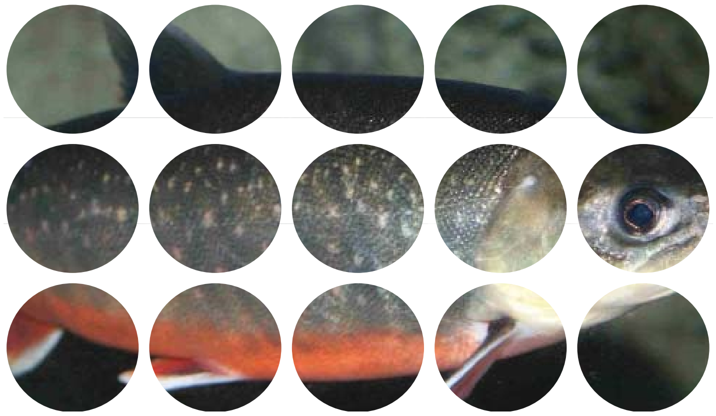

This review was co-ordinated by the Freshwater Biological Association (FBA)
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December 2005

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ISBN: 0-900386-74-6

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A REVIEW OF **FRESHWATER ECOLOGY** IN THE UK

FRESHWATER BIOLOGICAL ASSOCIATION

CONTENTS

SUMMARY

Good quality water is a product of ecosystem services, which we have always taken for granted but are now under unprecedented pressure. Legislative and policy drivers on water quality, flood risk management, biodiversity and climate change, but in particular the aim of the Water Framework Directive (WFD) to achieve "good ecological status", have placed freshwater science at the centre of decisions involving investment of billions of pounds. Scientific understanding, therefore, will be increasingly tested in Boardrooms, the Courts and the European Commission.

Until the late 1970s, the UK was considered to be at the forefront of research in freshwater ecology and limnology. Since the late 1970s there has been a reversal in this position, such that research activity has declined in the UK in absolute terms, and relatively compared with N. America, Japan, Australia/New Zealand and other parts of Europe. Indicators show a fall in publications and in the number of scientists, to the extent that there is increasing concern regarding our ability to provide the scientific understanding required to meet the scale of the problems we face. Key items of research infrastructure are also threatened.

To achieve the required science objectives we must establish a coordinated approach by both public and private sectors to address what is identified here as a national research deficit. The key recommendation in this respect is that a new strategy be established, in the form of a "cooperative research partnership (CRP)" for UK freshwater ecology. This would provide the mechanism to:

- **Provide added value to our key, long term research sites and data records.**
- **Safeguard and coordinate national facilities.**
- **Encourage more and better freshwater biological research, improved professional training and better uptake of science in catchment management.**
- **Make full use of new opportunities afforded by funding opportunities such as the new EU FP VII.**

We know some but not all of the science necessary to manage fresh waters effectively. Moreover, an active research community is necessary to meet the knowledge deficits and to provide the well-informed managers of the future. There are exciting science opportunities in areas with crucial relevance to advances in ecological theory and to catchment and water management. For instance:

- **Understanding how freshwaters are linked to the landscape and more generally to the Earth System**
- **Using the ability of catchments to integrate, detect and buffer environmental change and temporal variability**
- **Characterising poorly known elements of biodiversity**
- **Identifying non-linearities and instances of regime change, resilience and hysteresis in freshwater ecosystems**

Such scientific progress will bring the outcomes that enable:

- **Significant environmental problems to be anticipated, and avoided or ameliorated**
- **Tools to be designed that provide management solutions**
- **Strategic management options for the sustainable use and restoration of freshwaters to be devised and assessed.**

INTRODUCTION

This review is the product of discussions between senior UK academics, researchers and stakeholders in Freshwater Ecology. It was co-ordinated by the Freshwater Biological Association and the NERC Centre for Ecology and Hydrology.

1.1 Freshwater ecology in the UK

Until the late 1970s, the UK could be considered to be at the forefront of research in freshwater ecology and limnology. Since the late 1970s there has been a perceived reversal in this position such that today freshwater ecology research is led by North America, Japan, Australia/New Zealand and some other parts of Europe. Is this because of an increase in research funding in these countries or is it due to a decline in resources and infrastructure in the UK? The need for an emphasis on freshwater ecology in the UK, and indeed more widely in Europe, is highlighted by the data and understanding required for the implementation of the Water Framework Directive. The ecological quality of freshwaters and how this changes in response to drivers and pressures within the catchment lies at the heart of this new legislation.

There have perhaps been strategic reasons for a decreased emphasis on freshwater ecology. Within NERC's new science strategy, for example, there has been a considered move to inter- and multi-disciplinary environmental 'earth system science' and away from research based on particular habitats. This is perhaps understandable in the face of such immediate and global environmental challenges. After all, freshwaters are part of landscapes embedded within and beneath neighbouring terrestrial systems and interacting with marine ecosystems 'downstream'. Nevertheless, the critical mass of underpinning scientific research in freshwater ecology must be maintained to ensure the delivery of the integrated activity.

It is clearly essential to understand where the science is now, to assess how it got here, and to determine options for the future. Accordingly, this review of UK Freshwater Ecology was initiated by CEH and FBA to determine the current status of freshwater ecology and to make recommendations for a future strategy. It has been widely discussed with scientists from UK research centres, universities and UK environmental managers and conservation agencies, and is set against the perception that:

(i) The UK's lead in freshwater ecology has been lost.

(ii) There is a new requirement for improved scientific understanding and trained freshwater ecologists to underpin the implementation of the WFD, to provide management solutions, and to minimise risk to the UK economy and quality of life.

1.2 Organisational problems

There are prima facie grounds to suspect that the structure of the UK's broad 'freshwater environment community' is part of the problem. The responsibility for different aspects of the UK freshwater environment lies with several different organisations with very different financial and management characteristics. This has made for a difficult interaction and the community is highly fragmented so it is not surprising that a coherent strategy has not been developed. No doubt due to financial pressures, there seems to be a rivalry between the potential funders of 'pure' and 'applied' science about who should pay for research, each claiming that the other should bear the cost. This problem is particularly severe for crucial strategic research, and has created a lacuna between purely curiosity-driven and applied science and scientists, to the detriment and frustration of both. Further, the turbulent interface between freshwater science and management seems particularly rough in the UK, where the relationship between researchers and environmental managers is ineffective, bureaucratic and often secretive, so that the best expertise is often not used.

An obvious organisational problem in the UK system lies with the former grant-aided bodies and, in the case of freshwater ecology, the Freshwater Biological Association. These were set up as scientific charities and had the responsibility, in return for UK Government grants, for national programmes of high quality, curiosity-driven research with longer-term strategic purposes. Their relationship with the Natural Environment Research Council (NERC) that ultimately took over these responsibilities and many of the assets of these charities has often been fractious. In the case of FBA, the charity still owns important sites and facilities that are now at risk of being lost to science because of the 'divorce' of NERC from the Association and the subsequent impoverishment of the latter. For example, the national freshwater FBA library, one of the best in the world and paid for by the UK tax payer, remains at Windermere at costs to both FBA and NERC CEH, while a solution as to its future is sought. A clear barrier to finding a solution lies in finance. As a result of the inevitable time delay as a solution is sought, the library is in undoubted decline and inaccessible to most scientists. Indeed, the origins of this report lay with individuals in FBA and NERC CEH who saw the damage being done and wanted a more sensible and constructive way forward. Similar financial and organisational problems beset other facilities around the country and a general decline in infrastructure quality and availability is in process.

1.3 Economic benefits for the UK

Clean fresh water is probably our most valuable, yet under-valued resource, and is a product of natural 'ecosystem services'. Protecting this resource is one of the key priorities for the future, given unprecedented pressures on inland waters and their ecology. Securing sustainable water supplies, for which we need 'functional ecosystems' and unimpaired biodiversity, requires well-informed investment decisions to protect and improve the quality and quantity of our waters.

Legislative and policy drivers on water quality, flood risk management, biodiversity and climate change, but in particular the EU Water Framework Directive (WFD), has placed freshwater science at centre-stage. The WFD stipulates that good ecological status must be achieved in surface waters by 2015. The route to achieving this target requires a chemical and ecological characterisation of all water bodies and an assessment of significant stresses or pressures. It is further required that an economic analysis of water use is undertaken to provide sufficient information to allow rational cost recovery by the water services and to enable the most cost-effective programme of management measures to be developed. This programme will comprise the options for achieving the desired ecological status within the timescale. These management measures are likely to range from relatively inexpensive changes in land use, such as the avoidance of arable agriculture close to sensitive river channels, to extremely costly technological solutions to clean up particular point source discharges. Clearly, the choice of measure will depend on its perceived effectiveness in improving ecological status. Securing the scientific basis for making these decisions is, therefore, mandatory to minimise the risks of, on the one hand, placing an excessive cost on industry and, on the other, adopting quality and quantity standards that cause ecological status to deteriorate even further.

Hitherto, the lack of scientific understanding of the ecological impact of different remediation and restoration measures, and of the basis for the setting the ecological standards themselves, has led to the adoption of a precautionary approach. Such an approach inevitably requires the more costly approaches be implemented. The investment of billions of pounds now depends on decisions based largely on a scientific judgement – and this scientific judgement will be increasingly tested in Boardrooms, the Courts and the European Commission.

THE MAGNITUDE OF THE PROBLEM

Here, we have gathered together statistical information on the state of UK freshwater ecological science, sufficient to test our impression that there has been a substantial decline in capacity and vigour.

2.1 Statistics - Publication

One possible indication of the health and productivity of UK freshwater biology lies in the output of publications in key journals. We have data from 1980 to 1996 in five, general journals in freshwater biology and ecology and for one of them, Freshwater Biology, throughout its history from 1971-2003 (Fig. 1).

This information requires careful interpretation. The five journals include the most prestigious single outlet in aquatic biology (Limnology & Oceanography, the journal of the American Society for Limnology and Oceanography) and a suite of others (Freshwater Biology, Archiv für Hydrobiologie, Canadian Journal of Aquatic Sciences, Hydrobiologia). Of course, nearly all active freshwater scientists publish in a range of journals much wider than this – in general ecology titles, for instance, or in more specialised journals in palaeolimnology, fish biology microbiology, or aquatic botany. However, here we seek to compare British output with that by freshwater biologists in North America and continental Europe.
It is possible, though it seems unlikely, that there has been some proportionate trend away from these particular journals by British, but not by other European or American, scientists. As long as this is not the case, we can then use this record as an indicator of the national health of our science.

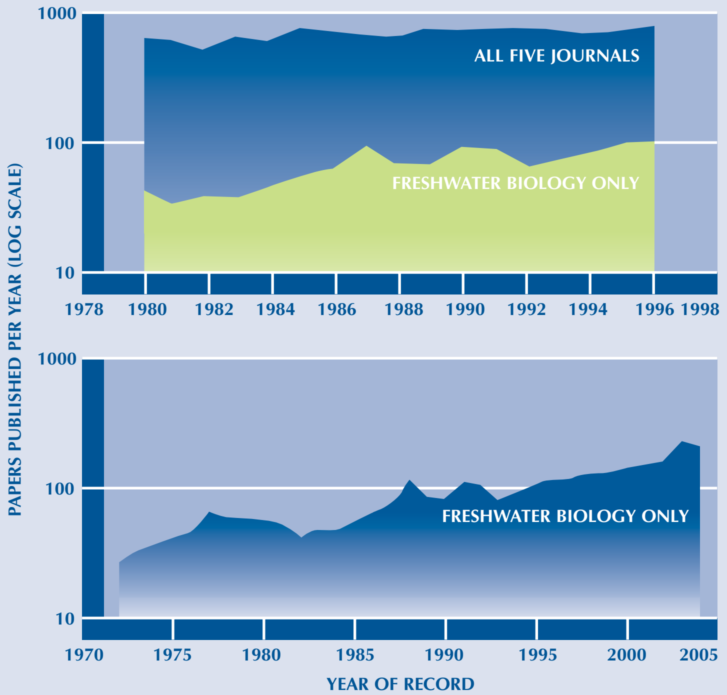

Figure 1.
Number of published papers in Freshwater Biology (1971-2003) and four other key journals (1980-1996). The overall trend is upwards.

We can first reject the possibility that this is a field in general decline, because both the 'five journals', and Freshwater Biology alone, showed a steady increase in total output (Fig. 1).
The contribution from North America was steady in the five journals overall and grew in Freshwater Biology, while non-UK Europe increased strongly in both records. Compare that with the British contribution (Fig. 2), which has declined substantially, particularly that from the FBA and its descendent NERC institutes (IFE, CEH).
The UK's relative position has clearly deteriorated strongly over the period and, in the case of FBA/NERC, this continued for twenty years until the late nineties. The Universities fared rather better, though even their absolute and relative output declined. Interestingly, there has been some indication of a recent resurgence (though this has not been sustained into 2004 in the case of Freshwater Biology).
Nevertheless, there are some new generation freshwater biologists in both University and NERC sectors who are making a renewed impact, partly as a result of NERC's 'capacity building' exercise beginning in 1997. But the numbers remain small and the system clearly still in a fragile state compared to the strategic importance of healthy freshwaters.

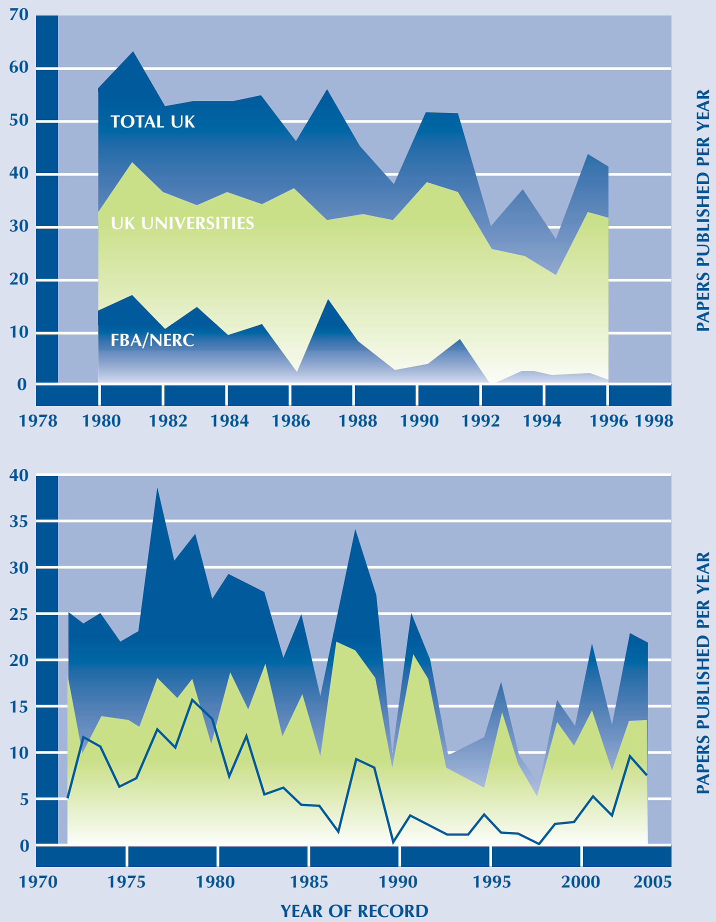

Figure 2.
UK output of of published papers in five leading freshwater ecology journals between 1980 and 1986 (upper panel), and between 1971-2003 in Freshwater Biology (lower panel). the overall trend is a decline. The possible recent recovery may be due to recent retirees completing papers.

2.2 Statistics - NERC Staff

For many years the Freshwater Biological Association (FBA) and latterly its research successors, the NERC Institute of Freshwater Ecology (IFE) and the Centre for Ecology and Hydrology (CEH), as well as some staff within the Institute of Terrestrial Ecology (ITE), have represented the largest single group of freshwater ecologists in the UK. Analysis of numbers of research staff since 1965 illustrates the change in emphasis on freshwater ecology that has occurred in these organisations (Fig. 3).

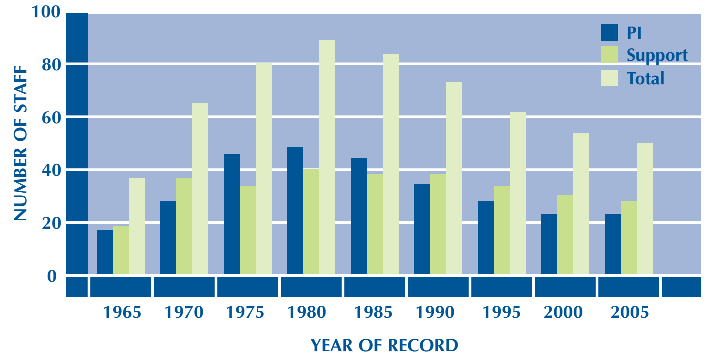

Figure 3.
Number of PI, support and total scientific staff working in FBA/IFE/ITE/CEH in 5-year blocks between 1965 and 2005. The trends are all downwards following the peak in 1980, the decline in PI's being steepest.

The numbers are based on annual reports for the FBA, IFE, ITE and databases held latterly by CEH, analysed every 5 years. There has, necessarily, been a subjective decision on which staff to include: the criterion has been whether or not they would have fitted the traditional FBA field. Similarly, judgement on whether or not a member of staff at a particular point in their career is a 'PI' or 'support' is subjective, as is the allocation of staff to studying primarily lakes or rivers (Fig. 4). The numbers exclude administrative staff and also staff in the freshwater section of the Culture Collection of Algae and Protozoa, which were housed at The Ferry House for about 15 years.

The total number of science staff increased from less than 40 in 1964 to a peak of about 90 in 1980. This increase in numbers came about

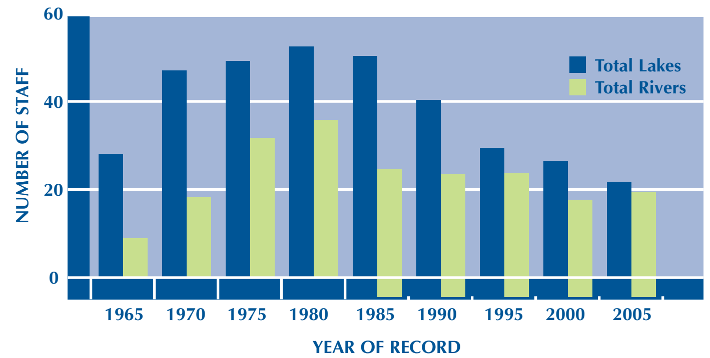

Figure 4.
Number of scientific staff working in FBA/IFE/ITE/CEH in 5-year blocks between 1965 and 2005 primarily studying lakes or rivers. The trend is sharply downwards from the 1985 peak although less dramatic for river ecologists.

at a time of rapid expansion in UK higher education and research. Since 1980, numbers have declined steadily to current (2005) estimates of 50, about 55% of peak numbers (Fig. 3). Numbers of 'PIs' have declined slightly more (currently 45% of 1980) than those of support staff (currently 70% of 1980) and this probably reflects the ageing of the research community which was established in the early 1980s.

The number of staff working on rivers increased rapidly from 1965, which was around the time of the founding of the FBA River Laboratory at East Stoke in Dorset (Fig. 4). In contrast, the foundation of the FBA laboratories on Windermere some 50 years earlier is reflected in the nearly 30 staff present at this time, but this also increased up until 1985 when 55 scientists were employed. Since 1980, the reduction in total number of staff working on river ecology has been substantial (to 67% of the peak) but the reduction in number of scientists working on lakes, since the peak in 1985, has been particularly marked (47%). The dramatic decline in lake ecologists since 1985 is perhaps further worrying in a strategic sense since the pressures on lakes, as defined within the WFD, are significant. Also, the declining numbers working on rivers should not be considered to be adequate for demand. As far as can be determined, these changes do not reflect any rational scientific or management strategy with respect to the requirement for freshwater ecology.

These numbers illustrate the large decrease in research capacity that has taken place within one major group of freshwater scientists, for which numbers are readily available.

2.3 Statistics - Academia

Mirroring strongly the trends among NERC staff (Section 2.2), the last 20 years have seen a near precipitous reduction in UK university faculty actively publishing in freshwater, whole-organism fields. A search of the ISI® data base for the period 1981-86 showed that 59 individuals published a total of 221 papers in major freshwater biological journals (Freshwater Biology, Limnology & Oceanography, Canadian Journal of Fisheries and Aquatic Sciences, Archiv für Hydrobiologie, Hydrobiologia). By 1999-2004, this number had been nearly halved, with only 32 UK university faculty still publishing actively in the same freshwater journals or their more recent equivalents (Journal of the North American Benthological Society, Aquatic Conservation; Annex C). Part of the reduction was due to 35 individuals who had retired, died, moved overseas, or left academic institutions (Annex D). At least nine others had effectively ceased publishing in this field due either to changes in their research interests or in their university role. Sixteen staff recruited in the intervening years have replaced only around one-third of the losses. Moreover, 17 currently active individuals were already publishing freshwater biological papers in the early 1980s and several among them will reach retirement the next 3-8 years. Further loss of expertise therefore seems inevitable.

Identifying clearly the reasons for these trends is far more difficult than quantifying their magnitude. Contributory factors include:

(i) **Loss and redistribution of activity.** Previous concentrations of freshwater biologists at Cardiff, Liverpool, Bangor, and the former London colleges of Chelsea/Kings College and Royal Holloway are now disbanded or diminished. Smaller concentrations exist in London (Queen Mary; University College), Glasgow, Birmingham and Cardiff so that many of those listed in Annex D are mostly dispersed across institutions.

CURRENT RESEARCH INFRASTRUCTURE

(ii) **Changing focus of activity in University biology departments.** Greater numbers of losses or retirements by comparison with fewer new appointments in freshwater biology implies that other biological fields must have taken precedence in replacing staff losses. These include health and molecular branches of biology. Indeed, several new appointments in freshwater 'biology' have occurred in geography departments rather than biology departments (e.g. UCL, Birmingham, Loughborough). While this implies a more holistic, large-scale focus on freshwater systems, with greater capacity for linking physical and biological processes, biological understanding has inevitably declined.

(iii) **Local influences rather than strategic thinking.** Linked to (ii), decision-making over appointments has reflected local criteria in individual universities rather than the broader, UK-wide, strategic needs for freshwater expertise now being expressed by a range of bodies.

(iv) **Under-funding.** Of all 435 grants awarded by NERC in the "freshwater ecology" category between 1991 and 2005, only 41 were won by any individuals listed in Annex C – in other words biologists publishing in freshwater journals. The majority has been gained instead by engineers and a range of physical scientists.

(v) **'Leadership' and influence from the freshwater biology community.** For a range of reasons, the freshwater biological community in the UK has failed to have stronger influence over science spending, appointments and research activity. For example:

- Some freshwater biological research in the past was perceived as being descriptive more than analytical, insufficiently linked with physical freshwater sciences and insufficiently targeted on key science questions.
- Freshwater biological outputs appear often in journals read only by other freshwater biologists so that important ideas do not reach more widely.

Freshwater biologists, because of their small and diminishing number, are now seldom in key positions of influence while being poorly represented on decision-making committees.

British freshwater biology has lost world leadership to institutions overseas, particularly in Australia/New Zealand, North America and other parts of Europe.

We recognise that reversal of these problems is a priority on which the freshwater community must act.

2.4 Strategic requirement of the EA

The EA has recently completed an internal self-assessment exercise to establish the skills baseline of its freshwater ecological and conservation staff. The basic messages are that:

- there are about 400 staff with freshwater ecological expertise, including fisheries;
- 80% have at least one degree;
- more than a third have 10 or more years work experience;
- there are very few taxonomic experts other than for macroinvertebrates and fish;
- there is strong competence in diagnostics of water pollution but little expertise on sampling strategy, statistical aspects of planning surveys and data quality control;
- there are major gaps in expertise on macrophytes, diatoms and lake ecology.

In general, the worry is that a combination of recruitment of generalists, a lack of coaching/mentoring from the most skilled practitioners, and extreme workload pressures is reducing the confidence in evidence-based decision making. Indeed, the same pressures are resulting in (limited) experience rather than scientific evidence being used.

To tackle these problems, and to prepare for the more challenging demands of the WFD, a workforce plan is being developed. This is based on future skills needs and turnover figures, plus a training programme. Without this, the ability of the EA to fulfil ecological monitoring requirements of the WFD either in-house or through commissioning contractors would be seriously compromised. There is a considerable mismatch between the current and future skills profiles, and recruitment/retention issues will become critical in the next 3-5 years. This affects the EA, SEPA, English Nature, CCWales and water companies. Already the demand for freshwater ecological advice for the WFD outstrips supply, including those ecologists in private consultancies.

The priority is to rectify the imbalance between declining expertise and increasing demand by better understanding and influencing the "supply chain" of knowledge and people. This means more clearly quantifying needs and targeting the "providers" (e.g. Universities, Research Institutes, Learned Societies) of good quality science, scientists and facilities.

3.1 Facilities

Large-scale experimental facilities represent immense scientific value, in that they facilitate collaboration, further cross-disciplinary research opportunities, and typically lead to the production of high impact publications. Such facilities are of particular value where they are coupled with long-term monitoring sites, providing both a real world context for experiments and a further, albeit less controlled, scale of investigation. However, the availability of large scale experimental facilities in Europe does not compare well globally, particularly with North America. There is currently no European comparison to the Experimental Lakes Area (58 lakes and drainage basins) or the North Temperate Lakes Long Term Ecological Research Area Network (26 sites, various habitats including stream basins and lakes).

Replicated artificial facilities where controlled experiments can be conducted do exist in the UK and Europe, but these are small scale compared to the experimental facilities available at the Sierra Nevada Aquatic Research Laboratory (nine replicate artificial channels each 50 x 1 m + four other river channels) and the Lewisville Aquatic Ecosystem Research Facility (166 mesocosms of various sizes + 18 channels). The European facilities that have been available historically are limited in number, and are declining. In the UK the most significant sites are the FBA's River Laboratory (artificial channels, fluvarium, fishing rights, floodplain, secure access) and Windermere site (water extraction and disposal rights on Windermere plus flow channel and replicate fish tanks/mesocosms), the University of Glasgow's Rowardennan facilities (fish observation tanks), and the University of Liverpool's experimental ponds (50 mesocosms each 3,000 L). Others are no longer functional (FBA's Lund Tubes, Waterstone Channels) and across Europe many facilities are threatened (Max Planck Institüt für Limnologie's river station at Schlitz, which will be closed at the end of 2006: Austrian Academy of Sciences river station at Lunz-am-See, already closed). Where experimental facilities do exist, they tend to be linked to individual University field stations, such that both the research area and access by the wider scientific community are limited. Naturally, any such facilities are constrained by the design of the experiments for which they were initially constructed, yet research priorities change over time. Large scale facilities suitable for many different uses are of the most value and here the facilities at the River Laboratory represent a significant resource, being constructed for varied use over the long-term. These facilities have produced high quality research and continue to do so. It is clear that experimental facilities for conducting freshwater ecology research in the UK do not exist to the same specification as available internationally. The availability of state-of the-art experimental facilities would provide an immediate scientific boost opening the possibility for direct studies relevant to the WFD.

An irreplaceable research facility is the Freshwater Biological Association's library (the UK's National Freshwater Library), plus the associated and unique Fritsch collection of illustrations of algae. This has remained at the FBA after the relocation of CEH Windermere to Lancaster and is arguably among the best freshwater libraries in the world, with an archive of rare, older literature now quite unavailable elsewhere. CEH finds itself unable to continue to support or to curate the library/Fritsch collection and the library is unlikely to get new accessions. The future of this resource is in severe doubt and it is presently not easily available to the science community, though FBA continues to house and care for it. This situation needs urgent clarification to find a solution and the lost opportunity to digitize the older literature and the Fritsch collection for the age of the internet needs to be addressed.

3.2 Monitoring networks

Long-term measurements represent a unique resource and document how systems have responded through time to environmental perturbation originating within the local catchment or as a result of regional or global influences such as acid rain or climate change. The UK is blessed with an excellent set of long-term records. The 'crown jewels' are the datasets that originated in the 1930s for some fish data but more typically in 1945 when a research programme started on phytoplankton dynamics in four lakes in the English Lake District Windermere N and S basins, Blelham Tarn and Esthwaite. This was instigated by the Freshwater Biological Association at Windermere which subsequently expanded the lakes studied to a fifth in the Windermere Catchment, Grasmere.

Since 1989 the monitoring has been undertaken by CEH (and its predecessor, IFE) and two more lakes were added to the programme in 1990. These data are nationally and internationally unique in terms of duration, frequency, consistency of method and breadth of measurements. Lake monitoring of a Scottish Loch, Loch Leven, by ITE and subsequently IFE and CEH was prompted by the International Biological Programme in 1967.

The FBA was also responsible for instigating long-term monitoring on two river sites in Dorset, the River Frome and Bere Stream, again with continuing monitoring by CEH. There are two other major programmes of long-term monitoring. The first is the Acid Waters Monitoring network directed by the Environmental Change Research Centre at University College London and funded by Defra, which started in 1988 and comprises 11 lakes and 11 streams. The second is the UK Environment Change Network (ECN), which is funded by a consortium of organisations that supply data to the network at, currently, 16 lakes and 28 rivers. The ECN started in 1992. The ECN is the UK's long-term, integrated environmental monitoring and research programme. ECN gathers information about the pressures on and responses to environmental change in physical, chemical and biological systems. It is supported by a consortium of 14 sponsoring organisations and nine research organisations. ECN can provide relevant data to issues such as climate change, air and water pollution, land use change and biodiversity loss. ECN is a multi-agency programme sponsored by: BBSRC, CCW, DARD (NI), Defra, Dstl, EA, EHS, EN, FC, NAW, NERC, SEERAD, SEPA and SNH.

Identifying long-term (defined as more than 10 years) continuous records of several or many environmental variables for both lakes and rivers provides an assessment of UK freshwater ecology data resources (Table 1 and Annex A). The type of information available varies and not all data are necessarily available over the whole time period. There is a good geographical spread of sites across the UK with a preponderance in northern England and Scotland reflecting the location of the major national water resources (Fig. 5). While it is not claimed that the meta-data in Table 1 are comprehensive they demonstrate the major research resource that is available nationally.

(Fig.5 and text continued overleaf)

Superimposed on these 'surveillance' monitoring sites is an intensive network of EA, SEPA and DOENI 'compliance' monitoring sites, which have existed for more than 10 years but with variable sampling frequency and patchy QA/QC. These data needs to be carefully collated to supplement the long-term monitoring science base and this ought to be undertaken at some appropriate time in the future. It is also clear that the monitoring was initiated for a variety of purposes and objectives; for example the Acid Waters Monitoring Network was established to assess the recovery from acidification as atmospheric emissions were reduced, whereas the ECN objective is to provide the evidence for global (climate) change impacts. As a result, the data are fragmented in location and in quality and are not easily accessible or readily available. In addition, each monitoring network is subject to ongoing financial pressures. It is recommended, therefore, that a UK web based database facility is established at the earliest opportunity. The development of a new Environmental Informatics initiative at CEH offers an opportunity to pursue this objective.

Taken together, the metadata indicate that a significant level of resource is required, in manpower alone, to maintain the sampling effort. QA/QC, databasing and interpretation of the data require yet further investment of resources that have to be identified. Crucial to the continuation of this activity, however, is that a case can be made that the sites remain relevant to the questions being addressed and a review of long-term monitoring is recommended at the earliest opportunity.

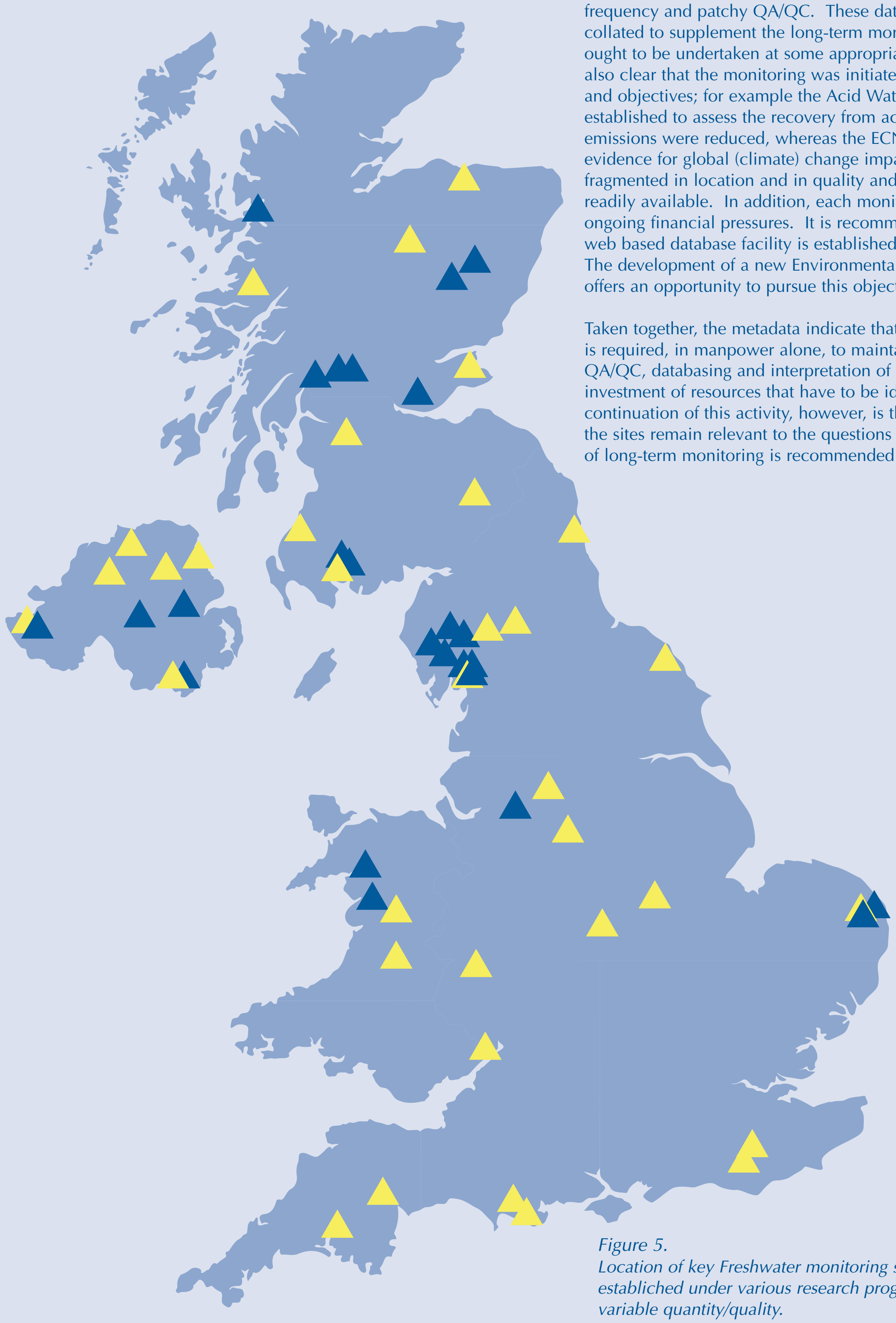

Figure 5.
Location of key Freshwater monitoring sites in the UK. These were establiched under various research programmes and so provide data of variable quantity/quality.

	Start Year	pH, Conductivity, Alkalinity	Phytoplankton (incl chlorophyll)	Zooplankton	Fish	Macrophytes	Sediment Diatoms	Benthic Invertibrates	Benthic Diatoms	Who did the Monitoring	Where the data are held
Lakes and Tarns											
Windermere N	1936	■	■	■	■		■		■	CEH & FBA	CEH & FBA
Windermere S	1945	■	■				■		■	CEH & FBA	CEH & FBA
Esthwaite	1945	■	■				■		■	CEH & FBA	CEH & FBA
Bleham Tarn	1947	■	■							CEH & FBA	CEH & FBA
Loch Leven	1967		■	■					■	CEH	CEH
Grasmere	1969	■	■							CEH & FBA	CEH
Blue Lough	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Burnmoor Tarn	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Llyn Cwm Mynach	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Llyn Llagi	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS & ECN
Loch Chon	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Loch Coire Fionnaraich	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Loch Coire nan Arr	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Loch Grannoch	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Loch Tinker	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Lochnagar	1988	■	■	■	■	■	■	■	■	UKAWMN	CEH & ENSIS & ECN
Round Loch of Glenhead	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
scoat Tarn	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS & ECN
Bassenthwaite	1990	■	■		■					CEH (coll=EA & FBA)	CEH
Derwentwater	1990	■	■		■					CEH (coll=EA & FBA)	CEH
Haweswater	1992				■					CEH (coll=UU)	CEH
Hickling Broad	1994			■						EA	ECN
Loch Davan	1994	■	■	■			■	■	■	SEPA	ECN
Loch Dee	1994	■	■	■			■	■	■	SEPA	ECN
Loch Katrine	1994	■	■	■			■	■	■	SEPA	ECN
Loch Kinord	1994	■	■	■			■	■	■	SEPA	ECN
Loch Leven	1994	■	■	■						CEH	ECN
Loch Lomond	1994	■		■		■	■	■	■	SEPA	ECN
Lough Erne	1994	■	■							DANI	ECN
Lough Neagh	1994	■	■							EA	ECN
Wroxham Broad	1994			■		■				EA	ECN
Rivers and Streams											
River Frome	1961	■			■					CEH	CEH
Bere Stream	1965	■								CEH	CEH
Plynlimon/Upper Severn Catchment	1970	■								CEH	CEH
Lathkill	1975	■	■			■	■	■	■	EA	ECN
Bradgate Brook	1977	■	■			■	■	■	■	EA	ECN
Afon Gwy	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Afon Hafren	1988	■	■		■	■	■	■	■	UKAWMN	CEH & ENSIS
Allt a' Mharcaidh	1988	■			■	■	■	■	■	UKAWMN, SEPA	CEH & ENSIS & ECN
Allt na Coire nan Con	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Beagh's Burn	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Bencrom River	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Coneyglen Burn	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Dargall Lane	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Narrator Brook	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Old Lodge	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS & ECN
River Etherow	1988	■			■	■	■	■	■	UKAWMN	CEH & ENSIS
Coquet	1992	■	■				■	■	■	EA	ECN
Trout Beck	1992	■	■			■	■	■	■	CEH	ECN
Eden (Kent)	1993		■			■	■		■	EA	ECN
Bure	1994							■		EA	ECN
Bush	1994	■	■							DANI	ECN
Cringle Beck	1994	■						■	■	EA	ECN
Eden (Cumbria)	1994	■				■	■	■	■	EA	ECN
Eden (Fife)	1994	■				■	■	■	■	SEPA	ECN
Esk	1994	■	■			■	■	■	■	EA	ECN
EXE	1994	■	■				■	■	■	EA	ECN
Faughan	1994	■	■				■	■	■	DOENI	ECN
Frome	1994	■	■				■	■	■	EA	ECN
Garvary	1994	■	■				■	■	■	DOENI	ECN
Lower Clyde	1994	■				■	■	■	■	SEPA	ECN
Spey at Fochabers	1994	■					■	■	■	SEPA	ECN
Stinchar	1994	■					■	■	■	SEPA	ECN
Tweed at Galafoot	1994	■				■	■	■	■	SEPA	ECN
Wye	1994	■	■			■	■	■	■	EA	ECN
Cree	1995	■					■	■	■	SEPA	ECN

Table1. Catalogue of key long-term datasets in the UK giving location, sampling dates, indication of variables measured, sampling frequency and data provenance

SCIENCE QUESTIONS/ DIRECTIONS/ OUTCOMES

In this section we illustrate the exciting strategic and fundamental opportunities afforded by freshwater ecological research.
The catchments of freshwater ecosystems act as integrators of both local and wide scale environmental conditions and change, whether anthropogenic or natural. In the UK, existing networks of key ('model') freshwater systems and long-term records (including some of the best known anywhere) should be exploited to tease out the consequences and causes of environmental changes at a variety of scales. Such model systems can be put in the context of important, wider environmental gradients (of nutrient enrichment, for instance), characterised by an array of comparative systems, that can be studied less intensively and for shorter periods in a series of non-manipulative, 'statistical' experiments. Enhanced field facilities at the model sites should then be used for manipulative experiments using key environmental variables, such as the frequency of disturbance from fluctuating flows and sediment input. Such approaches could be used to address key questions at a range of spatiotemporal scales. Most important, the outcome of such scientific progress will be of practical and financial value to the UK, and elsewhere, in the form, for instance, of early warning and surveillance systems, in scientifically informed management, and in practical tools for managers.

Here we present a series of priority areas and questions for research, each with an explanation of how science around each of the numbered questions could provide management outcomes.

Ecological Theory

Freshwaters can contribute to ecological theory, particularly because they are often more amenable than other systems to certain approaches. Example questions include:

1) What are the macroecological patterns (e.g. in species richness, abundance, body size) in freshwaters, and how do they compare with terrestrial and marine systems?
2) What is the role of diversity in determining ecosystem function?
3) How do body size and body size-abundance patterns determine food web topology and function?

Applied and strategic outcomes:

1) Prediction of ecological systems is difficult but is the only real test of understanding and crucial for management. Large, cross-system (macroecological) scales are often the only scales at which ecological systems are characterised by consistent patterns, yet we know relatively little of such patterns in fresh waters and they may be a better basis for prediction than the simple, empirical classification used so far.

2) A major question is how far ecosystem processes ('goods and services') are underwritten by biodiversity, and hence how do we predict what the consequences of losses in diversity may be?

3) The distribution of body size is a fundamental characteristic of natural communities and food webs, and could be used as a tool to characterise and measure ecological status

Linking freshwaters to landscapes and the Earth System

Freshwaters receive material from their catchment and export them to the ocean and exchange material with the atmosphere and so play an important role in the transport and transformation of materials within global biogeochemical cycles. Example questions include:

1) What is the flux of greenhouse gases (CO2, CH4, NOx) between freshwaters and the atmosphere?
2) What controls the export of dissolved organic carbon from catchments to freshwaters to the ocean?
3) What is the biogeochemical fate of agricultural chemicals (fertilizers, toxins) as they pass through catchments, food webs and ecosystems?

Applied and strategic outcomes:

1) Rivers and lakes may be underestimated sources of powerful greenhouse gases, particularly in hypernutrified systems running through agricultural landscapes: this needs measuring and characterisation, and measures taken to reduce it.

2) Increases in the output of DOC from catchments has been widely measured in Europe but poorly explained and its consequences are unknown.

3) Where is it important to minimise inputs of agrochemicals, in relation to eutrophication and the amplification of toxins through food webs? Can agrochemicals be immobilised, and where not, and how can their biodegradation by ecosystems be maximised?

Environmental Change and Temporal Variability

Freshwaters are sensitive to local environmental perturbation in the catchment as well as to changes in the climate. Palaeolimnological records of change document historical responses as do, with finer resolution but shorter duration, long-term records. Example questions include:

1) How do freshwater systems vary naturally within and between years?
2) How do freshwater biota react to extreme hydrological events?
3) How can natural and anthropogenic effects be distinguished?
4) What will be the effects of climate change on freshwaters of different types?
5) How can changes be attributed to the effects of climate and other drivers?

Applied and Strategic Outcomes:

1), 3) & 5) We will be able to distinguish climatic and more directly anthropogenic changes more precisely, which will be of use in surveillance.

2) & 4) We will be able to advise on managing rivers and their catchments to maximise their resilience to an increasingly extreme climate, thus minimising damage.

Biodiversity

Freshwater biodiversity is often concentrated in organisms of small body size, where short generation times give opportunities for studying effects of biodiversity on ecosystem function. Freshwaters are also often spatially isolated so that issues of dispersal and spatial heterogeneity become important. Example questions include:

1) What is the diversity of poorly known parts of the system (microbial communities, the meio- and microfauna, groundwater, hyporheic systems, floodplains, wetlands and small water bodies, and of riparian and marginal communities)?
2) What is the role of the natural fragmentation of freshwaters in the landscape in the maintenance of species and genetic diversity in local systems?
3) Can high local habitat heterogeneity (such as the intact morphology of river systems) buffer freshwater ecosystems against environmental perturbation?
4) What is the effect of the loss of local freshwaters in the landscape, e.g. via dry periods, over-abstraction or pollution, on regional diversity?

Applied and strategic outcomes:

1) We will have a better knowledge of the 'capital assets' of freshwater ecosystems.

2) & 4) We will be able to specify a 'critical load' of local habitat loss that will not threaten regional biodiversity by habitat fragmentation, and thus help maintain good ecological status through the maintenance of ecological connectivity.

3) We will be able to advise on whether the maintenance of an 'intact' physical morphology and diversity of fresh waters is effective in sustaining good ecological status.

Regime change, resilience and hysteresis

The response of whole systems to environmental perturbation depends very much on the nature and strength of trophic interactions, an area where freshwater scientists are at the forefront of ecological thought. Example questions include:

1) Are there regime changes and hystereses along enrichment and acidification gradients in aquatic systems where such non-linear phenomena are less well known (i.e. beyond shallow lakes)?
2) How do habitat interfaces (land-water, surface-groundwater) determine food web subsidies between neighbouring systems?
3) How do freshwater systems react to multiple stressors?
4) What are the links at the base of the food-chain (i.e. microbe-protist-meiofauna)?

Applied and strategic outcomes:

1) A better knowledge of ecological hystereses will inform our assessment of ecological recovery, and may offer a means to help the recovery of altered systems.

2) Connectivity between neighbouring systems is a major feature of 'good ecological status', and cross-system food web subsidies at the land-water interface are of enormous conservation importance (sustaining birds, bats and productive fisheries): we will be able to advise on how to maximise ecological benefit with least cost.

3) Anthropogenic stressors are seldom simple, and combinations are common (eg increased inorganic sediment along with increased nutrient loading and temperature). These combined effects are poorly understood and can be the subject of experiment with the right facilities, resulting in an increased ability to provide advice on protection and amelioration.

4) Can such links be used to characterise systems of 'good ecological status' and how can new technologies help elucidate such interactions?

An overall beneficial practical outcome: the sustainable use of freshwaters

Many of the questions outlined above underpin the secure management of freshwaters by providing the context for policy and decision-making in the UK and internationally. There is also a number of other directly-applied and pressing questions that need to be answered. Examples include:

1) How do we define 'good ecological status' in the context of the Water Framework Directive?
2) What will be the effect of a regime of increasing species invasion on freshwater diversity?
3) How do we predict the rate, direction and extent of recovery trajectories following ecological restoration?
4) How can catchments be managed to improve flood control and reduce nutrient concentration in freshwaters?

RECOMMENDATIONS

5.1 Summary Recommendations

The key recommendation is that we must establish a cooperative research partnership (CRP) in freshwater biology to facilitate a coordinated approach by public and private sectors and to address what is identified here as a national research deficit. Specifically this approach must:

- Provide added value to our key, long term research sites and data records.
- Safeguard and coordinate national facilities.
- Encourage more and better freshwater biological research, improved professional training and better uptake of science in catchment management.
- Make full use of funding opportunities such as those afforded by the new EU FP VII .

5.2 The whole community should respond

Freshwater ecology in the UK is essentially funded and regarded as a small-scale science, yet is faced with very large scale problems associated with a rising demand for clean water in an increasingly crowded island and in the midst of environmental change.
The lack of a long-term strategy for freshwater ecology, however, has clearly pushed it into a population and intellectual bottleneck, with an unplanned and undesirable loss of the scientific skills necessary to research and manage freshwater systems at a time when such skills are more necessary than ever. This report is not the first time that such problems have been identified, but they are now more pressing than ever. Less than a decade ago, and acknowledging a national decline in the subject, NERC funded a small programme (£1 million) of 'capacity building' fellowships and studentships in freshwater biology, and also enabled FBA to fund a few 'pioneer' fellowships. This 'new capacity' has been built, though we clearly need further, concerted action to encourage and reinforce regrowth in this strategically important discipline. This investment should be viewed as a success but the resources permitted very little capacity to be built and so it has not had the sustained impact that was desired; namely, providing a stimulus of new blood to the discipline. We would not recommend a simple repeat of this exercise.

Financial and other pressures have led NERC to make difficult choices in the allocation of its resources and some of these decisions, perhaps notably the consolidation of two CEH sites at Windermere and Merlewood to the University of Lancaster, have impacted the critical mass of scientists in freshwater ecology.
This is despite extraordinary and unprecedented global pressures on inland waters and their ecology, from a burgeoning human population and economic development. Closely related to this is the management imperative encapsulated in new 'policy drivers'.
In Europe, EU directives and national priorities on surface and groundwaters, on habitats, biodiversity action plans, on climate change indicators, flood management, nitrate vulnerable zones, and many others, have all highlighted a deficit in knowledge and manpower within institutes, agencies and ministries.
These weaknesses are by no means all in freshwater ecology, but the placing of the intangible 'good ecological status' at the centre of policy through the EU Water Framework Directive makes the ecological deficit particularly acute – while even Environment Minister Eliot Morley himself recently conceded that perhaps 95% of English and Welsh freshwaters would fail a test of 'good ecological status'.

The deficits in scientific capacity in the UK, both in the research community and in the agencies, are evident and widely acknowledged. Our **essential recommendation, therefore, is that the community as a whole needs to respond.** This community must include not only researchers and the traditional funders of freshwater ecological research, notably environmental agencies and government departments, but also those organisations whose business is underpinned by science and the ecosystem services that underpin water resources. A clear requirement in this respect is fully to engage the water companies whose input to freshwater ecology research to date has been minimal. **We strongly recommend that all organisations involved work together constructively for the purpose of safeguarding key long-term sites and improved stewardship of UK freshwater ecology research facilities, with the objective of promoting the delivery of science requirements and their practical outcomes.**

5.3 Bringing new resources to freshwater biology

By the measures we have been able to marshal, there are clear signs of ongoing national decline in the UK's capacity in the science of freshwater ecosystems. However, financial pressures on the, largely Government-funded, bodies responsible seem so severe that the sustained and substantial new funding required to remedy matters seems beyond us. This is **why we recommend a new cooperation between the parties on a national (or feasibly international) basis.**
The main public sector research body concerned is NERC, which supports freshwater ecological research through CEH and via University support. The Universities also carry out freshwater ecological research and teaching based on non-NERC sources of income. There are many public and private sector organisations whose business relies on freshwater biological science and who have some scientific capacity, the former including Defra, the Scottish Environment Protection Agency, the Environment Agency, DOE Northern Ireland and the national conservation agencies. In the private sector are the powerful water supply and sewerage plc's, whose activities depend on and determine the fate of the freshwater environment. Also in the private sector are stakeholders such as conservation charities and angling organisations, as well as the FBA itself. These organisations and others have an interest in the good ecological status of freshwaters, and could be part of the solution to deficits in the science.

Our recommendation turns to a model that has been successful elsewhere and could be modified for the British context. Cooperative Research Centres (CRC) are used, for instance in Australia, to focus resources and cooperation in strategically important areas of science. During its lifetime, the CRC in freshwater ecology in Australia created a more active, younger and arguably larger freshwater biological research community there than we have in the UK. Admittedly, problems around freshwater resources in Australia are obvious and high profile but the population is only about one third of that of the UK. A CRC normally receives core funding to about half its needs, more than covering a lightweight central administration, and has collaborating organisations (representing science users, researchers and other stakeholders) that subscribe to the CRC the remaining half of its income. The CRC then invites bids for moderate to large-scale strategic research projects from consortia of its subscribing organisations. These consortia thus often combine scientists and users, and carry out freshwater projects of a sort and scale that rarely seem to arise in the UK context.

A similar initiative would, we believe, provide the framework to take forward UK freshwater ecology by clearly enabling 'blue-skies' science to blossom whilst maintaining the all important contribution to policy and management. Such a goal was sought by the recent initiative in Sustainable Water Management but the specification of the science requirement foundered, largely due to the failure to involve key stakeholders adequately and because few scientists could see beyond the development of a traditional Thematic approach.

We recommend that the **UK community embarks on a Cooperative Research Partnership (CRP) in freshwater ecology,** based on the CRC model, which would seek to attract funding from a wide range of stakeholder organisations. Its outputs would be high quality strategic and applied science plus in-service training and research opportunities for agency staff. Therefore, we turn finally to the means by which such an organisation could operate and to the needs for infrastructure and facilities and how they might be met.

5.4 Using the heritage: a CRP in Freshwater Biology

We have shown the UK already possesses some of the finest heritage in freshwater ecology anywhere in the world.
This includes experience, skills and knowledge, long-term data, access to key sites, field experimental facilities and instrumented catchments, archives and a world-class freshwater library plus the Fritsch collection. At the heart of this heritage lie the sites with long-term data in the English Lake District (based on Windermere) and on the Frome in Dorset at The River laboratory (and one of NERC's 'LOCAR' sites).

We envisage the CRP, with representation of the partner organisations on a Research Committee, that would devise and administer a programme of projects that could be dispersed and based around the country as needs require (e.g. in a University or institute), or hosted at the residual and refurbished FBA laboratories and field facilities. Such projects would thus have access to improved national experimental facilities and data-sets on the FBA and CEH sites or elsewhere (such as NERC's LOCAR catchments). FBA's sites could also be used for high-level freshwater training courses, in collaboration with Universities or other organisations.

At the heart of this initiative would be the objective of improved strategic science, improved uptake of that science in management, improved professional training opportunities and the rejuvenation of the UK freshwater community and its research. **Thus we recommend support for a CRP that exploits the heritage of data, sites and facilities and national library, in support of a) more and better research at larger scales, b) better uptake of science in environmental management, and c) high level science training and development opportunities for the agencies.**

In the international dimension, UK facilities could also serve the needs of researchers in the EU, which could thus be a further source of funding once a UK core had been achieved. A set of long-term ecological research sited across the EU, each with long term records, could be absolutely invaluable in assessing and analysing environmental change. Individually, such sites have been vulnerable in their own countries. Together, they could be much stronger, and, in this context, FBA has embarked on a European membership initiative and bi-annual conference: this could eventually be extended into a Europe-wide CRP.

Annex A Catalogue of key long-term datasets in the UK

	Source of Metadata	UK Region	Start Year	End Year (na= on going)	Lenght of series (years)	pH, Conductivity, Alkalinity	Secchi depth, turbidity, suspended sediment	Temperature, dissolved oxygen	Nutrients (NH4, N, NO3, NO2, P, PO4, Si04	Major Ions (Cl, SO4, Na, K, Ca, Mg	Total & Particulate Carbon, Doc, OrganicMatter, Bod	Transition Metals & Aluminium	Phytoplankton (Incl Chlorophyll)	In/Out flow or discharge	Lake or River level/Stage	Zooplankton	Fish	Macrophytes	Sediment Diatoms	Benthic Invertibrates	Benthic Diatoms	Sampling Frequency	Who did the monitoring	Where data held
Lakes and Tarns																								
Windermere N	C,U	C	1936	Ongoing	69	■	■	■	■	■	■	■	■		■	■	■		■		■	Weekly/fortnightly	CEH & FBA	CEH & FBA
Windermere S	C,U	C	1945	Ongoing	60	■	■	■	■	■	■	■	■	■	■				■		■	Weekly/fortnightly	CEH & FBA	CEH & FBA
Esthwaite	C,E,U	C	1945	Ongoing	60	■	■	■	■	■	■		■	■	■				■		■	Variable	CEH/FBA	CEH & FBA
Bleham Tarn	C,U	C	1947	Ongoing	58	■	■	■	■		■	■	■			■						Variable	CEH/FBA	CEH & FBA
Loch Leven	U	S	1967	Ongoing	38		■		■				■								■	Variable	CEH	CEH
Grasmere	C	C	1969	Ongoing	36	■	■	■	■	■	■	■	■			■						Weekly/fortnightly	CEH/FBA	CEH
Rostherne Mere (Cheshire)	U	E	1967	1989	22								■				■	■	■	■	■	12 to 1 x per yr	CEH (coll=FBA)	Unknown
Blue Lough	A	NI	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Burnmoor Tarn	A	C	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Llyn Cwm Mynach	A	W	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Llyn Llagi	A,E	W	1988	Ongoing	17	■		■	■	■	■	■					■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS & ECN
Loch Chon	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Loch Coire Fionnaraich	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Loch Coire nan Arr	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Loch Grannoch	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Loch Tinker	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Lochnagar	A,E	S	1988	Ongoing	17	■		■	■	■	■	■	■			■	■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS & ECN
Round Loch of Glenhead	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS
Scoat Tarn	A,E	C	1988	Ongoing	17	■		■	■	■	■	■					■	■	■	■	■	12 to 1 x per yr	UKAWMN	CEH & ENSIS & ECN
Bassenthwaite	C,U	C	1990	Ongoing	15	■	■	■	■				■				■					Variable	CEH(coll=EA&FBA)	CEH
Derwentwater	C,U	C	1990	Ongoing	15	■	■	■	■				■				■					Variable	CEH(coll=EA&FBA)	CEH
Haweswater	U	C	1992	Ongoing	13												■					Variable	CEH(coll=UU)	CEH
Hickling Broad	E	E	1994	Ongoing	11											■						Variable	EA	ECN
Loch Davan	E	S	1994	Ongoing	11	■	■	■	■	■	■	■	■			■			■	■	■	Variable	SEPA	ECN
Loch Dee	E	S	1994	Ongoing	11	■	■	■	■	■	■	■	■			■			■	■	■	Variable	SEPA	ECN
Loch Katrine	E	S	1994	Ongoing	11	■	■	■	■	■	■	■	■			■			■	■	■	Variable	SEPA	ECN
Loch Kinord	E	S	1994	Ongoing	11	■	■	■	■	■	■	■	■			■						Variable	SEPA	ECN
Loch Leven	E	S	1994	Ongoing	11	■	■	■	■	■		■	■			■		■	■	■	■	Variable	CEH	ECN
Loch Lomond	E	S	1994	Ongoing	11	■	■	■	■	■	■	■				■						Variable	SEPA	ECN
Lough Erne	E	NI	1994	Ongoing	11	■	■	■	■	■			■									Variable	DANI	ECN
Lough Neagh	E	NI	1994	Ongoing	11	■	■	■	■	■			■									Variable	DANI	ECN
Wroxham Broad	E	E	1994	Ongoing	11											■		■				Variable	EA	ECN

Source of Information: A = Acid Water Monitoring Network; C = CEH database at Lancaster; E = ECN; U = UKEDIE UK Regions; C = Cumbria; E = Rest of England; S = Scotland; W = Wales; NI = Northern Ireland

	Source of Metadata	UK Region	Start Year	End Year (na= on going)	Lenght of series (years)	pH, Conductivity, Alkalinity	Secchi depth, turbidity, suspended sediment	Temperature, dissolved oxygen	Nutrients (NH4, N, NO3, NO2, P, PO4, Si04	Major Ions (Cl, SO4, Na, K, Ca, Mg	Total & Particulate Carbon, Doc, OrganicMatter, Bod	Transition Metals & Aluminium	Phytoplankton (Incl Chlorophyll)	In/Out flow or discharge	Lake or River level/Stage	Zooplankton	Fish	Macrophytes	Sediment Diatoms	Benthic Invertibrates	Benthic Diatoms	Sampling Frequency	Who did the monitoring	Where data held
Rivers and Streams																								
River Frome	U	E	1961	Ongoing	44	■		■	■	■				■			■					Variable	CEH	CEH
Bere Stream	U	E	1965	Ongoing	40	■		■	■	■				■								Weekly	CEH	CEH
Plynlimon/Upper Severn Catchment	U	W	1970	Ongoing	35	■		■	■	■	■											Weekly	CEH	CEH
Blackbrows Beck (Elliot)	U	C	1966	2000	34												■					Annually	FBA	Originator
Lathkill	E	E	1975	Ongoing	30	■	■	■	■	■	■	■	■					■	■	■	■	Variable	EA	ECN
Bradgate Brook	E	E	1977	Ongoing	28	■	■	■	■	■	■	■	■					■	■	■	■	Variable	EA	ECN
Afon Gwy	A	W	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Afon Hafren	A	W	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Allt a' Mharcaidh	A,E	S	1988	Ongoing	17	■	■	■	■	■	■	■	■				■	■	■	■	■	12 to 1 x per yr	UKWMN, SEPA	CEH & ENSIS & ECN
Allt na Coire nan Con	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Beagh's Burn	A	NI	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Bencrom River	A	NI	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Coneyglen Burn	A	NI	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Dargall Lane	A	S	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Narrator Brook	A	E	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Old Lodge	A,E	E	1988	Ongoing	17	■		■	■	■	■	■					■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS & ECN
River Etherow	A	E	1988	Ongoing	17	■			■	■	■						■	■	■	■	■	12 to 1 x per yr	UKWMN	CEH & ENSIS
Afon Cwym	U	W	1988	1999	16												■							
Afon Hore	U	W	1988	1999	16												■					Variable	CEH	CEH
Coquet	E	E	1992	Ongoing	13	■	■	■	■	■	■	■	■						■	■	■	Variable	EA	ECN
Trout Beck	E	E	1992	Ongoing	13	■	■	■	■	■	■	■	■					■	■	■	■	Variable	CEH	ECN
Eden (Kent)	E	E	1993	Ongoing	12		■	■	■	■	■	■	■					■	■		■	Variable	EA	ECN
Bure	E	E	1994	Ongoing	11															■		Variable	EA	ECN
Bush	E	NI	1994	Ongoing	11	■	■	■	■	■			■									Variable	DANI	ECN
Cringle Beck	E	NI	1994	Ongoing	11	■														■	■	Variable	EA	ECN
Eden (Cumbria)	E	C	1994	Ongoing	11	■	■	■	■	■	■	■						■	■	■	■	Variable	EA	ECN
Eden (Fife)	E	S	1994	Ongoing	11	■	■	■	■	■	■	■						■	■	■	■	Variable	SEPA	ECN
Esk	E	E	1994	Ongoing	11	■	■	■	■	■	■	■	■					■	■	■	■	Variable	EA	ECN
EXE	E	E	1994	Ongoing	11	■	■	■	■	■	■	■	■						■	■	■	Variable	EA	ECN
Faughan	E	NI	1994	Ongoing	11	■	■	■	■	■	■	■	■						■	■	■	Variable	DOENI	ECN
Frome	E	E	1994	Ongoing	11	■	■	■	■	■	■	■	■						■	■	■	Variable	EA	ECN
Garvary	E	NI	1994	Ongoing	11	■	■	■	■	■	■	■	■						■	■	■	Variable	DOENI	ECN
Lower Clyde	E	S	1994	Ongoing	11	■	■	■	■	■	■	■						■	■	■	■	Variable	SEPA	ECN
Spey at Fochabers	E	S	1994	Ongoing	11	■	■	■	■	■	■	■							■	■	■	Variable	SEPA	ECN
Stinchar	E	S	1994	Ongoing	11	■	■	■	■	■	■	■							■	■	■	Variable	SEPA	ECN
Tweed at Galafoot	E	S	1994	Ongoing	11	■	■	■	■	■	■	■						■	■	■	■	Variable	SEPA	ECN
Wye	E	W	1994	Ongoing	11	■	■	■	■	■	■	■	■					■	■	■	■	Variable	EA	ECN
Cree	E	S	1995	Ongoing	10	■	■	■	■	■	■	■							■	■	■	Variable	SEPA	ECN

Annex B Freshwater experimental research facilities in UK and around the world

Institutes				Comments	
UK					
River lab	FBA/CEH	UK	River	Artificial streams (flow through) Fluvarium (flow through)	Waterstone Channels No longer functional
Pitlochry	FRS	UK	River	Aquaria Fluvarium (flow through)	
Lund tubes	FBA	UK	Lake	Large scale lake enclosures	No longer functional
Windermere fish tanks	FBA	UK	Lake/River	Aquaria	
Centre for Aquatic Plant Management (formerly dismantledAquatic Weeds Research Unit)	BBSRC	UK	Lake	Mesocosms of various size, based at Sonning on Thames	CAPM staff transferred to NERC, site
Universities					
Rowardennan	Glasgow University	UK	River	Fish holding unit	Fish behaviour studies Observation tanks
Ness Gardens	Liverpool University	UK	Lake	50 temperature controlled ponds	
Europe					
Plön	Max Plank	Germany	Lake	Giant lake simulation system (Plankton Towers).	Change in direction: No longer limnology.
Silkeborg	NERI	Denmark	Lake	16 x temperature controlled ponds	
Wageningen	ALTERRA	Netherlands	Ditch/Lake	20 x artificial ditches 24 x mesocosms	
Balaton Limnological	Hungarian Academy of Sciences	Hungary	Lake	Experimental lake and Research wetland area Aquaria	
Schlitz	Max Plank	Germany	River		To close at end of 2006
Silkeborg	NERI INRA	DK France	River Lake	Artificial streams Experimental pond unit (Rheu, Ille et Vilaine).	
Lunz	Danube University, Vienna, BOKU	Austria	River	Biological Station Instrumented river	Original lab closed . No longer supported by central government funding, future threatened
Limnological Institute	University of Konstanz	Germany	Lake	18 mesocosms (varying sizes)	
World					
SNARL	University of California	USA	River	9 artificial channels (1m x 50m long) 4 controlled river channels	Linked to LTER network
Lower East Fork River	Proctor & Gamble	USA	River	Experimental Stream Facility (ESF) 8 artificial streams automatically monitored and recorded every few minutes temp, pH, O2, conductivity, stream flows, light levels, temperature and humidity, weather conditions	
Experimental Lakes	University of Manitoba	Canada	Lake	58 small lakes (1 to 84 ha in area) and their drainage basins, plus three additional stream segments	Area (ELA)

Institutes				Comments	
World					
Lewisville Aquatic Ecosystem Research Facility (LAERF)	US Corps of Engineers	USA	Lake	30 x 6,000L mesocosms (1.5 m deep) 24 x 1,845L mesocosms 18 x 14,000L mesocosms (3m deep) 20 x 1,200L temperature controlled mesocosms 74 x ponds (earthen or lined) 18 x flowing raceways	
Notre Dame Environmental Research Centre	University of Notre Dame	USA	Lake	30 lakes and bogs with a combined surface area of 1350 acres. Experimental aquaria	Linked to LTER network
Long Term Ecological Research Network	Various Universities and institutes, including US Forest Service	North America	Variety of ecosystems	26 "sites" including: Coweeta, Hubbard Brook, Luquillo, Andrews, Baltimore, Bonanza Creek, McMurdo Dry Valleys, North Temperate Lakes	Instrumented catchments with various linked experimental facilities
Tomakomai Experimental Forest (TOEF)	Hokkaido University	Japan	River	Artificial stream six stream tanks (observation)	
Cooperative Research Centre for Freshwater Ecology (CRCFE)		Australia			

Annex C UK university staff actively publishing in freshwater biology, 1999-2004

	Location	Research interests	N recent papers (1999-2004)
Battarbee RW†	UC London	Palaeolimnology	25
Hildrew AG†	QMU London	Stream ecology	30
Moss B†	Liverpool	Limnology	37
Ormerod SJ†	Cardiff	Stream/wetland ecology	44
Huntingford FA†	Glasgow	Fish behaviour	33
Metcalfe NB†	Glasgow	Fish behaviour	51
Laybourn-Parry J†	Nottingham	Lake meiofauna	28
Petts GE†	Birmingham	Geomorphology	30
Gurnell AM† KC	London	Geomorphology/hydrology	36
Cowx IG†	Hull	Fish management	33
Staff at other grades in:			
Fisheries			
Griffiths SW	Cardiff	Fish behaviour	20
Smith C	Leicester	Fish ecology	31 (?)
Lucas MC	Durham	River fish ecology	24
Meiofauna			
Rundle SD	Plymouth	River/pond meiofauna	19
Schmid-Araya JM	QMU London	Rotifers	13
Robertson AL	Surrey	Stream meiofauna	10 (?)
River macroinvertebrates			
Milner AM†	Birmingham	Stream invertebrates	18
Lancaster J	Edinburgh	Stream invertebrates	10
Ledger M	Birmingham	Algal/invertebrate interactions	7
Gee JHR†	Aberystwyth	Stream invertebrates	5
Young MR	Aberdeen	Malacology	12
Dobson M	MMU	Stream invertebrates	13
Woodward G	QMU London	Food webs	11 (?)
Wotton RS†	UC London	Organic matter processing	12
Macrophytes			
Murphy KJ†	Glasgow	Aquatic macrophytes	16
Pentecost A†	KC London	Stream bryophytes	16
Willby NJ	Stirling	River macrophytes	6
Pond/lake invertebrates			
Harper DM†	Leicester	Lake ecology	30
Jeffries MJ	Northumbria	Pond macroinvertebrates	6
Wood PJ	Loughborough	Pond/cave macroinvertebrates	15
Greenwood MT†	Loughborough	Pond/stream invertebrates	8
Biggs J	Oxford Brookes	Pond invertebrates	7
Shallow lake ecology			
Sayer CD	UC London	Shallow lake ecology, diatoms…	4

Notes

1. Other occasional freshwater biologists include Prof P. Read (Napier; mostly marine aquaculture); DT Bilton (Plymouth, mostly evolutionary); GR Carvalho (Hull, mostly marine fish genetics), H. Faulkener (Hertfordshire; mostly water quality), PH Warren (Sheffield, mostly general ecology).

2. All data were obtained from ®ISI web of Knowledge by i) searching all papers published in major, whole-organism freshwater journals between 1999-2004 (Freshwater Biology, Limnology & Oceanography, Canadian Journal of Fisheries and Aquatic Sciences, Archiv für Hydrobiologie, Hydrobiologia, Journal of the North American Benthological Society, Aquatic Conservation) and ii) listing all papers published by each named individual identified during stage (i). Papers on marine systems were excluded.

Staff employed on fellowships (i.e. in non-faculty positions) have been excluded (e.g. R. J. Flower, UCL), as have some very recently recruited faculty staff in freshwater biological areas who have yet to publish from UK addresses (e.g. Suzanne McGowan, Nottingham; N. J. Anderson, Loughborough).

3. † Indicates staff already actively publishing in freshwater biology by 1981-86.

(?) Indicates some uncertainty owing to moves between institutions.

Annex D Losses of full-time faculty from universities of staff formerly publishing in freshwater biological fields* in the period 1981-1986. For qualification see Annex C, note 2.

Staff	Former Academic Institution
Reynoldson T. B.	Bangor
Happey-Wood CM	Bangor
Brook A J	Buckingham
Edington JM	Cardiff
Benson-Evans K	Cardiff
Edwards RW	Cardiff
Learner MA	Cardiff
Bailey RG	Chelsea
Bark AW	Chelsea
Whitton BA	Durham
Bowler K	Durham
Savage AA	Keele
Badcock RM	Keele
Jones RI	Lancaster
Bullock JA	Leicester
Moody J	Leicester
Oldham RS	Leicester Polytechnic
Young JO	Liverpool
Eaton JW	Liverpool
Wakefield PM	Liverpool
Clymo RS	London
Green J	London
Duncan A	London
Denny P	London
Wade M	Loughborough
McLachlan A. J.	Newcastle
Adams J	Newcastle
Morris R	Nottingham
Holdich DM	Nottingham
Gower A	Plymouth
Andrew T.E.	Royal Holloway/Coleraine
Sleigh MA	Southampton
Thomas JD	Sussex
Townsend CR	UEA
Lawton JH	York