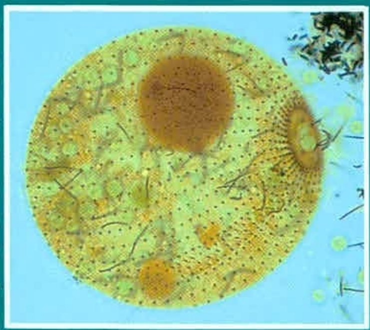

Institute of
Freshwater
Ecology

Annual Report 1994-95

Natural Environment Research Council

Foreword

The terrestrial and freshwater sciences are a diverse and complex area covering a wide range of scales in space and time. There is also a strong interaction between them and the economic and social sciences, industry and commerce. It is increasingly recognised that many of the long standing and the newly emerging environmental issues require a multi-disciplinary integrated research for their resolution. The 1993 White Paper "Realising our Potential - a Strategy for Science, Engineering and Technology", reaffirmed the NERC as the lead body for research, survey and training in the environmental sciences and provided the NERC with a new Charter. To meet its aims Professor John Krebs, the Chief Executive, working with the Council, restructured the NERC. A major element of this was the regrouping within the **Centre for Ecology and Hydrology** of the

Institute of Freshwater Ecology (IFE)
Institute of Hydrology (IH)
Institute of Terrestrial Ecology (ITE) and the
Institute of Virology and Environmental Microbiology (IVEM).

The combined activities of the Institutes cover the full range of terrestrial and freshwater sciences and this must give CEH internationally one of the strongest capabilities for holistic research, environmental monitoring and as a data resource. The CEH outreach is extensive. The two figures in Appendix 2 to this Report show the location of the principal CEH Institute stations in the UK and in those overseas countries in which CEH scientists are, or have been recently, active.

This Annual Report from the **Institute of Freshwater Ecology** describes a selection of the scientific research and monitoring that has taken place during the course of the year. It is clear from the Report that under the directorship of Professor Alan Pickering that IFE science is flourishing and I commend the Report to you.

I would also take this opportunity to draw your attention to the complementary Annual Reports for 1994/95 from the other CEH Institutes and to the CEH overview report.

Brian Wilkinson
Director
Centre for Ecology and Hydrology

Front Cover Illustrations:
Large photograph - *Windermere, Cumbria*
Small photographs - *Prototype Automatic Water Quality Monitoring Station developed under the EU LIFE programme.*
- Prorodon viridis, *a freshwater ciliated protozoon (0.1 mm) showing its mouth and symbiotic algae.*
- *Freshwater shrimp, a good indicator of water quality.*
- *Industrial activity can be detrimental to water courses.*

Report of the Institute of Freshwater Ecology 1994-95

Natural Environment Research Council

Institute of Freshwater Ecology Mission Statement

The Institute's mission is:-

"To conduct research of the highest quality and to develop integrated theory for the science of fresh and estuarine waters. This research will be conducted at the species, population, community and ecosystem levels and will include investigations of the genetic, physiological and behavioural mechanisms by which organisms interact with their environment. Research will also be undertaken into the biological, chemical and physical components and processes which control aquatic ecosystems, especially the mechanisms of response to natural and anthropogenic change. The Institute will study the dynamics of interactions between terrestrial and freshwater ecosystems, and the control of the chemical composition and physical structure of water bodies and their retention and transport of soluble and particulate material. The information gained will be used to develop strategies for the sustainable management, conservation and exploitation of freshwater systems at national and global levels.

The Institute will also collect, validate and manage relevant environmental data in the furtherance of its research programme and will act as an international resource of expertise and information. It will continue to develop its programme for long-term, multidisciplinary research, undertake commissioned research on behalf of its customer base, provide training of the highest quality and maintain its international reputation. The Institute of Freshwater Ecology will collaborate with the component Institutes of the Centre for Ecology and Hydrology, the Freshwater Biological Association and other organisations to ensure achievement of these aims."

Contents

Director's Introduction

Professor Alan Pickering
Acting Director Sept. 1993 – July 1995
Director August 1995 onwards

In the previous Annual Report I highlighted some of the changes in the way UK science is funded and administered. The rate of change has, if anything, increased in 1994/95. With the White Paper "Realising Our Potential" forming the backbone of the Government's strategy on science, engineering and technology, the Technology Foresight Initiative has attempted to identify those areas of research considered most likely to deliver the declared objectives of wealth creation (by increasing the UK's competitiveness) and improving the quality of life. Associated with this Initiative is the provision of new monies within the Foresight Initiative Challenge Fund. Research at the IFE falls within several areas identified by NERC as appropriate for support and development (including the management of freshwater resources) and, therefore, this new fund must be viewed as an opportunity for the Institute.

The Office of Science and Technology Scrutiny of Public Sector Research Establishments (including the NERC Institutes) reported its findings and recommendations during 1994/95. Whilst some of these have been accepted, the Government decided not to proceed with the particular proposals concerning possible regrouping of organisations on a geographical or a broad subject area basis. It is likely that aspects of this exercise will be revisited in the coming year. A further OST review, under the chairmanship of Professor Roger Whittenbury CBE, considered the role of the Culture Collection of Algae and Protozoa as part of a wider exercise involving all major UK microbial culture collections. The review group was impressed with the work of the two curators (at IFE and DML) and the final report concluded that CCAP, a unique biodiversity resource, was "in safe hands". We await with interest the OST's response to this report and to the implementation of its findings.

At the time of writing this Introduction, it has just been announced that OST will be transferred from the Office of Public Service and Science, Cabinet Office to the Department of Trade and Industry in order to "allow the Government's policy on science, engineering and technology to be developed alongside its policies on industry, and with due regard to the contribution of science, engineering and technology to long term wealth creation". It remains to be seen how this new change in circumstance will influence the management and funding of environmental research.

Turning now to the Research Councils per se, the NERC is also undergoing a major restructuring exercise with rationalisation of staff at several levels. An important part of the NERC restructuring has been the creation of the Centre for Ecology and Hydrology (see Appendix 2) for details). Professor W B Wilkinson has been confirmed as the Centre's first Director, with Professor T M Roberts as Deputy Director and Mr P Williams as Head of Administration. The creation of this new Centre is a very positive move which will undoubtedly facilitate closer cooperation between its component Institutes (IFE, IH, ITE and IVEM). The first results of this enhanced collaboration will be seen within the next year or so as new research programmes come to fruition. The IFE has just initiated joint research programmes with ITE on the microbial basis of methane oxidation in soils and on modelling the chemical availability of radionuclides in upland organic soils, with ITE and IH on upland forest canopy closure and its significance for chemistry, ecology and hydrology, and with IVEM and ITE on the role of microbial diversity in regulating ecosystem function. A complementary part of the restructuring within NERC is the introduction of a New Funding Model. The exact details are still to be finalised but there is no doubt that the model will have important implications for the way in which research institutes, such as the IFE, will be funded in the future. The IFE has maintained its very close working relationship and co-location (at Windermere and Wareham) with the Freshwater Biological Association (see Appendix 3 for further details).

As part of a programme designed to provide greater scientific leadership within the Institute and to improve the efficiency of our business, I have restructured the scientific staff into four Divisions, each led by a senior scientist (Grade 6). Cross-divisional collaboration is encouraged during regular (bi-monthly) meetings of the Divisional Heads with the Director and between-site collaboration is ensured by basing the divisional structure on a broad subject area which cuts across geographical location within the Institute. Further details of the new IFE divisional structure can be found in Appendix 6.

Against this background of change, and particularly those changes originating from the UK Government, it is almost inevitable that some of our "users" have found their own research budgets to be the subject of scrutiny and this has led to a particularly harsh financial climate for the funding of freshwater ecology during 1994/95. It is to the credit of IFE staff that commissioned receipts for 1994/95 exceeded £1.5 million. 1995/96 is likely to be more difficult and the Institute will have to exercise all it's ingenuity and innovation if it is to meet it's financial targets. I am confident that the staff will accept this challenge with the character and resilience they have shown in recent months and I am grateful for their continued support.

This Annual Report is a brief synopsis of aspects of the Institute's work during 1994/95 and bears testimony to the excellence of our science and the high quality of staff at all levels within the organisation. The award of the 1994 Ecology Institute Prize to Dr Colin S Reynolds for his outstanding contribution to limnology is, of course, a fitting tribute in recognition of his role in advancing our understanding of the ecology of lakes and reservoirs and in developing process-based, predictive models for the management of such systems, but it is also an award of which all members of the IFE should be justifiably proud because the working environment in which Colin has been able to develop his ideas is only as good as the staff that surround and support him.

The update to NERC's Corporate Plan identifies six key environmental issues which act as a focus for it's programme of basic and strategic science. This Annual Report is structured in such a way as to map the IFE research programme on to these issues and examples are given of our progress and success in these areas.

NERC Issue	Examples of IFE Research
Sustainable management	♦ commercially-exploited fish populations (salmon, eel, charr) ♦ river habitat survey and management
Understanding and protecting biodiversity	♦ microbial diversity and ecosystem function ♦ Culture Collection of Algae and Protozoa ♦ macroinvertebrates and RIVPACS III ♦ fish diversity and conservation
Waste management and bioremediation	♦ remediation of Seathwaite Tarn, an acid lake ♦ treatment of oil-contaminated beach materials
Environmental pollution	♦ statistical appraisal of the Harmonized Monitoring Scheme ♦ eutrophication of Bassenthwaite Lake ♦ metal particle interaction in rivers ♦ modelling upland water chemistry
Environmental risks and hazards	♦ stress and ecotoxicity in fish ♦ impacts of intensive fish stocking ♦ environmental risks of major engineering projects
Global change	♦ temperature and trout growth/ survival ♦ CO_2 and inorganic carbon utilization by algae

Of necessity, the detail contained in this Report is very limited but it does give an indication of the breadth of our portfolio. Further information can be readily obtained from the 119 research papers published during the year (Appendix 8) although it must also be emphasised that another extremely important component of our output is the 93 commissioned research reports (Appendix 8) to our broad customer base.

Finally, I would like to emphasise the point that the scientific progress so clearly illustrated in this Annual Report not only confirms the excellence of IFE science, but it also highlights the value of extensive, long-term data sets. Collectively, the IFE and FBA have developed this national resource. The format of the data ranges from fully-interactive, validated, computer data-bases to paper records of various types and, indeed, to collections of preserved material. I have already initiated a move to catalogue this resource and intend to bring the data into formats compatible with ITE's Environmental Information Centre and IH's National Water Archive. This can only be achieved if additional resources are made available for this important activity.

Sustainable Management of Land, Water and the Coastal Zone

Recovery of Windermere and its Arctic charr population

In response to advice from scientists at the Windermere Laboratory, North West Water implemented a scheme of tertiary sewage treatment at the two main works discharging to the lake. Phosphate precipitation from the final effluent at the Tower Wood works was commenced on 1 April, 1992, and about one month later at Ambleside. This was a significant turning point in the condition of the lake, as Figure 1a shows: the inexorable rise in the winter concentration of soluble phosphate, evident in the South Basin, from the mid sixties was steeply reversed, while the large crops of alga (represented as chlorophyll in Figure 1b) have been sharply reduced. The rapid recovery is as predicted for a deep lake in which there is little recycling and where, eventually, 96% of the soluble phosphorus entering the lake was sewage-derived.

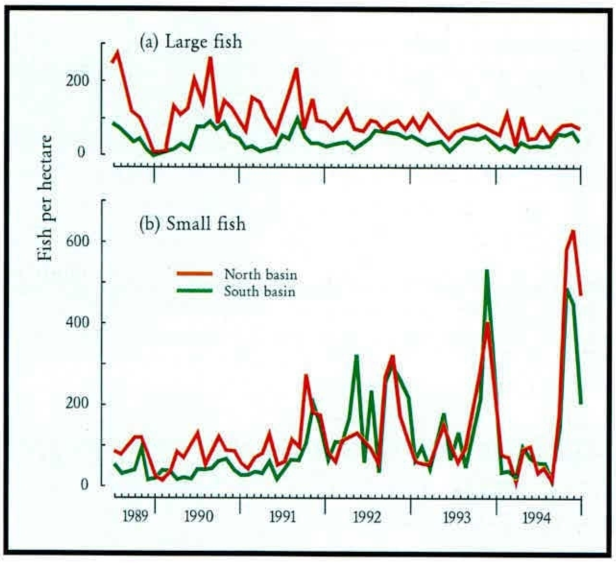

Figure 2. The numbers of (a) large and (b) small fish present in the North and South Basins of Windermere, from 1989 to 1994

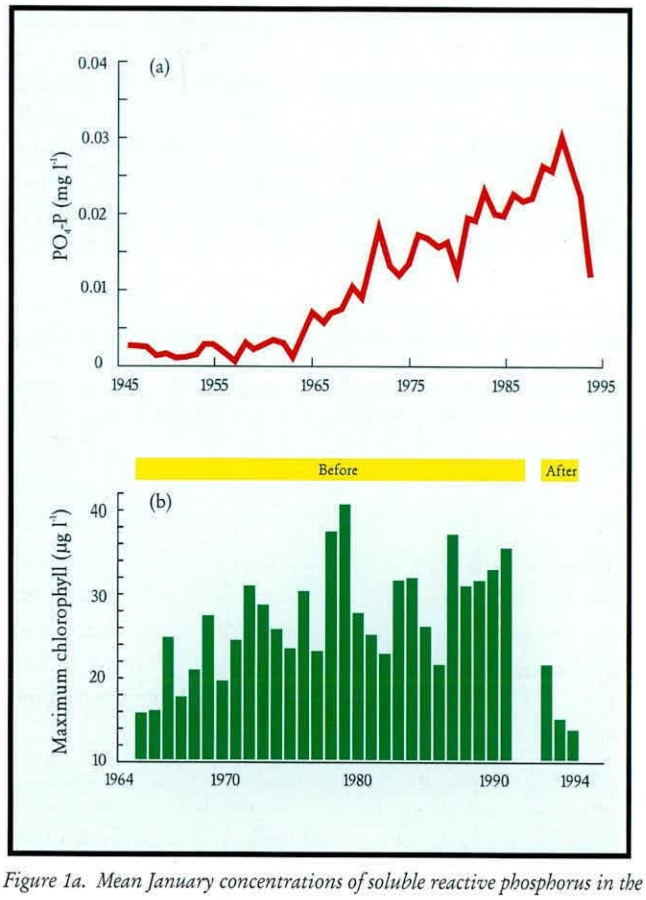

Figure 1a. Mean January concentrations of soluble reactive phosphorus in the South Basin of Windermere, 1945-1994; Figure lb. Maximum chlorophyll concentration in the upper 7m of the basin since observations commenced in 1964

The improvements thus engineered have already lowered the summer oxygen deficit in the hypolimnion of Windermere, thereby restoring the cold, aerated water environment necessary to the survival of Arctic charr. The South-Basin population had become depleted and had suffered poor recruitment in recent years, but it, too, has benefited from the lake restoration. Monthly day and night surveys with the echo-sounder showed that the density of fish in the North Basin (about 90% charr) was about two to five times that in the

South Basin (60-75% charr) in 1989, 1990 and 1991. Since the start of the phosphate reduction, there has been a steady increase in fish density in both basins, with highest densities being recorded at night. In 1992, 1993 and 1994, the nocturnal density of fish in the North Basin was rarely more than twice that in the South Basin and was often similar in the two basins. This steady improvement was chiefly due to increased numbers of small fish (length < 20 cm), especially in the upper water layer (depth 1 - 20 m) and in the South Basin (Figure 2). Although a similar improvement has still to be shown by larger fish above the size limit for removal by angling (20 cm) and there has been a marked decrease in the density of these fish in the upper water layer of the North Basin, the improved recruitment of young fish suggests that the stock available to charr anglers should increase in the next few years, especially in the South Basin. It is therefore important to continue the monitoring programme and thus ensure that there is advance warning of any marked changes in charr stocks.

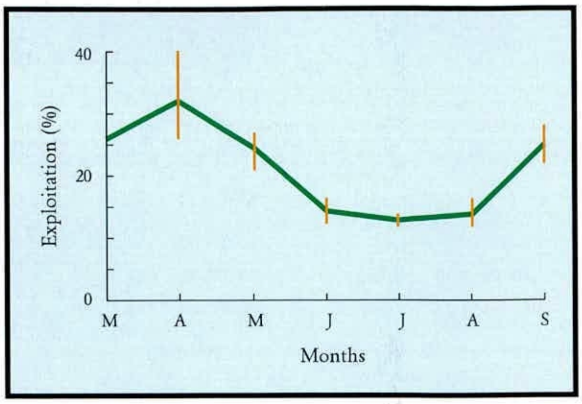

Figure 4. Monthly exploitation of River Frome salmon by angling (with SE)

Salmon counting/ exploitation

It has often been assumed that the stock of salmon in a river can be gauged from the numbers caught by anglers. Indeed, catch data are frequently used for this purpose without any real justification or validation. At the River Laboratory the details of salmon runs (determined by an automatic counter) and catches (from an angling log book) have been compared and the relationships between catches and runs examined. Only a few of the catch factors considered were correlated with counts and none could be regarded as reliable indices of stock. An r^2 value of only 0.36 was obtained for the correlation between total river rod catch and counter number. Of the 16 years studied only ten showed trends of catches in the same direction as the trends of counter numbers.

Perhaps the most interesting aspect of this study lies in the evidence of differential exploitation of the various age groups of salmon. Catchability of salmon is governed by many factors and closely follows the activity patterns of the fish. Salmon generally remain active for a few days or weeks after entering the river, they then become quiescent until they again resume activity prior to spawning, usually after the end of the rod fishing season. Rod fishing on the River Frome, as on other chalk streams, covers virtually the entire interval of time when fish are entering the river. The annual exploitation by rod is fairly low (averaging 11% of the upstream count). The highest exploitation rates are in the period when the larger, 3 sea-winter fish enter the river in the early part of the year. It is possible that, combined with the high exploitation rates observed in other chalk rivers, differential exploitation could be a factor in the observed decline of multi-sea winter fish.

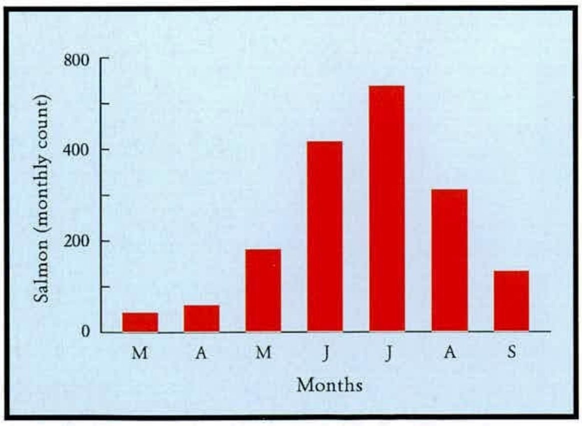

Figure 3. Monthly count of salmon on the River Frome

River habitat survey

NRA River Habitat Survey (RHS) The RHS Technical Group of specialists from NRA, IFE, Universities, etc., is developing a standard, nationally-applicable method for evaluating river habitats for uses ranging from catchment planning to national reporting. The survey attempts to encapsulate the habitat of 0.5 km sections of river by providing a context for assessing the quality of the river habitat based

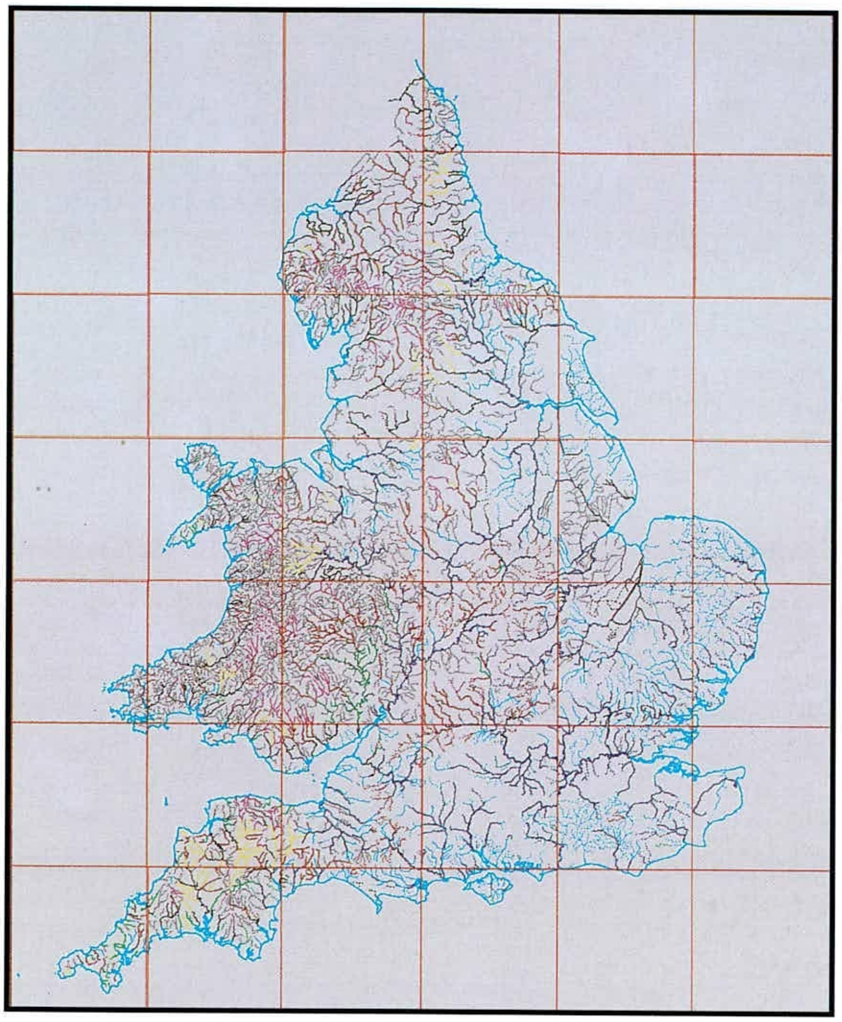

Figure 5. A preliminary map of river segment types in England and Wales based on predicted physical structure of the channel.

upon the presence, extent and pattern of physical features in terms acceptable to freshwater ecologists and geomorphologists. The end products will include a working classification of the quality of river habitats by reference to those general conditions to be expected for that stretch of river. The character of different reaches of rivers in differing regions of the country can reasonably be expected to be different in nature particularly under different physical conditions. The current separation to form 'segment' types with a minimum length of 5 km, is based upon physical factors which include rate of change of energy ie the slope of the river, the total energy ie from the water discharge and the substrate ie the geological rocks, being affected by that energy ie the erosion and movement of bank and bed materials. These physical interactions create the basis of the habitat which is then available for plants and animals but whose associations may be modified chemically by water flow from upstream in the catchment, and create the vegetational part of the habitat.

RHS is a rapid, field, form-based survey with regular 50 m transects and an overview of the 500 m section combined with the choice of description in 25 sections selected for ease of input for computer analysis and manipulation. This contrasts with the long-established, descriptive map-based method of River Corridor Surveys (RCS) which is designed to highlight habitats and features of special conservation importance for retention or enhancement during river management works. RHS also contrasts with the System for Evaluating Rivers for CONservation (SERCON) which is being developed to evaluate rivers based on the conservation criteria of naturalness, rarity, representativeness, diversity and fragility by computer processing of existing data on physico-chemical and biotic parameters.

The adjacent map illustrates by differences in colour the likely associations to be expected by streams and rivers in England and Wales; predictions for pristine quality of rivers in Scotland, Northern Ireland and Madeira, will shortly be available. This map shows for example in blue the large low-gradient lowland rivers on soft rocks eg sand, predominating in the south east, with, by contrast, in pink, the high altitude steep or very steep streams on hard rocks eg granite, of central Wales, Cumbria and North Devon.

Eel stock assessment

The eel (*Anguilla anguilla*) is the most widespread fish in UK fresh waters. It is exploited commercially during the elver stage when it is moving upstream, during its residential freshwater (yellow eel) stage and when it migrates downstream to the sea as a silver eel. The effect of such fishing on eel stocks is difficult to assess without knowledge of population densities in different waters, and there is little such information.

The problem has become more urgent because of the decline, since the early 1980s, of the numbers of elvers and glass eels reaching European rivers from spawning grounds in the Sargasso Sea (Figure 6). The reason for

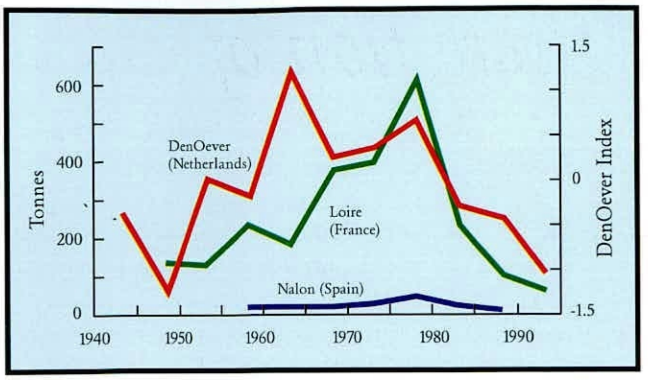

Figure 6. Catches of glass eels or elvers at three European elver stations: DenOever (Netherlands), Loire (France), Nalón (Spain).

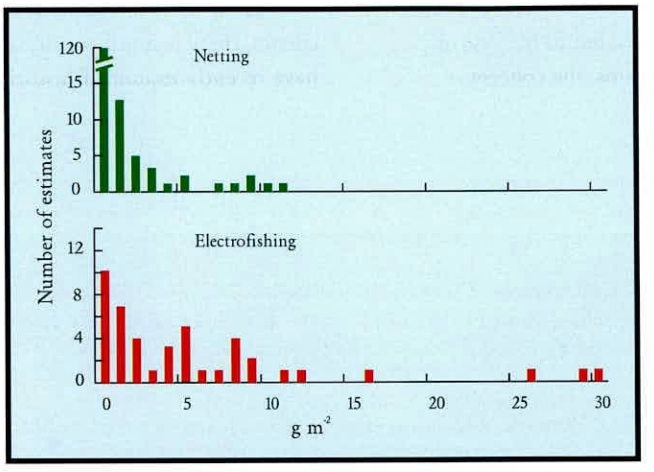

Figure 7. Biomass estimates (g m^{-2}) of eels caught by nets or electro-fishing from the River Ancholme and Lincolnshire drains. The data are from Fish Survey Reports, NRA Anglian Region.

this decline is unclear, although a change in the position of the Gulf Stream is thought to be a major contributing factor, with the conditions in rivers having more localised effects.

MAFF have a responsibility to maintain eels as a commercial resource, and recently it commissioned IFE to collate the available data on stock densities in the U.K.. Most data were obtained from unpublished NRA Fish Survey Reports and scientific publications. It was evident that the reliability of many of the population estimates is suspect, largely because their benthic habitat makes eels difficult to sample quantitatively by most electro-fishing and netting techniques (Figure 7). Also, in many fish surveys, eels are not the primary target species.

The impact of commercial fishing can be assessed more accurately if the age structures of the stocks and the commercial catches are known. Eels are aged from their otoliths ('ear bones'), but there are arguments about the best method to prepare them. The *EIFAC Working Group on Eel* recommends a technique that involves burning and breaking the otolith to reveal annual rings, but this has not always been used in UK studies.

The IFE review supports the recommendations of the *EIFAC Working Group on Eel* that further work on eel ecology is required, and it highlights those topics most pertinent to UK eels. These include the monitoring of the runs of elvers and silver eels, and the production of a standard age-determination procedure.

Understanding and Protection of Biodiversity

Microbial diversity

Microbial diversity is the least well understood component of biodiversity. Part of the problem is that the term "biodiversity" has little meaning unless the taxa to which it refers can be defined. These taxa are usually species, but in the case of micro-organisms, the concept of biological species (a closed reproductive community sharing a common gene pool) is meaningless and we need to find new, pragmatic, species concepts. In most cases, these concepts are individually tailored for different functional categories of micro-organisms. With respect to the microscopic ciliated protozoa, morphology is closely correlated with the phagotrophic function of the organism in nature, so the morphospecies concept of species is probably as valid, if not more so, than any other. Thus, when speaking of "biodiversity" with respect to ciliates, we refer to diversity of form and function (Figure 8). However, even for a group as well-studied as the ciliates, there is much confusion. We have recently examined historical trends in the descriptions of new species, quantified the value of taxonomic revisions, and derived the most probable number of free-living ciliate species in the biosphere. The derived figure is close to 3000 which is about half the number of species actually described so far.

Like many other groups of micro-organisms, ciliates tend to have very large population sizes and individuals are easily dispersed, so the probability of local extinctions and localised speciation is low. Thus each ciliate morphospecies is likely to be found in the same habitat type worldwide, and the majority of ciliate species (at least in the more frequently-studied habitats) have probably already been discovered. In any event it is unlikely that the final number of morphospecies will deviate greatly from the current figure of 3000.

The Culture Collection of Algae and Protozoa (CCAP) continues to play a key role in the *ex situ* conservation of microbial biodiversity. CCAP is probably the most diverse collection of cultured algae and protozoa in the world. Current research is directed

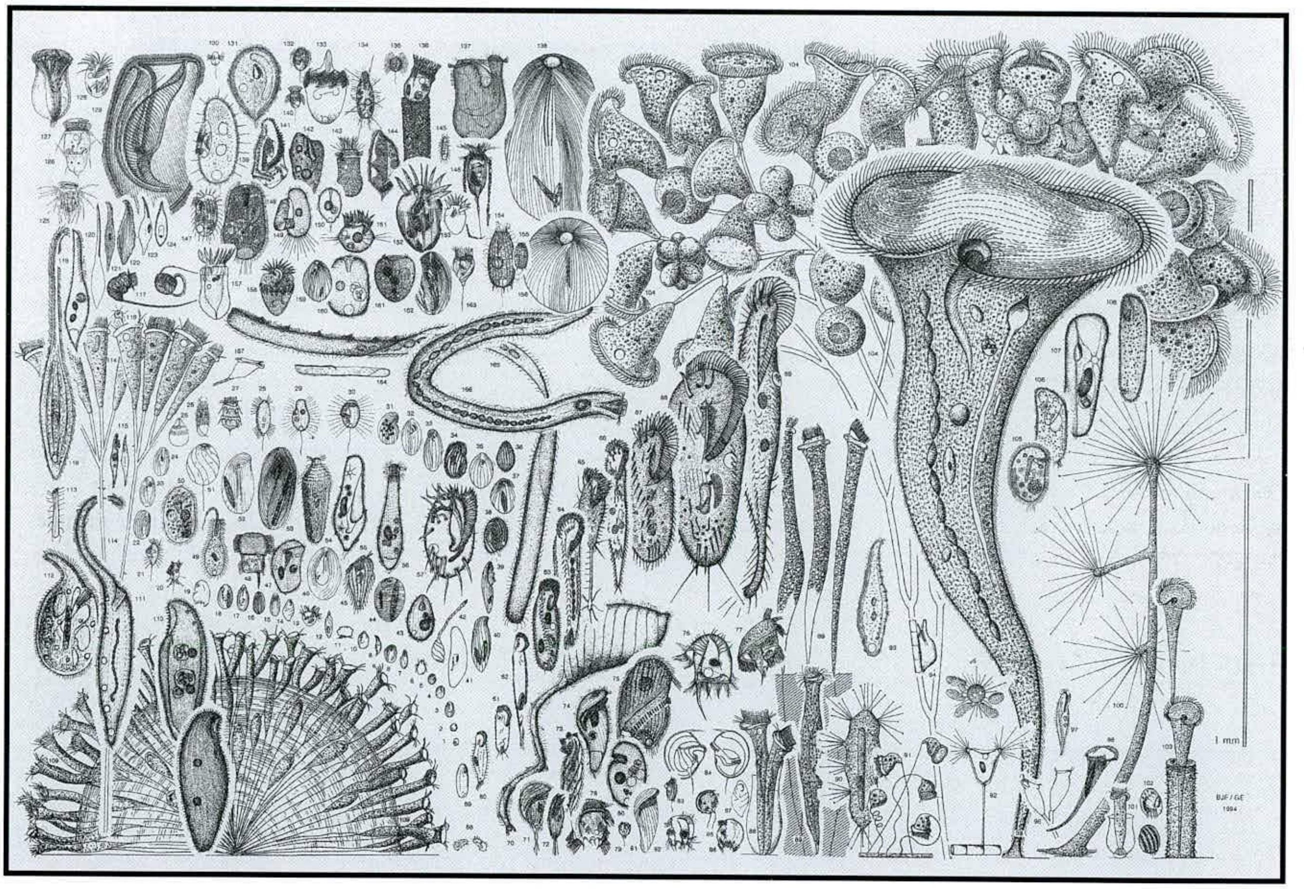

Figure 8. A representative selection from the variety of morphotypes in free-living ciliated protozoa; all drawn to scale.

towards preservation protocols for recalcitrant micro-organisms, and the causes of cell damage associated with freezing.

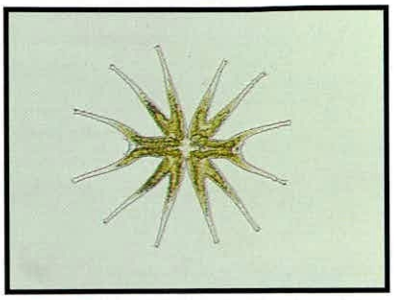

Figure 9. One of many cultured algae maintained in CCAP - Micrasterias hardyi *(CCAP 649/15)*

RIVPACS III

The new version of RIVPACS (River InVertebrate Prediction And Classification System) is now in place, following the latest round of analyses. RIVPACS is a software package which predicts the fauna to be expected at a river site in the absence of environmental stress (eg pollution or habitat degradation). By comparing the observed with the expected fauna, the biological quality of a site can be determined.

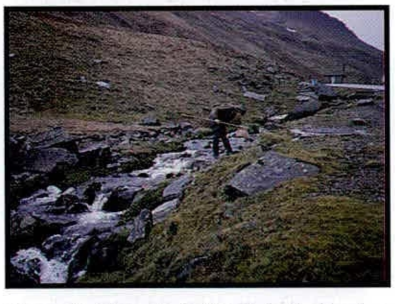

Figure 10. Site at high altitude in the Pennines with a species-poor assemblage.

RIVPACS III differs from previous versions in a number of important ways. For example, the reference data-set for the system is now more comprehensive. Within Great Britain, geographical coverage has been improved and there is a wider range of small stream sites. Additionally, the new system includes data for Northern Ireland and hence RIVPACS III can offer predictions for sites throughout the United Kingdom.

A series of rigorous site selection procedures were used prior to site acceptance for RIVPACS III and as a consequence, a number of the sites in RIVPACS II were rejected. The new reference data-set includes 614 sites in Great Britain and a further 70 sites in Northern Ireland.

After some exploratory analyses in which all UK sites were classified together, it was concluded that separate classification and prediction systems for Great Britain and Northern Ireland would offer the most reliable system in each case. Hence, within RIVPACS III there are two subsystems, the GB section with 35 classification groups and the NI section with 7 classification groups.

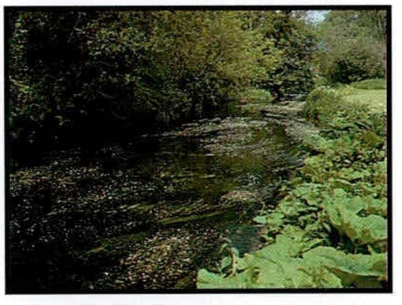

Figure 11. Chalk stream site with a species-rich assemblage.

In total, 642 macroinvertebrate taxa were recorded at the reference sites including species-poor assemblages at sites with harsh environmental conditions (Figure 10) and species-rich assemblages at some lowland sites (Figure 11).

RIVPACS III sets higher standards for prediction of the fauna than RIVPACS II as a consequence of the more comprehensive data-set, rigorous site selection process, and through modifications to the classification procedures which have increased the reliability of the predictions. As a result of the financial assistance of the National Rivers Authority, the Scottish Office and the Department of the Environment (Northern Ireland), the new system will be available for the biological component of the quinquennial survey in 1995.

Suitability indices for cyprinids

Introduction

The distribution of suitable habitat patches has been identified as a key factor controlling the success of fish species, particularly in Europe where river regulation has removed much of the habitat diversity present in lowland rivers. Reduced diversity principally affects cyprinid fishes, which predominate in the lower gradient reaches of rivers and which are of both commercial and recreational interest. The young-of-the-year (0+) fishes are particularly vulnerable because of their small size.

Because of the lack of knowledge of the ecology of young fishes in regulated rivers, initial research has concentrated upon the ecology of the fish fauna found in the River Great Ouse, UK. This river has suffered a loss of habitat diversity by being constrained within a trapezoidal channel, which is maintained by dredging and weed cutting, and the regulation of discharge by a number of automatic sluices.

Habitat use behaviour

Field studies have revealed that each fish species uses a specific suite of habitats with diel variation in habitat use superimposed upon seasonal changes in habitat use owing to morphological development of the fish (Figure 12). It is also apparent that the lack of spatial diversity may increase the amount of habitat overlap, resulting in increased competition for food and a

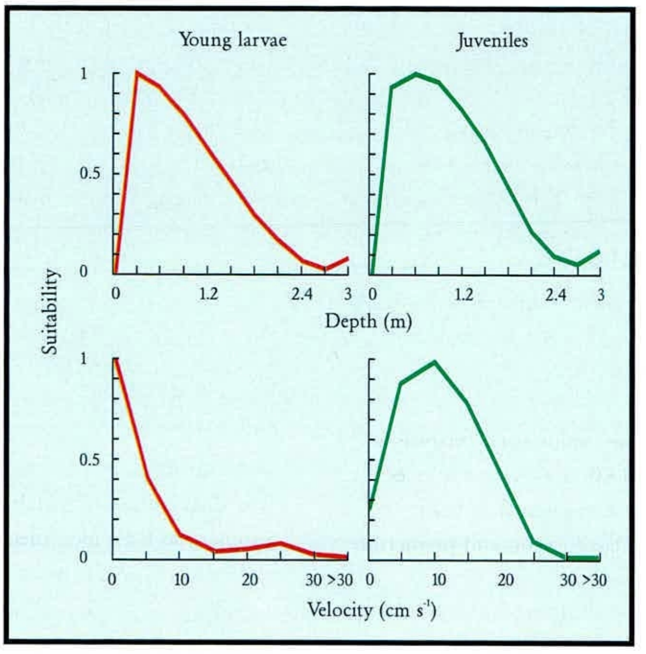

Figure 12. Habitat use by larval and juvenile 0+ roach in the River Great Ouse.

concomitant reduction in growth rate.

The current aim of this research is to produce a suite of habitat suitability indices for a range of species of cyprinid fish in the UK. This has involved the use of parallel field and laboratory studies to determine the optimal and range of conditions in which the species can survive and flourish.

Determination of habitat suitability

A survey detailing microhabitat availability and use by several species of young fish was carried out at 22 sites within the lower Great Ouse catchment using point sampling by electrofishing.

This study revealed that specialist fish species were initially limited by the availability of suitable spawning sites, with several species being limited to rare biotopes, such as potamic side arms and lotic tributaries. Much of the channel was found to be unsuitable for 0+ fish, with most fish being found within the marginal zone. Larval and juvenile fishes of several species were found to coexist in the river margins with both habitat use and diet being highly overlapped. In general, suitable conditions were the presence of instream cover, low velocities and shallow water. These can be correlated with elevated densities of micro-invertebrates, the preferred prey of young cyprinids, which are also associated with the marginal zone.

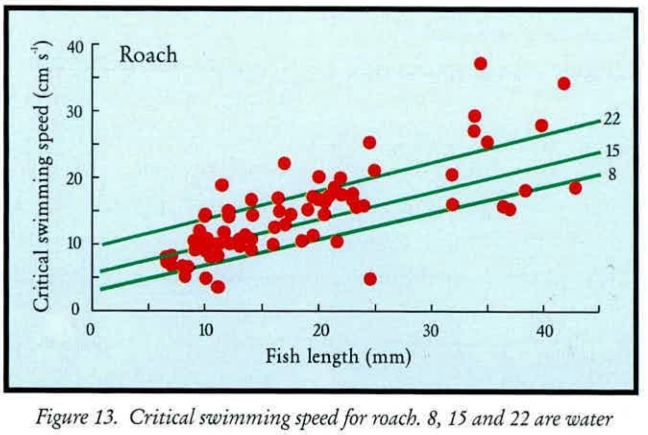

Figure 13. Critical swimming speed for roach. 8, 15 and 22 are water temperature degrees centigrade.

Swimming behaviour

Elevated velocities are particularly important in regulated rivers where the modified channels tend to remove excess water rapidly. Habitat use during floods has proved difficult to model using summer field studies because of the low velocities and high temperatures present during the summer field season. Winter field studies were also found to be impractical for the most part owing to low fish densities and poor weather conditions. To determine the critical and optimal velocities for young cyprinids, a small recirculating channel was used to exercise the fish. This work has revealed that the critical velocity is dependent upon both the size of the fish and water temperature (Figure 13) and that swimming ability is species specific, with rheophilic species swimming faster.

Conclusions

The derived suitability relationships for the River Great Ouse were used to determine the quality of the physical habitat available to the fish in a range of channel types and under a range of discharges. Initial results suggest that during the summer (low discharge) months, 5-20% of the river area provides habitat suitable for 0+ fishes. During winter periods of elevated discharge, this may be reduced to 0-5% owing to the rapid loss of low velocity patches. There is thus considerable scope for improving river habitat throughout the year and in particular during winter floods.

Figure 14. An extremely ripe female smelt (or sparling) with perhaps 100,000 eggs.

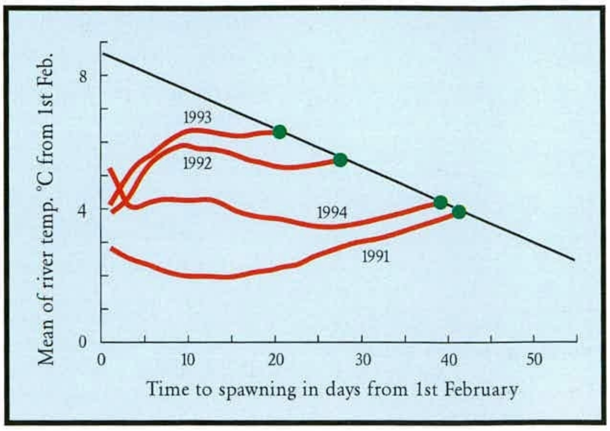

Figure 17. The relationship between mean temperature of the River Cree from 1 February and the timing of smelt spawning (●).

Conservation of the Solway smelt

The smelt *Osmerus eperlanus* (Figure 14) is an anadromous coastal fish which migrates in shoals into rivers to spawn during early spring. At least nine rivers along the Solway Coast supported fisheries for smelt until its decline earlier this century due to overfishing, pollution and physical

Figure 15. A main smelt spawning site on the River Cree near Newton Stewart.

barriers. Now, smelt spawn only in the River Cree. Their migration was studied from 1991 to 1994 as a basis for conservation management. Smelt enter the tidal reaches in January and "run" into the freshwater spawning area (Figure 15) in February/March. The onset of spawning was monitored by inspecting the river bed for smelt eggs (Figure 16) which are sticky and adhere to stones, plants and debris - hatching in about 20 days. First spawning ranged from 22 February to 14 March and eggs were found over a 2 km stretch. River flow, bed morphometry, tide elevation and water temperature were examined for their influence on the location and timing of spawning.

The River Cree smelt utilise spring tides for "lift" into the freshwater section. The extent to which they can ascend relies on the degree of river flow suppression by tidal forces - most critically, to enable passage through large riffles. The location of spawning, determined by these interactions, is important for egg survival to incubation - level fluctuations and siltation in the lower spawning area are extremely damaging. Spawning does not occur until water temperature has reached 6° C. However, the thermal regime of the lower river in the preceding weeks is important to fish condition and readiness to spawn. Mean river temperatures over these periods and the timing of first spawnings are remarkably well related (Figure 17). The temporal influence of temperature is the primary governing factor in initiating spawning - prevailing temperature, tide and flow

Figure 16. A mass of smelt eggs (1 mm) stuck to a moss covered stone.

dictate exactly where and when. With this knowledge, conservation management can be established.

The re-establishment of smelt populations in other Solway rivers is now required. The opportunity exists to create a programme based on scientific study where conservation enhancement of smelt and legislative control of its exploitation can proceed in a structured and sustainable form.

Responses of minnows to alarm substance under near-natural conditions

Mechanical damage to the skin of ostariophysan fish liberates an alarm substance, Schreckstoff, from club cells in the epidermis. Nearby conspecifics or individuals of closely related species detect these chemicals by olfaction and perform species-specific fright reactions which have been assumed to reduce the risk of predation. Surprisingly, only a handful of studies have examined the responses of natural communities of fish to Schreckstoff and these have often employed indirect observation techniques including the use of fish traps.

The fluvarium at the River Laboratory represents a unique opportunity to observe fish behaviour

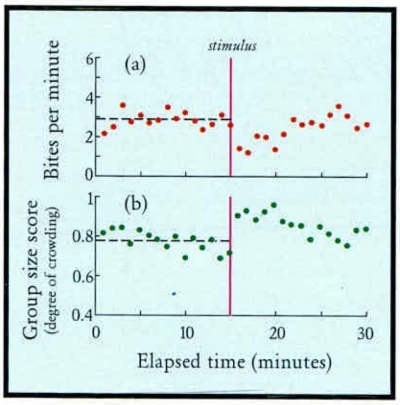

Figure 18 :
a) The influence of Schreckstoff on minnow feeding rates under natural conditions. b) The influence of Schreckstoff on minnow shoaling behaviour under natural conditions. (a) and (b) The horizontal bar represents the mean feeding rate before application of the stimulus.

under near-natural conditions. Shoals of European minnows, *Phoxinus phoxinus*, were introduced into the fluvarium and left to settle down for several hours and then feeding behaviour and shoal size were recorded for 15 minutes before and after a chemical stimulus was introduced. The stimuli used were distilled water (control) and skin extract.

These data reveal in detail how minnows respond to Schreckstoff under near-natural conditions. The changes in behaviour observed here are consistent with the hypothesis that a threat was perceived but not quantified. Interestingly, these responses are much more subtle than those observed in a multitude of laboratory studies.

Fish introductions

The introduction of new species is one of the most insidious threats facing the conservation of fish communities around the world, partly because once populations are established they become extremely difficult to remove.

Within the UK, many fish introductions or translocations have occurred over the last few decades. Two particularly notable species in this context are the roach *Rutilus rutilus* and the ruffe *Gymnocephalus cernuus*, both of which have recently been introduced to the only U.K. lakes, Bassenthwaite Lake and Derwentwater in the Lake District, still containing the rare vendace *Coregonus albula*.

Both species have been introduced to Bassenthwaite Lake. The roach was first recorded in this lake in 1987, but now dominates the fish community of the inshore areas even though it still shows an age structure dominated by young fish and a rapid growth characteristic of a newly-introduced population (Figure 19). The first ruffe in this lake was found in 1991 and the population is still in an early phase of colonisation, with only a limited range of age classes present which show fast growth (Figure 20). Like the roach, the ruffe has become an abundant member of the inshore community, although it also occurs alongside the vendace in the deeper areas. Derwentwater has so far only been colonised by roach, of which just a few individuals have been found. However, it is likely that ruffe will arrive in the near future via the River Derwent which connects it to Bassenthwaite Lake.

The implications of these introductions for the continued survival of the vendace populations are difficult to predict, but they may be grave given the well established ability of young roach to out-compete other planktivorous fish for food supplies and the reputation of ruffe as a consumer of vendace eggs.

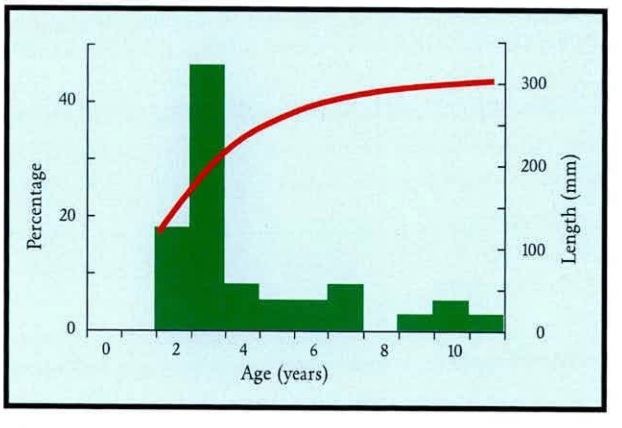

Figure 19. Age frequency distribution (green) and growth (red) of roach in Bassenthwaite Lake

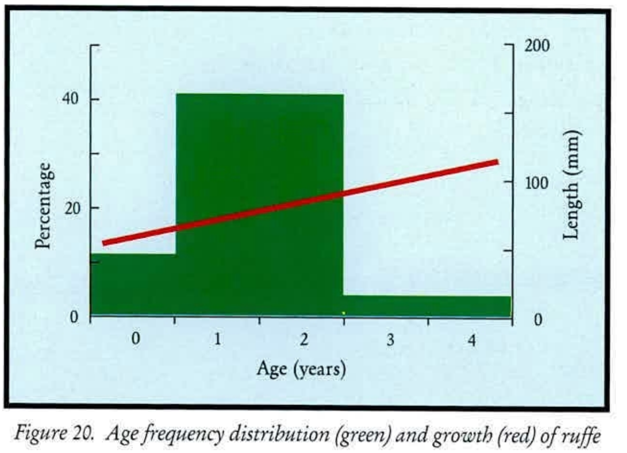

Figure 20. Age frequency distribution (green) and growth (red) of ruffe in Bassenthwaite Lake