, PA. 1993. *Advanced numerical modelling of fluvial dunes: a review.* 36p. Bundesanstalt fur Gewasserkunde.

Ladle, M. 1993. *Meon and Hamble low flow investigations.* 15p. Mott MacDonald.

Ladle, M and Dawson, FH. 1993. *Flow regime requirements River Darent.* 38p, 3 figures. Institute of Hydrology.

Lyle, AA and Bailey-Watts, AE. 1993. *Contributions to the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) programme on eutrophication risk assessment: I. Effects of light attenuation by humic colouring and turbidity on chlorophyll production. II. Factors controlling lake stratification. Final report to the Water Research Centre.* 45p, 8 figures. Water Research Centre.

Maberly, SC, Jaworski, GHM, Clarke, KJ and Parker, JE. 1994. *The physiological control of blue-green algae by carbon dioxide.* 31p. The BOC Foundation.

Marker, AFH, Butterwick, C and Garbutt, RA. 1993. *A short pilot study of the phytoplankton of rivers of the Humber catchment.* 50p. RACS(r), LOIS special topic committee and NERC grants committee.

May, L and Bailey-Watts, AE. 1993. *Bassenthwaite Lake: an assessment of the effects of phosphorus reduction at the Keswick STW on the seasonal changes in nutrients and phytoplankton, using a dynamic model.* 42p, 17 figures. National Rivers Authority North West Region.

Noble, L, Jolly, I, Bethel, A and Pettman, I. 1993. *Editorial revision of ECDIN ecotoxicological files (final report).* 31p. Joint Research Centre.

Reynolds, CS, Cranwell, PA, Cubby, PR, Davies, PS, Haworth, EY, Irish, AE, James, B, Jaworski, GHM, Maberly, SC, Lishman, JP, Parker, JE, Rigg, E and Roscoe, JV. 1994. *The restoration of Windermere by the reduction of phosphorus loading. Second interim report.* 12p, 1 table, 14 figures. North West Water.

Welton, JS, Beaumont, WRC, Dear, BE and Ladle, M. 1994. *Quality control report on fish ageing in Sussex area of NRA (Southern Region).* 3p, 2 tables. National Rivers Authority Southern Region.

Welton, JS, Beaumont, WRC and Dear, BE. 1993. *The status of Atlantic salmon (Salmo salar L.) in the River Frome, Dorset.* 36p. Ministry of Agriculture, Fisheries and Food.

Welton, JS, Dear, BE, Beaumont, WRC and Pinder, AC. 1993. *1993 survey of the coarse fish of the River Tees before construction of the barrage. Progress report.* 75p. National Rivers Authority Northumbrian Region.

Welton, JS, Dear, BE, Beaumont, WRC, Pinder, AC, Crisp, DT and Ladle, M. 1994. *1993 survey of the coarse fish of the River Tees before construction of the barrage. Interim report.* 96p. National Rivers Authority Northumbrian Region.

Welton, JS and Ladle, M. 1993. *An experimental treatment of Simulium posticatum with Bti at selected sites on the River Stour, Dorset, 1993.* 41p. North Dorset District Council.

Winfield, IJ. 1993. *Ecology of the vendace, Coregonus albula, in Bassenthwaite Lake. Progress report for period April 1993 - September 1993.* 9p, 3 figures. North West Water.

Winfield, IJ. 1993. *Ecology of the schelly, Coregonus lavaretus, in Haweswater. Progress report for the period April 1993 - September 1993.* 13p, 6 figures. North West Water.

Winfield, IJ, Fletcher, JM and Cubby, PR. 1994. *Ecology of the vendace, Coregonus albula, in Bassenthwaite Lake.* 62p, tables, figures. North West Water.

Winfield, IJ, Fletcher, JM and Cubby, PR. 1993. *Status of rare fish. Draft final report.* 92p, tables, figures. National Rivers Authority.

Wright, JF, Armitage, PD, Clarke, RT, Winder, JM and Symes, KL. 1993. *An investigation of the relationship between the aquatic plant and animal communities of rivers. Report for the period April 1992 to March 1993.* 129p. Scottish Natural Heritage.

Wright, JF, Clarke, RT and Blackburn, JH. 1993. *Macroinvertebrates in lowland rivers in summer. A guide to macroinvertebrate-habitat associations.* 107p. Scottish Natural Heritage.

Wright, JF, Gunn, RJM, Blackburn, JH, Winder, JM and Symes, KL. 1993. *Enhancement of RIVPACS for biological assessment of the quality of Scottish rivers. A progress report for the period November 1992 to October 1993.* 6p. The Scottish Office, Environment Department.

Wright, JF, Gunn, RJM, Blackburn, JH, Winder, JM, Symes, KL, Grieve, NJ, Furse, MT, Clarke, RT and Moss, D. 1993. *Testing and further development of RIVPACS (phase 2). Progress report for the period April 1993-June 1993.* 17p. National Rivers Authority.

Wright, JF, Moss, D, Gunn, RJM, Blackburn, JH, Winder, JM, Symes, KL, Grieve, NJ, Furse, MT and Clarke, RT. 1994. *Testing and further development of RIVPACS (phase 2). Progress report for the period July 1993-December 1993.* 21p. National Rivers Authority.

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