25

Conclusion: Directions for Research on Wetlands in Britain

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INTRODUCTION

Background

The Terrestrial and Freshwater Sciences Committee of the Natural Environment Research Council (NERC) recognised that wetlands were an area of public concern. They commissioned a report on the directions that research on wetlands might take. This chapter is an abbreviated version of that report. The views expressed are those of members of the group (listed above) that produced the report: they are not necessarily those of the NERC.

What are wetlands?

There are three largely distinct views of what comprises a 'wetland':

(1) The first view is that of those interested in the producer and decomposer cycles at the bottom of the trophic pyramid. It includes only peatlands, freshwater marshes and saltmarshes.

(2) The second view is that of those primarily interested in the top of the pyramid (particularly in birds, fish and man; and in water quality, water quantity, and habitat and food chain support). It includes shallow lakes, streamsides and estuaries as well as peatlands, freshwater marshes and saltmarshes. This is the view of, for example, the Convention on 'Wetlands of International Importance Especially as Waterfowl Habitat' adopted at Ramsar in Iran during 1971 and now ratified by 75 States. At the start of 1994 the total area of the 648 wetlands declared was 434 000 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.

(3) The legal view of wetlands may conflict with scientific views but is not directly relevant here.

Most of the gaps in *basic* research relate to processes integral in the development and maintenance of ecosystem structure and function especially in relation to the first view above, but of fundamental importance also to the second view. This report concentrates on the core of those characteristics and processes which typify the following list of generally recognisable site-types or categories:

- Mires accumulating soils which, in the case of bogs, are acid and almost entirely organic, and in fens may be either or both organic and inorganic.
- Freshwater marshes with at least seasonally waterlogged mineral soils but not accumulating much peat.
- Saltmarshes with soils flooded by tidal seawater at least once every two months.

Plus

- Complexes which contain the above three as integral parts, e.g. riverine marginal wetlands, floodplains 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 in at least part of the matrix.

Lakes and rivers are important but are outside the scope of this report.

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 which appear to have advantages in the wetland environment, such as aerenchyma in roots, or insectivory on peatlands dependent on rainwater.
- They are easily damaged or destroyed by simple land management techniques such as draining, which may have hydrological consequences distant from the treatment area both in time and space.

Value of wetlands

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

(1) Natural value lies:
  (a) in effects on water flow, such as flood control in floodplain areas set aside as at least semi-natural wetlands;
  (b) in the ability to sequester carbon and to store a record of archaeology, vegetation and atmospheric deposition;
  (c) as a habitat between land and water with associated specialised organisms;
  (d) in stabilising the margins of water bodies.
(2) Sustainable uses include:
  (a) runoff modification;
  (b) light grazing, reed harvesting, and (in some cases) fishing;
  (c) forestry on naturally afforested peatlands;
  (d) human recreation.

(3) Destructive uses include:
   (a) peat mining on a commercial scale;
   (b) forestry on peatlands not naturally afforested;
   (c) heavy grazing and arable farming.

Some of these uses involve authorities or organisations that are beneficiaries of wetland research.

Occurrence and diminution of wetlands

Wetlands cover about 10% of the UK if floodplains are included, and 6% of the earth's land surface (Maltby and Turner, 1983). They are almost everywhere diminishing in area and integrity (Maltby, 1991). Matthews and Fung (1987) give estimates (Table 25.1) of the area of methanogenic wetland.

The scale of estimation of area is important because, for example, in Scotland some 10% (9300 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.

The floodplain 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 (45 000 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 the 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.

TABLE 25.1 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

Source: Matthews and Fung, 1987.
FB = forested bog; N-FB = non-forested bog; FS = forested swamp; N-FS = non-forested swamp; A = alluvial.

PRIORITY AREAS FOR SCIENTIFIC RESEARCH ON WETLANDS IN BRITAIN

The following are areas in which there is a special need for 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
G Restoration (re-creation) of wetlands
H General.

Within these B, C and D (which are concerned with primary processes) underpin E, F and G, while A underlies all the rest.

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). A survey of the types and extent of fens has been made 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 satellite platforms, 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 Russia 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 of loss.

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.

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 stepwise. It is barely a decade since 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 and 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 the steady-state and 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 peat, 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 *all* depths in peatlands, not just the top metre or so, and for tracing of the paths of water movement on a scale of millimetres to centimetres. 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.

Microbiology

It is estimated that northern peatlands *alone* contain about 450 Gt of carbon (Gorham, 1991) which is about the same as the total in the earth's atmosphere (Houghton *et al.*, 1990). 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 and 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. Microbiologists might be encouraged to work in teams, for example with ecologists, pedologists and micrometeorologists, so that the microbiologists' attention is directed towards 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 interrelation with CH_4 production, and N in possible N_2O production from wetlands as NO_3^- inputs increase. Further microbiological questions concern the effects of mycorrhiza, which are known to link ericaceous shrubs and some liverworts, and the role of VA mycorrhiza. 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 nucleic acid 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. When molecular techniques are developed to show the quantity of specific enzymes involved in, say, CH_4 production then major advances will follow. As with remote sensing of wetland processes it is not obvious that the techniques are practicable yet, but they are worth pursuing.

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.

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 may contain archaeological remains and are prime source of records of 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.

Peatlands are also massive stores of carbon. The microbiological implications have been considered in the previous section and here the interactions with climate are discussed. Peatlands have conventionally been considered to be sequestering carbon but Clymo (1984) showed 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 about 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? As with hydrology, theory has outstripped field measurements.

A specific part of a research programme to answer these questions 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.

The part that river marginal wetlands and floodplains 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 of the balance of elements other than carbon, particularly over river marginal wetlands and over floodplains.

Faunistic diversity and interaction

In general, there is 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 and Whittaker, 1978). Sparser but no less interesting are studies on insects in the Cairngorms, Snowdonia, and on saltmarshes 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 do populations of wetland invertebrates and of wetland 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 birds.

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 scale of a few metres) is known to be fairly stable over periods with these timescales (Walker and Walker, 1961; Svensson, 1988a, 1988b; etc.). Yet the whole surface vegetation can also change, probably in response to changes in climate (Svensson, 1988a, 1988b). Some large changes in peatland vegetation are going on at present (e.g. Chapman and Rose, 1991).

The development of erosion is a natural process 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 extremely slow and may follow a different path.

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 on wetlands.

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 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.

Restoration (and re-creation) of wetlands

Probably three times as much money is spent on wetland restoration, re-creation, and maintenance worldwide as on all the topics A–F above. Most of this work is in Germany, 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 judged only after decades. Most of the schemes have had limited success to date. Control of the water table and water quality are the primary tools of most wetland restoration 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. But basic science, of the kind recommended above, is likely to be needed to guide and improve these practical projects. Relevant basic science ought to be included as part of such projects.

General

The answers to wetland problems often 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 required contributions in ecology, hydrology, microbiology, modelling and numerical analysis from one person. The advances in the hydrology of large peat masses resulted from co-operation between ecologists and engineers. The NERC TIGER (Terrestrial Initiative in Global Environmental Research) programme 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 inter-disciplinary 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.

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