Institute of Freshwater Ecology

Expert review group on wetlands
- Combined report of the work of the ERG

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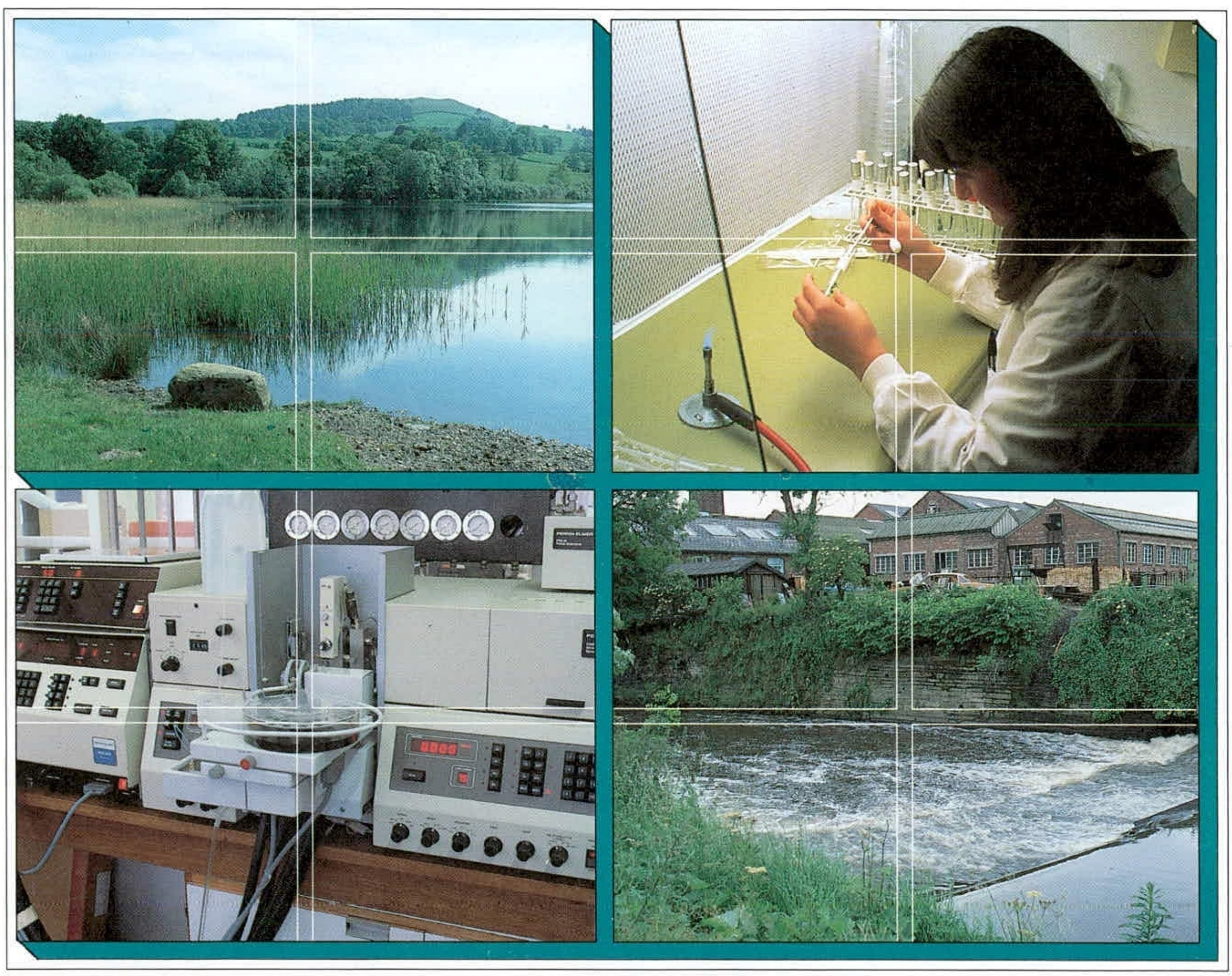

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EXPERT REVIEW GROUP ON WETLANDS
- Combined report of the work of the ERG

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REPORT BY

THE NERC EXPERT REVIEW GROUP ON

WETLANDS

21 April 92

to

Terrestrial and Freshwater Sciences Committee

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1 INTRODUCTION

1.1 Background

The NERC Terrestrial and Freshwater Sciences Committee considered that wetlands were an area of public concern and that research in the area should be reviewed.

The terms of reference were to review research and to make recommendations on the future direction of NERC-supported research to the Director of Terrestrial and Freshwater Science. These terms of reference were to be enabling.

The Expert Review Group (ERG, composition in Appendix 1) held meetings on 4 December 92 and on 22 February 93.

This report arises from those meetings. It outlines the scope of wetlands and the key processes in their development and maintenance. It identifies areas in which the ERG concludes that research needs to be stimulated.

1.2 What *are* wetlands?

There are two largely distinct views of 'wetland':

(a) Those interested in the producer and decomposer cycles at the bottom of the trophic pyramid include only peatlands, freshwater marshes and saltmarshes;

(b) Those primarily interested in the top of the pyramid (particularly in birds, fish & man, and interested in water quality, water quantity, and habitat and food chain support) include shallow lakes, streamsides and estuaries as well. This is the view of, for example, the international Ramsar Convention on 'Wetlands of International Importance Especially as Waterfowl Habitat' adopted at Ramsar in Iran during 1971 and now ratified by 75 States. In March 1993 the total area of the 592 wetlands declared was 368 x 10^3 km^2. This view of wetlands is especially important in questions of conservation, because they often require an integration across whole landscapes and a consideration of the interaction of human societies with wetlands, especially in Third World development strategies currently being formulated.

We have tried to hold both these views in mind but find that most of the gaps in *basic* research relate to processes integral in the first view, which therefore dominates in this report.

The ERG concentrated on the core of those characteristics and processes which typify the following list of generally recognisable site-types or categories:

- mires (i.e. bogs and fens accumulating soils which are almost entirely organic);

- freshwater marshes with at least seasonally waterlogged mineral soils but not accumulating much peat;

- salt marshes with soils flooded by tidal seawater at least monthly;

plus

- water bodies which contain the above three as integral parts e.g. riverine marginal wetlands, flood plains and estuarine areas (but not estuary ecosystems themselves).

An operational definition for the first three, and for the margins of the fourth, is that one would normally need to wear Wellingtons to work on them, but would not need a boat.

These wetland systems have three factors in common:

- porous solid matrices partially or completely filled with water that may be moving or stagnant;

- water present near or above the surface of the matrix for at least part of the year thus emphasising the transitional state of water rather than its permanence;

- microbiological activity, on substrates within the system, usually creating anoxic conditions.

Lakes and rivers are important but most of us believed they were were outside our terms of reference. There is conflict between the scientific and legal understanding of 'wetland' which we also ignored.

1.3 Key features of wetlands

Most wetlands have the following characteristics:

- they are at least seasonally waterlogged with consequent anoxia a short distance below the surface;
- their physical, chemical and ecological properties are strongly dependent on the timing and nature of water movement;
- they have organised heterogeneity, often hydrologically controlled, on several scales from a few centimetres to kilometres;
- they exchange H_2O, CO_2, CH_4 and N_2O with the atmosphere;
- their vegetation is dominated by species which have features adapting them to the wetland environment (aerenchyma in roots, insectivory) or are involved in modifying the environment (*Sphagnum*) or both;
- they are easily damaged or destroyed by simple land management techniques such as draining, which may have hydrological consequences distant from the digging both in time and space;
- they are often dominated by highly adapted or strongly habitat-modifying vegetation.

1.4 Value of wetlands

Wetlands have three sorts of value: natural value, value for sustained use by people, and value for destructive use.

Natural value lies:

- in effects on water flow - floodplain areas set aside for flood control can maintain at least semi-natural wetlands;
- in the ability to sequester carbon and to store a record of archaeology, vegetation, and atmospheric deposition;
- as a habitat between land and water;
- in stabilising the margins of water bodies;

Sustainable uses include:

- runoff modification;

- exploitation for grazing, reed harvesting, and (in some cases) fishing;

- human recreation.

Destructive uses include:

- peat mining on a commercial scale, which is incompatible with any other use;

- forestry - viewing timber production as a means of using otherwise unproductive land has led to the planting of oligotrophic peatlands though this is an unpromising use of these wetlands;

- arable farming.

Some of these uses involve authorities or organisation that are beneficiaries of wetland research. A few of them (NRA for example) recognise this.

1.5 Occurrence and diminution of wetlands

Wetlands cover about 10 % of the UK if flood plains are included, and 6 % the Earth's land surface (Maltby & Turner 1983). They are almost everywhere diminishing in area and integrity (Maltby 1991). Matthews & Fung (1987) give the following estimates of the area of methanogenic wetland (10^3 km^2):

Zone	Latitude	FB	N-FB	FS	N-FS	A	Total	Total land
Arctic	80N-60N	929	506	7	26	0	1468	
Boreal	60N-45N	889	381	35	87	0	1392	
Temperate	45N-20N	174	3	80	114	10	381	
Tropics	20N-30S	80	12	905	736	152	1885	
Temperate	30S-50S	5	0	51	47	33	136	
World total methanogenic wetland							5262	130770
British Isles total							15	131

FB = forested bog; N-FB = non-forested bog; FS = forested swamp;
N-FS = non-forested swamp; A = alluvial.

The scale of estimation of area is important because, for example, in Scotland some 10% (9,300 km^2) of the total land area of 93,000 km^2 is considered to be mire (peat covered land) when mapped at 1:250,000, but the estimate may be as high as 20% when determined from more detailed maps, implying possible variation by a factor of two. There is, in addition, some 150 km^2 of intertidal mud-flats in Scotland as part of a total of 750 km^2 for Britain. The intertidal zone in Scotland covers a total area of 1250 km^2 which is about one third of that of all Britain.

The flood plain wetlands of the Cambridgeshire fenlands and the Somerset levels, and estuary borders such as the Solway, are extensive, but, with a few small exceptions, they have been so drained and managed that their characteristics are much changed.

In the Netherlands barely 1 % of the original peatland remains. Even in the now environmentally aware USA almost half (45000 km^2) of the wetland, estimated retrospectively by sampling, has been lost in the last 200 years, often under tax concession but without much real sustainable gain to agriculture. About half the original peatland in UK has been drained or otherwise altered (Immirzi *et al.* 1992). A series of NCC sponsored surveys shows that the area of relatively undamaged fenland in East Anglia declined from 3400 km^2 in 1637 to 10 km^2 in 1983. Between 1910 and 1978 about 60 % of Welsh lowland mire sites were lost. In four sample areas 86 of the 120 lowland raised bogs (and 96 % of the area) were lost between 1840 and 1978.

1.6 Current research

The UK has a good record of research on all types of wetland: CB Crampton, VJ Chapman, Pearsall, Godwin, Conway, Walker, Cragg, Gorham and many others began the work. Today, in the UK, work on wetlands is funded at about 1.1 M£/yr by the NERC, and the EC Wetlands Programme and IUCN Wetland programmes at Exeter are funded at 0.16 M£/yr. A summary of NERC funded projects follows. ~~More details are given in Appendix 2.~~

Expenditure (k£) by NERC on wetlands 92-93 or estimated annual rate

	Proj.	CR	CR/SB	SB	Total
TFSD Institutes	21[‡]	200[‡]	102	172[¶]	474
NERC RM Grants	7[‡]			77[‡]	77
Studentships	37			296	296
NERC TIGER II	8			310	310
LOIS (<u>bids</u> only)	10		(306)		
TOTAL					1157

Proj. = projects; CR = contract; SB = Science Budget; CR/SB = mixed; LOIS = Land Ocean Interaction Study; TIGER = Terrestrial Initiative in Global Environmental Research.

[‡] Excludes projects that were in the database but did not seem to be wetland based e.g. capercaillie, goshawk, pheasant, Water of Ae (a district), Cameroon rain forest etc.

[¶] 103 k£ reported under TIGER rather than TFSD.

The largest coherent programme is that supported under TIGER II.1 for work on the production of trace greenhouse gases. The large number of NERC Responsive Mode (RM) studentships is interesting.

There is a much larger rate of spend (about three-fold greater) in the USA and in the EC on projects with practical objectives related to maintenance and restoration of wetlands. Such projects often reveal the lack of basic science in the area, but they do not usually provide an opportunity to undertake it. An exception is the EC DGXII funding of a major project, coordinated at Exeter, on wetland processes.

2. PRIORITY AREAS FOR SCIENTIFIC RESEARCH

The ERG identifies the following as areas in which there is a special need for UK research now or in the near future.

A Description and inventory

B Hydrology

C Microbiology

D Wetlands as sinks, stores and transformers of matter

E Faunistic diversity and interaction

F Maintenance of functioning and stability

and the more applied area of

G Restoration (re-creation) of wetlands.

as well as

H General

Within these we identify B, C and D (which are concerned with primary processes) as underpinning E, F and G and note the underlying role of A.

2.A Description and inventory

Types of wetland vegetation have been delimited in the National Vegetation Classification (NVC), but extent has not. In Scotland the Macaulay Land Use Research Institute has surveyed the vegetation (using a different system) and extent of peatlands. A further survey of wetland extent has been made by NERC's Institute of Terrestrial Ecology (ITE). The types and extent of fens (a subset of peatlands) have been surveyed from Sheffield University.

Some attempts have been made to use automatic classification of data remotely sensed from the air or from satellites. At present the techniques cannot distinguish such radically different systems as *Cladium* and *Phragmites* fens even from the air.

In all such work two questions arise:

- what units should be recognised?
- what area does each occupy?

Why are these questions worth asking? The main reason is that processes, such as the production of CH_4, are often measured on small areas but the results have to be scaled up to global values. Recognisable units and area inventories are essential. Vegetation, as an integrator of site processes and conditions, is the most often used characteristic but it *is* a surrogate for function. The problem is complicated by the existence on peatlands, at least, of mosaics at several different scales (approximately 1 m, a few hundred metres, and several kilometres) the larger including the smaller.

The existing ground-based inventory in Britain is inadequate for scaling locally-measured processes. There are large areas of wetland outside Britain (for example the Pripet marshes or the west Siberian plain) that are scarcely known and are difficult to travel in, and for which automatic classification from remotely sensed data is the only feasible solution. The pioneering work of Ivanov (1975) at St. Petersburg, has shown that regular catenae of surface features offer promise as aids to interpretation. New platforms, such as the ATSR2, which can reveal the short-wave radiation loading of the atmosphere and hence the energy and water budgets of the surface layers, are appearing. They may allow more about the *functioning* of the ecosystem to be inferred. The relation between function and structure must also be investigated on the ground, and this may require relatively long-term measurements. But Ivanov's work on sequences of surface features which are linked by function could be tested outside the CIS (former USSR) and with new methods.

A second reason for inventory is that, on a global scale, the area of relatively untouched wetlands is probably still diminishing. We need to know the rates.

The UK has expertise in vegetation classification, but has not so far been among the leaders in remote sensing of wetlands. Cooperation among NERC, National Rivers Authority (NRA), International Waterfowl & Wetlands Research Bureau (IWRB), IUCN and Universities should be encouraged.

Recommendations

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

2.B Hydrology

The prediction of runoff characteristics from natural and modified wetlands of all kinds is an active field with considerable practical consequences for water conservation and flood control. Work is needed both on theory and on field measurement for such effects as overland flows, pipe flow and seasonal change in the depth of the transition to reducing conditions. Of particular concern are alluvial and inorganic-substrate wetlands bordering rivers, because they affect the rate of flow and chemical composition of the river water.

In general an understanding of hydrology is crucial to an understanding of how a wetland works, and of how and when a wetland will respond to climatic change, drainage, or other alteration. Progress in this understanding can be rapid but often step-wise. It is barely a decade ago that it was established that saturation in rain-fed peatlands is maintained by a dynamic groundwater mound, rather than by capillarity (Ingram 1982), and that flow in such systems may be very complex (e.g. Gilman & Newson 1980), though Ivanov (1975) in the USSR had made major advances in understanding even earlier. The first of these discoveries has revolutionised our understanding of how it is that peatlands come to have the shapes that they do.

In the last five years there have been further rapid advances in understanding both of the steady-state and of the dynamic flow of water in wetlands both in the UK and in the USA. One important reason for these advances has been the ready availability of desk-top computers able to run quite complex hydrological simulations, and parallel-processor computers whose power is generally ahead of need. In general, models have therefore run ahead of empirical techniques and measurements.

There is still much fundamental work to be done on the theory of water movement in porous matrices as well as on realistic models of peeat, and there is a worldwide shortage of soil physicists (as opposed to those with some physical training and insight which they apply to complex porous systems). Theoretical insights are needed into flow heterogeneity, including piping in large peatlands and saltmarshes, and transfer across mineral based wetlands, and of the causes of seasonal variation.

But the main need now is for better techniques of measurement and for more measurements. Examples are the need for measurements of hydraulic conductivity at <u>all</u> depths in peatlands, not just the top metre or so, and for tracing of the paths of water movement on a scale of mm to cm. Such measurements are needed to inform and constrain the building of models. There is also a need for more routine measurements ('monitoring') of simple climatic and hydrological variables, such as water-table, and not-so-simple measurements of water balance. Such measurements are necessary because some of the wetland phenomena, such as their floristic composition, are probably related to extreme, and therefore uncommon, hydrological and climatic events. The simple variables are fairly readily recorded with automatic weather stations, which are now sufficiently reliable. Instruments for water balance measurements, such as reliable lysimeters for use in peatlands, exist but accurate measurements using them need time and skill at present. Such equipment needs to be developed further and simplified for routine operation.

Recommendations

B.1: give priority to the development of wetland hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices and in peat with realistic characteristics.

B.3: continue support of work on the hydrology of wetlands in catchments.

2.C Microbiology

It is estimated that northern peatlands alone contain about 450 Gt of carbon (Gorham 1991). This is about the same (Houghton *et al.* 1990) as the total in the Earth's atmosphere. This massive store, most of it accumulated since the last glaciation, represents a spectacular failure of the usual processes of decomposition. The causes are obscure. Anoxia itself does not prevent rapid breakdown by methanogens, as sewage digesters show. Much of the organic matter may be refractory, but it disappears quite rapidly when spread on a garden. There is a wide range of microbiological questions to be answered. The questions have been there for 65 years since Waksman's pioneering work (Waksman & Tenney 1927), yet microbiologists have still to make a concerted attack on them. It is known that anaerobic decay continues slowly throughout the whole depth of anoxic peat producing CH_4 and CO_2 which diffuse to the surface. The peat is almost isothermal so this flux is probably almost constant. There is also a seasonally fluctuating production of these same gases from close below the water-table. The rates and causes of these differences and fluctuations are only now beginning to be investigated in the TIGER programme. Evidence is appearing which shows that CH_4-oxidising bacteria are active in the surface layers of peat. What effects do they have on the effluxes to the atmosphere? Questions such as these have implications for climate change as well as being intrinsically interesting. Few microbiologists are used to working with the complexities of wetlands in the field except, for example, for the exploratory testing of the effects of disturbance or of the sort of comparative work undertaken 20 years ago in the IBP on the rate of breakdown of standard cellulose strips. The ERG suggests that microbiologists should be encouraged to work in teams, for example with ecologists, pedologists and micrometeorologists, so that the microbiologists' attention is directed toward the major problems and their context in the field. We note the similarities between the processes in the surface of wetlands and of lake sediments.

There are microbiological questions linked to cycles of other elements too: examples are S and its inter-relation with CH_4 production, and N in possible N_2O production from wetlands as NO_3 inputs increase. Further microbiological questions concern the role of mycorrhiza, which are known to link ericaceous shrubs and some liverworts. Their importance in the economy of a wetland surface is unknown.

Molecular techniques such as the PCR (Polymerase Chain Reaction) allow the identification of specific DNA sequences and thus, in favourable cases, of particular microorganisms or functional groups of microorganisms. This is a useful supplement to traditional enrichment methods of establishing existence, but is not (we think) particularly important of itself. But if molecular techniques could be developed to show the quantity of specific enzymes involved in, say, CH_4 production then major advances would follow. As with remote sensing of wetland processes it is not obvious that the techniques are possible yet, but they are worth pursuing as soon as a plausible case can be made.

Recommendations

C.1: encourage microbiologists to work on the major problems of organic matter accumulation, particularly peat, with multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

2.D Wetlands as sinks, stores and transformers of matter

Wetlands contain sequential deposits that may be continuous for several millennia and within which decay rates are low and vertical movements may be negligible. These deposits are the prime source of records of archaeological, biological, chemical and physical conditions in the past and of their changes through time, especially since the last glaciation (Godwin 1981). The surface layers of peatlands retain a record of atmospheric metal fluxes during the industrial revolution (Clymo *et al.* 1990). These archives are there to be examined for as long as the wetlands remain little damaged. The ERG sees no need for any special action.

Peatlands are also massive stores of carbon. The microbiological implications have been considered in 2.C but here it is the interactions with climate which matter. Peatlands have conventionally been considered to be sequestering carbon. Recent examination of this belief (Clymo 1984) shows that the rate of loss of carbon in decay at all depths is likely to be a significant proportion of the rate of fixation at the surface, and that peatlands may be no more than perhaps 30 % as effective at sequestering carbon as they were when they began to grow. Are they extending the area they cover at present? If the climate becomes warmer or drier or both then what will happen to peatlands? Will they decay and become net sources of carbon at the southern part of their present latitudinal zone? At what rate? Will new peatlands form to the north of the present peatland zone? At what rate will these sequester carbon? These are a few of the questions to which answers are required fairly urgently. As with hydrology, theory has outstripped field measurements. More theory is needed but the greater need is for more data to test and constrain the theory. This is a field in which the UK has the expertise to make a significant contribution.

A specific part of such a programme is to get more detailed estimates of gas fluxes to and from the surface of wetlands. The TIGER programme has begun this and is developing advanced micrometeorological methods for integrating fluxes automatically over the highly heterogeneous surface of wetlands. This too is an area the ERG believes needs continuing support.

The part that river marginal wetlands and flood plains play in the transformation, storage and release of compounds of N, P and pollutants entrained in their water supply is an area of growing concern. Most such areas in Britain are used for agriculture and are therefore subjected to standard farming practices which often increase grazing on wetlands, the supply of solutes to them, and the abstraction of water from them. The consequences of these processes and of their interaction with hydrology are areas needing further work. Sampling variation is high and there is a need for improved and more versatile portable instruments for the field determination of many determinands, for example oxides of nitrogen.

Recommendations

D.1: investigate the factors and processes determining the role of wetlands as sinks, sources and transformers of organic and inorganic materials.

D.2: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.3: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.4: encourage synoptic studies, particularly of river marginal wetlands and over floodplains, of the balance of elements other than carbon.

2.E Faunistic diversity and interaction

In general, the ERG could find little information on wetland fauna and their ecological roles except for the Moor House NNR, about which a great deal is known because of 40 years of sustained work originating in the University of Durham (Coulson & Whittaker 1978). Sparser but no less interesting are studies on insects in the Cairngorms, Snowdonia, and on salt marshes on the North Sea coast and in the Severn estuary. There is also some work on the population numbers of wetland birds. Even so, recent studies stimulated by the attempts to afforest parts of the Flow Country in northern Scotland, showed the hitherto unestablished importance of these wetlands for several large and conspicuous species.

More specific questions about faunistic diversity, population interaction, community organisation and functioning do not have satisfactory answers at present. For example:

- what is the role of invertebrates in the initial stages of breakdown of plant matter and what are their interactions with their habitat?

- the local dynamics of dotterel populations depend on two-year cycles in the population of tipulids. How, in general, do populations of invertebrates and those of the larger vertebrates interact?

- on saltmarshes the seed production of *Limonium* is inversely related to population size of aphids. How, in general, do populations of inveertebrates and of plants interact?

- what are the ecological roles of animals in general? How do they use different wetland habitats as a resource? How does this explain the association between, for instance, certain wetlands and some rarer bird species;

- what roles do wetlands play in maintaining faunistic diversity in *surrounding* areas?

Recommendations

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds.

2.F Maintenance of functioning and stability

How wetlands function as a component of the drainage basin or as an economic resource is, in most cases, not understood. There are many hydrological and ecological problems to be solved before wetland resilience can be understood and sustainable utilisation undertaken.

For example, peatland vegetation and processes are stable in the sense that the systems as a whole have been in existence and, as judged by the fossil record, have had much the same suite of vegetation types and processes for millennia. Their microtopography (on a scales of a few metres) is known to be fairly stable over periods with these timescales (Walker & Walker 1961, Svensson 1988, and many others). Yet the whole surface vegetation can also change, probably in response to changes in climate (Svensson 1988). Some large changes in peatland vegetation are going on at present (e.g. Chapman & Rose 1991).

The development of erosion is a natural process in saltmarshes, and may be so in Pennine peatlands at least (Tallis 1987) though greatly exacerbated by human activities. In some cases self-healing occurs; in others, such as the North York Moors, recovery after severe fire is extrememly slow and may follow a different path (Maltby *et al.* 1990).

Some wetland systems seem to be remarkably tolerant of high concentrations of solutes in the water: *Phragmites* reedbeds are used in water purification. Other wetlands seem to be fragile particularly in their inability to tolerate the continued addition of pollutants. The causes of these differences are not understood. Nor are the differences in the ability to resist invasion by different native or alien plants.

For saltmarshes in eastern North America it is beginning to be possible to explain how simple wetland communities fit together. This follows manipulative experiments in the field and in more controlled conditions, and gives information about predation, competition, recruitment and the effects of physical and chemical variables. More studies of this kind are needed.

All these examples concern stability, fragility, resilience and the 'assembly rules' by which communities are constructed and maintained. In few cases can we say clearly why a system is as it is now or what it would become if external changes were imposed on it. In addition to its intrinsic interest, such knowledge is needed for practical problems of wetland maintenance and reconstruction, as well as being important in the management of water quality.

The problems are complex and some of the concepts are slippery, but the ERG concludes that this area of wetland research has been largely neglected.

Where plausible hypotheses about mechanisms exist - and some do - then they should be tested.

Recommendation

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, ecosystem functioning and the 'assembly rules' for wetland communities.

2.G Restoration (and re-creation) of wetlands

Three times as much money is spent on wetland restoration, re-creation, and maintenance as on all the topics A - F above. Most of this work is in the Netherlands and the USA. Examples in Britain are peatland restoration at Thorne Moors and saltmarsh restoration for flood control on the Essex coast. The process of re-establishment of vegetation is likely to take years and success may be judgeable only after decades. Most of the schemes have had limited success to date. In wetlands other than salt marshes, control of watertable and water quality are the primary tools of most schemes. Decisions about what plant propagules to supply at what density on what surface and at what scale are often made on the evidence of small scale pilot experiments or none. There are inevitable pressures to produce visible results quickly and this militates against undertaking the necessary basic science. The ERG concluded that basic science, of the kind recommended in the previous sections, is likely to be needed to guide and improve these practical projects. Relevant basic science ought to be be included as part of such projects. There is a need, and there are opportunities, for scientists to do this particularly in the Third World. But the undertaking of such practical projects is outside the NERC remit.

2.H General

We have been impressed at how often the answers to wetland problems require expertise in two or more fields. In the past an individual in one field has learned enough about the necessary ancillary discipline(s) to be able to progress. For example, the advances in concepts concerned with wetlands as sinks and stores of matter, described in 2.D, required contributions in ecology, hydrology, microbiology, modelling and numerical analysis from one person. The advances in the hydrology of large peat masses described in 2.C resulted from cooperation between ecologists and engineers. TIGER has enforced the construction of consortia most of which contain at least three disciplines, and that arrangement is already producing results which would not have been produced by solitary individuals: the minimum effective number of different specialists needed if progress is to be made is increasing.

This problem is made worse by the difficulty of locating information about previous work in unfamiliar disciplines: there is no continuing interdisciplinary forum for the exchange of information and ideas, and no relevant database.

Recommendation

H.1: encourage a forum for discussion among different disciplines concerned with wetlands.

3. SUMMARY OF RECOMMENDATIONS

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

B.1: give priority to the development of wetland hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices and in peat with realistic characteristics.

B.3: continue support of work on the hydrology of wetlands in catchments.

C.1: encourage microbiologists to work on the major problems of peat accumulation and to do so in multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

D.1: investigate the factors and processes determining the role of wetlands as sinks, sources and transformers of organic and inorganic materials

D.2: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.3: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.4: encourage synoptic studies, particularly over river marginal wetlands and floodplains, of the balance of elements other than carbon.

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds.

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, ecosystem functioning and the 'assembly rules' for wetland communities.

H.1: encourage a forum for discussion among different disciplines concerned with wetlands.

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APPENDIX 1. ERG MEMBERSHIP

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Dr H. A. P. Ingram
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School of Geography, University of Leeds

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APPENDIX 1

Secretary's Think Piece for first meeting on 4 Dec 1992

NATURAL ENVIRONMENT RESEARCH COUNCIL

TERRESTRIAL & FRESHWATER SCIENCES DIRECTORATE

EXPERT REVIEW GROUP ON WETLANDS - Stir-up provocative notes

Wetlands are currently an issue for the environmentally aware. Examples are overwintering sites for birds, peatland extraction and nutrient stripping in tertiary water treatment. They are sites that are easily destroyed, drained or the easy option for new transport links. Their value is frequently underestimated. They are not well understood because of their variety. Their functioning as ecosystems and hydrological systems need more study if sensible protective measures are to be taken.

TFSD seems to fund research, as multi-disciplinary comparative studies, to about £1 M per year within its institutes on a variety of topics within the broad definition of wetlands although much seems to be currently related to saltmarsh (£?00 k); there is however no major initiative in this area. Is this because wetlands have already been well studied or little public interest in fundamental research; targeted uses eg ornithological studies, are well supported(?).

THE FOLLOWING ARE THOUGHTS, NON-QUESTIONS OR STUDIES AT ALL STAGES OF DEVELOPMENT

1. What is a wetland? (Is the normal definition acceptable?) Are they permanently wet or waterlogged, have emergent vegetation, rarely have open water areas?
Can they be saline or semi-saline? must they be flat or in depressions or can they be on hillsides?

2. What are the types of wetland?

- Acid wetlands/peat bogs,...mires
- Alkaline wetlands/fens - very limited eg Wicken, Bridgewater, East Stoke, Romney Marsh with other 'sites' are river banks or lake margins or drained & ploughed-up;
- Saline wetlands/saltmarshes
- Seasonally or occasionally inundated wetlands (water & flood meadows?)
- Drained wetlands river meadows
- raised or perched wetlands?

3. What are the proportions of each type, have the proportions changed and by how much? What is their size and how are they linked or distributed? Wetland corridors as a landscape feature?

4. Have they been surveyed from the ground or can their reflectance be classified from remotely sensed imagery? (ITE countryside survey or land classes, NRA are commissioning wetland study for their responsibilities)

5. How are wetlands perceived? (socio-economic value)

6. Which wetlands are of most value? (low nutrient alkaline, nutrient budgets N, P, others?) Have they been studied?

7. What are their characteristics?
- physical (organic, or fine organic-rich inorganic silts)
- chemical
- biotic vegetation
- hydrological

8. Have we sufficient detail of how they are formed, function and develop?
- plant populations changes, species richness, diversity
- material accumulation (peat, silt accumulation?, salt?
- hydrological groundwater processes, equipment development?
- evapotranspiration and other processes?
- sediment dynamics, micro-hydrodynamics tidal studies?
- do physical or mathematical models assist, are we in need of superfast computers or parallel processors?

9. Have sufficient plant or animal species or communities been studied? Can parallels be drawn with other vulnerable species or communities? How are biota within sites linked with the surrounding areas? (feeding of protected birds, invasive plants?)

10. Are wetlands susceptible to discrete or diffuse impacts or change? What are the indicators of change? Do we know the consequences of changes? What are tolerances and thresholds of change? Can impacts or change be ameliorated or reversed?

what types of impact or change
- global - thermal carbon availability or rainfall
- national - rain or solid deposition (eg ITE's map)
- regional - drainage, politics
- local - construction (transport, leisure, marinas)
  - tidal barrages (vegetation & sedimentation
  - gravel extraction
  - cut-over peatland restoration
  - temporary with reinstatement, can they recover?
- can they be rebuilt? Wetland reconstruction/restoration (Bjork of Sweden)

11. Linear wetlands, solute transport across, temporary accumulation or permanent de-nitrification effects? marginal vegetation or fringes to reduce bank erosion of lakes or river from boat wash or in re construction?

12. Uses/construction of wetlands - what areas are realistically needed? Local industrial uses? Can nutrients be stripped for long enough or is return to air of nitrogen fast enough, is there best function in concentrating toxic inorganic and organic compounds for later disposal? (ICI?)
Reed harvesting? (better reeds for roofing - nutrient)

13. Links with industry eg heathland reinstatement & Oil industry - water colour in peat wetlands - compensatory pumping

WHAT ARE THE ISSUES?

14. Are change to wetlands sufficiently important? Are global issues of immediate interest (green house gasses etc?

15. Should overseas wetlands be studied, and cooperated studies with in other EC, or countries or regions? Should key wetlands be studied U.K., Europe or less developed areas?

16. Equipment pool (to facilitate complex or multiple studies)?

17. What are the remaining issues?

18. Have we progressed since IBP-wetlands or in ecosystem functioning?

19. What other agencies or interest groups are involved, what are their policies? Should we adopt a policy to cooperate, overlap or lead?
- (National River Authority, UK national and Nature conservation bodies, British Trust for Ornithology and international trusts, and government departments (MAFF, DoE, etc)
- NRA & EN complain of ring-fence protection for reserves but with little protection to water levels; some local TNC have developed pumping schemes for wetland preservation
peat land drying in Fenlands and ...
- NRA perceive the need for national definition for resource planning, classification for use at regional scale, register of wetlands, improved sensitive methodology, compensatory pumping, evapotranspiration, overland flow, water balances.
- EN similarly and in respect to wildlife, perceive the needs in the main areas of catchment planning, development and functioning of wetlands, use of buffer zones, management of lowland wet grasslands and developing monitoring programmes but focusing particularly in the areas of abstraction, enrichment & pollution, interdepartmental relations, monitoring, restoration & creation of wetlands & rivers, data on sites & distribution, and site designation and value
- DoE policy Group - Wetlands subgroup P Kostirgan for G Waters (Somerset levels MAFF/DoE) EC Wild Birds Directive Annex 1. 79/409/EEC Official Journal L103/1 25.4.79

- How should environmental sites which are being managed by concerned groups for single uses only to the detriment of the wetland be viewed.
- How are Environmentally Sensitive Areas dealt within & without?
- Maff buffer zones project
- Joint Water Group, D. Witherington, RSPB & voluntary bodies, an Issues orientated group
- RAMSAR Convention sites,
- International Waterfowl and Wetlands Research Bureau (IWRB)

APPENDIX 2

Secretary's Report of first meeting on 4 Dec 1992

INTERIM REPORT BY
THE NERC EXPERT REVIEW GROUP ON
WETLANDS

FEBRUARY 22 1993

FHD February 10 1993

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OVERVIEW

The Terrestrial and Freshwater Sciences committee of the NERC considered that wetlands were an area of some public concern and that NERC should be seen to be active in this area.

The terms of reference were to make recommendations on NERC directed support of wetlands research in the future and to report on these recommendations to the Director of Terrestrial and Freshwater Science. These terms of reference were to be enabling rather than prescriptive and to include amendments if considered necessary by the Group including such aspects as the need for other experts, short-term consultancies, etc.

The Expert Review Group held two meetings, one on December 4th. 1992 which followed the guidance in the Introduction to Expert Review Groups for Wetland (WL2/92) given by NERC, and the second in February 1993, in which the report of this first meeting was reviewed and amended. The interests of the ERG members was wide ranging from peat stratigraphy and botany through function orientated studies based in hydrology and chemistry to human sociology (see Appendix 1). This report outlines the background to wetland studies, discusses the definitions used, key wetland processes, change to wetlands in area and quality, draws some firm conclusions about wetlands research in general and makes recommendations for future studies and initiatives linked or otherwise with existing initiatives eg Land-Ocean Interaction Study (LOIS), to be funded by NERC. Priority research areas are highlighted within five main themes associated with wetlands:

1. maintenance of stability
2. hydrological details
3. wetlands as sinks, store and transformers
4. microbiology
5. recreation of wetlands (including sustainable development)

In addition

1. need to create critical masses of researchers
2. the specific topics above for next five years
3. committee with watching brief, restricted duration and linked both to UK and world projects for delivery of science and other disciplines especially engineering (meeting only 1-2 pa for 3-5 years)
4. protection of the subject (wetlands) and stimulation at scale of £1 M pa plus support from outside bodies and cooperate with other bodies

and opportunities for new (and exciting)/(or continuing) research initiatives or strategies and technology transfers, are identified. The report concludes with specific recommendations for further research.

Brief summaries of work funded by NERC is appended.

1. AN INTRODUCTION (Meeting report starts at 1.2 with definitions of wetlands)

1.1 Preamble on wetlands

Wetlands are diverse, widely distributed and often found in lower lying areas of any region or on the coast. The rate, quality and manner of their collection of water adds to their structural variety which in turn provides the maximum potential for the widest range of flora and accompanying fauna of many ecosystems ie they have a high biodiversity. Wetlands are often the last sites which man finds relatively easy to exploit and therefore they continue to be susceptible to physical development or pollute. Wetland development by external funding, may be the most important factor in the continuing exploitation of such biodiverse areas. Conversely wetlands allow the presence of many potential pathogens and may accentuate the effects of natural hazards when population pressures are high. Wetlands seem to provide a good indicator of planetary health with their diverse interactions between the physical and the biotic but few are well understood and therefore many more sites need to be preserved for their role in the world.

What are wetlands and are they biologically diverse?

Are there many species to be found in wetlands or are there just many types of wetland? The answer seems to be yes to both, however the definition of wetlands can vary greatly according to the study group, geographic region, environmental or political viewpoint!. The difficulties over the definition of wetlands illustrates their variety. Thus in broad terms wetlands are normally wet, they often have much vegetation and they often have a richer and a more diverse population of plants and animals (biota) than any other major ecosystems. The term 'wetland' includes a wide range of interactions between the biotic and the abiotic, that is, the non-biological physical and chemical environment, in which free water is available. Their often naturally variable or changing nature adds to their structural variety and creates a wealth of habitats for wildlife to exploit. Wetland plants can adapt to a wide range of unusual conditions and as such, are likely to have a wide range of unusual genes.

Wetlands types result from specific combinations of parameters especially physical, including hydrological characteristics & the rate of accumulation or exchange of organic or inorganic silts, chemical and biotic responses of vegetation. These parameters range greatly, for example, hydrology varies in the wetness of the soils from permanent or periodically inundated, in the supply, rate and movement of the waters from static, regular to rapid, the permanence of water levels and the seasonal or periodic variation and rate of evaporation. Whereas water in its supply as rain or from upstream, varies in its character such as acidity or alkalinity, nutrient levels and its concentration of especially sodium, chloride and carbonate. This richness or dominance by gradients of interaction of these parameters ie ecotones, is related to the high biodiversity at both the species and as genetic level.

Thus wetlands can become difficult to define precisely: do wetlands, for example, need to be permanently wet or just waterlogged most of the time? Are they still wetlands if they dry out occasionally? Must they have emergent vegetation or will submerged or floating be sufficient? Can they have open water areas and if so, how deep can the water be? Can they be saline or semi-saline? Can they only be flat or in depressions or can they be on hillsides and watered by springs?

What is the status of wetlands and how is it changing?

The decline of wetlands has received greater awareness over the recent decades as they have been stripped, drained or otherwise exploited to increasing degrees; those which remain are of thus greater importance, but are they typical or do they represent those which are almost too difficult for man to exploit such as the Makgadikgadi soda lake of Botswana with its flamingo populations?

There are many types of impact or change, from the **global** such as thermal, carbon availability or rainfall, **national** as rain or solid deposition, **regional** as drainage, politics, **local** as construction (transport, leisure, marinas, tidal barrages, gravel extraction, cut-over peatland, **temporary** with reinstatement.
Wetlands are subjected to many discrete and diffuse impacts and changes but their tolerances and thresholds, the indicators or consequences and potential for their amelioration are often poorly understood or unknown.

The number, quality and character of natural wetlands continues to decline although both their perception and their status are receiving greater public awareness, and greater numbers of sites are being given some form of protection. Wetlands continue to be modified to reduce the effects of natural disasters caused by a greater requirement for land resulting from the effects of increasing population pressures, whereas others are being modified for opportunistic purposes. Thus, depending upon the perspective, it can appear as a question of life now versus death but how far should local piecemeal development be assisted by outside or international money?

In Europe, many of the wetlands have already been lost over the last 2000 years and it is estimated that even in the now environmentally aware USA almost half, 45,000 km^2, has been lost in the last 200 years, often under tax concession but without real sustainable gain to agriculture.
Environmental awareness of wetlands has been raised so much that in, for example, the UK environmental groups have bought small wet meadows areas and have also funded compensatory pumping schemes to maintain water levels in a few wetlands.

As wetlands provide a good indicator of planetary health by their varied interaction with plants and animals especially by such obvious examples as changes in the numbers and migration of wetland birds, large scale surveys should be undertaken using satellite imagery. This would allow questions about the international status and change of wetlands to be answered together with some estimate of the relative size, proportions and changes of each wetland type and their distribution and linkage, to be answered. Ground surveys are still needed to identify flora, calibrate reflectance and confirm topographical features and although such methodology has to a large extent been developed and tested in the UK & elsewhere for land use and other features such as hedgerows and riparian corridors, it is expensive to undertake.

What part has Britain played in study of wetlands?

Britain and its scientists have always been in the forefront of the study and conservation of wetlands studies cooperating with many nations and peoples. The target is continually changing and progress differs through the varying phases from exploration, mapping, identification of biota, classification and study of the underlying processes or their perturbation by mans activities.
Britain has undertaken studies of wetlands in many parts of the world for many decades but by the early 1900s, and in the footsteps of earlier explorers and naturalists who began to documented in a standard way the vegetation and animals, explanations of the distribution, abundance and succession of biota in wetland habitats were beginning to be studied in detail by the Freshwater Biological Association (FBA) under Pearsall, whilst at the same time as British vegetation being classified by Tansley at Cambridge and others were studying groups of organisms such as waterplants (Ann Arber). By the middle of the century scientists such as Lambert were studying competition between fen species, Gorham at University College, London was studying the chemistry, nutrient input and cycling of bogs and Ranwell on saltmarshes and their sediments. Pollen from wetland sediments was being analysed from quaternary period by Godwin from Cambridge and also at FBA. Later, however, efforts became divided between studies of processes of wetland environments and specific groups of organisms, particularly birds (British Trust for Ornithology & International Waterfowl and Wetlands Research Bureau, IWRB).

Cooperative studies with British scientists on most continents of the world culminated in the 1970s & 1980s with the International Biological Programme which compared the production of the biotic groups of various wetlands by scientists of many nations, with other major ecosystems or biomes of the world. Synthesis of the studies of primary production of wetland species have been coordinated by Westlake (FBA).

Currently UK research continues on a variety of process orientated or multi-disciplinary comparative topics within the restrictive definition of wetlands which is funded to about £1 M per year primarily by the Natural Environment Research Council in the Institutes of its Terrestrial and Freshwater Directorate and British Universities' projects. If, however, the broad definition of wetlands is used then some £10 M per year of research is financed, with additional funding for special initiatives on a variety of topics on biotic, physico-chemical and hydrological processes in freshwater, estuarine and semi-aquatic areas. The current thrust in the UK is mainly related to key processes which affect wetlands such as formation, hydrology, functioning and development in peatlands and saltmarshes, and particularly plant population changes, species richness, diversity, material accumulation and decomposition (Queen Mary College, London), hydrological groundwater, evapotranspiration and atmospheric processes (NERC Institute of Hydrology, Wallingford, sediment dynamics and micro-hydrodynamics (ITE South, Reading University), seawater tides and species change, sediment dynamics of saltmarshes, green-house gas production, nutrient effects on riparian corridors & their species diversity, genetic variation & conservation of rare species and also work continues on weed control (NERC Institute of Terrestrial Ecology and AFRC) and ornithology (NERC Institute of Terrestrial Ecology & International Waterfowl and Wetlands Research Bureau, IWRB). Related studies are also funded, such as characterisation & evaluation of the type and extent of wetlands by analysis of remotely sensed data (NERC Remote Sensing

Applications Development Unit); this type of study could allow the overseeing of the progressive and cumulative reduction of wetlands by piecemeal local exploitation.

Water treatment using artificial reedstands are showing a resurgence in USA and Germany and alternative species are being studied in Australia. Scientists in the UK have studied their implementation to reduce pollution eg India or allow water reuse for agriculture and to grow, for example, industrial crops in Egypt (by cooperation with Portsmouth Univ.), following gradual decline of sewage farms or wetland finally ceasing in for example the 1950's in UK. At least one multinational company in Britain is using artificial wetlands to remove from its effluent and concentrate toxic inorganic and organic compounds. Such wetlands in common with bably managed or enriched wetlands tent to be species poor ie not biodiverse and may become virtual momocultures. Linear or riparian wetlands by watercourse, are been studied in several countries to reduce the solute transport of nutrients across from agricultural areas to watercourses by temporary accumulation or permanent de-nitrification Wetland marginal vegetation or fringes to reduce bank erosion of lakes or river from boat wash or in re construction?

Latterly, in the UK at least there has been an unexplained increase in the rate of die-back of Phragmites reed in eutrophic waters for which physiological studies needed but this seems to be related to seasonality. Similarly it has been noticed that reeds used for roofing breakdown faster when from water rich in nutrients.

Who is responsible for preventing further decline in wetlands?

In UK, there are statutory bodies with responsibilities for wetlands such as National Rivers Authority, and government departments, whilst national conservation, ornithological and voluntary bodies maintain both active campaigns and nature reserves.
Within Europe the European Commission formulates policy and protective legislation (eg. Wetlands EC Wild Birds Directive Annex of 1979). Complaints of ring-fence protection for reserves accompanied by lack of sufficient protection of water levels are typical of developments schemes. There is a great need for national definitions for resource planning, classification for use at regional scale, register of wetlands, improved sensitive methodologies, compensatory pumping, studies of evapotranspiration, overland flow & water balances (National Rivers Authority). Similar aims are seen by the conservation bodies, in respect of wildlife, for catchment planning, development and functioning of wetlands, use of buffer zones, management of lowland wet grasslands and developing monitoring programmes, but focusing particularly in the areas of abstraction, enrichment & pollution, interdepartmental relations, monitoring, restoration & creation of wetlands & rivers, data on sites & distribution, and site designation and value.

The Darwin initiative by the British government promises to.. details from IoB Environment Division by deploying the strength of UK in with the conservation and sustainable use of biodiversity and natural habitats..

In summary, wetlands are currently an issue for the environmentally aware. with interest ranging from problems of general conservation, overwintering sites for birds, peatland extraction and nutrient stripping. Wetlands are sites that are easily destroyed, drained or the easy option for new transport links. Their value is frequently underestimated. They are not well understood because of their variety. Their functioning as ecosystems and hydrological systems need more study if sensible protective measures are to be taken. However, in conclusion, the final question must be who can, pragmatically, prevent the further loss of wetland sites? Is it the 'developed' countries, who have almost totally developed their own wetland sites or the third world countries who struggling to maintain their current status or recovering from physical or monetary exploitation? Should other international agencies or interest groups be involved (WWF, IUCN), what should their policies be? Should the UK adopt a policy to cooperate, overlap or lead?

1.2 The definition of 'wetlands'

Opinion on producing a working definition of wetlands varied from
- that of the chairman - a pragmatic view that they were site accessible by Wellington boots or waders, and which therefore included peatlands, salt marshes and coastal wetlands but excluded whole estuarine systems, lakes and rivers except their margins; through various grades, provisions and alternatives such as in the context as used by
- 'European' ecologists which includes peatlands, raised bogs, saltmarshes plus a wide range of other well defined site-terms ie RAMSAR but in which there is not only no genetic connection but much confusion because relatively deep water bodies are included;
- process (and function) orientated definition, thus, for example, in USA any or all combinations of particular conditions of hydrology, biota and soil conditions need to exist before it is legally a wetland, but such a definition which can accommodate genetic variants and includes ecosystem sites with regular flooding or the water table is at or close to surface, and have adapted vegetation, soil conditions or hydrology which leads to a range of genetic types but which avoids the complications of the inclusion of eg mudflats; this may possibly be reworded as
- interaction between water and solid matter originating on land could be used to avoid complication or alternatively to include the
- **transitional element of water rather than its permanence**; but at the other extreme the
- non-restrictive world wide definitions such as under the Ramsar convention which also includes estuarine, shallow saline etc. and is useful when considering vertebrates and has considerable practical conservation value.

It is suggested that two definitions should be used ranging between the two main groups :

- the **restrictive** - which describes them as 'wet land', that is, areas in which water levels vary near the soil level and bear vegetation adapted to more or less continuous waterlogged soils; these are, in particular, the mires which include a variety of wet sites especially bogs, wet heaths, fens, flushes, springs and soakaways; to the

- the **broad** - which describes them as 'the transition zone lying between the permanently wet and the generally dry'; this gives a clue as to the variety and richness of species to be expected living there and the variation in habitat with changing water level allowing species from the range of wetter and drier habitats either side to colonise from time to time together with those adapted to both. This definition of wetlands includes not only mires but marshes, swamps, peatlands, floodplains, mangroves, estuarine sites, together with artificial wetlands and the shallower large bodies of standing open water.

The broader definition is clearly a functional one relating to the fauna, flora or the general habitat and primarily covers the convention on Wetlands of International Importance Especially as Waterfowl Habitat from the intergovernmental treaty made in, and named after, RAMSAR, Iran in 1971. This agreement currently obligates 70 states to accept that wetlands of international importance must be designated 'Ramsar sites' and to maintain their character but also to plan that other wetland sites should be used wisely and should be designated as nature reserves. Although there are in excess of 560 Ramsar sites covering 36 M hectares, this is only a mere one five hundredth of the land surface.

The group decided to concentrate on those systems which have processes in common based upon sites within the restrictive definition but to remember that this was a rather artificial boundary which was being imposed for purely practical reasons and that no new or NERC definition of wetlands was to be implied.
[The definition 'wandered' as the meeting progressed and the implications of it were discussed in relation to specific points, sites or processes.]

1.3 What are the common and what are the unique features of wetlands?

Common features are water, gas and solid material, some of which is living.
It was considered that these features could be categorized in three areas.

1. Hydrology -
predominated by the precesses of storage or movement of water; non-saline or rainfed, to saline division important

2. vegetation and other biota
predominated by the adaption or response of particular species of biota; non-saline to saline division of most importance to invertebrates

3. soil or substrate conditions
prevalence of anaerobic or anoxic conditions and their variation in time and space but noting that not all wetland sites are anoxic, for example, sloping sites where water movement maintains high Redox potentials (this is therefore an anomaly to the discussion of consistent processes or processes in common, but relates back to hydrology conditions). High organic content (except in spring-fed and salt marsh wetlands) with its key role of organic material in biogeochemical cycling but which also relates to the strong autecological functioning

Special features of wetlands include

4. human impact is usually a wish to drain

5. combinations of form, development and function but exception which could be highlighted when function are performed to a high degree.

6. Wetlands are an integral part of whole drainage basins and coastal systems with particular linkages interacting with effects from upstream and producing effects downstream or across a boundary such as an internal boundary in a deepwater lake system or coastal marine systems with the consequential effects to other ecosystems. This allows other Ramsar sites to be included by coupling but not strictly scientifically. In the UK, the National Rivers Authority must take account of any act which may degrade the environmental or ecological quality of water & the lands adjacent to water bodies in England and Wales.

7. Repositories of history especially but not exclusively vegetational record. (Wetland archaeology has increased pressures to maintain water levels not only in peatlands but in other wetland types.)

Focused process-orientated recommendations should they be studied on continua or discrete differences.

1.4 Significant worldwide developments and problems of relevance to research on wetlands in the last 5 years (or since the mid 1980s)

[Wetlands areas - data to be supplemented by group members]

Wetlands cover an numerically and areal important areas of the world which amount to 3% of world surface and 7%? of Britain (incl flood plains?).

A full inventory of UK wetlands is required but should this include divisions from the broad definition ie including estuaries, rivers, open water wetlands, etc., be included in these figures or should they be excluded but with data on relevant research groups and recommendations for sources of wetland information? Peatland data available but not for fens. The need for an inventory should be a recommendation.

Should there be cooperation with remote sensing surveys eg ITE land classification of 32 classes at a divisions of 1 km or National Rivers Authority proposals for photographic or spectral imagery at division of 2-20 m, to identify, in particular, the areas, extent, type or definition (inclusion of eg. flood plains open waters) and rate of change of wetlands in Britain, in Europe or the World?.

Advances in last five years - needs to be ordered/prioritized!

1. perceptual advances from seeing wetlands as interesting places to their role as functional entities originally in USA and now Europe. This change is suggested as resulting from:

a. a backlash effect resulting from increased awareness of the consequences of watercourse channelisation and flood plain drainage but also from the hunting and the bird lobbies;

b. studies by European scientists in the Third World in the provision of better methods of project development in drainage, irrigation, etc.;

c. improvement in environmental awareness by engineers through better exchanges with ecologists in UK (& Ireland) Europe & elsewhere

2. Remote imagery or photography from satellites or planes is effective but requires good ground truths.

3. Methanogenesis

4. Hydrological processes steady progress over some 15 years ago but more recently examples include:

a. work on raised mires as a peculiar type of lake with turned down edges and maintained by hydrodynamic effects, but which has led to theoretical developments such as poisson model for groundwater models and effects of perturbations especially by agencies eg.

5. Public perception increased or values of peatlands and their vulnerability

6. Discovery that peatlands are not just a high latitude northern hemisphere phenomena

7. recognition that hydrology of peatlands extends far beyond surface delineation in both USA

and UK

8. clearer understanding of effects, indicated by IBP, for coastal wetlands and fisheries, such as the role of intact wetlands eg Spartina, in Louisiana & Gulf of Mexico for commercial shrimp fisheries etc for stocks, spawning and habitat for young stages, also in tropics for Macrobrachium,

9. applied studies on the ability of wetlands to absorb pollutants such as heavy metals, oil.

10. wetlands and climate change effects and interactions are starting to be recognised but little understood as yet. Wetlands are considered very responsive to even small climatic changes and therefore gives the an indicators role. Recommendation for encouragement of further work.

11. better AMS and therefore better isotope tracing at low concentrations

12. some recent revival of pollen analysis and improvements in techniques to allow analysis down to the 2-3 year level but also climate chronologies deduced from flooded logs by 30,000 years and some? British coasts salt marsh ages revised upwards to the order of 8-10,000 years old.

13. reedbed technologies

14. salt marshes

15. predictive modelling of hydrological systems but for which data are not yet available to support, calibrated or test; these could include the Carolina model, the work of K. Bevens, Lancaster & IH. Interprocess modelling eg peat decomposition and hydrology, groundwater flows and nutrient dynamics.

16. Has the interest in modelling been improved by the availability of faster or just more computers or just reflect the change in interest in the processes involved? Should more emphasis be placed upon collection of field data now models are more sophisticated than their validation from field data would justify? The example of hydrological models for the Broads was given but questioned as the fundamental physics of water movement through different types of peat, was said not to be fully explained.

17 New instrumentation, especially small reliable field data loggers, computers. mass spectrometers, micro-meteorological techniques, new theodolite (EDMs)for small height differences or gradients, over relatively long distances, GPS positional systems with height facilities

Opinion was divided on the question of whether or not there have been many new conceptual advances or have most of these 'advances' merely been evolutionary development or application of previous studies? One other alternative explored was the reason for lack of studies in wetlands at present related to under funding, lack of appointments in this academic field, lack of challenges or lack of scientists interested. The fundamental assumptions upon which much of recent work was based and the rate of advance in areas such as the interactions between the requirements of individual organisms and their physical or chemical environment, was challenged and discussed particularly in relation to lack of resources. Examples such as nutrient measurement characterisation of compounds involved (eg phosphorus), equilibria and uptake rates by vegetation, was given. Would collaboration between different disciplines aid funding? No coordinating body unifying approach and funding between ecology, hydrology, marine etc aspects for wetlands but acknowledging the differences between application for studentships and grants by for example composition of committees or their members interests.

Discussion on the presence of new conceptual insights in relation to absence of funding, interaction with colleagues of adjacent disciplines ie critical mass.
Recommendation for strategy to achieve critical mass in some manner from differing disciplines eg plant ecologists and hydrologists but also engineers to achieve acceptable solutions. Much synergism to be achieved fro such es plant strategy analysis ground water hydrologists, soil analysts, ecologists. prime time to take off because of current economic impacts eg as special topic or initiative on wetlands; at minimal workshops also thought of as effective.
Current problems in both institutes and universities of people in their normal laboratory still trying to research these problems; stronger mechanisms
The perception that group thought that there were few conceptual advances may relate to the relative lack of intense interaction on wetland subjects; the calling of an ERG on wetlands may reflect the absence of rapid forward progress in conceptual aspects of wetland research just as much as the public interest requires NERC to be seen to be doing something but this view was not widely held and it was suggested that communication may be the problem.
Summarising
1. wetlands are a field which need interaction
2. prime focus interest and difficult to assemble critical masses; this was seen a becoming more difficult
Therefore above are true and need more assemblages of people. Although a new multi discipline institute may not be a solution in the short term, groups should at least work on strategically-selected common sites eg fen, river marginal systems, flood plains.. for both fundamental and for applied studies although the dangers of isolation of non-participating scientists esp theoreticians, or the absence of their input to the core work was emphasised.
Focus needed to go beyond adventitious such as Regional Centres but certainly a name plate is needed as it is sufficiently important. Comparisons were made with the problems of study of atmospheric studies.

Clear stepwise or phased approach to wetland research with continuity is required

Recommendation for
1. regular meetings of key group leaders
2. multidisciplinary special topic (£1 M, 5 grants but less likely in near future as backlog of requests) possibly funded internally but to expand to full topic guided by steering group; a community programm (£10 M) may be more appropriate or alternative funding from eg World Bank, European money or putative polluters or ; strong case to quality current publically-perceived pertinent questions

In summary
1. specialists need to get together
2. regular group meeting because of small size and dispersion of research groups but also of the enormous size and diversity of wetland problems
3. lack of critical mass of UK scientists
4. lack of funds
5. disparate character of work to date

Plant Life initiative in raised bogs but also case for more determined case towards wetland policy - early day motion - and for bigger initiative.

1.5 Identify significant (worldwide) developments and problems in wetland research for the next five years. Identify critical areas for research

Significance of wetlands in broad terms

1. Biodiversity
2. maintenance or improvement of environmental quality
3. Health and welfare of human community

This encompasses the functional importance of wetlands and current inadequacy of science base in making the important links between what wetlands ecosystems do, how they work and how is it valuable in relation to functional benefits.

Processes based thus, for example, in environmental quality it is transformation of nutrients and materials and their significance in water quality, flood control in health and welfare, ground water recharge in litigation.
Biological process-related factors such as the assembly rules for biological communities which inhabit wetlands which link to processes in the manner in which organism participate in processes and how this insight enable us to understand the causes of **fragility** of such systems and the maintenance of stability when not being perturbated. Is this fragility and its thresholds, to do with changes to the system, and thus impairment of its functioning either as a habitat, in terms of biodiversity, or from performing environmental services such as carbon fixation, and thus changes in environmental quality; this underlies the change from basic ecology and allows forecasting to be undertaken.

A parallel to this broad approach there was also agreement that still there is a need for basic understanding of many process despite the broad attempts to manage wetlands in this crude way, such as the manner in which water moves (hydraulic conductivity) and the effect on vegetation which is so critical to nutrient transmission and toxins etc. uses of natural or introduced labelled molecules & their type and transport paths and rates of movement even. Is the assumption true that simple physical laws van be used to predict water movement? Information is needed on sites eg only a few of the thousands of fen sites in the UK have even had their water levels measured, but concern was expressed over the method of packaging of the need for such information and its funding; one strategy considered was the effects of even slight perturbation on stability of wetland systems ie comparison of the understanding of the systems currently with those of progressively altered by eg water table changes, but basic information on such aspects is needed. This was considered not to be generally an academic function; data is needed on the number of sites currently being monitored. (do NERC's proposed set-up of ECN freshwater sites fit here?). The costs of monitoring the 8 terrestrial sites at £0.2-.3 M pa, was discussed. EC science programmes are said not to consider monitoring of any type.
Recommendation to support monitoring within justifiable science programme preferable if multi-discipline studies which require common environmental parameters (cooperate with NRA ? studies) (LTER equivalent). Key network possible, but are most useful parameters especially chemical being used? The significant indicator parameter (predictors) for wetland monitoring need to be agreed between specialists from different disciplines after which the within-discipline scientist must fine tune such measurements to allow prognostication to be more realistic.

1.6 Identification of critical areas for wetland research for the next five years.

SELECTION FROM THE FOLLOWING ARE REQUIRED from current base and assuming 5 years study on same (goals and achievement methodology for significant advances)

In summary the type of approach should encourage
1. circumstances for in which good ideas can be formed
2. good testing of above ideas
3. sensible monitoring to provide background

Specific problems at all scales are

1. How is **stability** maintained
2. what makes systems **fragile** and how are they linked to outside influences
3. how does water move and its pathways particularly at the small scale and especially when **perturbed** and its degree of **resilience**

and

4. understanding how wetlands act as sinks, stores and transformers of nutrients, contaminants and carbon
5. role of organic compounds in plant nutrition (esp. mires) as sequestering, chaelating and hydrolysing agents (improvements in analytical techniques needed)
6. mycorrhiza (microbiology poorly developed in UK especially by the absence of studies of more than one microorganism group or in real environmental situations)
7. breakdown of cellulose materials (etc.) in ananoxic conditions (ATP related) (perceived to be a difficult problem esp in acid conditions)
8. Faunal diversity and functioning poorly known from
   a. the role of invertebrate in initial stages of breakdown (literature search - see appendix?) but also
   b. the role of fauna in their use of wetlands eg. Dragonflies, birds etc. and
   c. habitat exploitation by avian species eg Flow country, in relation to eg. conservation (data required? from where, hummock hollow niches Old Squaw duck in Alaskan studies peat and linkage, UK? work Sweden, Germany) - functions investigation required.
   d. the presence of wetlands in the maintenance of diversity in surrounding areas

Do some proposals fall between two studentship groups?

In summary, expected developments including pure to applied research, in the next five years are:

A. GENERAL PROBLEMS

1. causes of **stability (and its maintenance)** and fragility, resilience and responses to perturbation, sensitivity to change
2. assembly rules for biological communities by processes but progress may be faster than above

B. HYDROLOGY (at all scales water movement and in connection with chemistry & plant nutrition)

3. **water movement, its speed and pathways and effects on chemistry; modelling of ground and surface water,** is expected to proceed more and field test water cycling and nutrients as a single item

C. WETLANDS AS SINKS, STORES AND TRANSFORMERS of substances of various types, denitrification and phosphorus and linked to buffer zones and policy for both applied management and for pure science; functional analysis and regulatory

D. SPECIFIC GROUPS OF ORGANISMS, joint importance of

6. **microbiology including mycorrhiza and breakdown processes,**

and

7. **biota and their process orientated studies** through their diversity, functioning, and their role in food chains, including in particular invertebrate, bird, amphibians and fish

E. MANAGEMENT in general, including sustainable development and in view of outlook for UK in which large areas of Fens and river valleys may become available for rehabilitation in next decade (Brian Traffords arterial drainage map shown - available for report?)

9. **wetland re-creation or rehabilitation** areas of reservoirs gravel pits, industrial uses opencast mining and experimental marshes

10. **predictors** eg predicting a Redox regime from knowing a water table regime of wetland in regard to water quality functioning (dynamic or probability statements) or peat bog

11. **integrated catchment management** from NRA with MAFF (re. set-a-side) to reestablish wetlands on flood plains (as sink for nutrients, eroded soils), water quality management. Concern was expressed over problems with engineering implications as no engineers present on ERG but this can be remedied.
Maximise this with **conservation** and management practises such as cutting to give a diverse sward but little is known between nutrient enrichment and management.

12. importance of wetlands to international species which are only temporary visitors eg **migrating** species but also salt marches for fish feeding

13. spread of industrial pollution from Developed and in **Third World countries**

14. problems with health programmes using **'primitive' pesticides** by spraying wetlands

15. **sustainable wetland management** and its science base, for **Third world countries** than any other area ($100-150 M), such as, carrying capacities of mangroves for fisheries and grazing levels allocation of water resources without impairing other functional benefits and product markets (see IUCN newsletters).

16. distillation of climate record and palaeological data to produce data, such as recent past rainfall records and hydrology, not unique but more readily accessible; peatlands fairly well explored but not other wetlands. Dutch making detailed measurements of many parameters from stable isotopes to Isopods in order to reconstruct wetness of areas before written records were available.

Wetland problems concerned with global warming are current but some engineering consultancies suggest .. ;
Freshwater resources are currently the primary limitation for development and is likely to be the **source of international & intranational problems** over next 10-50 years eg Slovackia-Hungary Danube Plain but whilst the river is captured, it is the wetlands that suffer.

1.7 State of UK expertise (data sources to be analysed see Appendices)

The ERG considered that the UK wetland studies are strong in peatland ecology but very weak in microbiological expertise and the UK is being overtaken by others countries in several areas eg ?? . However in general the UK is still undertaking experimental and autecological studies and there is a backlog of UK literature. It was perceived by the ERG that in general the initiative may also have been lost in wetland studies although earlier studies on successional and evolutionary processes of saltmarshes had been at the forefront of research. It was pointed out that, although NERC spends a significant part of its wetland money in this area such as in ITE which undertakes some both pure and applied studies, it was considered not to be in very coordinated way although LOIS may redress this balance and a significant backlog may still be awaiting publication due to the current pressures of maintaining commissions.

Evidence on the position on the quality and quantity of published UK studies was considered to be lacking although data on NERC supported studentships and grants were available (Appendix ?)
References to be analyzed from
- Allen & Pyes Saltmarshes book
- ASFA or other bibliographic data base by country (Appendix table)
- FBA library (to be tabled)

Publication of the IBP book on the production of wetlands should undertaken by NERC.

Identify areas of deficiency esp soil physics currently USA & Australia but this is related to drought effects and not excess water ie wet soils physics

Absence of wetland microbiology

1.8 Implications for developments for other areas of science. Dependency of progress on developments in other areas of science, instrumentation or experimental techniques

The ERG considered that there were many implications from the study of wetlands for other areas of science
- hydrology water supply and water quality, one of the areas likely to benefit
- channel engineering for the maximise drainage of wetlands, funded by SERC, would benefit from expertise from wetland specialists!
- global carbon flux change interdependent with other studies
- climate change
- repository of historic record or change, for botanists, palaeontologists and archaeologists as techniques of interpretation and resolution improve, (currently only found when peatlands are destroyed as remote imaging systems not sufficiently well developed eg ground probing radar system or even infra red systems)
- reliable ageing techniques for surfaces especially in peatlands
- chemical analysis at microlevels of elements or ions in water with high organic material
- methodological advance through linkage with other areas of expertise ie water-air, soil-water, water-deepwater but wetlands are a climax with multi-discipline requirements and dependency on many other studies

Discussion on instruments and experiments suggests that use of supported experimental sites including IUCN sites, would be worthwhile. The ERG thought that the blocks in instrumentation development seemed to have been removed although there were still some teething problems. Areas discussed included methane (and water vapour) measurement and micrometeorology, micro hydraulic laser based measurements (despite being expensive), microhydrology, update of passive pressure water levels and conductivity to water supply resources benefits and equipment to study the physics of wet soils.

1.9 Social or economic impacts from developments and outside beneficiaries

The ERG saw the social or economic impacts to be within several areas including; water supply including in the short-term discolouration of water supply but in the long-term deterioration of upland storage, wildlife conservation, landscape and community recreation fisheries, biofuels. Other beneficiaries of wetland research are likely to include: National Rivers Authority and water companies, Overseas Development Authority, Countryside Commission, Ministry of Agriculture, Fisheries & Food, NationaL Wildlife Agencies (English Nature, Scottish Natural Heritage, Welsh .. , Department of the Environment, European Commission?,
planners at all levels from supranational, national, county to parish level.

1.10 Social, economic or political effects on the development and the needs for research results or capabilities

A series of factors were thought to be relevant ranging from Brussels initiatives such as the implementation in 1997 of the Habitats Directive, the request by DGXI to DGXII for an Instrument of Functional Analysis on wetlands (c2000 AD) but rest with new Environment Commissions in EC and UK and for which the implication are not yet known.
Other directives such as the Nitrate Directive which requires the definition of vulnerable zones, then Phosphate Directive.
Land planning in relation ecological economics and the costing of services performed by differing ecosystems ie forecasting of denitrification and groundwater recharge and flood control, carbon tax but also cost of replacing landscape feature if that service is lost.
(linked with sea surge, SERC). Economics only as good as science delivery.

1.11 UK priorities and actions necessary implementation routes and requirements

Critical mass was considered crucial and a variety of ways were discussed from
- an unusual type of Special Topic with outside funding with additional rule that team would only be funded if brought together from different disciplines, it was not clear if LOIS would fund coastal wetlands but different type of river catchment with fens but the cost of making sites useable was discussed. Comparison were made with the funding for the HYRAX Special topic which incorporated meteorological Office, National Rivers Authority and SERC and also Environmental Change Network (NERC funds two from 8 sites). Existing sites should be utilised before new sites instrumentalised. Problems of site choice when funded by international agencies and choice for Third World sites with their differing criteria.
The ERG considered that overall theme for NERC was to consider that it is primarily interested in the science before any other consideration but that liaison with this (NERC) initiative with applications in Third World or Eastern European countries (from World Bank, GEF funds, Environmental Bank for Reconstruction & Development, European & Scandinavian Aid agencies, commercial areas) should be given a high priority by, for example, constituting a small working group with IUCN, WWF, IWRB, etc. partly to take up the funding available for well found science on topics such as tropical peatlands in carbon balance.
- a limited life small group meeting twice yearly to provide a focus for developments
- a special Institute or a network of collaborative centres on wetlands (comparisons were made with IBP Moorhouse site) SITE LIST OF POTENTIAL SITES HERE

Special priorities for group should be international applications but only the last of the following key areas identified was seen generally as likely sources of funds and then only by liaison with open water wetland groups and through management related projects than for research,
1. maintenance of stability
2. hydrological details
3. wetlands as sinks, store and transformers
4. microbiology
5. recreation of wetlands (including sustainable development)

UK sources of funds after NERC (Appendix); NRA & DoE for flood protection general (£0.5 M pa) and possibly on saltmarshes;

FINAL SUMMARY - rewrite

1. need to create critical masses of researchers
2. particular topics for next five years
3. committee with watching brief, restricted duration and linked both to UK and world projects for delivery of science and other disciplines especially engineering (meeting only 1-2 pa for 3-5 years)
4. protection of the subject (wetlands) and stimulation at scale of £1 M pa plus support from outside bodies and cooperate with other bodies

Extras

QUESTIONS

1. Wetland hydrology in relation to work on hydrology under A&APS (HEAC Sub-committee - Aquatic and Atmospheric Physical Sciences) but this ERG is directive and not responsive mode.

see NRA 114 inception report wetland definition and mission with priorities on management.

prepare IBP wetlands write up from DFW

John Gardiner NRA thames re WRA engineers & wetlands

6.1 ERG MEMBERSHIP

Professor R S Clymo (Chairman)	School of Biological Sciences, Queen Mary College, London
Dr F H Dawson (Secretary)	Institute of Freshwater Ecology, River Laboratory, Wareham, Dorset
Mrs A M Roberts (TFSD representative)	NERC HQ, Swindon
Dr B Bertram	Fieldhead, Amberley, Nr Stroud, Glos
Dr T Burt	School of Geography, University of Oxford
Mr K Gilman	Institute of Hydrology, Llanbrynmair, Powys
Dr H Ingram	Department of Biological Sciences, University of Dundee
Dr R James	School of Biological Sciences, University of East Anglia
Professor M J Kirkby	School of Geography, University of Leeds
Professor J A Lee	Department of Environmental Biology, University of Manchester
Dr E Maltby	Department of Geography, University of Exeter
Dr B D Wheeler	Department of Animal and Plant Sciences, University of Sheffield
Professor D Wilcox	Department of Environmental Studies, Coleraine

APPENDIX 3

Secretary's Report of second meeting on 22 February 1993

INTERIM REPORT BY

THE NERC EXPERT REVIEW GROUP ON

WETLANDS

MARCH 30 1993

to

Terrestrial & Freshwaters Sciences Committee

FHD March 5 1993

Contents **page**

1 INTRODUCTION

1.1 Background

The Terrestrial and Freshwater Sciences committee of the NERC considered that wetlands were an area of some public concern and that NERC should be seen to be active in this area.

The terms of reference were to make recommendations on NERC directed support of wetlands research in the future and to report on these recommendations to the Director of Terrestrial and Freshwater Science. These terms of reference were to be enabling rather than prescriptive and to include amendments if considered necessary by the Group including such aspects as the need for other experts, short-term consultancies, etc.

The Expert Review Group held two meetings, one on December 4th. 1992 which followed the guidance in the Introduction to Expert Review Groups for Wetland (WL2/92) given by NERC, and the second on February 22nd. February 1993, in which the report of this first meeting was reviewed, restructured and amended. The interests of the ERG members was wide ranging from peat stratigraphy and botany through function orientated studies based in hydrology and chemistry to human sociology (see Appendix 1). This report outlines the background to wetland studies, discusses the definition of wetlands, the key processes involved in their maintenance, change to area and quality of wetlands, draws some firm conclusions about wetlands research in general and makes recommendations for future studies and initiatives linked or otherwise with existing initiatives eg Land-Ocean Interaction Study (LOIS), and continuing responsive mode funding by NERC (Appendix 2).

1.2 Introduction to wetlands

Wetlands are diverse, widely distributed and often found in lower lying areas of any region or on the coast. The rate, quality and manner of their collection of water adds to their structural variety which in turn provides the maximum potential for the widest range of flora and accompanying fauna of many ecosystems ie they have a high biodiversity. Wetlands are often the last sites which man finds relatively easy to exploit and therefore they continue to be susceptible to physical development or pollute. Wetland development by external funding, may be the most important factor in the continuing exploitation of such biodiverse areas. Conversely wetlands allow the presence of many potential pathogens and may accentuate the effects of natural hazards when population pressures are high. Wetlands seem to provide a good indicator of planetary health with their diverse interactions between the physical and the biotic but few are well understood and therefore many more sites need to be preserved for their role in the world.

A convention on Wetlands of International Importance Especially as Waterfowl Habitat but relating to the fauna, flora or the general habitat, was made under an intergovernmental treaty in, and named after, RAMSAR, in Iran during 1971. This agreement currently obligates 70 states to accept that wetlands of international importance must be designated 'Ramsar sites' and to maintain their character but also to plan that other wetland sites should be used wisely and should be designated as nature reserves.

INCLUDE ANY OF THIS BELOW ?

What part has Britain played in study of wetlands?

Britain and its scientists have always been in the forefront of the study and conservation of wetlands studies cooperating with many nations and peoples. The target is continually changing and progress differs through the varying phases from exploration, mapping, identification of biota, classification and study of the underlying processes or their perturbation by mans activities.

Britain has undertaken studies of wetlands in many parts of the world for many decades but by the early 1900s, and in the footsteps of earlier explorers and naturalists who began to documented in a standard way the vegetation and animals, explanations of the distribution, abundance and succession of biota in wetland habitats were beginning to be studied in detail by the Freshwater Biological Association (FBA) under Pearsall, whilst at the same time as British vegetation being classified by Tansley at Cambridge and others were studying groups of organisms such as waterplants (Ann Arber). By the middle of the century scientists such as Lambert were studying competition between fen species, Gorham at University College, London was studying the chemistry, nutrient input and cycling of bogs and Ranwell on saltmarshes and their sediments. Pollen from wetland sediments was being analysed from quaternary period by Godwin from Cambridge and also at FBA. Later, however, efforts became divided between studies of processes of wetland environments and specific groups of organisms, particularly birds (British Trust for Ornithology & International Waterfowl and Wetlands Research Bureau, IWRB).

Cooperative studies with British scientists on most continents of the world culminated in the 1970s & 1980s with the International Biological Programme which compared the production of the biotic groups of various wetlands by scientists of many nations, with other major ecosystems or biomes of the world. Synthesis of the studies of primary production of wetland species have been coordinated by Westlake (FBA).

Currently UK research continues on a variety of process orientated or multi-disciplinary comparative topics within the restrictive definition of wetlands which is funded to about £1 M per year primarily by the Natural Environment Research Council in the Institutes of its Terrestrial and Freshwater Directorate and British Universities' projects. If, however, the broad definition of wetlands is used then some £10 M per year of research is financed, with additional funding for special initiatives on a variety of topics on biotic, physico-chemical and hydrological processes in freshwater, estuarine and semi-aquatic areas. The current thrust in the UK is mainly related to key processes which affect wetlands such as formation, hydrology, functioning and development in peatlands and saltmarshes, and particularly plant population changes, species richness, diversity, material accumulation and decomposition (Queen Mary College, London), hydrological groundwater, evapotranspiration and atmospheric processes (NERC Institute of Hydrology, Wallingford, sediment dynamics and micro-hydrodynamics (ITE South, Reading University), seawater tides and species change, sediment dynamics of saltmarshes, green-house gas production, nutrient effects on riparian corridors & their species diversity, genetic variation & conservation of rare species and also work continues on weed control (NERC Institute of Terrestrial Ecology and AFRC) and ornithology (NERC Institute of Terrestrial Ecology & International Waterfowl and Wetlands Research Bureau, IWRB). Related studies are also funded, such as characterisation & evaluation of the type and extent of wetlands by analysis of remotely sensed data (NERC Remote Sensing Applications Development Unit); this type of study could allow the overseeing of the progressive and cumulative reduction of wetlands by piecemeal local exploitation.

Water treatment using artificial reedstands are showing a resurgence in USA and Germany and alternative species are being studied in Australia. Scientists in the UK have studied their implementation to reduce pollution eg India or allow water reuse for agriculture and to grow, for example, industrial crops in Egypt (by cooperation with Portsmouth Univ.), following gradual decline of sewage farms or wetland finally ceasing in for example the 1950's in UK. At least one multinational company in Britain is using artificial wetlands to remove from its effluent and concentrate toxic inorganic and organic compounds. Such wetlands in common with bably managed or enriched wetlands tent to be species poor ie not biodiverse and may become virtual momocultures. Linear or riparian wetlands by watercourse, are been studied in several countries to reduce the solute transport of nutrients across from agricultural areas to watercourses by temporary accumulation or permanent de-nitrification Wetland marginal vegetation or fringes to reduce bank erosion of lakes or river from boat wash or in re construction?

Latterly, in the UK at least there has been an unexplained increase in the rate of die-back of Phragmites reed in eutrophic waters for which physiological studies needed but this seems to be related to seasonality. Similarly it has been noticed that reeds used for roofing breakdown faster when from water rich in nutrients.

1.3 The definition of 'wetlands'

The ERG decided neither to use a rigorous definition nor to make its own new definition, but concentrated on that the core of characteristics and processes which are typify the following list of generally recognisable semi-functional site-types or categories:

- mires (ie bogs & fens, as precumulating systems with entirely organic soils)
- freshwater marshes with at least seasonally waterlogged mineral soils not accumulating peat
- salt marshes with soils experiencing water logging by tidal inundation at least monthly,

plus

- water bodies which were a functional integration of, connected to or strongly linked by scale to the above three eg riverine marginal wetlands, flood plains, estuarine areas (but not estuaries ecosystems themselves)

The ERG accepted that a good rigorous scientific definition was needed, and that the approach of a list bridged the differences between a narrow or restrictive definition based on sites with processes in common which typically including
- porous matrices ie interactions between water and solid matter

originating on land,
- water present for at least part of the year ie emphasising the **transitional element of water rather than its permanence,**
- microbiological activity with substrates for microbes to work on creating the typical layers of anoxic sub-layer,
could be workable if linked to sites in which several of these processes were involved.
In contrast, it was considered that the wider types of definition also had some advantages as they included estuarine, shallow saline etc. and could be useful when considering vertebrates and practical conservation value, although they could be more diffuse such as the RAMSAR definition which includes waters up to 6 m in depth, all enclosed waters, etc., but such definitions should be incorporated for they are likely to include most habitat management work or Third World studies. Sites at which primarily limnology or conservation studies were the primary focus, were excluded by this definition but these exclusions served only to emphasise the need for a scientific definition and the casual use (or general misuse) of the term 'wetlands'.
Other complicating factors considered included:
- the conflicting relationship between the scientific and the legal definition of 'wetlands' in different countries and the consequential effects. For example in the USA, a process (and function) orientated definition, combinations of particular conditions of hydrology, biota and soil conditions need to exist before it is legally a wetland, however such a definition can accommodate genetic variants and includes ecosystem sites with regular flooding or the water table is at or close to surface, and have adapted vegetation, soil conditions or hydrology which leads to a range of genetic types but which avoids the complications of the inclusion of eg mudflats.
- the effect by which the higher the level of an organism in the food chain the wider area which needs to be considered and the more catholic the definition required; this should include the primarily scientific rather than the conservation aspects

Wetland systems = wetland 'ecosystem'

Deep lakes

----

enclosed water bodies or
<6 m water depth
shallow lakes

SOILS

PERMANENTLY WET

HYDROLOGY
waterlogging of soil
P : E
permanency of water
volume movement

MINERAL SOIL

rivers

Fen

pond

river margins

SEASONALLY WET
with 'long wet'

SEMI ORGANIC SOILS.

swamps

freshwater marsh

flood plain

mangroves

salt marshes

HIGH ORGANIC ACCUMULATION

springS

estuarine sites

REGULARLY WET
Tidal/ coastal

seashores

flushes

mudflats

soakaways

IRREGULAR FLOODING

peatlands

raised bog

heath

wet heath

Bog

soda lakes

ORGANIC SOILS

DRY

salt lakes

FRESHWATERS | HIGH NUTRIENT WATER | SEA WATER | SALT

SALINITY

1.4 The key features of 'wetlands'

The basic feature common to wetlands incorporates some degree of waterlogging with concomitant physico-chemical repercussions. This basic concept may then be modified by factors and their seasonality, such as hydrology, soils, or water chemistry. Transition states are acknowledged such as those between mire & heath or marshes & wet or other meadows, and drained naturally-wet or other areas ie temporary in agricultural areas, and to be subject to the majority of these processes. However, tidal seawater as the main driving force in creating an estuary is not a wetland in same way as waterlogged soils create as wetlands.

Wetlands are not considered fragile in themselves but are respond to degradation or perturbation by differing extent.

Wetlands are characterised by their organised heterogeneity at all scales such that it is difficult to say they are organised, for example, in the manner of a forest (?) as they consist of small and large scale mosaics organised in trends across areas which compound to create a particular type wetland.

The wetlands are particularly important in climate interactions and change because of the exchange of water, carbon dioxide, oxides of nitrogen and methane with the atmosphere.

1.5 The occurrence of wetlands

Wetlands are both numerically and areally important areas of the world which amount to 7% of Britain, if flood plains are included, and 3% of world surface.

British Isles

The scale of determination of area is important because for example in Scotland, some 10% (9,300 km2) of the total land area of 93,000 km2, is considered to be mire (peat covered land) when mapped at 1:250,000, but it could be as high as 20% when determined from more detailed maps ie possible variation of a factor of two . There is, in addition, some 150 km2 of intertidal mud-flats in Scotland as part of a total of 750 km2 for Britain. The intertidal zone in Scotland is 1250 km2 which is about one third of that of Britain. (The area of England & Wales is 151,000 km2.) Flood plain areas are extensive and some concern was expressed on the relevance of their inclusion when agriculturally developed eg Cambridge fens versus the Somerset levels but also at both their loss and degradation in general from loss of eg hydrological integrity at the margins and not just physical destruction of system. Alternative interference such as the damning off of flood plains by berms etc was considered important.

In Europe, many of the wetlands have already been lost over the last 2000 years and it is estimated that even in the now environmentally aware USA almost half, 45,000 km^2, estimated retrospectively by sampling, has been lost in the last 200 years, often under tax concession but without much real sustainable gain to agriculture.

Europe soil map for

Gore ed volume Vol 4 of ecosystems of world
At world level, the 560 or more Ramsar sites they cover in total 360,000 km2 hectares being a one four hundredth of the world land surface (148,000,000 km2) .

Peat wetland 50-60% of all wetlands on worldwide basis

1.6 The importance of wetlands and consequences of loss

Wetlands are important because they allow
Flood control,
ground water control,
recharge and discharge,
shore line stability,
forestry,
nutrient transformation

2. PRIORITY AREAS OF SCIENTIFIC RESEARCH

The gaol or driving force to enable to promote and undertake research to maintain the stability of wetland ecosystems, understand their functioning and enable their sustainable utilisation. The ERG was conscious that management driven topics were more frequently funded than curiosity driven research. However it is recognised that basic knowledge is required for management projects such as the continued existence of microbes and the reason for their particular rate of breakdown which may lead to the accumulation of peatlands.

2.1 Overview of Priority areas

Priority research areas are highlighted within the following main themes associated with wetlands:

1. description and inventory (now feasibly in UK from vegetation survey by interpretive surveillance from remotely sensed data to identify changes in key habitats but requires more advancement in imagery to determine species differences, physical features, etc.)
2. hydrology & hydrological details
3. wetlands as sinks, store and transformers
4. microbiology
5. faunistic diversity and interaction
6. maintenance of functioning and stability (including maintenance, stability and functioning to bring ecological integrity, benefits, social aspects)

and from these aims the more applied area of

7. restoration (recreation) of wetlands (as maintenance restoration & sustainable utilisation an area upon which three times as much money is spent as on 1-5 upon which success is dependant but for which there is still little understanding even for such fundamental factors as the choice of initial vegetation

Diagram of 1-6 ?

Within each area below (2.2.1-7), this report considers aspects and comments applicable from the following: the scope of science within the area; developments in last five years; probable developments in next five years at (a) conceptual, (b) factual & (c) equipment level; strengths and weaknesses of UK expertise including manpower and special equipment; interdependence with other areas; economic or social impacts with timescales and if any outside beneficiaries; predictions on any likely social or political changes with anticipated research requirements; priorities in UK work and mechanisms of implementation.

2.2 Priority Research areas

2.2.1. Description and inventory

In the last quinquennium, several UK groups have undertaken categorization and their recognition, mainly by almost uncoordinated inventories of eg peatlands by remote sensing, fen ecosystems by ground surveys together with the comprehensive survey for the NRA have been initiated; these have been using previously existing methodologies ie mainly list collecting. Survey has started to pass from vegetation to habitat categorization and its definition but concern is being expressed now for the next quinquennium that mesotopes will be given different names in response to various external influences but scientific definitions are needed for legislative, engineering and global climate flux studies. This could be undertaken through process-relaxant and effective functional units currently based upon vegetation but which should incorporate processes but requires the **definition of such areas in terms of scale, pattern, mosaics,** areas of high local activity and perturbation (Maltby notes expected) through improvements of instrumented calibration sites in different geographic regions to allow for study of the same physicochemical parameters culmination in different functional site types.
Remote sensing (passive visible and active microwave) is now improving in UK and it is hoped that over the next quinquennium, better surveys of not only vegetation through interpretive surveillance but physical parameters such as surface moisture, allowing the identification of and change to key habitats but this may still require more advancement in imagery before species differences, physical features, etc. can be correctly and objectively surveyed. (?).
A classification is required that has a functional meaning for even the most obvious of wetland features, the vegetation, is only a surrogate for the function of the wetland system in that area, region or continent. This functional classification is of critical importance with interfaces with human activities such as farming.

The ERG considered that the UK being innovative in terms of the correct groups for classification systems eg the hydrological classification of mires, numerical and ordination analysis but trailed the leader, USA, in the inventory work which spends $25 M pa.

Much technology already available
Cooperative studies with other agencies eg NRA, IWRB, to bring NERC skills

2.2.2. hydrology & hydrological details

Advances in the last quinquennium were considered to be mainly incremental and by the further development of hydrology of domed peat masses, Poisson hydraulic models, computing power, data storage and facilitated modelling to the point where it is easier to model than to obtain the necessary data; the latter may be a potential danger.

In the near future, it was felt that self-regulating lysimeters for both large and small biosurfaces would become straightforward, much more data and sophistication in obtaining it (with more relevant refereeing of proposals!), eddy correlation? methane and carbon dioxide flux measuring apparatus. The general role of wetland areas in catchment studies particularly a) run-off production in drainage basins particularly in relation to their position along watercourses eg upstream vs downstream, etc, and b) the potential of physical mechanistic models to predict function of transport in wetlands but also c) others such as attenuation of flood hydrographs and variable source area models or d) educational aspects to include such topics as the myths about the supposed sponge-like characteristics of bogs which is unfounded. Model development on internal dynamics and external run-off models should continue but measurements for testing and refining needed on a large scale for application in moderation of drainage and also water supply but in terms of degradation of wetlands in both the local and global context scenarios such as the seasonality and gaseous exchanges with the environment.

Knowledge of groundwater dynamics is advanced in terms of models but again limited in field data collection terms, particularly in prediction in nature and behaviour in river valleys and mass flow (lines, nets, fractals), patterns, linkage and its emergence from small to regional scales in relation to ground water abstraction in relation pollutants from sewage and agriculture and in which wetlands may be themselves be

modifying.
Further analysis of long-term existing data sets to as surrogates to isolate the effects of wetland in catchments.

ADD CORROBORATIVE DETAIL!

The UK was considered to be well established in hydrology with many advances in modelling having been undertaken but people with an adequate training in soil physics were considered unavailable as are wetlands soil and depth maps in UK except in Scotland.

2.2.3. Wetlands as sinks, store and transformers

Wetlands can be viewed as sinks, stores and transformers of substances of various types,such as nutrients, contaminants and carbon, they denitrify and accumulate phosphorus and they are linked to buffer zones and to regulatory policy for both applied management and for pure science but they are strongly linked with hydrological and microbiological effects. Peatlands in particular are repositories of history ie the long term stratigraphic history, especially but not exclusively the vegetational record. (Wetland archaeology has increased pressures to maintain water levels not only in peatlands but in other wetland types.) The recent revival of pollen analysis and improvements in techniques now allows analysis down to the 2-3 year level but also climate chronologies deduced from flooded logs by 30,000 years has allowed upward revision of the ages of some British coasts salt marshes to the order of 8-10,000 years old.

In the last quinquennium there has been a growing interest in denitrification in lowland wetlands, particularly flood plain and wet flood plain systems, with incremental progress in role of peatlands in carbon storage together with adherence mechanism by peatland plants for nitrogen.

In the next quinquennium further progress on the science behind the role of wetlands as modifiers which under local or global climate change may alter or cease to function with repercussion for buffer zones designation, fen peats and flood plains, with continued work on lowland wetlands, carbon cycling in the global context, nitrogen and phosphorus nutrients in relation to eutrophication effects with the implications for foodchains, field assessment of nitrification and denitrification (paddy fields and eg class 4 sites) in lowlands but also contaminants such as aluminium mobilisation in uplands, nitrogen deposition and stores if peatland dry out.

Sampling variation is high and improved and more versatile portable instrumentation is required for the filed determination of several determinands for example oxides of nitrogen.

2.2.4. microbiology

In the last quinquennium, little work seems to have been done and it was felt that there was a desperate need for such work for even such obvious key questions the main one of which is the mechanism by which organic material accumulates and is different in different circumstances. The response that breakdown is less fast in anoxic conditions, is a null response because comparisons with sludge digesters which exhibit very fast rates show that this cannot be the reason.
The significance of symbiotic mycorrhizal relationships with some vegetation linked with nitrogen is confused by their probable absence of many plant species without such relationships.
One unifying theme linking the microbially induced Redox in relation to water tolerance in plants of many wetlands but also across the organic to inorganic spectrum for sediments.

The ERG considered that the UK has numerous and skilled microbiologists available but they are not working on wetland problems. (HUGH I. TO PRODUCE FURTHER EVIDENCE ON THE BALANCE BETWEEN TAXONOMY AND PROCESS STUDIES.)

2.2.5. faunistic diversity and interaction

In general, it was felt that little information was available on fauna except for the Moor House Pennine site, and that this was a serious omission. However, little is known about the real habitat for species which move more than very short distances, there are few zoologists studying species except avian ones in wetlands and UK zoologists although expert tend to concentrate on specific taxonomic groups but rarely look at wetlands. Faunal assemblages are often said to be assemblages of very particular species or to those species found more generally widespread.

More specific questions were raised on faunal diversity and functioning such as:
the role of invertebrate in initial stages of breakdown;
b. the role of fauna, habitat exploitation and their use of

wetlands eg. Dragonflies, birds etc. or by avian species in eg Scottish Flow country, in relation to eg. conservation; hummock hollow niches Old Squaw duck in Alaskan studies peat and linkage;
c. the presence of wetlands in the maintenance of diversity in surrounding areas
and the comparative autecology of the species

For the recent past, it was considered that the UK had as good a base in the vertebrate groups as elsewhere but this may be little. The complication of migrational movement and ecological roles result in temporary periods in particular habitats and over a wide range of wetland and other habitats

External advice should be sought.

2.2.6. maintenance of functioning and stability

An integrating topic at a higher scale than above (2.2.1-5) considered to embody the concepts of maintenance, stability and functioning to bring ecological integrity, benefits and social aspects and examining the causes of stability (and its maintenance) and fragility, resilience and responses to perturbation, sensitivity to change and incorporating assembly rules (biodiversity) for biological communities.

Wetlands are dynamic but for example they have persisted for a very long time and are therefore considered to be stable at some definable level. On the small scale, hollows or peaks in peat bogs seem to have persisted for many centuries (?) but their explanation draws upon components from topics above (2.1.1-5). In general, wetlands are apparently exhibit little by way of succession and as such may be a unchanged record of previous times and thus how stochastic events may have influenced this eg gene pool variation or more external factors. The effects of perturbation, human or climatic, can be variable responding by correction whereas other respond adversely. One example of the latter include the Pennine blanket peat which is responding to erosion by more erosion, but the mechanism by which this type of response occurs needs to be explained. Thus the question is why are some systems self healing whereas others are not or alternatively why can some systems maintain the ability or resilience, to give high water quality whereas other result in dramatic reductions when for example water levels in lowland areas are changed. The time scale over which changes occur and its dynamics is of relevance to both fundamental and applied studies. The limits of tolerance are not known for many environmental perturbations in natural systems in contrast to the current return to reedbed for nutrient or removal of other contaminants. By contrast some plant populations are able to withstand considerable change in land drainage input rich in nutrient are able to maintain a strong diverse character and flora.

Wetlands may now be remnants or parts of much large assemblages at former sites and not remnant of whole sites eg Shropshire heaths, and how does this reflect on the recovery of sites from stress or perturbation.

The UK has produced a reasonable stratigraphical record with successional processes, some gross characterisation of environmental conditions associated with several of the major vegetation types and habitats with data on actual conditions and to examine in a experimental way some sites. The major problem was however that the time scale was to long for most research proposals in common with many other subjects but relates to the unpredictable nature year to year nature of climate but may need to be overcome by the intensive study of transition zones or where small areas are known to be changing; encouragement of long term study sites of peat and lowlands sites was worthwhile but the expense and long term commitment of 20 years, was acknowledged but serious consideration should be given to such sites during the wetting-up of wetland sites for relevant monitoring.

2.2.7. restoration (recreation) of wetlands

Wetland restoration, recreation, maintenance and construction is an area upon which three times as much money is spent as on all the other topics isolated above but despite much activity in Holland, USA & some in UK. There is so far little sustainable wetlands except in the sense of setting up of wetland gardens and little real understanding as such success is dependant upon these as yet not satisfactorily explained topics. The mechanism of setting-up or returning to a naturally functioning and sustaining wetland ecosystem is a fundamental as well as practical problem. Other attempts in UK have been to produce a diverse and raised bog in the Brew Valley and on Thorn Moor but also the consequences of returning lowland sites back to their origins such as wet meadows and predicting the effect on soils which have not been anoxic for decades by restoring its hydrology. Some difficult was found in deciding whether such problems were applied scientific methodology or intrinsically fundamentally science but with immediate application such as in reed bed technology. The carrying capacity of all natural wetlands was also considered worthy of study.

The ERG considered that fundamental scientific efforts in this area should be made both to support applications and efforts in this area (ie applicable science responding to artificial changes) and to be able critically appraise them, as they are clearly of practical importance.
In general the committee felt that the best possible use should be made of funding earmarked for fundamental science rather than to allow it to support albeit marginally commissioned studies.

(as maintenance restoration & sustainable utilisation

3. RECOMMENDATIONS

3.1 In general there is a need to create critical masses of researchers, to work and interact together on the specific topics above during next five years. Such work should be overseen by a committee with watching brief, restricted duration and linked both to UK and world projects for delivery of science and other disciplines especially engineering (meeting only 1-2 pa for 3-5 years). Protection of the subject (wetlands) and stimulation at scale of £1 M pa plus support from outside bodies and cooperate with other bodies is recommended. Several opportunities for new (and exciting) research initiatives or strategies and the continuation of other topics and technology transfers, are identified. The specific recommendations for further research together with their justification are itemised below.

1. mechanism to collect people together regularly (6-monthly or annually) for a limited (5 years) to review annually review the deliverables as itemised above (2.2.1-7).

2. need to increase and broaden the interaction and synergism with other disciplines which have expertise but as yet little contact with wetlands (eg engineering for applied topics) and effort in wetland research as it is perceived that research is continuing and not to be lacking large equipment or any single item missing (except representative and instrumented sites?). A Special Topic could be one mechanism if application were only accepted when from more than one discipline as (2.2.1-5) but primarily a focus is needed as good topics can be funded through the normal system otherwise wetland funding should only be funded by joint approaches. Recognition should be given to the term 'wetlands' to ensure that applications do not fall between funding committees.

3. coherency of approach is required for wetlands as a group and not it sub-units ie specific sites or specific processes; there is need for a coherent identity from which to publicise state of the art information on wetlands

4. mechanism to fulfil the need for data to support the advances in interactive modelling

5. public concern over the loss of wetlands especially pollution, species or processes, was recognised as an integral part of the need for funding (!) (possible link through to Danube Basin study funded by World Bank ($15 M) and pan-European studies by IUCN to show broader funds)

4. ERG MEMBERSHIP

Professor R S Clymo (Chairman)	School of Biological Sciences, Queen Mary College, London
Dr F H Dawson (Secretary)	Institute of Freshwater Ecology, River Laboratory, Wareham, Dorset
Mrs Ann M Roberts (TFSD representative)	NERC HQ, Swindon
Dr B Bertram	Fieldhead, Amberley, Nr Stroud, Glos
Dr T Burt	School of Geography, University of Oxford
Mr Kevin Gilman	Institute of Hydrology, Llanbrynmair, Powys
Dr Hugh Ingram	Department of Biological Sciences, University of Dundee
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Professor M J Kirkby	School of Geography, University of Leeds
Professor J A Lee	Department of Environmental Biology, University of Manchester
Dr Ed Maltby	Department of Geography, University of Exeter
Dr B D Wheeler	Department of Animal and Plant Sciences, University of Sheffield
Professor D Wilcox	Department of Environmental Studies, Coleraine

APPENDIX 4

Chairman's Draft Final Report with corrections approved by Chairman's Deputy Prof. J. Lee

FINAL REPORT BY

THE NERC EXPERT REVIEW GROUP ON

WETLANDS

15 April 1993

to

Terrestrial & Freshwater Sciences Committee

Contents

1 INTRODUCTION

1.1 Background

The NERC Terrestrial and Freshwater Sciences Committee considered that wetlands were an area of public concern and that research in the area should be reviewed.

The terms of reference were to review research and to make recommendations on the future direction of NERC-supported research to the Director of Terrestrial and Freshwater Science. These terms of reference were to be enabling.

The Expert Review Group (ERG, composition in Appendix 1) held meetings on 4 December 92 and on 22 February 93.

This report arises from those meetings. It outlines the scope of wetlands and the key processes in their development and maintenance. It identifies areas in which the ERG concludes that research needs stimulating.

1.2 What are wetlands?

There are two largely distinct views of 'wetland': those interested in the producer and decomposer cycles at the bottom of the trophic pyramid see only peatlands, freshwater marshes and saltmarshes, whilst those primarily interested in the top of the pyramid (particularly birds, fish & man) see them particularly as shallow lakes, streamsides and estuaries. This latter definition is that of the international Ramsar Convention on 'Wetlands of International Importance Especially as Waterfowl Habitat' adopted at Ramsar in Iran during 1971 and now ratified by 75 States. This view is especially important in questions of conservation because it often requires an integration of approach across whole landscapes. We have tried to hold both views in mind but find that most of the gaps in *basic* research relate to the first view.

The ERG concentrated on the core of those characteristics and processes which typify the following list of generally recognisable site-types or categories:

- mires (i.e. bogs and fens and other peatlands accumulating soils which are almost entirely organic);

- freshwater marshes with at least seasonally waterlogged mineral soils but not accumulating much peat;

- salt marshes with soils flooded by tidal seawater at least monthly;

and for which an operational definition is a site in which one would normally only need to wear Wellingtons to work on a wetland.

plus - water bodies which contain the above three as integral parts e.g. riverine marginal wetlands, flood plains and estuarine areas (but not estuary ecosystems themselves).

These systems have in common:

- porous solid matrices partially or completely filled with water that may be moving or stagnant;
- water present for at least part of the year thus emphasising the transitional state of water rather than its permanence;
- microbiological activity, on substrates within the system, creating anoxic conditions.

Systems in which limnology or conservation are the primary focus of interest were excluded although they are recognised to be of great importance. There is conflict between the scientific and legal understanding of 'wetland' which we ignored.

1.3 Key features of wetlands

Most wetlands have the following characteristics:

- at least seasonally waterlogged with consequent anoxia a short distance below the surface;
- strongly dependent on timing and nature of water movement;
- organised heterogeneity on all scales from a few centimetres to kilometres;
- exchange H_2O, CO_2, CH_4 and N_2O with the atmosphere;
- easily damaged or destroyed by simple land management techniques such as draining, which may have hydrological consequences away from the digging both in time and space.

1.4 Uses of wetlands

Wetlands are used (or abused) for:

- water control;
- forestry;
- grazing livestock
- peat mining;
- sport;
- conservation.

1.5 Occurrence and diminution of wetlands

Wetlands cover about 7 % of Britain, if flood plains are included, and 4 % of the Earth's land surface. They are almost everywhere diminishing in area and integrity. Matthews & Fung (1987) give the following estimates:

Wetland area in Mm^2 ($1Mm^2 = 10^3\ km^2$):

Zone	Latitude	FB	N-FB	FS	N-FS	A	Total
Arctic	80N-60N	929	506	7	26	0	1468
Boreal	60N-45N	889	381	35	87	0	1392
Temperate	45N-20N	174	3	80	114	10	381
Tropics	20N-30S	80	12	905	736	152	1885
Temperate	30S-50S	5	0	51	47	33	136
Total							5262
British Isles							230
Earth's land							130770

FB = forested bog; N-FB = non-forested bog; FS = forested swamp; N-FS = non-forested swamp; A = alluvial.

The scale of estimation of area is important because, for example, in Scotland some 10% (9,300 km^2) of the total land area of 93,000 km^2, is considered to be mire (peat covered land) when mapped at 1:250,000, but it may be as high as 20% when determined from more detailed maps implying a possible variation of a factor of two. There is, in addition, some 150 km^2 of intertidal mud-flats in Scotland as part of a total of 750 km^2 for Britain. The intertidal zone in Scotland is 1250 km^2 which is about one third of that of all Britain.

The flood plains of the Cambridgeshire fens and the Somerset levels, and estuary borders such as the Solway, are extensive but, with a few small exceptions, they have been so drained and managed that their characteristics are much changed.

On the European mainland in the Netherlands barely 1 % of the original peatland remains. Even in the now environmentally aware USA almost half (45000 km^2), of the wetland, estimated retrospectively by sampling, has been lost in the last 200 years, often under tax concession but without much real sustainable gain to agriculture.

1.6 Current research

The UK has a good record of research on wetlands: CB Crampton, Pearsall, Godwin, Conway, Chapman V.J., Walker, Cragg, Gorham and many others began the work. Today it is funded at about 1.1 M£/yr by the NERC. A summary follows; details are given in Appendix 2.

Expenditure (k£) by NERC on wetlands 92-93 or estimated annual rate

	Proj.	CR	CR/SB	SB	Total
TFSD Institutes	21*	200*	102	172@	474
NERC RM Grants	7*			77*	77
Studentships	37			296	296
NERC TIGER II	8			310	310
LOIS (bids only)	10			(306)	
TOTAL					1157

Proj = projects; CR = contract; SB = Science Budget; CR/SB = mixed.
LOIS = Land Ocean Interaction Study.

* Excludes projects that were in the database but did not seem to be wetland based e.g. capercaillie, goshawk, pheasant, Water of Ae (a district), Cameroon rain forest etc.

@ 103 k£ reported under TIGER rather than TFSD.

The largest coherent programme is that supported under TIGER II.1 for work on the production of trace greenhouse gases: but wetlands are incidental to the TIGER objectives. The large number of NERC Responsive Mode (RM) studentships may indicate the interest in the area and the possibility of working in some parts of it with limited resources.

There is a much larger rate of spend (about three-fold greater) in the USA and in the EC on projects with practical objectives related to maintenance and restoration of wetlands. Our experience is that such projects often reveal the lack of basic science in the area.

2. PRIORITY AREAS FOR SCIENTIFIC RESEARCH

The ERG identifies the following as areas in which there is a special need for UK research now or in the near future.

A Description and inventory

B Hydrology

C Microbiology

D Wetlands as sinks, stores and transformers of matter

E Faunistic diversity and interaction

F Maintenance of functioning and stability and the more applied area of

G Restoration (re-creation) of wetlands.

as well as

H General

Within these we identify B, C and D as underpinning E, F and G.

2.A Description and inventory

Types of wetland vegetation have been delimited in the National Vegetation Survey (NVS), but extent has not. In Scotland the Macaulay Land Use Research Institute has surveyed the vegetation (using a different system) and extent of peatlands. A further survey of wetland extent has been made by NERC's Institute of Terrestrial Ecology (ITE). The types and extent of fens (a subset of peatlands) have been surveyed from Sheffield University.

Some attempts have been made to use automatic classification of data remotely sensed from the air or from satellites. At present the techniques cannot distinguish such radically different systems as Cladium and Phragmites fens even from the air.

In all such work two questions arise:

- what units should be recognised?

- what area does each occupy?

Why are these questions worth asking? The main reason is that processes, such as the production of CH_4, are often measured on small areas but the results have to be scaled up to global values. Recognisable units and area inventories are essential. The difficulties in agreeing units are of long standing. Vegetation, as an integrator of site processes and conditions, is the most often used characteristic but it *is* a surrogate for function. The problem is complicated by the existence on peatlands, at least, of mosaics at several different scales (approximately 1 m, a few hundred metres, and several kilometres) the larger including the smaller.

The existing ground-based inventory in Britain is better than most but is inadequate for scaling locally-measured processes. There are large areas of wetland outside Britain (for example the Pripet marshes or the west Siberian plain) that are scarcely known and are difficult to travel in, and for which automatic classification from remotely sensed data is the only feasible solution. At present the techniques are inadequate, although the pioneering work of Ivanov (1975) and colleagues at St. Petersburg have indicated that regular continuas of surface features offer promise as aids to interpretation. New platforms, such as the ATSR2 which can reveal the short-wave radiation loading of the atmosphere and hence the energy and water budgets of the surface, are appearing. They should allow more about the *functioning* of the surface to be inferred. The relation between function and structure must also be investigated on the ground, and this may require relatively long-term measurements but for example Ivanov's work on sequences of surface features which are linked by function could be tested outside the CIS and with new methods.

A second reason for inventory is that, on a global scale, the area of relatively untouched wetlands is probably still diminishing. We need to know the rates.

The UK has expertise in vegetation classification, but has not so far been among the leaders in remote sensing of wetlands. Cooperation among NERC, National Rivers Authority (NRA), International Waterfowl & Wetlands Research Bureau (IWRB) and Universities should be encouraged.

Recommendations

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

2.B Hydrology

It is barely a decade ago that it was established that saturation in rain-fed peatlands is maintained by a dynamic groundwater mound, rather than by capillarity (Ingram 1982), and that flow in such systems may be very complex (e.g. Gilman & Newson 1980), though Ivanov (1975) in the USSR had made major advances in understanding even earlier. The first of these discoveries has revolutionised our understanding of why it is that peatlands have the shapes that they do. In general an understanding of hydrology is crucial to an understanding of how and when a wetland will respond to climatic change, drainage, or other alteration.

In the last five years there have been further rapid advances in understanding both of the steady-state and of the dynamic flow of water in peatlands both in the UK and in the USA. One important reason for these advances has been the ready availability of desk-top computers able to run quite complex hydrological simulations, and parallel-processor computers whose power is generally ahead of need. Models have therefore run ahead of empirical techniques and measurements. Lack of computers in the former USSR may account for the lack of world-class hydrological work there in the same period.

There is still much fundamental work to be done on the theory of water movement in porous matrices, and there is a worldwide shortage of soil physicists (as opposed to those with some physical training and insight which they apply to complex porous systems). But the main need now is for better techniques of measurement and for more measurements. Examples are the need for measurements of hydraulic conductivity at all depths in peatlands, not just the top metre or so, and for tracing of the paths of water movement on a scale of mm to cm. These sorts of measurement are needed to constrain the building of models. There is also a need for more routine measurements ('monitoring') of simple climatic and hydrological variables, such as watertable, and of not-so-simple measurements of water balance. Such measurements are necessary because some of the phenomena on wetlands, for example their floristic composition, are probably related to extreme hydrological and climatic events. The simple variables are fairly readily recorded with automatic weather stations, which are now sufficiently reliable. Instruments for water balance measurements, such as reliable lysimeters for use in peatlands, exist but accurate measurements need time and skilled attention; such equipment needs to be developed further and simplified.

The prediction of runoff characteristics from wetlands is another active field with considerable practical consequences for water conservation and flood control. Work is needed both on theory and on field measurement.

Recommendations

B.1: give priority to the development of hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices with realistic characteristics.

B.3: continue support of work on the hydrology of whole catchments.

2.C Microbiology

It is estimated that northern peatlands alone contain about 450 Gt of carbon (Gorham 1991). This is about the same (Houghton *et al.* 1990) as the total in the Earth's atmosphere. This massive store, most of it accumulated since the last glaciation, represents a spectacular failure of the usual processes of decomposition. The causes are obscure. Anoxia itself does not prevent rapid breakdown by methanogens, as sewage digesters show. Much of the organic matter may be refractory, but it disappears quite rapidly when spread on a garden. There is a wide range of microbiological questions to be answered. The questions have been there for 65 years since Waksman's pioneering work (Waksman & Tenney 1927), yet microbiologists have still to make a concerted attack on them. It is known that anaerobic decay continues slowly throughout the whole depth of anoxic peat producing CH_4 and CO_2 which diffuse to the surface. The peat is almost isothermal so this flux is probably almost constant. There is also a seasonally fluctuating production of these same gases from close below the watertable. The rates and causes of these differences and fluctuations are only now beginning to be investigated in the TIGER programme. Evidence is appearing which shows that CH_4-oxidising bacteria are active in the surface layers of peat. What effects do they have on the effluxes to the atmosphere? Questions such as these have implications for climate change as well as being intrinsically interesting. Few microbiologists are used to working with the complexities of wetlands in the field. The ERG suggests that microbiologists should be encouraged to work in teams, for example with ecologists and micrometeorologists, so that the microbiologists' attention is directed toward the major problems and their context in the field. We note the similarities between the processes in the surface of wetlands and of lake sediments (in which IFE has special expertise).

There are microbiological questions linked to cycles of other elements too: examples are S and its inter-relation with CH_4 production, and N in possible N_2O production from wetlands as NO_3 inputs increase. Further microbiological questions concern the role of mycorrhiza. These are known to link ericaceous shrubs and some liverworts. Their importance in the economy of a peatland surface is unknown.

Molecular techniques such as the PCR (Polymerase Chain Reaction) allow the identification of specific DNA sequences and thus, in favourable cases, of particular microorganisms or functional groups of microorganisms. This is a useful supplement to traditional enrichment methods of establishing existence, but is not (we think) important of itself. But if molecular techniques could be developed to show the quantity of specific enzymes involved in, say, CH_4 production then major advances would follow. As with remote sensing of wetland processes it is not obvious that the techniques are possible yet, but they are worth pursuing as soon as a plausible case can be made.

Recommendations

C.1: microbiologists be encouraged to work on the major problems of peat accumulation and to do so in multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

2.D Wetlands as sinks, stores and transformers of matter

Peatlands are prime stores of vegetation and archaeological history during and particularly since the last glaciation (Godwin 1981). They also retain a record of atmospheric metal fluxes during the industrial revolution (reviewed in Clymo *et al.* 1990). These archives are there to be examined for as long as the peatlands remain little damaged. The ERG sees no need for any special action.

Peatlands are also massive stores of carbon. The microbiological implications have been considered in **2.C** but here it is the interactions with climate which matter. Peatlands have conventionally been considered to be sequestering carbon. Recent examination of this belief (Clymo 1984) shows that the rate of loss of carbon in decay at all depths is likely to be a significant proportion of the rate of fixation at the surface, and that peatlands may be no more than perhaps 30 % as effective at sequestering carbon as they were when they began to grow. Are they extending the area they cover at present? If the climate becomes warmer or drier or both then what will happen to peatlands? Will they decay and become net sources of carbon at the southern part of their present latitudinal zone? At what rate? Will new peatlands form to the north of the present peatland zone? At what rate will they sequester carbon? These are a few of the questions to which answers are required fairly urgently. As with hydrology, theory has outstripped field measurements. More theory is needed but the greater need is for more data to test and constrain the theory. This is a field in which the UK has the expertise to make a significant contribution.

A specific part of such a programme is to get more detailed estimates of gas fluxes to and from the surface of wetlands. The TIGER programme has begun this and is developing advanced micrometeorological methods for integrating fluxes automatically over the highly heterogeneous surface of wetlands. This too is an area the ERG believes needs continuing support.

The part that flood plains play in the transformation, storage and release of compounds of N, P and pollutants entrained in their water supply is an area of growing concern. Most such areas in Britain are used for agriculture and are subject to standard farming practices. Sampling variation is high and there is a need for improved and more versatile portable instruments for the field determination of many determinands, for example oxides of nitrogen.

Recommendations

D.1: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.2: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.3: encourage synoptic studies, particularly over floodplains, of the balance of elements other than carbon.

2.E Faunistic diversity and interaction

In general, the ERG could find little information on wetland fauna and their ecological roles except for the Moor House NNR, about which a great deal is known particularly because of 40 years of sustained work originating in the University of Durham (Coulson & Whittaker 1978), but sparser and no less interesting are studies on insects in the Cairngorms, Snowdonia & salt marshes on the North Sea coast or the Severn estuary, in addition to work on the population numbers, in particular, of wetland birds. Even so, recent studies enforced by the attempts to afforest parts of the Flow Country in northern Scotland, showed the hitherto unestablished importance of these wetlands for several large and conspicuous species. There are few zoologists studying species, except birds, in wetlands and UK zoologists tend to concentrate more on specific taxonomic groups than the wetland habitats or community organisation.

More specific questions about faunistic diversity, population interaction, community organisation and functioning, do not have satisfactory answers at present. For example:

- what is the role of invertebrates in the initial stages of breakdown of plant matter? (& their interactions with their physico-chemical habitat?)

- what are the ecological roles of animals in general? How do they use different wetland habitats as a resource? How does this explain the association between, for instance, certain wetlands and some rarer bird species

- what roles have wetlands in maintaining faunal diversity in surrounding areas?

Recommendation

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds

2.F Maintenance of functioning and stability

Peatland vegetation and processes are stable in the sense that the systems as a whole have been in existence and, as judged by the fossil record, have had much the same suite of vegetation types and processes for millennia. The microtopography of peatlands (on a scales of a few metres) is known to be fairly stable over periods with these timescales (Walker & Walker 1961, Svensson 1988, and many others). Yet the whole surface vegetation can also change, probably in response to changes in climate (Svensson 1988). Some large changes in peatland vegetation are going on at present (e.g. Chapman & Rose 1991).

The development of erosion appears to be a natural process in Pennine peatlands at least (Tallis 1987) though greatly exacerbated by human activities. In some cases self-healing occurs; in most it probably does not cf salt marshes.

Some wetland systems seem to be remarkably tolerant of high concentrations of solutes in the water: *Phragmites* reedbeds are now being again used in water purification. Other wetlands seem to be fragile particularly in their ability to tolerate the continued impact of pollutants but this is little understood as is the effect of species change by for example, native or invasive plants.

All these examples concern stability, fragility, resilience and the 'assembly rules' by which communities are constructed and maintained. In no single case can we say clearly why a system is as it is now or what it would become if external changes were imposed on it. In addition to its intrinsic interest, this sort of knowledge is needed for practical problems of wetland maintenance and reconstruction, as well as being important in the management of water quality.

The problems are complex and some of the concepts are slippery, but the ERG concludes that this area of wetland research has been largely neglected. Where plausible hypotheses about mechanisms exist - and some do - then they should be tested.

Recommendation

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, and the 'assembly rules' for wetland communities.

2.G Restoration (re-creation) of wetlands

Three times as much money is spent on wetland restoration, re-creation, and maintenance as on all the topics **A - F** above. Most of this work is in the Netherlands and the USA with some (for example Thorne Moors) in Britain. The process of re-establishment of vegetation is likely to take years and success may be judgeable only after decades. Most of the schemes have had limited success to date (cf species in artificial wetlands). Control of watertable and water quality are the primary tools of most schemes. Decisions about what plant propagules to supply at what density on what surface and at what scale are often made on the evidence of small scale pilot experiments or none. There are inevitable pressures to produce visible results quickly and this militates against undertaking the necessary basic science. The ERG concluded however that the basic science was needed to guide and improve these practical projects but that this should be undertaken as part of the project and not separately. The ERG therefore makes no recommendation.

2.H General

We have been impressed at how often the answers to wetland problems require expertise in two or more fields. In the past an individual in one field has learned enough about the necessary ancillary discipline(s) to be able to progress. For example, the advances in concepts concerned with wetlands as sinks and stores of matter, described in **2.D**, required contributions in ecology, hydrology, microbiology, modelling and numerical analysis from one person. The advances in the hydrology of large peat masses described in **2.C** resulted from cooperation between ecologists and engineers. TIGER has enforced the construction of consortia most of which contain at least three disciplines, and that arrangement is already producing results which would not have been produced by individuals. Yet there is no continuing forum to encourage discussions between disciplines that will lead to joint actions.

Recommendation

H.1: encourage a forum for discussion among different disciplines concerned with wetlands for as long (only) as it is productive.

H.2: facilitate the publication of data from previous research such as the synthesis volume from the IBP Productivity of Wetlands.

3. SUMMARY OF RECOMMENDATIONS

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

B.1: give priority to the development of hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices with realistic characteristics.

B.3: continue support of work on the hydrology of whole catchments.

C.1: microbiologists be encouraged to work on the major problems of peat accumulation and to do so in multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

D.1: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.2: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.3: encourage synoptic studies, particularly over floodplains, of the balance of elements other than carbon.

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, and the 'assembly rules' for wetland communities.

H.1: encourage a forum for discussion among different disciplines concerned with wetlands for as long (only) as it is productive.

H.2: facilitate the publication of data from previous research such as the synthesis volume from the IBP Productivity of Wetlands.

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APPENDIX 5

Secretary's Update of Chairman's Draft Final Report

FINAL REPORT BY

THE NERC EXPERT REVIEW GROUP ON

WETLANDS

16 April 1993

to

Terrestrial & Freshwater Sciences Committee

Contents

1 INTRODUCTION

1.1 Background

The NERC Terrestrial and Freshwater Sciences Committee considered that wetlands were an area of public concern and that research in the area should be reviewed.

The terms of reference were to review research and to make recommendations on the future direction of NERC-supported research to the Director of Terrestrial and Freshwater Science. These terms of reference were to be enabling.

The Expert Review Group (ERG, composition in Appendix 1) held meetings on 4 December 92 and on 22 February 93.

This report arises from those meetings. It outlines the scope of wetlands and the key processes in their development and maintenance. It identifies areas in which the ERG concludes that research needs stimulating particularly the sympathetic hearing of multidisciplinary bids to NERC rather than by a Special Topic.

1.2 What *are* wetlands?

There are two largely distinct views of 'wetland': (a) those interested in the producer and decomposer cycles at the bottom of the trophic pyramid see only peatlands, freshwater marshes and saltmarshes whilst (b) those primarily interested in the top of the pyramid (particularly birds, fish & man) for the benefit of society as water quality, water quantity, habitat and food chain support, see them particularly as shallow lakes, streamsides and estuaries. The latter is for example the view of the international Ramsar Convention on 'Wetlands of International Importance Especially as Waterfowl Habitat' adopted at Ramsar in Iran during 1971 and now ratified by 75 States. This latter view is especially important in questions of conservation because it often requires an integration of approach across whole landscapes and consideration of the interaction and foodchain support of human societies using wetlands especially in the expanding Third World development strategies currently being formulated. We have tried to hold both views in mind but find that most of the gaps in *basic* research relate to processes integral in the first view.

The ERG concentrated on the core of those characteristics and processes which typify the following list of generally recognisable site-types or categories:

- mires (i.e. bogs and fens and other peatlands accumulating soils which are almost entirely organic);

- freshwater marshes with at least seasonally waterlogged mineral soils but not accumulating much peat;

- salt marshes with soils flooded by tidal seawater at least monthly;

and for which an operational definition is a site in which one would normally only need to wear Wellingtons to work on a wetland.

plus - water bodies which contain the above three as integral parts e.g. riverine marginal wetlands, flood plains and estuarine areas (but not estuary ecosystems themselves).

These core wetland systems have three factors in common:

- porous solid matrices partially or completely filled with water that may be moving or stagnant;
- water present for at least part of the year thus emphasising the transitional state of water rather than its permanence;
- microbiological activity, on substrates within the system, frequently creating anoxic conditions.

Other systems in which limnology or nature conservation are the primary focus of interest were excluded from consideration. There is conflict between the scientific and legal understanding of 'wetland' which we also ignored.

1.3 Key features of wetlands

Most wetlands have the following characteristics:

- at least seasonally waterlogged with consequent anoxia a short distance below the surface;
- strongly dependent on timing and nature of water movement;
- organised heterogeneity on all scales from a few centimetres to kilometres;
- exchange H_2O, CO_2, CH_4 and N_2O with the atmosphere;
- easily damaged or destroyed by simple land management techniques such as draining, which may have hydrological consequences away from the digging both in time and space.
- dominated by highly adaptable or strongly habitat-modifying vegetation

1.4 Value & pressures on wetlands

Wetlands are used (or abused) for:

- water control;
- forestry;

- grazing livestock
- commercial peat mining;
- sport;
- conservation.

1.5 Occurrence and diminution of wetlands

Wetlands cover about 7 % of Britain, if flood plains are included, and 6 % of the Earth's land surface with 3-4 % peat-forming. They are almost everywhere diminishing in area and integrity. Matthews & Fung (1987) give the following estimates:

Wetland (methanogenic) area in Mm^2 ($1Mm^2 = 10^3$ km^2):

Zone	Latitude	FB	N-FB	FS	N-FS	A	Total
Arctic	80N-60N	929	506	7	26	0	1468
Boreal	60N-45N	889	381	35	87	0	1392
Temperate	45N-20N	174	3	80	114	10	381
Tropics	20N-30S	80	12	905	736	152	1885
Temperate	30S-50S	5	0	51	47	33	136
Total							5262
Wetland area of British Isles							230
Total Earth land surface							130770

FB = forested bog; N-FB = non-forested bog; FS = forested swamp; N-FS = non-forested swamp; A = alluvial.

The scale of estimation of area is important because, for example, in Scotland some 10% (9,300 km^2) of the total land area of 93,000 km^2, is considered to be mire (peat covered land) when mapped at 1:250,000, but it may be as high as 20% when determined from more detailed maps implying a possible variation of a factor of two. There is, in addition, some 150 km^2 of intertidal mud-flats in Scotland as part of a total of 750 km^2 for Britain. The intertidal zone in Scotland is 1250 km^2 which is about one third of that of all Britain.

The flood plain wetlands of Cambridgeshire Fenlands and the Somerset levels, and estuary borders such as the Solway, are extensive, but, with a few small exceptions, they have been so drained and managed that their characteristics are much changed.

On the European mainland in the Netherlands barely 1 % of the original peatland remains. Even in the now environmentally aware USA almost half (45000 km^2), of the wetland, estimated retrospectively by sampling, has been lost in the last 200 years, often under tax concession but without much real sustainable gain to agriculture.

1.6 Current research

The UK has a good record of research on all types of wetland: CB Crampton, Pearsall, Godwin, Conway, VJ Chapman, Walker, Cragg, Gorham and many others began the work. Today UK it is funded at about 1.1 M£/yr by the NERC. The UK (Exeter) is a major leader in EC Wetlands Programme and IUCN Wetland programmes. A summary of NERC funded projects follows; more details are given in Appendix 2.

Expenditure (k£) by NERC on wetlands 92-93 or estimated annual rate

	Proj.	CR	CR/SB	SB	Total
TFSD Institutes	21*	200*	102	172@	474
NERC RM Grants	7*			77*	77
Studentships	37			296	296
NERC TIGER II	8			310	310
LOIS (<u>bids</u> only)	10	?		(306)	
TOTAL					1157

Proj = projects; CR = contract; SB = Science Budget; CR/SB = mixed; LOIS = Land Ocean Interaction Study; TIGER = TFSD Initiative for Global Environmental Research.

* Excludes projects that were in the database but did not seem to be wetland based e.g. capercaillie, goshawk, pheasant, Water of Ae (a district), Cameroon rain forest etc.

@ 103 k£ reported under TIGER rather than TFSD.

The largest coherent programme is that supported under TIGER II.1 for work on the production of trace greenhouse gases: but wetlands are incidental to the TIGER objectives. The large number of NERC Responsive Mode (RM) studentships may indicate the interest in the area and the possibility of working in some parts of it with limited resources.

There is a much larger rate of spend (about three-fold greater) in the USA and in the EC on projects with practical objectives related to maintenance and restoration of wetlands. Our experience is that such projects often reveal the lack of basic science in the area but to which EC DGXII is focusing funding a major project with a high proportion of UK scientists (esp. Exeter); IUCN also currently contributes about £ m pa. to wetland research

2. PRIORITY AREAS FOR SCIENTIFIC RESEARCH

The ERG identifies the following as areas in which there is a special need for UK research now or in the near future.

A Description and inventory

B Hydrology

C Microbiology

D Wetlands as sinks, stores and transformers of matter

E Faunistic diversity and interaction

F Maintenance of functioning and stability

and the more applied area of

G Restoration (re-creation) of wetlands.

as well as

H General

Within these we identify B, C and D as underpinning E, F and G and noting the primary role of A.

2.A Description and inventory

Types of wetland vegetation have been delimited in the National Vegetation Classification (NVC), but extent has not. In Scotland the Macaulay Land Use Research Institute has surveyed the vegetation (using a different system) and extent of peatlands. A further survey of wetland extent has been made by NERC's Institute of Terrestrial Ecology (ITE). The types and extent of fens (a subset of peatlands) have been surveyed from Sheffield University.

Some attempts have been made to use automatic classification of data remotely sensed from the air or from satellites. At present the techniques cannot distinguish such radically different systems as *Cladium* and *Phragmites* fens even from the air.

In all such work two questions arise:

- what units should be recognised?
- what area does each occupy?

Why are these questions worth asking? The main reason is that processes, such as the production of CH_4, are often measured on small areas but the results have to be scaled up to global values (eg Exeter). Recognisable units and area inventories are essential. The difficulties in agreeing units are of long standing. Vegetation, as an integrator of site processes and conditions, is the most often used characteristic but it *is* a surrogate for function. The problem is complicated by the existence on peatlands, at least, of mosaics at several different scales (approximately 1 m, a few hundred metres, and several kilometres) the larger including the smaller.

The existing ground-based inventory in Britain is better than most but is inadequate for scaling locally-measured processes. There are large areas of wetland outside Britain (for example the Pripet marshes or the west Siberian plain) that are scarcely known and are difficult to travel in, and for which automatic classification from remotely sensed data is the only feasible solution. At present the techniques are inadequate, although the pioneering work of Ivanov (1975) and colleagues at St. Petersburg, has indicated that regular catenae of surface features offer promise as aids to interpretation. New platforms, such as the ATSR2 which can reveal the short-wave radiation loading of the atmosphere and hence the energy and water budgets of the surface layers, are appearing. They should allow more about the *functioning* of the surface to be inferred. The relation between function and structure must also be investigated on the ground, and this may require relatively long-term measurements but for example Ivanov's work on sequences of surface features which are linked by function could be tested outside the CIS (former USSR) and with new methods.

A second reason for inventory is that, on a global scale, the area of relatively untouched wetlands is probably still diminishing. We need to know the rates.

The UK has expertise in vegetation classification, but has not so far been among the leaders in remote sensing of wetlands. Cooperation among NERC, National Rivers Authority (NRA), International Waterfowl & Wetlands Research Bureau (IWRB), IUCN and Universities should be encouraged.

Recommendations

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

2.B Hydrology

In general an understanding of hydrology is crucial to an understanding of how and when a wetland will respond to climatic change, drainage, or other alteration.Progress in this understanding can be rapid but often step-wise, thus it is barely a decade ago that it was established that saturation in rain-fed peatlands is maintained by a dynamic groundwater mound, rather than by capillarity (Ingram 1982), and that flow in such systems may be very complex (e.g. Gilman & Newson 1980), though Ivanov (1975) in the USSR had made major advances in understanding even earlier. The first of these discoveries has revolutionised our understanding of why it is that peatlands have the shapes that they do.

In the last five years there have been further rapid advances in understanding both of the steady-state and of the dynamic flow of water in peatlands both in the UK and in the USA. One important reason for these advances has been the ready availability of desk-top computers able to run quite complex hydrological simulations, and parallel-processor computers whose power is generally ahead of need. In general, models have therefore run ahead of empirical techniques and measurements. The previous lack of computers in the former USSR may account for the lack of world-class hydrological work there in the same period.

There is still much fundamental work to be done on the theory of water movement in porous matrices, and there is a worldwide shortage of soil physicists (as opposed to those with some physical training and insight which they apply to complex porous systems). Theoretical insights are needed into flow heterogeneity, including piping in large peatlands and transfer across mineral based wetlands but also seasonal variation. The main need now is for better techniques of measurement and for more measurements. Examples are the need for measurements of hydraulic conductivity at <u>all</u> depths in peatlands, not just the top metre or so, and for tracing of the paths of water movement on a scale of mm to cm. These sorts of measurement are needed to inform and constrain the building of models. There is also a need for more routine measurements ('monitoring') of simple climatic and hydrological variables, such as water-table, and of not-so-simple measurements of water balance. Such measurements are necessary because some of the phenomena on wetlands, for example their floristic composition, are probably related to extreme hydrological and climatic events. The simple variables are fairly readily recorded with automatic weather stations, which are now sufficiently reliable. Instruments for water balance measurements, such as reliable lysimeters for use in peatlands, exist but accurate measurements need time and skilled attention; such equipment needs to be developed further and simplified for routine operation.

The prediction of runoff characteristics from natural and modified wetlands is another active field with considerable practical consequences for water conservation and flood control. Work is needed both on theory and on field measurement for such effects as overland flows, pipe flow and seasonal change in oxidising layers.

Recommendations

B.1: give priority to the development of hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices with realistic characteristics.

B.3: continue support of work on the hydrology of wetlands in whole catchments.

2.C Microbiology

It is estimated that northern peatlands alone contain about 450 Gt of carbon (Gorham 1991). This is about the same (Houghton *et al.* 1990) as the total in the Earth's atmosphere. This massive store, most of it accumulated since the last glaciation, represents a spectacular failure of the usual processes of decomposition. The causes are obscure. Anoxia itself does not prevent rapid breakdown by methanogens, as sewage digesters show. Much of the organic matter may be refractory, but it disappears quite rapidly when spread on a garden. There is a wide range of microbiological questions to be answered. The questions have been there for 65 years since Waksman's pioneering work (Waksman & Tenney 1927), yet microbiologists have still to make a concerted attack on them. It is known that anaerobic decay continues slowly throughout the whole depth of anoxic peat producing CH_4 and CO_2 which diffuse to the surface. The peat is almost isothermal so this flux is probably almost constant. There is also a seasonally fluctuating production of these same gases from close below the water-table. The rates and causes of these differences and fluctuations are only now beginning to be investigated in the TIGER programme. Evidence is appearing which shows that CH_4-oxidising bacteria are active in the surface layers of peat. What effects do they have on the effluxes to the atmosphere? Questions such as these have implications for climate change as well as being intrinsically interesting. Few microbiologists are used to working with the complexities of wetlands in the field except, for example, for exploratory testing of disturbance or comparative estimate of breakdown of cellulose. The ERG suggests that microbiologists should be encouraged to work in teams, for example with ecologists, pedologists and micrometeorologists, so that the microbiologists' attention is directed toward the major problems and their context in the field. We note the similarities between the processes in the surface of wetlands and of lake sediments.

There are microbiological questions linked to cycles of other elements too: examples are S and its inter-relation with CH_4 production, and N in possible N_2O production from wetlands as NO_3 inputs increase. Further microbiological questions concern the role of mycorrhiza. These are known to link ericaceous shrubs and some liverworts. Their importance in the economy of a peatland surface is unknown.

Molecular techniques such as the PCR (Polymerase Chain Reaction) allow the identification of specific DNA sequences and thus, in favourable cases, of particular microorganisms or functional groups of microorganisms. This is a useful supplement to traditional enrichment methods of establishing existence, but is not (we think) important of itself. But if molecular techniques could be developed to show the quantity of specific enzymes involved in, say, CH_4 production then major advances would follow. As with remote sensing of wetland processes it is not obvious that the techniques are possible yet, but they are worth pursuing as soon as a plausible case can be made.

Recommendations

C.1: microbiologists be encouraged to work on the major problems of organic matter accumulation, particularly peat, with multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

2.D Wetlands as sinks, stores and transformers of matter

Wetlands can be a prime record of biological, chemical or physical change or event, but many of these processes and their consequences to the environment remain imperfectly understood.

Peatlands are the prime stores of vegetation and archaeological history during the interglacial and especially since the last glaciation (Godwin 1981). They also retain a record of atmospheric metal fluxes during the industrial revolution (reviewed in Clymo *et al.* 1990). These archives are there to be examined for as long as the peatlands remain little damaged. The ERG sees no need for any special action.

Peatlands are also massive stores of carbon. The microbiological implications have been considered in **2.C** but here it is the interactions with climate which matter. Peatlands have conventionally been considered to be sequestering carbon. Recent examination of this belief (Clymo 1984) shows that the rate of loss of carbon in decay at all depths is likely to be a significant proportion of the rate of fixation at the surface, and that peatlands may be no more than perhaps 30 % as effective at sequestering carbon as they were when they began to grow. Are they extending the area they cover at present? If the climate becomes warmer or drier or both then what will happen to peatlands? Will they decay and become net sources of carbon at the southern part of their present latitudinal zone? At what rate? Will new peatlands form to the north of the present peatland zone? At what rate will they sequester carbon? These are a few of the questions to which answers are required fairly urgently. As with hydrology, theory has outstripped field measurements. More theory is needed but the greater need is for more data to test and constrain the theory. This is a field in which the UK has the expertise to make a significant contribution.

A specific part of such a programme is to get more detailed estimates of gas fluxes to and from the surface of wetlands. The TIGER programme has begun this and is developing advanced micrometeorological methods for integrating fluxes automatically over the highly heterogeneous surface of wetlands. This too is an area the ERG believes needs continuing support.

The part that river margins and flood plains play in the transformation, storage and release of compounds of N, P and pollutants entrained in their water supply is an area of growing concern. Most such areas in Britain are used for agriculture and are therefore subjected to standard farming practices which stress wetlands by often major increases in nutrients, grazing or water abstraction. Sampling variation is high and there is a need for improved and more versatile portable instruments for the field determination of many determinands, for example oxides of nitrogen.

Recommendations

D.1: investigate the factors and processes determining the role of wetlands as sinks, sources and transformers of organic and inorganic materials

D.2: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.3: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.4: encourage synoptic studies, particularly over floodplains, of the balance of elements other than carbon.

2.E Faunistic diversity and interaction

In general, the ERG could find little information on wetland fauna and their ecological roles except for the Moor House NNR, about which a great deal is known particularly because of 40 years of sustained work originating in the University of Durham (Coulson & Whittaker 1978), but sparser and no less interesting are studies on insects in the Cairngorms, Snowdonia & salt marshes on the North Sea coast or the Severn estuary, in addition to work on the population numbers, in particular, of wetland birds. Even so, recent studies enforced by the attempts to afforest parts of the Flow Country in northern Scotland, showed the hitherto unestablished importance of these wetlands for several large and conspicuous species. There seem to be are fewer zoologists studying species of animal, except for birds, in wetlands and UK zoologists tend to concentrate more on specific taxonomic groups than the wetland habitats or community organisation.

More specific questions about faunistic diversity, population interaction, community organisation and functioning, do not have satisfactory answers at present. For example:

- what is the role of invertebrates in the initial stages of breakdown of plant matter & what are their interactions with their physico-chemical habitat?

- what are the ecological roles of animals in general? How do they use different wetland habitats as a resource? How does this explain the association between, for instance, certain wetlands and some rarer bird species

- what roles have wetlands in maintaining faunal diversity in <u>surrounding</u> areas?

Recommendations

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds

2.F Maintenance of functioning and stability

The functioning of wetlands as a component of the drainage basin or as an economic resource are, in the majority, lacking in adequate scientific understanding and require many hydrological and ecological problems to be solved to allow determination of their resilience and sustainable utilisation.

Peatland vegetation and processes are stable in the sense that the systems as a whole have been in existence and, as judged by the fossil record, have had much the same suite of vegetation types and processes for millennia. The microtopography of peatlands (on a scales of a few metres) is known to be fairly stable over periods with these timescales (Walker & Walker 1961, Svensson 1988, and many others). Yet the whole surface vegetation can also change, probably in response to changes in climate (Svensson 1988). Some large changes in peatland vegetation are going on at present (e.g. Chapman & Rose 1991).

The development of erosion appears to be a natural process in Pennine peatlands at least (Tallis 1987) though greatly exacerbated by human activities. In some cases self-healing occurs; in most it probably does not such as the effects of fire on peatlands of the N. Yorkshire Moors (cf salt marshes).

Some wetland systems seem to be remarkably tolerant of high concentrations of solutes in the water: *Phragmites* reedbeds are now being again used in water purification. Other wetlands seem to be fragile particularly in their ability to tolerate the continued impact of pollutants but this is little understood as is the effect of species change by for example, native or invasive plants.

All these examples concern stability, fragility, resilience and the 'assembly rules' by which communities are constructed and maintained. In no single case can we say clearly why a system is as it is now or what it would become if external changes were imposed on it. In addition to its intrinsic interest, this sort of knowledge is needed for practical problems of wetland maintenance and reconstruction, as well as being important in the management of water quality.

The problems are complex and some of the concepts are slippery, but the ERG concludes that this area of wetland research has been largely neglected. Where plausible hypotheses about mechanisms exist - and some do - then they should be tested.

Recommendation

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, ecosystem functioning and the 'assembly rules' for wetland communities.

2.G Restoration (re-creation) of wetlands

Three times as much money is spent on wetland restoration, re-creation, and maintenance as on all the topics **A - F** above. Most of this work is in the Netherlands and the USA. Examples in Britain are peatland restoration at Thorne Moors and saltmarsh restoration as form of flood control on the Essex coast. The process of re-establishment of vegetation is likely to take years and success may be judgeable only after decades. Most of the schemes have had limited success to date (cf species in artificial wetlands). In wetlands other than salt marshes, control of watertable and water quality are the primary tools of most schemes. Decisions about what plant propagules to supply at what density on what surface and at what scale are often made on the evidence of small scale pilot experiments or none. There are inevitable pressures to produce visible results quickly and this militates against undertaking the necessary basic science. The ERG concluded however that the basic science was needed to guide and improve these practical projects but that this should be undertaken as part of the project and not separately. Although opportunities for scientists to apply such knowledge in the expanding need in the Third World for sustainable wetland utilisation strategies, the ERG did not as a whole wish to make any recommendation.

2.H General

We have been impressed at how often the answers to wetland problems require expertise in two or more fields. In the past an individual in one field has learned enough about the necessary ancillary discipline(s) to be able to progress. For example, the advances in concepts concerned with wetlands as sinks and stores of matter, described in **2.D**, required contributions in ecology, hydrology, microbiology, modelling and numerical analysis from one person. The advances in the hydrology of large peat masses described in **2.C** resulted from cooperation between ecologists and engineers. TIGER has enforced the construction of consortia most of which contain at least three disciplines, and that arrangement is already producing results which would not have been produced by individuals; existing information is not even generally available from previous major initiatives particularly the comparative data on IBP wetland sites. Yet there is no mechanism (database) to keep isolated individuals or groups informed or a continuing forum to encourage discussions between disciplines that will lead to joint actions. Although the proposal of a Special Topic was discussed at length the majority preferred a scientific discussion group with wetland science being supported by acceptances of good proposals by the relevant NERC committee.

Recommendation

H.1: encourage a forum for discussion among different disciplines concerned with wetlands for as long (only) as it is productive; to raise awareness and facilitate the publication of existing data from research

3. SUMMARY OF RECOMMENDATIONS

A.1: exploit the possibilities of new remote-sensing platforms and instruments to derive structure- and function-based inventories of wetlands.

A.2: encourage existing work to relate structure and function on the ground, for its own sake and as support for A.1.

B.1: give priority to the development of hydrological field methods and measurements.

B.2: support theoretical developments directed to the flow of water in porous matrices with realistic characteristics.

B.3: continue support of work on the hydrology of wetlands in whole catchments.

C.1: microbiologists be encouraged to work on the major problems of peat accumulation and to do so in multidisciplinary teams.

C.2: develop molecular techniques for measuring the *activity* of microorganisms of particular functional groups when practicable.

D.1: investigate the factors and processes determining the role of wetlands as sinks, sources and transformers of organic and inorganic materials

D.2: extend existing work on the carbon-sequestering ability of peatlands and on their response to change in climate.

D.3: develop and apply micrometeorological methods of integrating gas fluxes to and from wetland surfaces over large areas.

D.4: encourage synoptic studies, particularly over floodplains, of the balance of elements other than carbon.

E.1: extend to other wetland types the solid base of work, mainly on invertebrate functioning, at Moor House NNR.

E.2: develop the study of wetlands as a resource especially for rare birds

F.1: encourage investigation of the processes involved in the stability and resilience of wetlands, ecosystem functioning and the 'assembly rules' for wetland communities.

H.1: encourage a forum for discussion among different disciplines concerned with wetlands for as long (only) as it is productive; to raise awareness and facilitate the publication of existing data from research

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