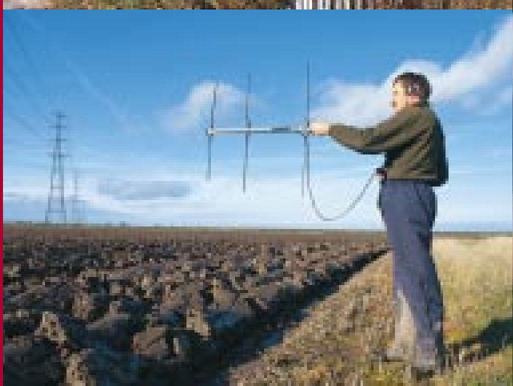
ENGLISH NATURE

Report Number
620

Development of eco-hydrological guidelines for wet heaths - Phase 1

English Nature Research Reports



working today
for nature tomorrow

English Nature Research Reports

Number 620

Development of eco-hydrological guidelines for wet heaths - Phase 1

J.O. Mountford (CEH Monks Wood), R.J. ROSE (CEH Dorset) and
J. Bromley (CEH Wallingford)

Centre for Ecology and Hydrology
Monks Wood
Abbots Ripton
Huntingdon
Cambridgeshire
PE28 2LS

ISSN 0967-876X

Executive summary

This report describes a review of information on the eco-hydrology of wet heaths in Britain, and to assess how far it is possible to identify their water supply mechanisms and preferred regimes for water and nutrients.

The first component of the research was a review of published and unpublished eco-hydrological information on wet heaths. Particular attention was paid to the Wetland Framework of Wheeler and Shaw (2001) and the use of Sum Exceedence Values (SEV) for characterising water-regimes of plant species and communities.

The core of the report is a critical evaluation of this information, beginning with data on individual species and continuing with descriptions of community water-regimes. The autecological review assessed both quantitative information and classifications where species are ranked by their "indicator value" eg the Ellenberg system. Data for the main dominants of wet heaths are available, but there is insufficient information on the full range of wet heath species to construct an overall typology of wet heath eco-hydrology.

The main sources of information on the eco-hydrology of wet heaths and their species are the community descriptions of the *National Vegetation Classification* (Rodwell 1991b). The material from the *NVC* was reviewed and augmented with later literature, outlining the current state of knowledge. From these sources it was possible to assess wet heaths and their component species in terms of their sensitivity to environmental change.

The report advanced a sketch that attempted to conceptualise "how wet heaths work". Heath type is at least partly determined by climate, and the soil water-regime is influenced by temperature, rainfall and hence evapotranspiration. Heath types are clearly arranged along an axis from Continental to Oceanic climates, as well a second axis from soils that are only periodically waterlogged to those that are permanently damp.

Wet heath sites were divided into three broad eco-hydrological categories: a) those with impeded drainage where SEVs might be most useful in typifying water-regime; b) small depressions on undulating land; and c) those with clear soligenous effects where WETMECs might be readily applied. This classification was supplemented by an assessment of variation in response to nutrient regime and microtopography. The role of management in shaping heath composition was also discussed.

In the absence of sufficient quantitative data to construct a full typology of wet heaths by Water Supply Mechanism or by SEV, interim ecological targets were derived from this critical assessment and presented in two preliminary summaries: a) a diagram showing how wet heaths (and related vegetation types) are distributed in relation to soil type, soil moisture and management; and b) a tabulation of wet heaths by the landscape situation within which they occur, their possible WETMEC and their ecological type (pH and soil fertility).

The report contains a bibliography of important source works and a listing of major centres of ongoing relevant research.

Contents

1. Background and approach

1.1 The project

The present research extends an approach that began with the work of Wheeler and Shaw (2001) and Wheeler and others (2004) ie an attempt to marshal existing quantitative information on the eco-hydrology of plant communities so as to be able to assess the likely effects of consented permissions and activities on those habitats and species with conservation designations. The statutory nature conservation agencies want to be able to make accurate predictions on the effects of hydrological change.

To that end English Nature (supported by the Countryside Council for Wales and The Environment Agency) commissioned the NERC Centre for Ecology and Hydrology to review extant literature and unpublished reports to produce guidelines, ie a *Wetland Framework* in the sense of Wheeler and Shaw (2001), for assessing the impacts of potential change. This project focussed on Northern Atlantic wet heaths (with *Erica tetralix*) and Temperate Atlantic wet heaths (with *Erica ciliaris* and *E. tetralix*) and works towards providing guidelines wherever the information collected is sufficiently robust. Seven communities of the *National Vegetation Classification* (Rodwell 1991b) are included:

H3 *Ulex minor-Agrostis curtisii* heath (three sub-communities)
H4 *Ulex gallii-Agrostis curtisii* heath (four sub-communities)
H5 *Erica vagans-Schoenus nigricans* heath (two sub-communities)
M14 *Schoenus nigricans-Narthecium ossifragum* mire
M15 *Scirpus cespitosus-Erica tetralix* wet heath (four sub-communities)
M16 *Erica tetralix-Sphagnum compactum* wet heath (four sub-communities)
M21 *Narthecium ossifragum-Sphagnum papillosum* valley mire (sub-communities)

The approach was to collate the available data and to provide clear statements of the extent and quality of current information on the ecohydrology of the Atlantic wet heaths. This allows the identification of important gaps in knowledge and to make recommendations for the setting of future targets.

1.2 Project objectives

As set out in the English Nature invitation to tender, CEH was commissioned to meet the following objectives:

- Review relevant information on the water resource and nutrient requirements of wet heath habitats.
- Critically evaluate the information, identifying any gaps and/or requirements for further data collection.
- Produce interim, "best available" recommendations for ecological target setting.

1.3 Methods

The review of extant knowledge (Sections 2 and 3) gathered eco-hydrological data on wet heath communities from three main types of source:

Scientific journals and books: These provide high quality data in terms of objectivity and statistical rigour, having been peer-reviewed. However, there are relatively few scientific studies specifically related to the ecohydrology of wet heathland plants, so such data are necessarily very limited. Amongst the most useful sources are those comparative studies of plant ecology that rank or classify species in terms of their responses to environmental factors such as water-regime, fertility or pH eg Ellenberg (1974, 1979), Grime and others (1987) and Hill and others (1999, 2004). The community accounts of the *National Vegetation Classification* (Rodwell 1991b) obviously provide the best synopsis of ecological knowledge on the seven wet heath types. The review employed these key sources as a consistent context within which to assess published papers. Much of this additional literature was already held by CEH, but to ensure completeness, the search included bibliographic databases held by other institutions (eg English Nature and RSPB), the Web of Science and the catalogues and CD-ROMs held by the CEH libraries.

Published and unpublished reports: Reports by the statutory agencies (JNCC, English Nature, SNH and CCW) and by other conservation organisations (eg the National Trust and RSPB) were obtained by interrogating the bibliographic databases and via personal contacts. Other key sources include the *Proceedings* of the *European Heathland Workshops* and the *National Heathlands Conferences*. Such reports contain a mixture of scientific research and observational data and are a rich source of information. The work of Sheffield and Open Universities together with CEH is central to current thinking on eco-hydrology and reports of their results provide a further body of information for assessing the site-specific and autecological data (Wheeler and Shaw 2001; Wheeler and others 2004). The particular theme of wet heath restoration had already been reviewed by some of the CEH team (Rose and Webb 2000).

Ongoing research: The first project objective also requires CEH to identify where relevant ongoing research on wet heathland is taking place, both in the UK and elsewhere in Europe. CEH Dorset is itself a major site for such work, and its geographical location at the focus of wet heath community diversity in Britain means that much of the classic historical research as well as present effort are centred there. Similarly CEH Wallingford has outstanding expertise and accumulated data on peat hydrology and the eco-hydrology of raised mires. CEH Monks Wood not only holds the national databases on species distribution and ecology, but has also led approaches to the use of indicator species in eco-hydrology. Outside the UK, key European researchers contacted included Francois Rozé (France), Jan Bakker (Netherlands) and Johannes Prueter (Germany). The European Heathland Workshop and English Nature European Heathlands website were also used to establish links.

Wet heath Environmental Impact Assessments (EIA): During discussion with the project steering group, it was suggested that a useful source of information on the water-regimes of wet heaths might be present in those EIA statements and reports made in response to proposed development (via public enquiries etc) on or adjacent to heathland SSSIs and nature reserves. Consequently, members of the steering group trawled for such experience and reports within English Nature and CCW, as well as the North York Moors National Park *Moorland Research Review*. The CEH project team also made a thorough search of those databases and libraries to which they had access. However, despite considerable effort by all parties concerned, no extra data sources were located, and the evaluation (and remainder of the report) is thus derived entirely from material cited in the bibliography.

2. Review of relevant information

Objective: To obtain new information from both published and unpublished literature sources and combine them with existing bibliographic data sets. Produce a listing of the ongoing research being done on wet heath habitats**.**

The bibliography of references compiled during this project is included as section 6 (Part I) of the present report, with those main centres of ongoing wet heath research listed in Part II.

Within the bibliography, certain works (identified by ***K***) are clearly more broadly useful. The closest approach to a complete review of the eco-hydrology of wet heaths is provided by the relevant volume of the *National Vegetation Classification* (Rodwell 1991b), which effectively summarises most published information to that date on the water and nutrient requirements of wet heath species and communities. Much of this information is qualitative, however, ranking wet heath species and communities along axes of soil moisture and/or nutrient content, without attaching numerical values to these axes.

Similarly, all the chief sources of species-by-species information on eco-hydrology, preferred pH range and nutrient requirement also take a qualitative approach, deriving indicator vales (Ellenberg 1974, 1979; Hill and others 1999, 2004) or using a broad classification of preferred regimes (Grime and others 1987).

During the 1990s, novel approaches were taken to characterisation of the water-regime requirements of species. The work of David Gowing's team (Cranfield and Open Universities) and their collaborators applied the concept of Sum Exceedence Values (see section 3 for outline of the SEV approach) for aeration and drought stress to British wetland habitats, focussing particularly on lowland wet grassland (Gowing and others 2002; Wheeler and others 2004). Bromley and others (2004) applied this approach to raised mire vegetation in a case study at Thorne Moor in Yorkshire, gathering data relevant to a number of key wet heath species: *Calluna vulgaris, Erica tetralix* and *Molinia caerulea*, as well as other species with a broader amplitude or whose core habitat is elsewhere eg *Betula pubescens, Eriophorum angustifolium, E. vaginatum, Pteridium aquilinum* etc.

For the purposes of the present research, the key approach is that of the *Wetland Framework* (Wheeler and Shaw 2001, Wheeler and others 2004), an outline of which is given in the box on page 12, together with an explanation (on page 13) of the Situation Types, Wetland Water Supply Mechanism Types (WETMECs) and Ecological Types outlined for Eastern England by Wheeler and Shaw (2001). CEH has sought to assess how applicable this approach is to wet heaths, ie what information is required, where the current gaps in such information are and what further research is needed in order to fully apply the *Wetland Framework* to such communities. In particular, CEH has tried to assess whether wet heaths can yet be allotted convincingly to the broad WETMECs described by Wheeler and Shaw (2001) as well as to the Situation Types and Ecological Types that contribute to the overall *Wetland Framework* methodology. Wheeler and Shaw (2001) state that it is desirable to identify and characterise WETMECs from other parts of Britain, partly to refine the system as it was derived in eastern England, but also to extend the approach to cover habitats and communities (like wet heaths) that are hardly addressed in their report.

The WETLAND FRAMEWORK and WETLAND WATER SUPPLY MECHANISM TYPES (WETMECs)
(Adapted from Wheeler and Shaw 1994, 2001; Wheeler and others 2004)

The *Wetland Framework* identifies the main distinctive wetland "habitats" that occur in Eastern England, focussing particularly on wetland statutory sites. The approach is described as "bottom-up" ie because the authors have abundant high quality data on vegetation and environmental factors (included hydrology) for some 80 sites within the region, they were able to produce a rigorous *de novo* framework based on analysis of field data. The approach used multivariate classification of stand data, using Ward's Method analysis (CLUSTAN: package). In no sense is the *Framework* a preconceived classification into which sites and parts of sites have been "forced". It should also be noted that their classification is **not** focussed at the site level, but rather at the within-site scale, recognising that one wetland site may have several different supply mechanisms *etc* and hence different wetland types.

The Framework itself comprises a typology of wetland habitats based on three kinds of unit (see table on page 13):

Situation Types .ie the broad landscape context within which the wetland occurs. Six categories were used in Eastern England that can also be related to hydrotopographical elements. Most wetland sites in Easter England belong to a single Situation Type.

Wetland Water Supply Mechanisms (WETMECs) included nine types, further subdivided into 31 sub-types and described in terms of their ecological characteristics, ecological types (see below), vegetation types, groundwater sources, "naturalness", conservation value and vulnerability.

Ecological Types are also derived from field types and include a classification of base-richness and of fertility.

Wheeler and Shaw (2001) state that the main wetland "types" of Eastern England can be effectively identified by combining the WETMECs and the Ecological Types. The approach recognises that *NVC* communities (Rodwell 1991-2000) are abstractions and as such may not correspond precisely with the WETMEC, ie an *NVC* type may include several WETMECs and the same WETMEC may support more than one *NVC* community. Within fens, the authors recognise that the main axis of variation in floristic composition corresponds quite well to variation in base richness, and inversely to variation in availability of phytotoxins (eg aluminium, ferrous and manganous cations), whereas the second axis is clearly related to fertility, and the third to variation in summer water-level.

WETMECs explain what "makes the system tick" in hydrological terms, and the categories (see page 13) are based on water source together with water level, piezometric head (ie degree of lateral water-movement) and those conditions near the soil surface that influence the distribution of water to the root zone. Some WETMECs correspond quite well with earlier attempts to derive hydrotopographical elements (Wheeler and Shaw 1994), but are more rigorous whilst probably less nationally applicable (being based on Eastern English site data). It should also be noted that described WETMECs are not absolute units, but can intergrade and, of course, new WETMECs are likely to be identified as the approach is more widely applied in terms of habitat and geography.

The *Wetland Framework* thus has different levels, which are (in principle) independent from one other, and the approach was designed to be used hierarchically. Thus the highest level units (Situation Types) are the broadest but are least informative, whilst the lower levels (WETMEC sub-type and their associated Ecological Types) are the most precise and useful, but often rather difficult to determine. Thus it is normally straightforward to place a site into its landscape context (Situation Type), though some site examination and some familiarity with the methodology is required to define the WETMEC, and more detailed investigation is needed to proceed to the WETMEC sub-types. The base-status category can be determined from field pH measurements (see page 13), but the fertility category was determined by Wheeler and Shaw (2001) using a *Phalaris arundinacea* phytometer. Hence, accurate fertility classification requires some phytometric analysis of soils samples, though some approximation can be derived by examination of the plant communities and use of Ellenberg N indicator values.

In terms of wet heath *NVC* communities, only two (**M14** and **M21**) are given any kind of coverage in the *Wetland Framework* for Eastern England. Nonetheless, the descriptions of the WETMECs are sufficiently detailed to permit some attempt to place the remaining wet heath types into a highly preliminary classification. This is described in Section 4 of the present report.

Wetland Framework Types for Eastern England: Component elements
(after Wheeler and Shaw 2001)

Wetland "situation types"

Basin Wetland	Topogenous wetland receiving water from surrounding slopes, ie effectively enclosed and collecting precipitation falling on and around it.
Lakeside Wetland	Transitional wetland from open water of lake or pool.
Coastal/Floodplain Wetland	Floodplains (including water-managed floodplains and other sites that are rarely flooded) by rivers or on flattish land by the sea (but free from sea-flooding).
Plateau-plain Wetland	Wetland on essentially level land where impeded drainage provides wet (often waterlogged and anaerobic) growing conditions.
Valleyhead Wetland	In the headwaters of small valleys, usually occupying one or both slopes and the valley floor. "**Basin valleyhead wetlands**" are similar but with a basin topography for all or part of the site.
Hillslope Wetland	Wetlands on a hillside, but not organised into a valleyhead configuration eg a small spring-fed area on a sloping hillside.

Summary of Water Supply Mechanism Types (WETMECs)

Permanent Seepage Slope (1)	Wetland fed by "permanent" springs or seepages. Usually sloping. Water level permanently near surface (water visible or oozes underfoot).
Intermittent Seepage (2)	Wetland fed by intermittent springs and seepages, or groundwater always shallowly subsurface. Often sloping. "Dry" analogue of **Type 1**.
Fluctuating Seepage Basin (3)	Small hollows with quite strongly fluctuating water-levels. Often with standing water, but water can sink subsurface in dry periods. Often no outflow.
Seepage Percolation Basin (4)	Small hollows & some "floodplains" fed mainly by groundwater inputs, often through (or beneath) rather loose vegetation mat. Watertable often close to surface, usually not flooded. Often with a permanent outflow.
Summer "dry" Percolation Surfaces (5)	Drier analogue of **Type 4** (often partly drained **Type 4**), but groundwater inputs. often mainly canalised through dykes *etc*, with limited transmission through the peat. Surface often may mainly receive just precipitation inputs, at least during low groundwater periods.
Surface Water Percolation Floodplains (6)	Wet areas in floodplains, often around open water or reflooded peat workings, fed by lateral flow of surface water (from rivers *etc*) through (or beneath) a loose vegetation mat. Also receives episodic surface flooding.
Summer "dry" Floodplains (7)	Floodplains and hollows fed mainly by episodic inundation by surface water but with little transmission of water through the peat. Often flooded in winter but sometimes with quite low summer watertables.
Valley Bottom Wetlands (8)	Poorly drained valley bottom areas, often saturated in winter but with fairly low summer watertables. Water sources often not known. Not normally flooded from rivers, though some examples were formally active floodplains
Drained Ombrogenous Surfaces (9)	Drained surfaces on ombrogenous peat, fed directly/exclusively by precipitation. Excludes "rain-fed legacy-telluric sites" ie surface once fed by telluric water but now precipitation-dependent because of drainage.

Summary of Ecological Types
a) Base richness categories

1:	Base Rich	pH 6.5-8.0	Fen
2:	Sub-neutral	pH 5.5-6.5	Fen
3:	Base Poor	pH 4.5-5.5	Bog (~Poor Fen)
4:	Acidic	pH <4.5	Bog

b) Fertility categories (Wheeler & Shaw categories based on phytometric estimates)

1:	Oligotrophic
2:	Mesotrophic
3:	Eutrophic
4:	Hypertrophic

Much of the material discussed in subsequent sections is derived from these key works, but other sources were marshalled in this exercise, and may be broadly classified as follows in terms of the topics that they address:

- Classification of wet heath types: Atkinson (1984); Chapman and others (1989); Chapman and Clarke 1980; Crowder and others (1990); Daniels (1978); Rose (1953)
- Water-regime requirements of wet heath species and their growth responses: Bannister (1964a, 1964b, 1965); Bragazza and Gerdol (1996); Bromley and others (2004); Bullock and others 2000; Crowder and others (1990); Daniels and Eddy (1990); Davies (1984); El-Kahloun and others (2000); Gimingham (1960); Gurnell (1981); Heath and Luckwill 1938; Jones and Etherington (1970); Loach (1968); Nordbakken (1996); Rose and others (1998); Rose and Webb (2000); Rutter (1955); Specht (1979); Spink and Parsons (1995); Stokes and others 2001; Webster (1962a, 1962b)
- Eco-hydrology of wet heath communities and related habitats: Bromley and others (2004); Grootjans and others (1996); Gurnell (1981); Gurnell and Gregory (1986; 1995); Hill and Box (1999); Humphries and others (1995); Rose and Webb (2000); Rutter (1955); Specht (1979); Webster (1962a, 1962b)
- Studies of the response of wet heath species to nutrient availability and pH: Aerts and others (1990); Bannister (1965); Bobbink and others (1998); Bragazza and Gerdol (1996); Hill and Box (1999); Jones and Etherington (1970); Loach (1968); Ohlson and Malmer (1990); Roelofs and others (1996); Rose and Webb (2000); Spink and Parsons (1995); Ulrich (1983); van Breemen and others (1992); Webster (1962a, 1962b)
- Site-specific studies, with reference to eco-hydrology and nutrient regime: Daniels and Pearson (1974); Hopkins (1983); Newbould (1960)
- Investigations of particular plant communities, with reference to eco-hydrology and nutrient regime: Hopkins (1983)
- Management of wet heaths and other peatlands: Rowell (1990)
- Wet heath restoration: Aerts and others (1995); Hill and Box (1999); Jansen and others (2004); Pywell and others (1995); Roelofs and others (1996); Rose and Webb (2000)

3. Critical evaluation

Objective: To synthesise and evaluate the information collected by the review. To pinpoint gaps in our understanding of the ecohydrology of wet heath habitats and prioritise research requirements in terms of conservation needs**.** This process will include the assessment of the suitability of the 'Wetland Framework' approach for these communities.

As revealed by this review, the main themes and plant attributes indicated as important by these sources are:

- Water-regime requirements of individual wet heath species and communities, expressed either in terms of duration of waterlogging or depth to watertable, including definition of niches in terms of probability distributions, mire micro-topography and/or interactions with nutrient levels.

- Nutrient-regime requirements of individual wet heath species and communities, expressed in terms of pH, nutrient content (Ca, Mg, N, P in mg/l and Al:Ca ratio), redox status and interaction with competitive species. An important body of work addresses how atmospheric inputs affect peat chemistry and community composition.

3.1 Autecological approaches – defining species requirements

The eco-hydrology of wet heaths can, to some extent, be investigated by examination of the known autecology of the constant species. Certain species are constant over almost the whole range of *NVC* wet heath communities (**H3-H5**, **M14-M16** and **M21**), though often varying in their cover-abundance between communities, eg *Calluna vulgaris, Erica tetralix, Molinia caerulea* and *Potentilla erecta*. Others are restricted as constants to two or three communities or sub-communities and may be more useful as indicators of particular water- or nutrient-regimes on wet heaths eg 1) under more drought-prone situations: *Agrostis curtisii, Dicranum scoparium, Erica cinerea, Festuca ovina* and *Ulex* spp; 2) where liable to seasonal or continuous waterlogging: *Drosera rotundifolia, Eriophorum angustifolium, Narthecium ossifragum, Rhynchospora alba* and *Trichophorum cespitosum*; and 3) where there is some mineral or nutrient enrichment: *Carex panicea, Schoenus nigricans* and *Succisa pratensis*. Still others are confined to a single community or sub-community of wet heaths, possibly with their centre of distribution outwith the wet heath habitat.

Table 3.1 summarises the ecology of those species that occur with constancy IV or V (ie >60% of samples) in at least one sub-community of the seven *NVC* communities under review in the present research. Information is tabulated as follows: 1) constancy in *NVC* types **H3-H5**, **M14-M16** and **M21**; 2) Ellenberg indicator values for moisture (F), fertility (N) and reaction (R) (after Hill and others 1999); 3) soil-water nutrient levels ie μmol/kg of dry soil for ammonium, nitrate and phosphate, meq/kg of dry soil for base cations and mol/mol for Al:Ca ratio (after Roelofs and others 1996) with some pH values derived from Rose and Webb (2000); and 4) CSR established strategy (after Grime and others 1988). An indication of sensitivity to ecological change by examining the change index (from 1930-1969 to 1987-1999) reported in the *New Atlas of the British and Irish Flora* (Preston and others 2002) – see Table 3.2.

The “Ellenberg approach” (Indicator values) is now well established in the UK and has been modified for the British context by Hill and others (1999). It is widely used in Britain and on mainland Europe for assessing the ecological conditions that apply to particular sites, and as such has proven valuable (Mountford and Chapman 1993). However, there are fundamental weaknesses in using such indicator values for informing site management, or assessing the likely impact of, for example, hydrological change. Hence, for the purposes of the present study, the Ellenberg Indicator system is best used as a preliminary pointer to site conditions, but should thence be employed only in combination with (and subsidiary to) the *Wetland Framework* (Wheeler and Shaw 2001) or the use of Sum Exceedence Values (Gowing and others 1997, 2002). At outline of the derivation and use of indicator values is given below.

Ellenberg values for moisture (f), fertility (n) and reaction (r): Derivation, use and weaknesses

(Adapted from Ellenberg 1974, 1979; Hill and others 1999, 2004)

In an attempt to provide a comprehensive synopsis of the ecological behaviour of plant species, Ellenberg (1974, 1979) assigned "indicator values" to about 2000 species of vascular plants in the western part of Central Europe. These values were based on nearly 40 years of ecological experience, drawing upon the results of many research workers both in the field and in controlled experiments. The optimum of a species in relation to soil moisture or water level was described by the "**F**" or "Water Value" using a twelve -point scale, 1 in the scale being extremely dry, 12 for plants wholly immersed in water. Similarly, Ellenberg derived 9-point scales for reaction (from 1 for extreme acidity to 9 for basic reaction) and for fertility (from 1 for extremely infertile sites to 9 for extremely rich or polluted sites). He also devised indicator values for light, temperature, continentality and salinity. The validity of the "F" value was tested on 240 species in the Netherlands and was found to be reasonably dependable (Ter Braak and Gremmen, 1987). The approach was further tested for the UK by Mountford and Chapman (1993) and found to be reasonably robust, at least for the **F** value.

In the UK context, Hill and others (1999, 2004) derived new values for moisture, fertility and reaction (as well as light and salinity) by a variety of means. Firstly, a large dataset was constructed merging all the quadrat data from the 1990 Countryside Survey (Barr and others 1993) with the summarised quadrat data from volumes 1-4 of *British Plant Communities* (Rodwell 1991-5). Using these data, new values were calculated by comparing original indicator values of species with the mean values of their associated species (Hill and others 2000), and these derived values are the basis of the tabulated **F**, **N** and **R** values used here. This approach was practical for all but the most uncommon species, where a wide range of published sources were used. Where there was a large discrepancy between the UK calculated value and that from Ellenberg's original system, the new value was carefully examined and tested against other field data and experience.

For the purposes of wet heath eco-hydrological guidelines, the UK revision of the Ellenberg system therefore provides useful information based upon abundant rigorous field data. Thus for each wet heath *NVC* type or each wet heath site, it would be possible to derive mean indicator values for moisture (**mF**), fertility (**mN**) and reaction (**mR**), ie the mean indicators values of all individual species represented either in the constancy tables or at a particular site (Mountford and Chapman 1993). This would enable the water-regime (or nutrient/pH regime) of each community/site to be **ranked,** which might help identify coarse differences between sites etc. However, the Ellenberg approach has the fundamental weakness that it is a 1-dimensional ranking from dry to wet, and fails to take account of the seasonal aspects, ie whether a site is wet only outside the growing season, or whether there can be impeded drainage and waterlogging during spring and summer. Eco-hydrological research has clearly shown that it is not overall mean wetness that is the key factor in determining species occurrence and competitive interactions, but rather wetness at critical times of the year, eg inception of growth in the spring. Thus, whilst retaining the Ellenberg approach, and especially its UK revision, as a valuable tool in investigating site characteristics, the present report has sought to focus on the temporal processes that distinguish wet heath habitats.

Table 3.1 Ecological attributes of major wet heath species

Species Name	Constancy in NVC wet heath types							Ellenberg values			Soil water nutrient levels					Al: Ca ratio	CSR
	H3	**H4**	**H5**	**M14**	**M15**	**M16**	**M21**	**F**	**N**	**R**	**NH_4**	**NO_3**	**PO_4**	**Base Cation**	**pH**		
Agrostis curtisii	V	V	I			I	I	6	1	2					4-6.2		
Anagallis tenella			IV	IV				8	3	5							
Aneura pinguis				IV	I		I										
Calluna vulgaris	IV	V	I	II	IV	V	IV	6	2	2					<4.5		SC
Campylium stellatum			IV	IV	I												
Carex echinata					II		I	8	2	3							S
Carex flacca		I	III					5	2	6							S
Carex panicea		I	II	II	II	II	I	8	2	4	41	17	0	13.6	5.48	0.0	S
Carex pulicaris			IV		I			7	2	5							
Dicranum scoparium		II			II	II											
Drosera intermedia				II		I	I	9	1	2	40	15	3	5.4	4.98	0.2	
Drosera rotundifolia			I	III	II	I	V	9	1	2	34	13	5	3.6	4.71	0.6	
Eleocharis multicaulis			I	II		I	I	9	1	4							
Erica cinerea	V	IV	I		II			5	2	2							S
Erica tetralix	IV	IV	V	V	V	V	V	8	1	2	45	13	5	4.4	4.55		S
Erica vagans		I	V					6	1	4							
Eriophorum angustifolium			I	II	III	II	V	9	1	4					<5.0		S
Festuca ovina		II	IV		I			5	2	4							S
Hypnum jutlandicum	I			III	II	II	I										
Juncus squarrosus		I			II	II		7	2	2					<5.0		S
Kurzia pauciflora	I			III		I	II										
Molinia caerulea	V	V	V	V	V	IV	V	8	2	3	69	20	4	5.0	4.71	0.4	SC
Myrica gale				II	III	I	II	9	2	3							
Narthecium ossifragum				V	III	II	V	9	1	2	46	12	3	6.4	5.32	0.0	

Species Name	Constancy in NVC wet heath types							Ellenberg values			Soil water nutrient levels					Al: Ca ratio	CSR
	H3	H4	H5	M14	M15	M16	M21	F	N	R	NH_4	NO_3	PO_4	Base Cation	pH		
Pinguicula lusitanica			I	II		I	I	8	2	4							
Pinguicula vulgaris					I			8	2	6							
Potentilla erecta	I	IV	IV	II	V	II	II	7	2	3	52	16	3	6.9	4.83	0.2	S/CSR
Rhynchospora alba				II		I	II	9	1	2	37	15	5	3.9	4.78	0.2	
Schoenus nigricans	I		V	V	I			8	2	7					5-7.0		
Scorpidium scorpioides			II	IV	I												
Serratula tinctoria			V			I		6	2	6							
Sphagnum auriculatum				IV	I	I	III										
Sphagnum compactum					I	IV											
Sphagnum palustre				II	II		I										
Sphagnum papillosum				II	II	I	V								3.5-6.0		
Sphagnum recurvum					I		III										
Sphagnum subnitens				IV	II	I	II										
Sphagnum tenellum				I	I	III	II								3.5-5.0		
Succisa pratensis			IV		I	I	I	7	2	5	54	18	5	13.6	5.47	0.0	S
Trichophorum cespitosum		I			IV	III	I	8	1	2					3.5-5.5		
Ulex europaeus	III		I			I		5	3	5							SC
Ulex gallii		V	IV	I		I		6	2	3							
Ulex minor	V					I		6	2	1							
Vaccinium myrtillus		II			II			6	2	2							SC

Table 3.2 Change index in major wet heath species from 1930-1969 to 1987-1999 (after Preston and others 2002).

Species Name	**Change index**	**Species name**	**Change index**	**Species name**	**Change Index**	**Species name**	**Change index**
Agrostis curtisii	-0.26	*Drosera rotundifolia*	-0.56	*Molinia caerulea*	-0.34	*Serratula tinctoria*	**-0.21**
Anagallis tenella	-0.54	*Eleocharis multicaulis*	+0.47	*Myrica gale*	-0.75	*Succisa pratensis*	**-0.57**
Calluna vulgaris	-0.64	*Erica cinerea*	-0.94	*Narthecium ossifragum*	-0.32	*Trichophorum cespitosum*	**-0.31**
Carex echinata	-0.75	*Erica tetralix*	-0.91	*Pinguicula lusitanica*	-0.83	*Ulex europaeus*	**-0.34**
Carex flacca	+0.53	*Erica vagans*	-0.07	*Pinguicula vulgaris*	-0.76	*Ulex gallii*	**+0.20**
Carex panicea	-0.31	*Eriophorum angustifolium*	-0.79	*Potentilla erecta*	-0.50	*Ulex minor*	**+0.20**
Carex pulicaris	-0.51	*Festuca ovina s.l.*	-0.15	*Rhynchospora alba*	-0.43	*Vaccinium myrtillus*	**-0.61**
Drosera intermedia	**-0.50**	***Juncus squarrosus***	**Decline**	***Schoenus nigricans***	**-0.53**		

Note: Among wet heath species (with lower constancy in **H3-H5**, **M14-M16** and **M21**) but showing very marked declines were *Pedicularis sylvatica* (-1.28) and *Platanthera bifolia* (-1.67)

The published literature does give some characterisation of the water-regime requirements of particular wet heath species, allowing the ranking approaches of Ellenberg and others to be expanded and related to seasonal variation in water-regime eg:

Calluna vulgaris is able to tolerate a wide range of internal water deficits, partly accounting for its wide eco-hydrological amplitude (Bannister 1964a), but shows signs of stress after 40 days waterlogging (Bannister 1964b) and where soil aeration is thus reduced (Specht 1979) although it shows no response to increased CO_2 and indeed appears to increase in cover where H_2S is produced (Webster 1962a). In *Molinia*-dominated wet heaths, shoots of *Calluna* are often most frequent on the grass tussocks, ie above the groundwater and in free-draining soil (Rutter 1955).

Drosera spp (*D. intermedia* and *D. rotundifolia*) have a shallow rooting depth (<60mm) and are thus effectively limited to micro-sites with either a high watertable (20-400mm below surface) or a high rainfall and humidity. Both species are killed by drought, but *D. intermedia* can withstand prolonged submergence (Crowder and others 1990).

Erica tetralix is sensitive to water-stress and is thus restricted to wetter (even waterlogged) soils (Bannister 1964a), showing no signs of stress even after 120 days waterlogging (Bannister 1964b; Jones and Etherington 1970) and indeed showing increased cover where poor aeration of the root-zone leads to production of CO_2 and H_2S (Webster 1962a). In this regard, it is also far more tolerant than *E. cinerea* (Davies 1984). However, where competing with dominant *Molinia*, *E. tetralix* can often be most frequent raised above the groundwater on the grass tussocks themselves and is less tolerant of watertable fluctuations (Rutter 1955).

Gentiana pneumonanthe shows mortality that is positively correlated with winter rainfall, and thus probably with more prolonged waterlogging within its preferred **M16** vegetation (Rose and others 1998).

Molinia caerulea shows variation in its growth form over a range of hydrological conditions (Gurnell 1981), and the tussock height is positively related to the summer watertable height (Rutter 1955). *Molinia* may grow where the summer watertable height is anything from 300-600mm below the soil surface, and is more tolerant of a fluctuating watertable than *Erica tetralix* (Rutter 1955). *Molinia* is reduced in vigour within stagnant waterlogged soils (Loach 1968; Webster 1962b), and its cover is reduced where poor aeration lead to increased CO_2 and H_2S (Webster 1962a). However, some roots do usually penetrate below the permanently waterlogged zone (Rutter 1955).

Narthecium ossifragum requires a lateral flow of water in order to provide the roots with dissolved oxygen (Spink and Parson 1995).

Ulex spp – see box on page 21 (refers to nutrient regime also).

Similarly, preferred nutrient regimes of wet heath species have been investigated, focussing either on the main dominants or on species of some special conservation interest:

Erica tetralix shows maximum development in oligotrophic situations (Bannister 1966) and out-competes *Molinia caerulea* at low nutrient levels. However, *Calluna vulgaris* out-competes both species over a wide range of nutrient regimes (Aerts and others 1990).

Narthecium ossifragum can occur in both oligotrophic and minerotrophic mires (Spink and Parson 1995).

Rhynchospora alba is frequently the only vascular plant present in wet depressions within peaty heath, and therefore faces little or no inter-specific competition for nutrients (Ohlson and Malmer 1990).

Ecology and eco-hydrology of Ulex species

Ecological research work on *Ulex* species has concentrated on the productivity and wild fire management of *Ulex europaeus* stands and the geographical ranges and morphological differences between the dwarf gorses, *U. gallii* and *U. minor*. The *NVC* descriptions do contain some information on the typical hydrological conditions for heath communities. However, *U. gallii* and *U. minor* are important species in the derivation of some heath types, and there is thus some risk of confounding water-regime requirements of the *NVC* types with those of particular species. Nonetheless some indication of the eco-hydrology of the three species can be obtained, if only in the most general of terms.

Ulex europaeus. Normally confined to free-draining soils, *U. europaeus* is noted for **M16** (**M16b**) and the drier heaths of **H1-H6**, as well as occurring in **M25** (two sub-communities). **M16b** is relatively species-rich, with some species associated with wetter mire communities (eg *Sphagnum auriculatum* and *Myrica gale*) but also a reduced frequency of the typical *Sphagnum* species of **M16** (*S. compactum* and *S. tenellum*), which are usually associated with less saturated conditions. This combination reflects a tussock and runnel structure to the vegetation, with *U. europaeus* on the tussocks, avoiding higher water-tables and seasonal waterlogging. *U. europaeus* is a constant species in all sub-communities of **H6,** which occurs on free-draining brown earths that are base-rich and calcium poor, but is much reduced in both in frequency and abundance in the wetter mineral soils and shallow peats typical of **H5**. *U. europaeus* occurs on drier, eastern, English heaths (eg **H1**) and is a common component of *U. minor* heaths (**H2** and **H3**), where it is a preferential species of **H3c**. However, it is less common in the western, dry, *U. gallii* heaths (eg H8) and although not recorded within the **H4** constancy tables, stands of ‘dry’ and ‘humid’ heath in Dorset with abundant *U. gallii* have local scattered *U. europaeus* (Chapman and others 1989). Other plant communities where *U. europaeus* occurs include grasslands and scrub, where although the soils exhibit considerable variation, the water regime is consistent, ie may be parched in summer but are neither frequently nor seasonally waterlogged.

Ulex gallii* and *Ulex minor. The national distribution of the two species shows a marked separation between *U. gallii* in the west and *U. minor* in the east of the country. Bullock and others (2000) showed that the area occupied by *U. gallii* was marginally wetter, with cooler summer maximum temperatures than that of *U. minor*. However, at the smaller scale of Dorset, where both species occur (although rarely together), no climatic effects were evident. The rooting pattern of the two species was investigated by Stokes and others (2003), excavating roots of mature plants with similar stem diameters (2cm), growing on the same site. The maximum depth attained by *U. minor* was 40cm whereas the roots of *U. gallii* extended to 100cm.

- *Ulex gallii* is known from a number of heath and mire communities, indicating a tolerance of a range of soil types. Although recorded from **M14** and two sub-communities of **M16**, like *U. europaeus* it is probably restricted to small elevated areas of ground (tussocks *etc*). It is a constant species on the drier free-draining **H6** and **H8** heaths and equally abundant in the **H4** and **H5**, which exhibit hydrological conditions that are intermediate between the free-draining dry heaths and the seasonally waterlogged mire communities.
- *Ulex minor* is confined to the **H2** and **H3** heaths (where it is a constant), with a small presence in the same sub-communities of **M16** as *U. gallii*. The **H2** *Calluna vulgaris-Ulex minor* heaths are the drier of the suite of *U. minor* heaths, although within each sub-community (particularly **H2c**) there are species present more normally associated with wetter heathland. The **H3** community may be considered the *U. minor* equivalent of the **H4** *Ulex gallii* community, and the differing floristic composition of the sub-communities appears to stem primarily from past management or disturbance events rather than soil conditions. Although not included in the *NVC* constancy tables, *U. minor* is also a component of **U3** acid grassland in Dorset.

A literature search for information on the eco-hydrology of the dwarf gorses failed to identify anything other than these broad qualitative differences. The findings for *U. gallii* and *U. minor* suggest that the two species are very similar in their hydrological requirements, occurring in situations where soils are free-draining, or at least not subject to waterlogging, and are thus confined to the driest types of “wet heaths”. Information on rooting depth may infer that *U. gallii* is less tolerant of droughting than *U. minor*.

Amongst those cited in the Bibliography, two papers have either defined watertable response surfaces or niches for nutrient-poor mires in Italy and SE Norway (Bragazza and Gerdol 1996; Nordbakken 1996) – Bragazza and Gerdol (1996) also assess the response surfaces in relation to pH. Those wet heath species for which such information exists include:

Calluna vulgaris	*Drosera rotundifolia*	*Kurzia pauciflora*
Rhynchospora alba	*Sphagnum compactum*	*Sphagnum tenellum*
Trichophorum cespitosum	*Vaccinium myrtillus*	*Vaccinium oxycoccos*

3.2 Autecological approaches - sensitivity of wet heath species to water-regime

Wet heath communities show a range of eco-hydrological requirements and sensitivities both between and within *NVC* types. Thus, for example the sub-communities of **H3** appear to have essentially similar hydrological requirements (but differ in their prevalent management or disturbance regimes), whilst the sub-communities of **H4** exhibit a wider range of soil moisture conditions. There is no one factor that can determine the likely assemblage of species but a combination of hydrology, climate, soil type and the management (or disturbance) to which the plant community is subject (see the “Wet heath trajectory diagram” on page 33).

The occurrence of a species within a wet heath is not necessarily an indication that the hydrological characteristics of the site are within a certain range. Small differences in topography such as vegetation tussocks or depressions caused by the trampling of stock can provide sites that are either continuously above the mean groundwater level or are inundated for greater periods of time than the surrounding soil surface. This within-site patterning leads to a complex vegetation assemblage where plants usually associated with drier conditions (eg *Erica cinerea*, *Calluna* and *Agrostis curtisii*) are closely associated with plants that require continuously wetter conditions (eg *Drosera* spp., *Rhynchospora* spp. and *Sphagna*). The rooting systems of some wet heath plants have been shown to vary in depth and form with soil hydrology (*Polygala serpyllifolia* and *Potentilla erecta*), whilst other plants (*Juncus squarrosus* and *Trichophorum cespitosum*) have root systems that extend below the watertable (Heath and Luckwill 1938).

The various factors that combine to create conditions that are suited to a certain vegetation type are interrelated and therefore clear examples of the impact of a particular factor are not easily presented in isolation. Growth rates of species can vary with different conditions (eg *Molinia*, Webster 1962b) or similar growth rates can be maintained where different factors required for growth limit production (eg *Calluna*, Chapman and Clarke 1980). The range of habitats in which a particular species will survive is often very variable. Some are restricted by certain combinations of environmental conditions while others are more wide-ranging in their requirements. Autecological and community information can be compared to indicate the relationships between species and their tolerated range of eco-hydrological conditions eg

1. The relative proportions of *Calluna vulgaris* and *Erica tetralix* give an indication of the degree (duration) of waterlogging at a site ie dominant *C. vulgaris* indicates less waterlogging, whilst greater cover of *E. tetralix* reflected prolonged waterlogging.

2. The relative proportions of *E. tetralix* and *Molinia caerulea* correspond to the degree of lateral soil water movement, which results in aerobic soil conditions. There is more *M. caerulea* where such movement produces aerobic conditions, and more *E. tetralix* were stagnant water leads to a less aerobic situation.

3. The presence of either dwarf gorse (*Ulex gallii* or *U. minor*) indicates an absence of soil waterlogging (see also page 21 of this report).

4. As noted above, *Drosera* spp. require a relatively stable, high watertable, normally within 100mm of the surface (Crowder and others 1990), and are thus restricted to **H5** heath and those wet heaths included within the mire group. *Rhynchospora alba* occupies a similar set of wet heath mire communities to the *Drosera* spp..

5. The particular hydrological conditions occupied by different species of *Sphagna* are described in relative terms by Daniels and Eddy (1990).

To some extent, one can use Ellenberg indicator values to infer which species are likely to be the most sensitive to environmental perturbation (see Table 3.1). Hence, one would expect that all the major wet heath species would be sensitive to any increase in fertility, since (with one exception) they have N indicator values of 1 or 2. However, Stevens (2004) has investigated the response of acid grassland to atmospheric nitrogen deposition, and that although *Calluna vulgaris* does indeed show a negative trend with nitrogen deposition, three other species that occur on some wet heaths (*Carex panicea, Dicranum scoparium* and *Vaccinium myrtillus*) actually showed a positive trend. However, she suggested that this unexpected trend might reflect altered competitive ability in other species and/or interactions with phosphorus limitation. Her results clearly demonstrate the caution that must be exercised in attempting uni-factorial explanations of community change. Notwithstanding this *caveat*, certain wet heath species might be expected to benefit from some mineral enrichment (higher pH) of the wet heaths (eg *Anagallis tenella, Carex flacca, Pinguicula vulgaris, Schoenus* nigricans and, to some extent, both *Succisa pratensis* and *Ulex europaeus*).

It is the water-regime requirements of wet heath species that most concern the present research, however. Hence, one can identify a group of species (all with Ellenberg **F** value of 9) that should be most sensitive to dewatering of the heath, ie *Drosera* spp, *Eleocharis multicaulis, Eriophorum angustifolium, Myrica gale, Narthecium ossifragum* and *Rhynchospora alba*, all of which are most typical of those wet heaths with the most protracted waterlogging (eg **M14** and **M21**). In contrast, other species with low F values (eg *C. flacca, Erica cinerea, Festuca ovina*, and *U. europaeus*) would be predicted to decline with longer duration of waterlogging in the heath soils.

Some *post hoc* indication of species sensitivity can be gained by examination of long-term monitoring of species distribution and abundance, and examining the ecological requirements of those species to show marked temporal and spatial trends. Thus *Atlas 2000* (Preston and others 2002) confirms that almost all of major wet heath species declined between the original survey data from 1930-1969 and the field campaign for the later project from 1987-1999 (see Table 3.2). However, it can only be inferred whether these declines are due to (*inter alia*) site destruction, drainage, greater site fertility or altered site management. Focussed studies on particular regions of the UK show similar trends (Mountford 1994), suggesting that almost all the major species listed in Tables 3.1 and 3.2 are sensitive to reduced site wetness, and adding several other sensitive wet heath species that have lower constancy in the communities examined by the present research eg *Dactylorhiza maculata, Eriophorum vaginatum* and *Pedicularis* spp.

3.3 Synecological approaches – characterising the water regime of wet heath communities, habitats and sites: A conceptual sketch

Although species-based approaches have many advantages, there is real difficulty in defining community (or site/habitat) needs through the overlaps in the tolerance limits of the component species. Thus the central challenge in drafting eco-hydrological guidelines is explaining "how wetlands work" (Wheeler and Shaw 2001). To that end, one needs to work at a range of scales from the national down to within-site, using different features of the eco-hydrological regime to characterise the particular wet heath (or part of a heath) that is of interest. Defining the "ecological space" within which a particular assemblage occurs requires examination of more than one environmental variable. Thus Wheeler and Shaw (2001) use landscape (Situation Type) to characterise the context, and then define the wetland through its water supply mechanism (WETMEC) and its ecological type (pH and fertility). To some extent, a similar hierarchical approach is possible with wet heaths.

3.3.1 Climate – interactions with water-regime and soil

Examining of the body of wet heaths indicates that climate is a key factor in discriminating types and indeed the terms Atlantic and North Atlantic heaths presuppose a major role for climate in determining type. In his preamble to heaths and mires, Rodwell too (1991b) spells out the geographical patterns in heath communities and suggests that oceanicity is vital in determining the distribution of particular assemblages. He derived a series of block diagrams (reproduced on pages 25-26 of the present study) that hypothesise how climate and soil type interact to determine the prevalent heath type. Thus, the typical soil type for the wettest heaths (classified as mires by the *NVC*) is a shallow peat or humic mineral soil that is subject to periodic waterlogging. However, different assemblages occur in the drier (more continental) south-eastern lowlands and in the montane north (**M16**) to the oceanic and hyperoceanic lowlands (**M15**) – see top figure on page 25. Similarly within the moist (rather than wet) heaths that occur on freer-draining rankers, sands and podzols, there is a clear geographical zonation with dwarf gorse heaths (**H3** and **H4**, and also **H8**) tending to replace *Calluna*-dominated heaths (**H1** and **H2**) in the oceanic southwest (see lower figure in page 25). Focussing closer, there is a clear trend toward a sub-Mediterranean climate and distinctive heath type in the far southwest (the **H5** Lizard heaths – see figure on page 26).

The oceanic climate is associated with higher rainfall and a more equable temperature regime, without extremes and with a reduced incidence of frosts. Such conditions reduce net evapo-transpiration and in many cases mean there is no moisture deficit through even the latter part of the summer (though a trend to such deficits is observed in the more sub-Mediterranean types). Thus, to some degree regardless of whether the soil is free-draining or not, the oceanic climate ensures continually moist conditions in the root zone, allowing more water-demanding species to compete successfully with more typically dry heath species such as *Erica cinerea*.

Following Rodwell (1991b), it is possible to rank the wet heaths along two axes: 1) February minimum temperature and mean annual maximum temperature; and 2) rainfall and number of wet days per year:

1) **Temperature – ranked from most to least continental**

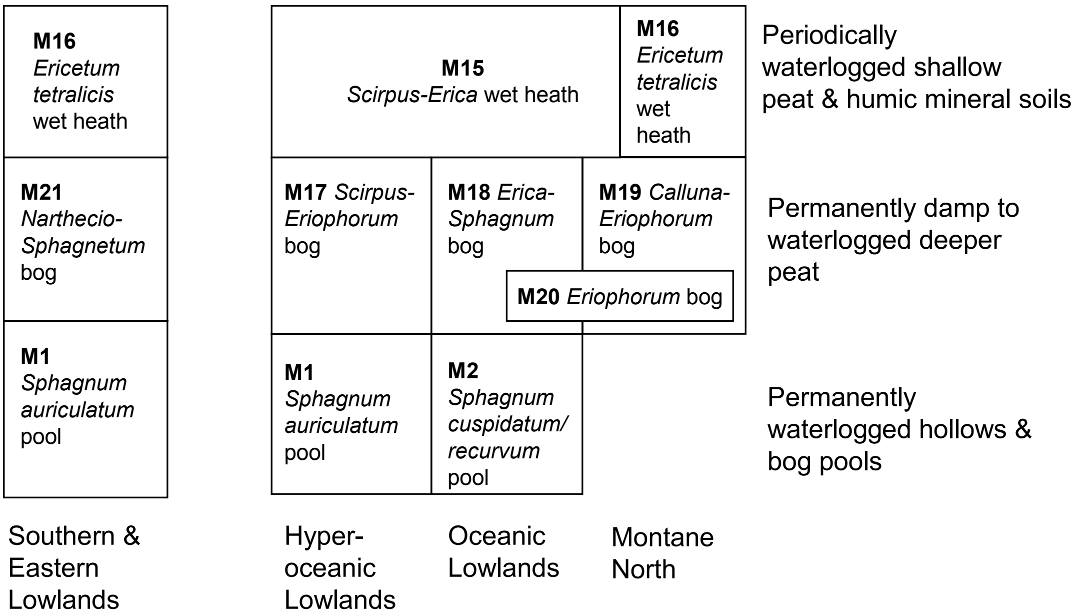
i. February minima $\geq +1.5^{o}$C, accumulated winter temperature $>0^{o}$C and mean annual maximum 27^{o}C: **H3**

ii. February minima $\geq +1.0\text{-}2.0^{o}$C and mean annual maximum $\geq +26^{o}$C: **M21**

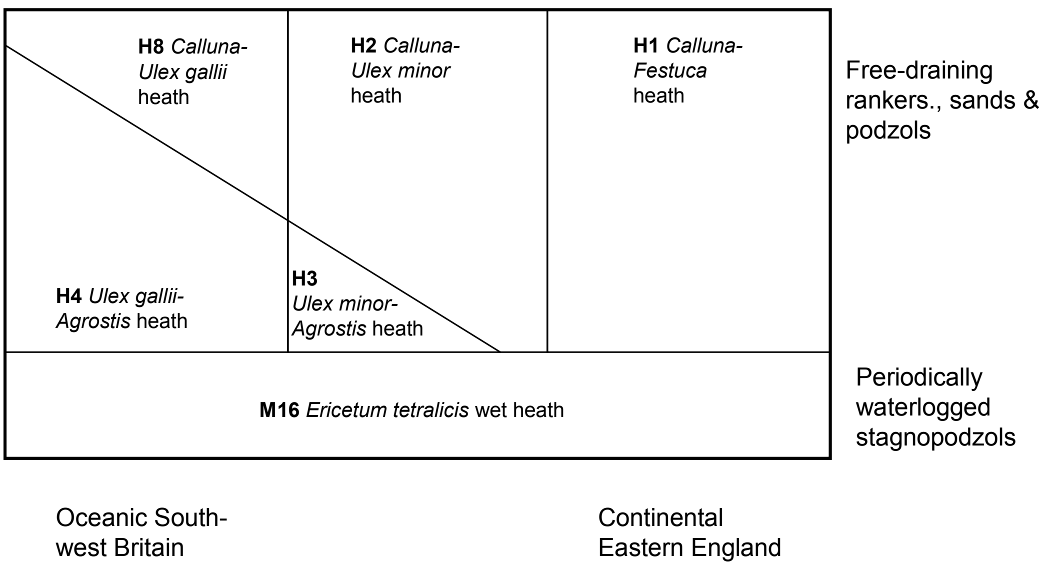
iii. February minima $\geq +2.0^{o}$C and mean annual maximum $\leq 27^{o}$C and <40 frosts **H4**

iv. February minima $\geq +4.0^{o}$C and mean annual maximum *ca* 25^{o}C and <20 frosts **H5**

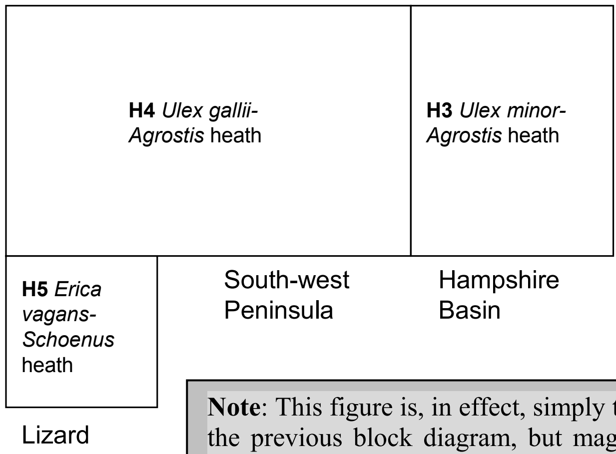
Bog and wet heath communities in relation to climate and soil
(After Rodwell 1991)



The increasing importance of moister lowland heaths with the climatic shift to the oceanic south-west (After Rodwell 1991)



Transition to wet heaths in the more oceanic parts of lowland Britain (After Rodwell 1991)



Note: This figure is, in effect, simply the southwest corner of the previous block diagram, but magnified to show further geographical variation in the southwest of England.

2) **Rainfall**

i.	Rainfall 800-1000mm *per annum*:	**H3**
ii.	Rainfall *ca* 900mm *per annum*:	**H5**
iii.	Rainfall 1000-1600mm and 140-160 wet days *per annum*:	**H4**
iv.	Rainfall *ca* 1000 to <1600mm and <180 wet days *per annum*:	**M16**
v.	Rainfall *ca* 1200mm and <160 wet days *per annum*:	**M21**
vi.	Rainfall (1200) to >1600mm and >180 wet days *per annum*:	**M15**

3.3.2 Water Regime: water supply mechanism (WETMEC) and Sum Exceedence Values

Three parameters are especially useful in understanding the water regime of wet heaths: a) the soil type, and especially whether it is primarily organic (peat) or mineral; b) the nature of the water supply; and 3) the fertility and pH of the soil. The phytosociological distinction used by Rodwell (1991b) to divide the "wet heaths" (**H3**-**H5**) from the "mires" (**M14**-**M16** and **M21**) may be of real significance in this discussion, since these coarse vegetation units do largely correspond to the sites with essentially mineral soils ("wet heaths") and those with strongly humic or peaty soils ("mires"). It may be also be the case that the different types of wet heath are best characterised by different approaches. The *Wetland Framework* approach already been described (pages 12-13); an outline of the second approach (SEVs) is given below.

3.3.3 Sum Exceedence Values (SEV)

Sum Exceedence Values have been used with considerable success in characterising and quantifying the water-regime requirements of wet grasslands (Gowing and others 1997, 2002) and, although not applied to wet heaths, have been tested at a raised mire site where many of the dominants are the same as on wet heaths (Bromley and others 2004). A full description of the SEV approach and how these values can be derived is given in Gowing and others (1997). The boxed text below outlines how they were calculated and employed for lowland wet grassland.

Sum exceedence values (sev): a tool for characterising water-regime needs in wild plant species and communities

(Adapted from Gowing and others 1997, 2002)

The level of water-stress tolerated by plants can be calculated using the SEV concept. Vegetation is recorded in microsites, ie a small relevé or quadrat *etc* that is micro-topographically uniform, not straddling distinct zones of elevation. Two stresses are calculated for each sample microsite: a) "drought stress" representing the level of soil drying experienced; and b) "aeration stress" representing the extent to which high soil water-tables prevent aeration of the plant roots. In the case of aeration stress a threshold watertable depth is calculated based on the critical depth given by the Gardner equation (Gardner 1958). When this is exceeded, the length of time (in weeks) and extent to which it is exceeded (in metres) are multiplied together to give a measure of plant stress (***Aeration SEV***). A similar approach can be used to calculate ***Drought SEV*** using soil water-tension instead of watertable depths, thus enabling sites with different soil moisture characteristics to be compared. A threshold value of is set for the summation of drought SEV (in the grassland example 0.5m tension). SEVs are calculated for the growing season (March-September) each year and a mean then taken to give an annual average SEV for each microsite. In its application in the UK, a baseline SEV was attributed to each microsite by calculating the average annual SEV for the period of approximately 20 years prior to the first botanical survey (calibrated using soil characteristics, dipwell data, stage-level data *etc*). New SEVs are then calculated for each microsite for the period between one botanical survey and the next, thus giving values to the water regime over each time period for comparison with the botanical data.

Calculated drought and aeration SEVs are calculated for as large a number of quadrats as practical, so as to provide a range of data-points for each important species. The eco-hydrological tolerances of individual species can then be portrayed as in the following example for *Lathyrus pratensis* (Figure 3.1) showing the frequency of the species relative to SEVs with the dark red zone representing highest relative frequency. This example was derived from more than 2000 microsites from seven study areas across England. This single-species depiction of water-regime may then be complemented by a community-based approach (Figure 3.2), where the community tolerance ranges for six *NVC* grasslands are shown, with their median and inter-quartile range.

Figure 3.1: *Lathyrus pratensis* – SEV range

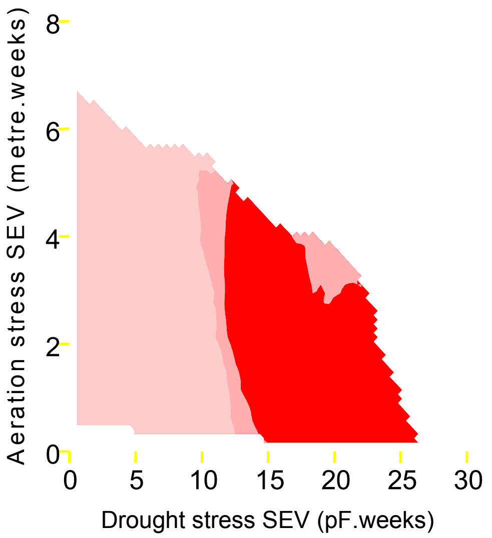
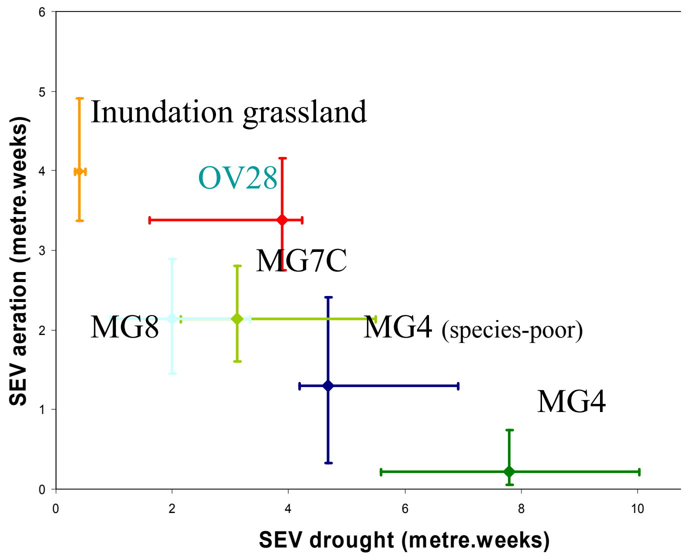


Figure 3.2: Community tolerance ranges



3.3.4 Characterising wet heath water-regimes

Examination of the literature on wet heaths shows a variety of possible regimes, and amongst the mainland European literature, the Dutch research is especially relevant, where distinctions between soligenous and groundwater-fed systems are regularly made. However, derivation of WETMECs, comparable with those described in Wheeler and Shaw (2001) and attempted below in the wet heath context, is not readily achieved. Nonetheless, the Dutch literature is extremely helpful in quantifying the water regimes for some heath types. For example, whilst studying sod-cutting as a means of wet heath restoration, Jansen et al (2004) found restoration was more successful where the water-table was between 30 and 90cm below the surface, whereas in situations where the lowest water-table was 90-130cm below the surface, *Molinia caerulea* increased rapidly to replace the wet heath target species. Thus for present purposes, the most useful approaches toward characterising the water-regime are those of Wheeler and Shaw (2001 – "W&S" in the summary below) and that of Sum Exceedence Values, ie:

Stands with impeded drainage – representing WETMECs not described by W&S (2001):

Impeded drainage may result from a high clay fraction within the soil and/or the development of an iron pan. However, in many British cases, the occurrence on wet heath is not absolutely dependent on the presence of such an impervious "liner", since moist-wet soil conditions are maintained by high rainfall eg:

- Impeded drainage on mineral soils (stagnogleys etc), often combined with high rainfall and relatively good aeration, to produce moist soils that may be seasonally wet, but only exceptionally waterlogged. Sites on level, though possibly somewhat undulating, ground or on very gentle slopes eg **H3** and **H4.**
- Impeded drainage on mineral soils (stagnogleys etc), combined with high rainfall and undulating topography or moderate slopes, to produce damp soils that are occasionally waterlogged and shows some soligenous processes eg **H5** and some stands of both **H4** and **M15c**.
- Impeded drainage on mineral soils or shallow peats on gentle slopes producing some throughput of water (runnels and soligenous processes) eg **H5b** and some stands of **M16c**.
- Impeded drainage on humic mineral soils or shallow peats, combined with high rainfall and some slope, to produce **continually** damp to wet soils that are seasonally waterlogged for short periods eg **M15** and **M16**.

Stands in small depressions (tiny basins) - representing WETMECs partly described by W&S (2001):

- Shallow depressions in undulating land surface, leading to localised topogenous wetlands on humic mineral soils with impeded drainage, eg some stands of **M16c**.

Stands with clear soligenous impact - representing WETMECs described by W&S (2001):

- Intermittent seepage of water through soakways and water-tracks on gentle slopes with peats and peaty mineral soils, producing relatively well aerated but continually wet soil conditions, eg **M15a, M16b** and some stands of **M21** where prolonged waterlogging.
- Continual seepage of water on wet mineral soils or peats producing flushing. Termed "permanent seepage slopes" (**WETMEC 1**) by Wheeler and Shaw (2001) eg **M14**.
- Permanently waterlogged sites on shallow peats and level or very gently sloping topography, influence by percolating groundwater and often with some soligenous influence (seepage) eg **M21**.

The stands with impeded drainage are probably best characterised using the SEV approach of Gowing and others (1997 and 2002), whereas those stands where topogenous wetlands or soligenous processes are most marked should lend themselves to the *Wetland Framework* approach and indeed East Anglian stands of both **M14** and **M21** have been included by Wheeler and Shaw 2001. Only in a very few cases (eg **M16** *Erica tetralix-Sphagnum compactum* wet heath, Hill and Box, 1999; Humphries and others, 1995) are there quantitative data on the maximum and minimum water-table depths, and the typical seasonal variation. Hence, at present the two potential approaches (SEV and WETMECs) remain untested in the absence of adequate field data for a range of stands.

3.3.5 Nutrient regime (pH and fertility) – Ecological Types

In terms of the Ecological Types defined by Wheeler and Shaw (2001), there is really rather little variety in the wet heaths. With regard to water base-richness, most stands are clearly acidic (pH <4.5), although some stands of **H4** and **M15** may be base-poor (pH 4.5-5.5). Some stands are very distinct from these typical heaths and have soils that are sub-neutral influenced by flushing with mire mineral-rich water (eg **M14** and **M15a**) or even base-rich (though calcium-poor) over serpentine and gabbro (**H5**). In the absence of a phytometrically-based classification, it may be assumed that all wet heaths are oligotrophic, with the exception of the permanent seepage slopes of M14, where mesotrophic conditions may develop in a small-sedge poor-fen.

3.3.6 Microtopography – humps, hollows and tussocks

There is abundant evidence of the impact of microtopography on the water-regime of wetlands and consequently on the composition of the vegetation at a particular point (or microsite), eg Silvertown and others 1999. In addition, various authors (eg El-Kahloun and others 2000; Rutter 1955) have related the growth form of the wet heath plants themselves to water- and nutrient regimes, especially in the case of tussock-forming species such as *Molinia caerulea*. Both forms of microtopographic variation (due to the ground surface or to the growth of the plants) result in marked variation in water-regime. Aeration and drought stress may be very different on the top of a tussock when compared to its base. In those wet heaths where tussock forming graminoids (*Schoenus nigricans* and *Trichophorum cespitosum*, as well as *M. caerulea*) are prominent it is notable how varied the floristic composition of the vegetation is. For a few communities and species, there are already good data on how critical such elevation may be (El-Kahloun and others 2000). Studies of the autecology of *Gentiana* *pneumonanthe* suggest that this species prefers the base of graminoid tufts, but elevated by as little as *ca* 5cm above the general level of the wet heath (Rose and others 1998). Thus in a very tussocky wet heath, horizontal distances of only 25-50cm may result in sufficiently different elevations to allow a range of species with quite distinct water-regime requirements to co-exist. In such situations, one should regard the main influence of the water-regime in shaping the type of wet heath being manifest in the dominant structural features of the vegetation (ie tussocks and ericoid shrubs), with those species epiphytic on the tussocks or, conversely, confined to runnels reflecting the fine mosaic of microtopographic variation.

3.3.7 The influence of management on wet heath communities

There has been relatively little scientific work done that concentrates on the effects of management on lowland **wet** heaths. Most information is based on observational reports that are an addition to the more extensive studies of dry heaths. The main forms of management on wet heath are cutting, burning and grazing. Locally, a further technique, cutting of peat turves, was traditionally practised on lowland valley mires (**M21** *etc*) but this form of vegetation management has not been transferred into the suite of modern conservation management methods. Thus transitions from open water to **M21** communities *via* **M1** *Sphagnum*/bog pool vegetation could be clearly seen in air photographs taken over Hartland Moor NNR (Dorset) in the 1980s but are no longer apparent.

Cutting (mowing *etc*) tends to favour plants that grow rapidly and reproduce vegetatively rather than those that are propagated by seed. Those that have their apical growing points at or close to the ground surface are also advantaged. Therefore, grasses tend to dominate over dwarf shrubs. The effects of cutting, especially on a regular basis, can be seen on roadsides where **U3** *Agrostis curtisii* grassland occurs in the cut swathe but grades into **H3** or **H4** heath away from the road.

Burning can be divided into two types. Managed burns in late winter can be beneficial in removing excess plant litter that can smother some of the low-growing species. This is particularly seen in **M16** where occasional burning creates favourable conditions for species such as *Gentiana pneumonanthe*. However, accidental burning in summer can cut deeply into the peat removing much of the heathland seedbank, as well as the characteristic bryophyte and lichen species. Such burning can result in the regrowth of species poor forms of wet heath vegetation that are dominated by grasses. Lichen-rich communities such as **H3b** are particularly susceptible to this type of disturbance.

Following management by cutting or burning, wet heath vegetation passes through a series of stages of species dominance based on productivity and growth form. Mature stands of **H3** and occasionally **H4** are predominantly *Calluna*. The initial phase after management is grass dominated, usually by *Molinia caerulea* from rootstocks or seedling regrowth of *Agrostis curtisii*. During the next phase, grasses are gradually replaced by the more rapidly growing woody species (*Ulex minor, U. gallii* and *Erica tetralix*), as individual sub-shrubs increase in size and eventually coalesce to form a shrub-dominated heath. The final phase is marked by the slower-growing *Calluna* tending to overtop both *E. tetralix* and *U. minor* (and in some cases out-competing *U. gallii*) to become dominant.

Grazing on wet heath has been used as a management tool to reduce the dominance of palatable grasses. Cattle and ponies tend to favour grazing *M. caerulea* at certain times of year but always avoid *E. tetralix*, resulting in an increase of the dwarf shrub content of the vegetation. Sheep tend to prefer to graze the more nutritious shorter grass swards (usually regrowth after burning or previous cattle grazing), and also graze intensively on *Calluna* in winter and early spring when grass has a low calorific value. Intensive sheep grazing on **M15** can result in a reduced presence of dwarf shrub and *M. caerulea* and an increase in unpalatable grasses such as *Nardus stricta*, eventually leading to **U5** *Nardus stricta-Galium saxatile* grassland. Other influences of over-grazing (including localised impacts near water troughs and supplementary feeding areas *etc*) can be clearly seen in heathland vegetation. In addition to the vegetation browsing, nutrient enrichment by dunging and damage to the soil structure by poaching leads to a flush of grass growth and disturbed ground that may be colonised by invasive species.

4. Interim ecological targets

Objective: Work towards the development of a 'Water Framework' for wet heaths, or, should this be currently impracticable, to use the knowledge base created in objectives 1 and 2, and 'best available' estimates to make a set of interim recommendations for ecological targets for the water resource requirements for wet heaths.

Much of the material that could contribute to interim ecological targets is described in section 3, where the data are critically evaluated. In this section, attention is confined to preliminary attempts to distil this limited information into a simple form. The great majority of the best information on the eco-hydrology of wet heaths is outlined in the relevant volume of the *National Vegetation Classification* (Rodwell 1991b), though it must be stressed that the patterns reported there are largely derived from floristic variation (not hydrological study) and are overwhelmingly qualitative in nature.

The next stage in summarising the known eco-hydrology and habitat requirements of wet heaths comprised a first (and provisional) attempt to draft a trajectory diagram for wet heaths and related communities (see Figure on page 33). Such diagrams were successfully derived for wet grasslands, mires, swamps and aquatic communities by Wheeler and others (2004). In those cases, supported by abundant research data for many stands, it was possible to assert likely changes from one community to another under particular ecological pressures eg altered depth of water, increased nutrients, succession etc. This is not possible as yet with wet heaths. However, the figure does attempt to display how wet heath types are arranged in relation to two axes of environmental variation:

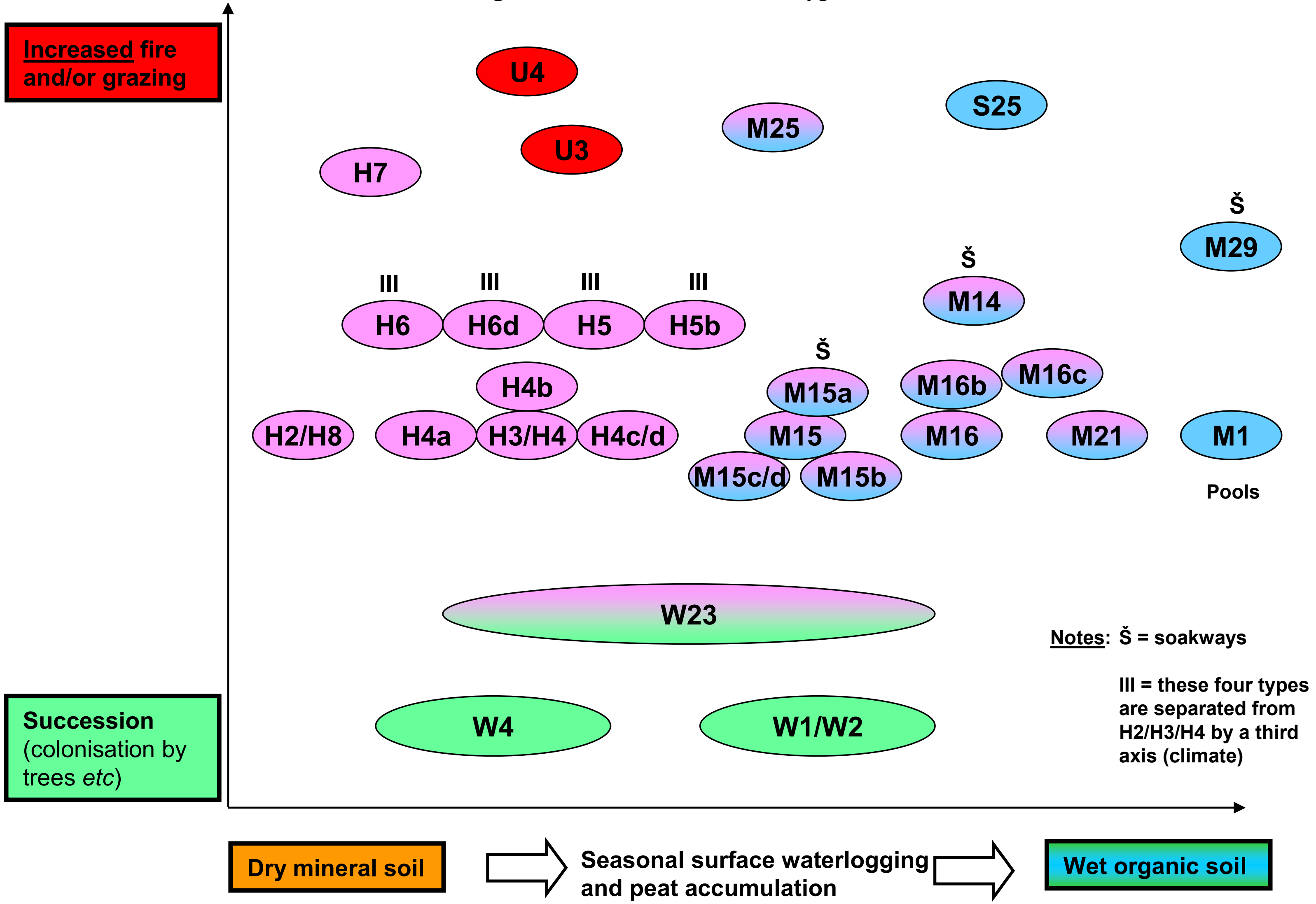
i. From dry mineral soil through unreasoned seasonal waterlogging and hence peat accumulation to wet organic soil.

ii. All heaths are secondary climaxes, kept in place by some disturbance through burning or grazing etc. However, it is possible to infer how these heath types would change were burning/grazing to become more intense (toward the top of the diagram) or suspended, this allowing succession (toward the bottom of the diagram).

Following the argument developed in section 3.3, it should be remembered that wet heaths are markedly shaped by climatic factors, and a full trajectory diagram should attempt to refine the current draft and add the information portrayed on pages 25-26 as a third axis of variation.

Finally, the water-regime, nutrient-regime and landscape context information reviewed in section 3 is summarised in a table (page 34), which tries to follow the *Wetland Framework* approach as far as possible. This very preliminary classification is made acknowledging that some heath types (notably those dependent on impeded drainage) may not be best dealt with in the WETMEC system as so far developed. The clear conclusion from this process is that more research effort is needed to develop new WETMECs for wet heaths, and also to test the use of Sum Exceedence Values on these habitats

Wet heath communities in relation to management/succession and soil type and moisture



Preliminary Classification of *NVC* wet heath communities in terms of their Situation Type (landscape context), WETMECs and Ecological Types (water base-richness & soil fertility). For approach see Wheeler and Shaw 2001 (W&S)

NVC number	**NVC name**	**Situation Type**	**WETMEC (number)**	**Ecological Type**
H3	*Ulex minor-Agrostis curtisii*	Plateau-plain? Very gentle slopes (*ca* 3°)	Does not fit with W&S – Impeded drainage	**Acidic oligotrophic**
H3a	Typical sub-community			
H3b	*Cladonia* sub-community			
H3c	*Agrostis curtisii* sub-community			
H4	*Ulex gallii-Agrostis curtisii*	Plateau-plain? Gentle slopes (*ca* 5°)	Does not fit with W&S – Impeded drainage	**Acidic to base-poor oligotrophic**
H4a	*Agrostis curtisii-Erica cinerea* sub-community	Hillslope? Moderate to steep slope		
H4b	*Festuca ovina* sub-community		Higher rainfall	
H4c	*Erica tetralix* sub-community			
H4d	*Scirpus cespitosus* sub-community		Very high rainfall	
H5	*Erica vagans-Schoenus nigricans*	Plateau-plain? Very gentle slopes (*ca* 2°)	Valley bottom wet-land (**8**)? Seasonal waterlogging – fluctuating	**Sub-neutral to base-rich oligotrophic**
H5a	Typical sub-community			
H5b	*Eleocharis multicaulis* sub-community	By runnels	Longer waterlogging	
M14	*Schoenus nigricans-Narthecium ossifragum*	Hillslope. Moderate slope (*ca* 7°)	Permanent Seepage Slope (**1**) (inc. water tracks)	**Sub-neutral oligo- to mesotrophic small sedge (poor) fen**
M15	*Scirpus cespitosus-Erica tetralix*	Hillslope. Moderate slope (*ca* 8°)	Drained ombrogenous surface (**9**)?	**Acidic to base-poor oligotrophic**
M15a	*Carex panicea* sub-community	Gentler slope	Intermittent seepage (**2**)?	**Base-poor to sub-neutral**
M15b	Typical sub-community			
M15c	*Cladonia* sub-community			
M15d	*Vaccinium myrtillus* sub-community			
M16	*Ericetum tetralicis*	Plateau-plain? Very gentle slopes	Closest to summer "dry" percolation surface (**5**) – fluctuating and artesian inputs	**Acidic oligotrophic**
M16a	Typical sub-community			
M16b	*Succisa pratensis-Carex panicea* sub-community		More soligenous	
M16c	*Rhynchospora alba-Drosera intermedia* sub-community		Wetter hollows and runnels	
M16d	*Juncus squarrosus-Dicranum scoparium* sub-community			

NVC number	NVC name	Situation Type	WETMEC (number)	Ecological Type
M21	*Narthecio-Sphagnetum*	Plateau-plain? Very gentle slopes	Intermittent seepage (**2**) or seepage percolation basin (**4**)? Groundwater influenced. Some stands Permanent Seepage Slope (**1**)	**Acidic oligotrophic**
M21a	*Rhynchospora alba-Sphagnum auriculatum* sub-community			
M21b	***Vaccinium oxycoccos-Sphagnum recurvum* sub-community**			

5. Bibliography

5.1 Books, published papers and reports

Notes:
1. Key synoptic sources of information are indicated ***K***
2. Those sources cited and used with Rodwell (1991b) are indicated ***NVC***

AERTS, R., BERENDSE, F., de CALUWE, H., & SCHMITZ, M. 1990. Competition in heathland along an experimental gradient of nutrient availability. *Oikos,* 57, 310-318.

AERTS, R. and others. 1995. The potential for heathland restoration on formerly arable land at a site in Drenthe, The Netherlands. *Journal of Applied Ecology*, 32, 827-835.

ATKINSON, T. 1984. The plant communities of valley mires in the New Forest, Hampshire. *Journal of Biogeography*, 11, 289-317.

BANNISTER, P. 1964a. The water relations of certain heath plants with reference to their ecological amplitude. II. Field studies. *Journal of Ecology*, 52, 481-497. ***NVC***

BANNISTER, P. 1964b. The water relations of certain heath plants with reference to their ecological amplitude. III. Experimental studies: general conclusions. *Journal of Ecology*, 52, 499-509. ***NVC***

BANNISTER, P. 1966. Biological Flora of the British Isles: *Erica tetralix* L. *Journal of Ecology*, 54, 795-813. ***NVC***

BARR, C.J. and others. 1993. *Countryside Survey 1990: Main report*. London: HMSO

BOBBINK. R, HORNUNG, M., & ROELOFS, J.G.M. 1998. The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. *Journal of Ecology*, 86, 717-738.

BRAGAZZA, L.B. & GERDOL, R. 1996. Response surfaces of plant species along water-table depth and pH gradients in a poor mire on the southern Alps (Italy). *Annales Botanici Fennici,* 33: 11-20.

BROMLEY, J. and others. 2004. *Sensitivity of water levels and mire plants.* Final report of CEH project C01528. NERC Centre for Ecology and Hydrology

BULLOCK, J.M. and others. 2000. Geographical separation of two *Ulex* species at three spatial scales: does competition limit species' ranges? *Ecography,* 23, 257-271.

CHAPMAN, S.B., & CLARKE, R.T. 1980. Some relationships between soil, climate, standing crop and organic matter accumulation within a range of *Calluna* heathlands in Britain. *Bull. Ecol*., 221-232.

CHAPMAN, S.B., CLARKE, R.T., & WEBB, N.R. 1989. The Survey and Assessment of Heathland in Dorset, England, for Conservation. *Biological Conservation*, 47, 137-152.

CROWDER, A.A. and others. 1990. Biological Flora of the British Isles: *Drosera* L. *Journal of Ecology*, 78, 233-267.

DANIELS, R.E. 1978. British mires and mire communities. *Journal of Ecology*, 66, 773-802. ***K***

DANIELS, R.E. & EDDY, A. 1990. *Handbook of European Sphagna*. London: HMSO.

DANIELS, R.E., & PEARSON, M.C. 1974. Ecological studies at Roydon Common, Norfolk. *Journal of Ecology*, 62, 127-150. ***NVC***

DAVIES, M.S. 1984. The response of contrasting populations of *Erica cinerea* and *Erica tetralix* to soil type and waterlogging. *Journal of Ecology,* 72: 197-208.

EL-KAHLOUN, M., BOEYE, D., VERHAGEN, B., & Van HAESEBROECK V. 2000. A comparison of the nutrient status of *Molinia caerulea* and neighbouring vegetation in a rich fen. *Belgium Journal of Botany,* 133: 91-102

ELLENBERG, H. 1974. Zeigerwerte der Gefasspflanzen Mitteleuropas. 1. Auflage. *Scripta Geobotanica*, 9, 1-97. ***K***

ELLENBERG, H. 1979. Zeigerwerte der Gefasspflanzen Mitteleuropas. 2. Auflage. *Scripta Geobotanica*, 9, 1-122. ***K***

GIMINGHAM, C.H. 1960. Biological Flora of the British Isles: *Calluna vulgaris* (L). Hull. *Journal of Ecology*, 48, 455-483. ***NVC***

GOWING, D.J.G. and others. 1997. *Water regime requirements of the native flora - with particular reference to ESAs.* Final report to Ministry of Agriculture, Fisheries and Food. Cranfield University [MAFF Project BD0209].

GOWING, D.J.G. and others. 2002. *The water regime requirements and the response to hydrological change of grassland plant communities.* Final report for DEFRA-commissioned project BD1310. Silsoe: Cranfield University.

GRIME, J.P., HODGSON, J.G., & HUNT, R.R. 1988. *Comparative Plant Ecology*. London: Unwin Hyman. ***K***

GROOTJANS, A.B. and others. 1996. Ecohydrology in The Netherlands: principles of an application-driven inter-discipline. *Acta Botanica Neerlandica,* 45(4), 491-516.

GURNELL, A.M. 1981. Heathland vegetation, soil moisture and dynamic contributing area. *Earth Surface Processes and Landforms*, 6: 553-570.

GURNELL, A.M., & GREGORY, K.J. 1986. Water table level and contributing area: The generation of runoff in a heathland catchment. *Conjunctive Water Use* (Proceedings of the Budapest Symposium, July 1986). IAHS Publ. no. 156, p 87-95.

GURNELL, A.M., & GREGORY, K.J. 1995. Interactions between semi-natural vegetation and hydrogeomorphological processes. *Geomorphology*, 13, 49-69.

HEATH, G.H., & LUCKWILL, L.C. 1938. The rooting systems of heath plants. *Journal of Ecology*, 26, 331-352.

HILL, A., & BOX, J. 1999. Experimental translocation of wet heathland in Dorset, England: implications for restoration of mineral workings. *In:* FUCHS, P.E.K., SMITH, M.R. and ARTHUR, M.J., eds. *Minerals Planning in Europe*. The Institute of Quarrying. ISBN 0 9538003 0 X.

HILL, M.O. and others. 1999**.** *Ellenberg's indicator values for British Plants*. ECOFACT Volume 2. Technical Annex Published for DETR by the Institute of Terrestrial Ecology. ***K***

HILL, M.O. and others. 2000. Extending Ellenberg's indicator values to a new area: an algorithmic approach. *Journal of Applied Ecology*, 37, 3-15.

HILL, M.O., PRESTON, C.D., & ROY, D.B. 2004. *PLANTATT: Attributes of British and Irish Plants: Status, Size, Life History, Geography and Habitats*. Huntingdon: NERC Centre for Ecology and Hydrology. ***K***

HOPKINS, J.J. 1983. *Studies of the historical ecology, vegetation and flora of the Lizard District, Cornwall, with particular reference to heathland.* Bristol University: PhD thesis ***NVC***

HUMPHRIES, R.N., BENYOM, P.R. and LEVERTON, R.E. 1995. Hydrological Performance of a Reconstructed Heathland Soil Profile. *Land Contamination and Reclamation*, 3(2), 101-103.

JANSEN, A.J.M., FRESCO, L.F.M., GROOTJANS, A.P. and JALINK, M.H. 2004. Effects of restoration measures on plant communities of wet heathland ecosystems. *Applied Vegetation Science*, **7**, 243-252.

JONES, H.E., & ETHERINGTON, J.R. 1970. Comparative studies of plant growth and distribution in relation to waterlogging. I. The survival of *Erica cinerea* L. and *E. tetralix* L. and its apparent relationship to iron and manganese uptake in waterlogged soil. *Journal of Ecology*, 58, 487-496. ***NVC***

LOACH, K. 1968. Relations between soil nutrients and vegetation in wet-heaths. II. Nutrient uptake by the major species in the field and in controlled conditions. *Journal of Ecology*, 56, 117-127. ***NVC***

MOUNTFORD, J.O. 1994. Floristic change in English grazing marshes: the impact of 150 years of drainage and land-use change. *Watsonia*, 20, 3-24.

MOUNTFORD, J.O., & CHAPMAN, J.M. 1993. Water regime requirements of British wetland vegetation: using the moisture classifications of Ellenberg and Londo. *Journal of Environmental Management*, 38, 275-288.

MOUNTFORD, J.O. and others. 1999. *Assessment of the effects of managing water-levels to enhance ecological diversity.* Final report to the Ministry of Agriculture, Fisheries and Food. MAFF Commissioned Project BD1301.

NEWBOULD, P.J. 1960. The ecology of Cranesmoor, a New Forest valley bog. I. The present vegetation. *Journal of Ecology*, 48, 361-383. ***NVC***

NORDBAKKEN, J-F. 1996. Plant niches along the water-table gradient on an ombrotrophic mire expanse. *Ecography*, 19: 114-121.

OHLSON, M., & MALMER, N. 1990. Total nutrient accumulation and seasonal variation in resource allocation in the bog plant *Rhynchospora alba*. *Oikos*, 58, 100-108.

PRESTON, C.D., PEARMAN, D.A., & DINES, T.D., eds. 2002. *New Atlas of the British and Irish Flora.* Oxford: Oxford University Press

PYWELL, R.F., WEBB, N.R., & PUTWAIN, P.D. 1995. A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 397-409.

RODWELL, J.S., ed. 1991a. *British Plant Communities Volume 1: Woodlands and Scrub.* Cambridge: Cambridge University Press.

RODWELL, J.S. (ed) 1991b. *British Plant Communities Volume 2: Mires and Heaths.* Cambridge: Cambridge University Press. ***K***

RODWELL, J.S., ed. 1992. *British Plant Communities Volume 3: Grasslands and montane communities.* Cambridge: Cambridge University Press.

RODWELL, J.S., ed. 1995. *British Plant Communities Volume 4: Aquatic communities, swamps and tall-herb fens.* Cambridge: Cambridge University Press.

ROELOFS, J.G.M. and others. 1996. Restoration of aquatic and terrestrial vegetation on non-calcareous sandy soils in the Netherlands. *Acta Botanica Neerlandica* 45(4) pp. 517-541.

ROSE, F. 1953. A survey of the ecology of the British lowland bogs. *Proceedings of the Linnaean Society London,* 164, 186-212. ***NVC***

ROSE, R.J., CLARKE, R.T., & CHAPMAN, S.B. 1998. Individual variation and the effects of weather, age and flowering history on survival and flowering of the long-lived perennial *Gentiana pneumonanthe*. *Ecography*, 21, 317-326.

ROSE, R.J., & WEBB, N.R. 2000. *Restoration of wet heath scoping study.* Winfrith: NERC Centre for Ecology and Hydrology. 54pp +16pp. ***K***

ROWELL, T.A. 1990. Management of peatlands for conservation. *British Wildlife*, 1(3), 144-155.

RUTTER, A.J. 1955. The composition of wet-heath vegetation in relation to water table. *Journal of Ecology*, 43, 507-543.

SILVERTOWN, J. and others. 1999. Hydrologically defined niches reveal a basis for species richness in plant communities. *Nature,* 400, 61-63.

SPECHT, R.L. 1979. *Heathlands and Related Shrublands. Ecosystems of the World, 9A*: 383-389. Elsevier Scientific Publishing Co. ***K***

SPINK, A.J., & PARSONS, A.N. 1995. An experimental investigation of the effects of nitrogen deposition to *Narthecium ossifragum*. *Environmental Pollution*, 90(2): 191-198.

STEVENS, C.J. 2004. *Ecosystem properties of acid grasslands along a gradient of nitrogen deposition*. Open University: PhD thesis

STOKES, K.E., BULLOCK, J.M., & WATKINSON, A.R. 2003. Biological Flora of the British Isles: *Ulex gallii* Planch. and *Ulex minor* Roth. *Journal of Ecology*, 91, 1106-1124.

ter BRAAK, C.J.F., & GREMMEN, N.J.M. 1987. Ecological amplitudes of plant species and the internal consistency of Ellenberg's indicator values for moisture. *Vegetatio*, 69, 79-87.

ULRICH, B. 1983. Interaction of forest canopies with atmospheric constituents: SO_2, alkali and earth alkali cations and chloride. *In:* ULRICH, B. & PANKRATH, J. eds. *Effects of Accumulation of Air Pollutants in Forest Ecosystems*, 33-45. Dordrecht: D. Reidel Publ.

Van BREEMEN, N. and others. 1992. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. *Nature* 299: 548-550.

WEBSTER, J.R. 1962a. The composition of wet-heath vegetation in relation to aeration of the groundwater and soil. I. Field studies of groundwater and soil aeration in several communities. *Journal of Ecology*, 50, 619-638.

WEBSTER, J.R. 1962b. The composition of wet-heath vegetation in relation to aeration of the groundwater and soil. II. Response of *Molinia caerulea* to controlled conditions of soil aeration and ground-water movement. *Journal of Ecology*, 50, 639-650.

WHEELER, B.D. and others. 2004. *Ecohydrological Guidelines for Lowland Wetland Plant Communities.* Eds BROOKS, A.W., JOSÉ, P.V. and WHITEMAN, M.I. Peterborough: Environment Agency (Anglian Region).

WHEELER, B.D., & SHAW, S.C. 1994. Conservation of fen vegetation in sub-optimal conditions. *In*: (H. JANKOWSKA-HUFLEJT & E. GOLUBIEWSKA, eds. *Conservation & Management of Fens,* 255-265. Falenty: International Peat Society & Institute for Land Reclamation and Grassland Farming.

WHEELER, B.D., & SHAW, S.C. 2001. *A Wetland Framework for Impact Assessment at Statutory Sites in Eastern England.* Environment Agency R&D Note. W6-068/TR1 and TR2. ***K***

5.2 Centres and themes of ongoing research

Note: A number of individuals in research and conservation organisations both in the UK and Europe were contacted and asked to give details of any recent or ongoing research on aspects related to wet heath vegetation. While a number of those contacted expressed an interest in wet heaths the following provided positive responses in terms of recent or current work. All are from the UK, unless otherwise stated, and the information provided includes the name of the contact, their main ongoing wet heath project and their contact details. Contacts are listed in alphabetical order:

Pam Berry pam.berry@eci.ox.ac.uk University of Oxford Environmental Change Institute – School of Geography and Environment 1A Mansfield Road, Oxford, OX1 3SZ	Climate change modelling of a wide range of vegetation types including wet heath as part of the MONARCH 2 project.
Roland Bobbink R.Bobbink@bio.uu.nl) Landscape Ecology, Utrecht University, PO Box 800.84, 3508 TB Utrecht, The Netherlands	Ecological restoration of wet heaths with special reference to soil acidification and soil nutrient status.
Bridget Emmett bae@ceh.ac.uk NERC Centre for Ecology and Hydrology Bangor, Orton Building, Deiniol Road, Bangor, Gwynedd, LL57 2UP	Soil moisture response curves for several heathland plants on a range of heathland sites throughout Europe. (*Calluna* most relevant to wet heath)
Sébastien Gallet sebastien.gallet@univ-brest.fr Institut de Géoarchitecture Université de Bretagne Occidentale CS 93837 BREST cedex 29238 France	Recent work on the effects of (human) trampling on wet heath and wet heath management.
Anne-Laure Jacquemart jacquemart@ecol.ucl.ac.be Université Catholique Louvain Crt Rech Biodiversité Unite Ecol & Biogeog 5 Pl Croix Sud B-1348 Louvain Belgium	Restoration of wet heath and reserve management (most publications in French).

Andrew Nolan a.nolan@macaulay.ac.uk Macaulay Land Use Research Institute Aberdeen AB15 8QH	Unpublished data on sustainable grazing levels.
Robin Pakeman r.pakeman@mluri.sari.ac.uk Macaulay Land Use Research Institute Aberdeen AB15 8QH	Has a PhD student working on Habitat restoration: the success of both plant and insect communities on restored sites.
Robert Rose rjr@ceh.ac.uk NERC Centre for Ecology and Hydrology Dorset, Winfrith Technology Centre, WinfrithNewburgh, Dorchester, Dorset, DT2 8ZD	i) Time-series survey data on the extent and condition of wet heathland in Dorset. ii) Long-term data sets on the individual performance of *Gentiana pneumonanthe*.
Simon Weymouth simon.weymouth @forestry.gsi.gov.uk Forestry Commission New Forest District The Queen's House Lyndhurst Hampshire SO43 7NH	Wet heath and mire restoration under the New Forest LIFE project.

English Nature is the Government agency that champions the conservation of wildlife and geology throughout England.

This is one of a range of publications published by:
External Relations Team
English Nature
Northminster House
Peterborough PE1 1UA

www.english-nature.org.uk

Cover printed on Character Express, post consumer waste paper, ECF.

ISSN 0967-876X

Cover designed and printed by Status Design & Advertising, 2M, 5M, 5M.

Front cover photographs:
Top left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888