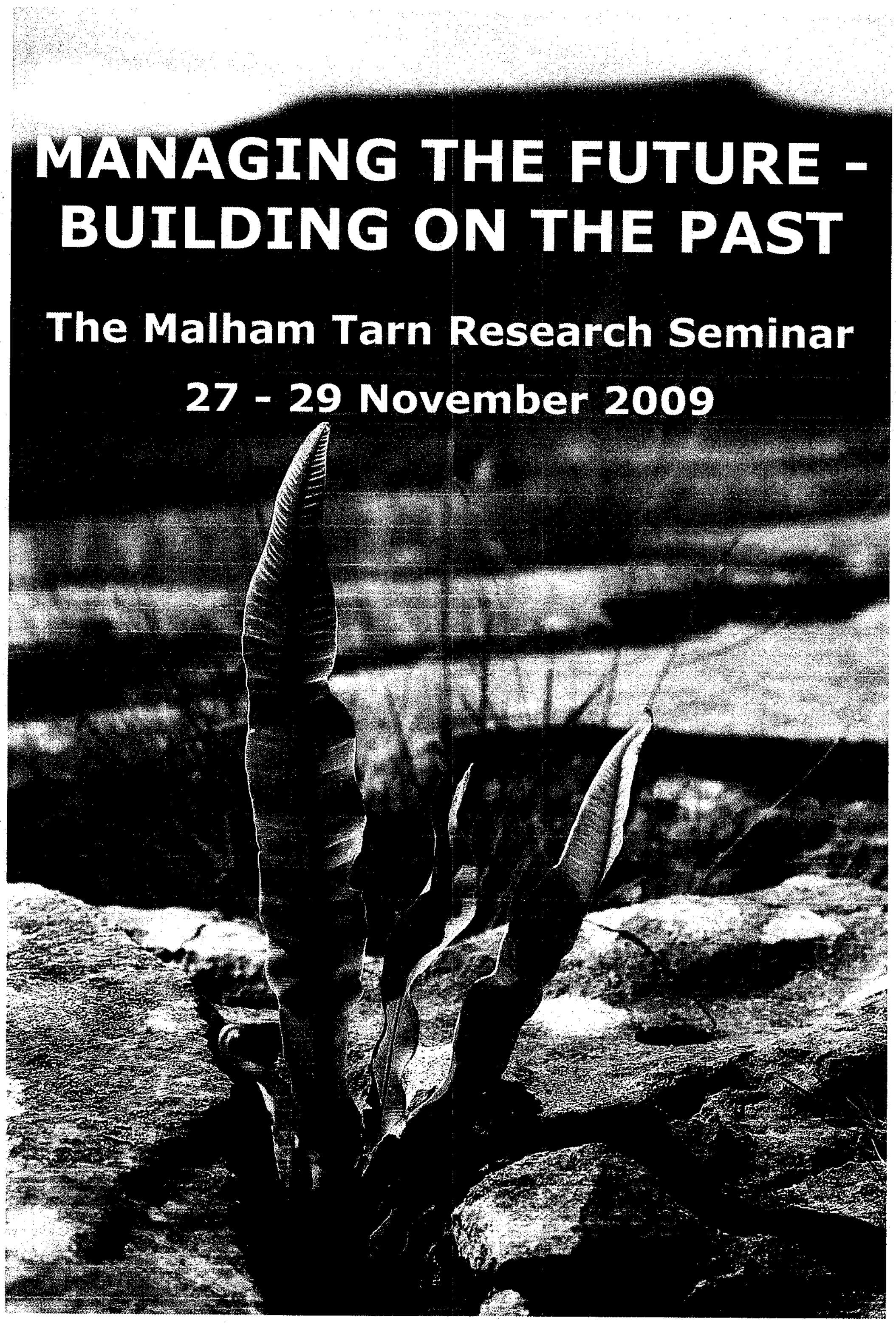
FSC

BRINGING ENVIRONMENTAL UNDERSTANDING TO ALL

MANAGING THE FUTURE - BUILDING ON THE PAST

The Malham Tarn Research Seminar

27 - 29 November 2009



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Cover photograph: Harts Tongue Fern and limestone pavement at Southernscales.

FOREWORD

The Malham Tarn Research Seminar continues to go from strength to strength and the 2009 meeting once again showed how seemingly disparate topics are underlain by many common links. Papers about limestone lead on to erratics, caves, records in peat and pollen of volcanic activity and previous climates, farming in the 14th century and eventually on to diatoms, green algae, *Carex flava* and the fleeting records of ice on the Tarn. Finally the report on the eco-hydrology of the Malham Wetlands linked us to the development of the Management Plan for the National Nature Reserve.

A recurrent strand in the Research Seminar has been how professional, amateur and research workers are all involved in developing the understanding of a location such as Malham Tarn. At the Field Centre we see all of these strands at work and the Seminar is one way to keep everyone in contact.

Since the seminar, The National Nature Reserve Management Plan has been published. This has enabled the development of a list of research topics with opportunities for workers at a number of levels. This is a significant step forwards and links with a number of research institutions have already been strengthened or established. For more information please contact the National Trust Office on 01729 -830416.

The next Malham Tarn Research Seminar will be held in November 2011 (Friday 18th – Sunday 20th). The final theme has yet to emerge but I am sure it will continue to provide everyone interested in Malham Tarn with an opportunity to share what they have been learning. I hope to see you there.

Thank you to all contributors and attendees. Thank you to Katherine Hearn for her able chairmanship Elizabeth Judson for compiling proceedings and to Robin Sutton for his photograph.

Adrian Pickles
July 2010

ACKNOWLEDGEMENTS

All contributors and attendees
Katherine Hearn for chairing the sessions
Malham Tarn Field Centre Staff for looking after us so well
Robin Sutton for the cover photograph
Elizabeth Judson for compiling proceedings and co-ordinating the weekend

PROGRAMME

Friday

4.30 -	Arrivals
7.00pm	*Dinner*
8.00pm	**Poster Displays and Informal Discussion**

Saturday

8.30 am	*Breakfast*
9.15 am	**Welcome and Introduction** - *Adrian Pickles,* **Chair-** *Katherine Hearn*

- Conserving white-clawed crayfish in the Craven Uplands - the EA Ribblesdale Crayfish Conservation Project - *Paul Bradley*
- Status of Carex flava in the British Isles - *Nigel Blackstock*
- Mollusc communities on different types of Limestone pavement - *Sue Willis and Adrian Norris*

10.50-11.10am Coffee

- Limestone pavements in a changing climate - *Cynthia Burek and Peter York*
- Palaeoecology and landscape history in upper Ribblesdale – an introduction to an ongoing project - *Helen Shaw*
- Megalab, OPAL: Snails, worms and engaging school students in real science – *Gill Gasson*
- Ecohydrology and the NVC plant communities of the Malham Wetlands - *Roger Meade and Alex Jones*
- Deposition of erratics in grikes on the Limestone pavements of Silverdale - *Peter Standing*

1.00-1.45 pm Lunch

- Developing the NNR Management Plan - Martin Davies
- Significance of pre-last glaciations depressions - Margaret Marker
- Karst and non-karst development of landscape on Limestones in Northern England - Helen Goldie
- Climate change & human impact in the first millennium BC; preliminary palaeoecological data from tarn moss, Malham - Graeme Swindles

3.30-3.50 pm Tea

- Diatoms and dates in the sediments of Malham Tarn - Allan Pentecost
- The Phenology of lake ice - Glen George
- A dairy on Malham Lings 1344-1362 - Mike Spence
- Scoska cave, Robinson Pot, moths and formations - David Hodgson

6.45pm	*Sherry*
7.00pm	*Dinner*
8.00pm	Discussion and Planning site visits

Sunday

8.30am	*Breakfast*
	Depending upon response, site visits and/or additional talks and discussion
12.30pm	*Lunch*

Ribblesdale Crayfish Conservation Project

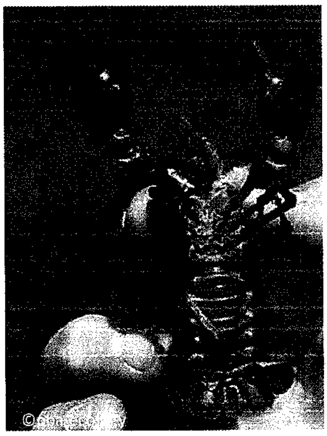
Paul Bradley

Introduction

White-clawed crayfish is not amongst Britain's rarest species, it is not the most highly protected by legislation, and might not at present have the most endearing relationship with the general public. But it has undeniably suffered amongst the most dramatic population declines and local extinctions throughout much of its range over recent decades, and faces predicted near extinction in this country within many of our lifetimes. Britain's only native crayfish is traditionally associated with species-rich freshwater habitats, and highly valued native salmonid fisheries.

White-clawed crayfish

The principal causes of the decline of our only native crayfish, are associated with the ill-advised introduction of American signal crayfish in the late 1970s, and misguided attempts to establish a commercial fishery in this, arguably Britain's most destructive invasive species. Were seed nurseries to promote the widespread planting of Japanese knotweed – one of Britain's most invasive terrestrial plant species - there would be rapid actions by regulators to curtail the trade, in the interests of protecting native terrestrial biodiversity. By contrast, this rapid and largely human-assisted invasion of rivers, streams, lakes, reservoirs and canals has thus far gone largely unchecked. Initial attempts to establish a market in the 1980s failed, and more recent promotion by celebrity chefs has similarly failed to capture the public's imagination. Not surprising, as even the largest signal crayfish produces very little edible flesh; the taste and texture of which is far inferior to that of saltwater prawn.


American signal crayfish

To address the decline of white-clawed crayfish then, we first need to improve awareness and education. But the potential benefits of doing so extend far beyond the conservation of a single species. The largely unchecked advance of aquatic invasive species threatens to permanently degrade the value of traditional angling – Britain's most popular participation pastime – at a huge economic and social cost to the country. And even a modest increase in Britain's flood defence budget, resulting from *e.g.* the extensive burrowing of American signal crayfish, would cost many more £Millions per annum. At present, there is no effective and widely applicable method of controlling the spread of American signal crayfish.

At the single species level, even if we were able to eradicate every American signal crayfish, white-clawed crayfish would probably continue to head towards near extinction in this country. Crayfish plague, a non-native pathogen from North America, has been decimating native populations of all Europe's native crayfish species over the last 100+ years. At present, there is no effective response to an outbreak of crayfish plague, other than to allow this devastating disease to run its course, removing entire accessible populations.

The future then for white-clawed crayfish might perhaps include isolated water bodies. Much effort in recent years has gone into the concept of 'Ark Sites' for white-clawed crayfish. However, even some of the most isolated extant populations have suffered catastrophic population decline over recent decades, the mechanisms were until now largely unknown.

The Ribblesdale Project

The River Ribble rises amongst the classic karst landscape of the Yorkshire 3-Peaks (Ingleborough, Whernside & Pen-y-Ghent). Prior to the mid-1990s, this river system supported one of the country's strongest white-clawed crayfish populations. A pollution incident followed by the arrival of 'crayfish plague', have together decimated the population, leaving just a few isolated fragments. The very detailed monitoring that has taken place in Ribblesdale since, now represents part of the most intensive investigation into the mechanisms of population change in white-clawed crayfish.

Strategically, Ribblesdale is situated at the leading edge of the national (and Europe-wide) collapse of native crayfish populations. To the north and west, survive some of Britain's strongest remaining populations of white-clawed crayfish. And further west, Ireland is one of the last countries in Europe that has so far avoided the catastrophic introduction of non-native crayfish species. A project centred upon Ribblesdale then is ideally located to begin to address the conservation of this most threatened species, and the human-assisted spread of American signal crayfish.

The Yorkshire Dales Millennium Trust has led a partnership project involving the Environment Agency, Natural England, Yorkshire Dales National Park Authority, with additional enabling funding support from Esmee Fairburn Trust and Tubney Charitable Trust, and helpful in-kind support from the Field Studies Council, National Trust, angling bodies, local farmers, and conservation groups. The overall aims of the project are to advance original science and to develop practical techniques that together will assist the conservation of white-clawed crayfish in Ribblesdale, and throughout the country.

1. Captive Breeding of White-clawed Crayfish

Captive breeding tanks

Following first outbreak of 'crayfish plague' in Ribblesdale, in August 2000, Environment Agency Fisheries Technical Officer Neil Handy has been refining techniques for captive breeding of white-clawed crayfish. Situated at a spring source emerging at the foot of a limestone escarpment above the Ribble, a series of on-line tanks represent the country's most successful captive breeding facility for white-clawed crayfish.

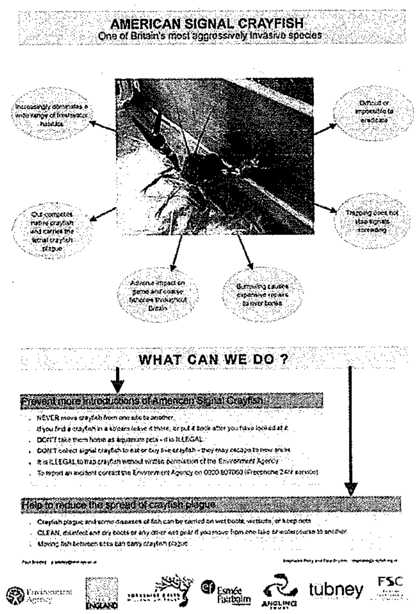
The current project has supported further development of this facility, investigation of conditions associated with successful breeding, and consideration of useful outcomes.

2. Education & Public Awareness Raising

The lack of knowledge and public awareness played a major role in the introduction and subsequent human-assisted spread of American signal crayfish throughout much of the country. Prior to the initial introduction to a farm in Dorset in 1976, the UK Goverment was advised that native populations of white-clawed crayfish in Britain had crashed, and that it was therefore reasonable to introduce American signal crayfish to fish farms and fish ponds throughout much of the country. In fact, England & Wales still supported some of the strongest populations of white-clawed crayfish at that time, and those people who were involved in the introduction of American signal crayfish were most likely aware of its invasive potential, and its capacity to carry crayfish plague.

EA information leaflet

Three decades on, the current project has attempted to raise public awareness of the country's only native crayfish species, the large populations of European conservation importance that still extend throughout some river systems of northwest England, and the ever growing threat of human-assisted spread of American signal crayfish.



Poster design

Environment Agency leaflets have been widely distributed throughout the region, including a leaflet tailored to food outlets requesting that crayfish be kept off the menu in northwest England. Two new posters have also been designed and printed; one to raise public awareness of the native white-clawed crayfish; and the second to raise awareness of the American signal crayfish, and actions that can be taken to prevent further illegal introductions to new areas.

Building upon news of continued captive breeding success, press releases have been issued, which have been widely taken-up. Press features have appeared in the Craven Herald, Westmorland Gazette, Yorkshire Post, Catch magazine, The Dalesman, plus numerous online sites and learned literature as far afield as Canada. Radio interview has been broadcast on BBC Radio Cumbria - breakfast, and TV features have been broadcast on BBC Northwest Tonight (Aug-10), and on national prime time BBC1 CountryFile (Feb-10).

To facilitate additional education outcomes, aquaria of captive bred white-clawed crayfish have been installed at five contrasting locations in the region: (i) a local primary school; (ii) a city secondary school; (iii) FSC Malham Tarn Field Centre; (iv) Lake District National Park Visitor Centre, Brockhole, Windermere; and, (v) the Lakeland Wildlife Oasis. At these locations, leaflets have been made available, posters have been displayed, and the native crayfish have been exhibited as part of a naturally functioning species-rich freshwater community. We have also assisted with a public open day at Brockhole.

The project has conducted educational training days for Environment Agency staff at both Central (Preston) and South (Warrington) North West Region Offices. Outcomes have also been widely disseminated at meetings, regional crayfish conference (Grassington) and national crayfish conference (Leeds). In addition, a two-day residential workshop has been convened (Jul-09), based at FSC Malham Tarn Field Centre, which brought together Environment Agency staff from every region, together with representatives of Defra, Natural England, Angling groups, Cefas, National Trust *etc.*

3. Feasibility of American Signal Crayfish Eradication

A substantial component of the project, led by Stephanie Peay, involved investigating the feasibility of known technologies and techniques that might be applied to the eradication of a headwater population of American signal crayfish. A preferred method was developed, which would involve careful, systematic and well-contained treatment of the infested reach with a natural biocide – pyrethrum.

A detailed method statement was developed, and costings were prepared. However, hydrological investigations found a connection between bedflow in part of the beck, and a nearby public groundwater abstraction. At the time, it was considered that biocide treatment could not then proceed, due to potential concerns from the general public. In fact, the biocide to be used appears to have been approved for use in some public water treatment. Toxicological studies elsewhere have shown that pyrethrum adheres readily to surfaces, and might not therefore be expected to be detected at the public groundwater abstraction.

For the present, the population continues to spread downstream, but has not yet reached the main River Ribble. It was decided that the biocide eradication attempt could not be taken forward within the timescale of the current project.

4. Water Quality Requirements of Isolated Populations

In view of the continued spread of invasive non-native crayfish species throughout much of mainland Britain, and (in areas of native crayfish distribution) the ever increasing threat of localised extinctions resulting from crayfish plague epizootic, much attention in recent years has focused upon isolated lentic sites, as possible 'Ark Sites' for white-clawed crayfish. However, our long-running investigations of extant lentic populations of white-clawed crayfish in Britain & Ireland, have found that these populations have also suffered significant population declines, and local extinctions. At lentic sites though, biological changes associated with water quality, rather than invasive crayfish/pathogen appear to be the driving mechanism.

Within the project area, we are very fortunate in having one of the strongest remaining lentic white-clawed crayfish populations – a privately owned isolated water body. The project has worked with the landowners/tenants and Natural England locally, to bring the site's immediate catchment successfully into Higher Level Stewardship. In partnership with the Environment Agency's water quality monitoring team, the project is now in the process of investigating water quality parameters associated with such an outstanding population.

Our investigation of water quality parameters associated with lentic white-clawed crayfish population status involves taking water samples at monthly intervals at three contrasting sites:

1. Privately owned water body - outstanding population.
2. Malham Tarn – Craven Limestone Complex SAC - population crash in the mid-1970s, leaving very small surviving remnant population.
3. EA captive breeding setup – Britain's most successful captive breeding attempt, now rearing 3rd generation white-clawed crayfish, and showing ecological gradient through a series of online tanks.

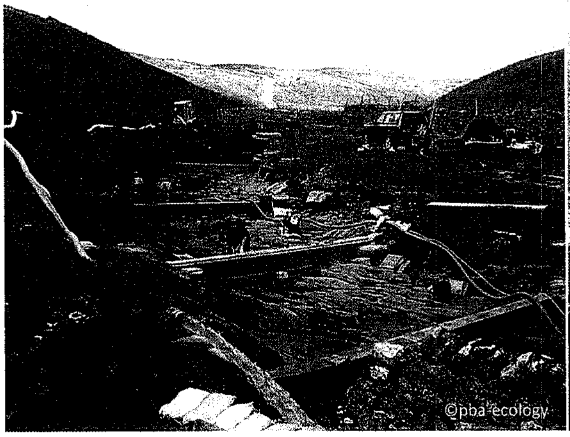
This water quality investigation is ongoing, and has been extended for a further year by continued EA internal funding. Results compiled thus far suggest that even a small change in water quality appears to significantly compromise breeding success in white-clawed crayfish at lentic sites. The concept of isolated water bodies as secure Ark Sites for white-clawed crayfish might thus be critically flawed, if it does not adequately consider the biological water quality of such sites.

It is possible that some proposed/commenced introductions of white-clawed crayfish to isolated water bodies throughout the country over recent years will be unsuccessful. Adult survival might be observed for some years, but very few currently unpopulated sites might be capable of establishing healthy recruiting populations of white-clawed crayfish. Nationally, a very small number of lentic sites might well be part of the future for this critically threatened species, but great care should be taken to adequately investigate the biological suitability of any currently unpopulated sites that might be considered for Ark Site introduction.

A detailed report will be prepared following the extended period of water quality investigation.

5. Crayfish Plague Eradication Attempt

Our ongoing research has shown that the causative pathogen of 'crayfish plague' has remained continually present in Ribblesdale since first infection in 2000. The infection appears to have arrived with stocked fish in July/August 2000, from a fish farm that is infested with American signal crayfish. Over the next few years, the disease spread though the river system, substantially reducing the species distribution, and leaving just a small number of isolated fragments. In September 2008, the disease was found to be localised at just one location in the upper catchment, below a series of waterfalls. The disease appears to have been localised at this one location since arriving there some years earlier. There is no known resistance to crayfish plague in white-clawed crayfish in this country. Until now, it has been generally accepted that epizootics are usually short-lived, and that reintroductions can safely proceed within just a few years of first confirmed infection.



Conservation Weirs

Following lengthy consultations and consideration of a range of options to eradicate the disease, a series of specially designed physical barriers were constructed above the waterfalls. With careful attention to detail, and appropriate operation, these precisely constructed 'conservation weirs' were found to be very effective in substantially restricting the downstream movement of white-clawed crayfish into the plague-infected zone. A detailed report on this work is being prepared.

It is highly likely that the lessons learned can be used to effectively intervene to control a proportion of future epizootics elsewhere in this country, and Europe.

The status of *Carex flava* L. s.s. (Cyperaceae) in the British Isles

Nigel Blackstock

Introduction

Carex flava L. s.s (fig. 1) is a rare plant in the British Isles. It was formerly thought to be extant at only one location, Roudsea Woods, Cumbria (vc 69). Two further historic populations from Ennerdale, Cumbria (vc 70), discovered by J. Dickinson in 1836, and Hebden, W. Yorks (vc 64), discovered by T. W. Edmondson in 1906, are known from only single voucher specimens held at **LIV** and **GH** respectively. Three further putative *C. flava* x *C. lepidocarpa* Tausch. (= *C.* x *pieperana* P. Junge) hybrid populations have been described from Malham Tarn Moss (vc 64), Greywell Moors (vc 12) and Coolagh Fen (vc H17) suggesting that *C. flava* was formerly more widespread than it is today. The first of these populations, Malham Tarn Moss, was originally thought to have been found by G. Shaw in 1946 (Shaw 1946) but a recent discovery by Dr Paul Ashton in the British Museum (**BM**) indicates that a specimen was collected from this site by A. W. Bradley in 1913 (Ashton pers. com.). The

Malham Tarn Moss population was considered by many botanists to be *C. flava* s.s. (Shaw, 1946; Davies, 1953; Clymo, 1960 etc.) but doubts to its true identity were raised by Jermy and Tutin (1968) who stated that "the only typical material" of *C. flava* in Britain "is from N. Lancs (vc 69)" i.e. Roudsea Wood. Jermy *et al.* (1982) further stated that plants intermediate to *C. flava* and *C. lepidocarpa* occur at Malham Tarn Moss. It is this treatment that was adopted by Stace (1997).

Fig. 1 *Carex flava* L.
photo: Blackstock 2009

A further population at Gait Barrows, Cumbria (vc 60) is known to have been introduced in 1998. Seedlings and smaller plants failed to become established but larger genets are still thriving. This may suggest that competition plays an important role in recruitment (Blackstock unpublished data).

A detailed morphometric analysis incorporating populations from Britain, Northern mainland Europe and North America of *C. flava* and *C. lepidocarpa* presented by Blackstock and Ashton (2001) challenged the view that the Roudsea Wood population was the only native population of *C. flava* in the British Isles. They found that the Malham Tarn Moss population could not be separated from the N. American, British or European populations of *C. flava* but was distinct from all populations studied of *C. lepidocarpa* and therefore concluded that the Malham Tarn Moss was *C. flava* s.s. Given the taxonomic difficulties within the *C. flava* complex it was desirable that molecular markers, such as allozymes, combined with multivariate statistical analyses of morphological data, were used to provide an additional line of evidence to support this conclusion. Allozymes have been used to successfully resolve taxonomic problems within the genus *Carex* (Bruederle and Fairbrothers 1986; McClintock and Waterway, 1993; Ford *et al.*, 1991) and specifically within the *C. flava* complex (Bruederle and Jensen 1991; Hedrén 1996; Hedrén and Prentice 1996; Hedrén 2003). This study will address the identity of the putative *C. flava* x *C. lepidocarpa* hybrids from Malham Tarn Moss, Greywell Moors and Coolagh Fen through: 1) identification of morphological variation within *C. flava* and *C. lepidocarpa* and the putative hybrid populations; 2) Identification of genetic markers that differentiate *C. flava* from *C. lepidocarpa*; 3) Identify whether these markers are present in the putative hybrid populations in an additive manner thus confirming hybrid origins; 4) consider pairwise genetic identities within *C. flava, C. lepidocarpa* and the putative hybrid populations.

Method

Specimens were collected from 27 populations from the British Isles, Northern Europe and North America. These included 13 populations of *C. flava*, 11 populations of *C. lepidocarpa* and the three putative hybrid populations of Malham Tarn Moss, Greywell Moors and Coolagh Fen. Eleven morpholagical characters and 11 enzyme systems giving 17 putative loci and 31 alleles were identified. Full details of the morphological characters and enzyme systems, along with the full methodology are given in Blackstock (2007).

Results

A scatter plot (fig. 2) derived from a principal component analysis along PC I and PC II indicates there are two distinct clusters, although separation is minimal. These clusters could be described as a *C. flava* cluster and *C. lepidocarpa* cluster. The *C. flava* cluster includes all populations described as *C. flava* as well as the putative hybrid populations from Malham Tarn Moss and Coolagh fen, although there is some separation of the latter population along PC II. The *C. lepidocarpa* cluster included all of the *C. lepidocarpa* populations and the Greywell Moors population.

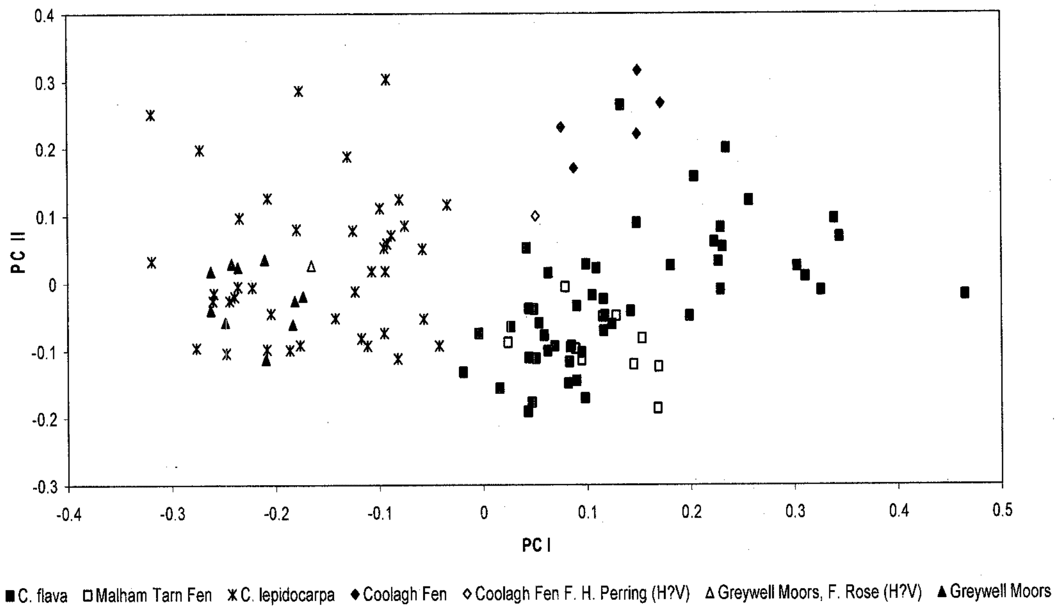


Fig. 2 A scatter plot derived from a principal component analysis along PC I and PC II of all C. flava, C. lepidocarpa and putative hybrid populations.

The allozyme analysis found 6 loci to be monomorphic thus leaving 11 polymorphic loci. A phenogram (fig. 3) derived by UPGMA clustering from a matrix of pairwise comparisons of Nei's (1978) genetic identities (Table 1) clearly shows two distinct clusters that can be ascribed to *C. flava* and *C. lepidocarpa.*

Table 1. Matrix of mean genetic identity coefficients (Nei 1978) derived from pairwise comparisons of all populations of the *C. flava* agg. sampled: observed range in values given below mean values.

	C. flava	*C. lepidocarpa*	Malham Tarn Moss	Greywell Moors	Coolagh Fen
C. flava	0.9839 (0.9045 – 1.0000)	0.6610 (0.5854 – 0.7647)	1.000 (0.9045 – 1.0000)	0.8149 (0.7632 – 0.8235)	0.7593 (0.7550 – 0.7748)
C. lepidocarpa		0.9329 (0.8406 – 0.9970)	0.6610 (0.5854 – 0.7647)	0.7960 (0.7642 – 0.8371)	0.8218 (0.7759 to 0.8825)
Malham Tarn Moss				0.8149	0.7593
Greywell Moors					0.8176

The low levels of genetic variation within *C. flava* is reflected by there being no differentiation for these populations ascribed to this taxon with the exception of three sites, Roudsea Wood, Västanå and Dalbyn. Malham Tarn Moss clearly falls within the *C. flava* cluster with the Greywell Moors population being slightly separated. The separation of the latter is, in part, due to the inclusion of the 6PGDb allele which is absent from *C. flava* but common to *C. lepidocarpa*. Four other alleles (ADHa, PGM-1b, PGM2b and

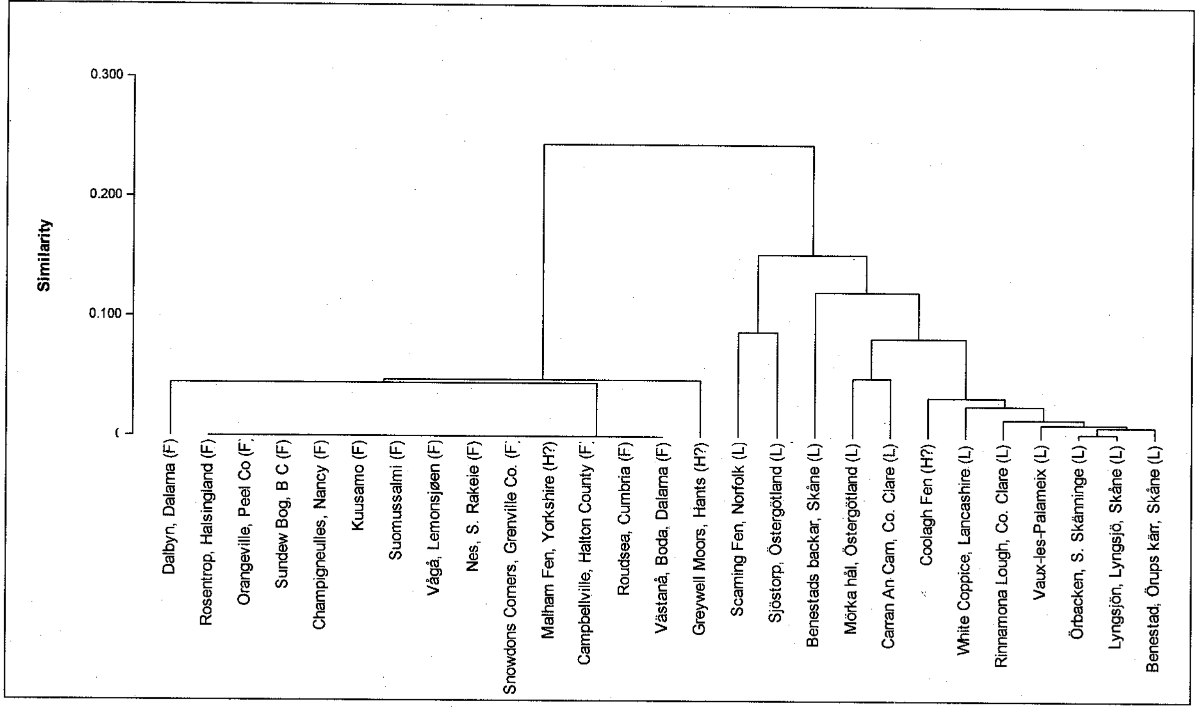


FIG 3 Phenogram of UPGMA AHC of allele frequencies between sites of *Carex flava* (F), *C. lepidocarpa* (L) and Putative hybrids (H?)

GDHa) that are fixed within *C. flava* but only found at low frequencies within *C. lepidocarpa* (<0.37) are fixed within the Greywell Moors population. This is a strong indication that *C. flava* was probably extant at Greywell Moors but is now extinct. All alleles found within the Coolagh Fen population are common within *C. lepidocarpa*. Of these, five alleles (6PGDb, ADHb, PGM-1a, PGM-2a and GDHb) found to be fixed in the Coolagh Fen population are absent from all *C. flava* populations sampled. The Malham Tarn Moss population was found to be identical to all *C. flava* populations samples, with the exceptions of Roudsea Wood, Västanå and Dalbyn mentioned above.

Conclusion

The morphological analysis supports Blackstock and Ashton (2001) that the Malham Tarn Moss is *C. flava* s.s. The Greywell Moors population belongs to *C. lepidocarpa* and that the Coolagh Fen population belongs to *C. flava*, although there is partial separation along PC II. This partial separation raises some doubts that are further emphasised by some qualitative differences between *C. flava* s.s and the Coolagh Fen population. The clustering with *C. flava* is primarily due to the unusually large utricles found within this population. That Coolagh Fen is not *C. flava* is supported by the allozyme analysis that strongly indicates that this population is an extreme phenotype of *C. lepidocarpa*. It is suggested that this may be, in part, due to the prevailing ecological conditions at Coolagh Fen.

Morphologically the Greywell Moors population cannot be separated from *C. lepidocarpa* but it has several alleles common to *C. flava* that are either not found or very rare in *C. lepidocarpa*. Schmid (1980) indicates that introgressive hybridization between sympatric taxa of the *C. flava* agg. does occur and that introgression followed by natural selection for *C. lepidocarpa* characteristics would leave individuals with a predominantly *C. lepidocarpa* morphology. There is some evidence to support this hypothesis from a study of *Carex vulpina* L. and *Carex otrubae* Podp. where the two species are sympatric at sites in Southern Britain (Smith and Ashton, 2006).The signature of introgression remains in allozyme patterns at Greywell Moors as these alleles are considered to be selectively neutral and therefore more likely to remain in the population. It is possible that a small population of *C. flava* was once extant at Greywell Moors but has subsequently become extinct, with some *C. flava* alleles remaining within the population of *C. lepidocarpa* as a product of introgression.

The Malham Tarn Moss population cannot be separated by either morphology or allozyme analysis from *C. flava*. Indeed it could be argued that the Malham Tarn Moss population is more typical of *C. flava* than that found at Roudsea Wood where there is some indication of introgression between *C. flava* and *C. demissa*. The Malham Tarn Moss population is very small (c. 10 genets, Blackstock, unpublished data) although the population does appear to be stable. This population needs to be carefully monitored to establish population numbers and stability and may benefit from periodic seed collection every two or three years in case the population is further threatened. Surrounding areas should also be surveyed to identify any hitherto unidentified genets.

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The Relationships between Molluscs and Limestone Pavements

Sue Willis & Adrian Norris

Introduction

This presentation outlines a combined research project, describing mollusc populations found on limestone pavement habitats. It was carried out as part of a wider project, 'the holistic classification of limestone pavements', described at the 2007 Malham Tarn Research Seminar (Willis, Alexander, & Burek, 2007). Over a three year period, 46 limestone pavements across North West England and North Wales were assessed, considering elements of both geodiversity and biodiversity, in order to build a holistic understanding of the main drivers that influence the ecology and form of limestone pavements.

The aim of studying mollusca with limestone pavements was to address the current dearth of published research on zoological aspects of limestone pavements and more specifically the mollusca assemblages found there. By dovetailing the expertise of national conchologist Adrian Norris, with data collected as part of the holistic study of limestone pavements, it was hoped that we would advance in our understanding of these subjects.

Limestone Pavement Geodiversity & Biodiversity Methodologies

Over 80 variables were measured on each randomly selected limestone pavement, including aspects of both geodiversity and biodiversity. Factors examined included grike depth, clint size, floral species present & indicators of grazing intensity (Willis, Burek, & Alexander, 2009). Statistical analyses of geodiversity and biodiversity data have produced six holistic classes of limestone pavement; the four classes present in Yorkshire are presented here. Colt Park limestone pavement was so distinctive that it formed a fifth single-member group.

- GROUP 1: <u>OPEN PAVEMENT GROUP</u>: This is the largest class, with pavements having mean grike depths in the mid-range (50-100cm deep) and includes Crummack Dale and Sulber, along with six other Yorkshire limestone pavements and all the Cumbrian pavements studied.
- GROUP 4: <u>WOODED GROUP</u>: This includes Oxenber Wood and Bastow Woods with four other wooded limestone pavements in Lancashire.
- GROUP 5: <u>COLT PARK WOOD</u>: Part of Ingleborough NNR and fenced since the early 1960s where the danger posed to livestock may account for the wood's survival.
- GROUP 6: <u>DEEPLY-BEDDED, FLORISTICALLY RICH GROUP</u>: Includes three pavements studied for molluscs, all above an elevation of 300 metres and on Asbian limestones. They have high rainfall and are rich in herbs. They include the deeply bedded pavements at Scar Close, Tennant Gill & Dale Head (also Malham Cove pavement, but this was not studied for molluscs).
- GROUP 7: <u>YOREDALE GROUP</u>: Includes Cam High Road (Coverdale) with three other Yoredale pavements in this group plus three Malham-Arncliffe pavements, including Lea Green (Grassington) and Bordley. These are limestone pavements where the clint and grike structure, although evident, is largely masked by vegetation. The shallow grikes lack the distinctive features of a damp and shaded microclimate and protection from grazing, which characterise deeper grikes.

Molluscs & Limestone Pavement Methodologies

A robust visual species search, which included sieving through leaf litter in wooded areas, was conducted within the defined pavement boundary. Analyses compared mollusc species with geodiversity & biodiversity data from the limestone pavement data analyses undertaken in 2007 & 2008.

Results

Several important snails were identified on limestone pavements, notably an ancient woodland species, *Cochlodina laminata* (Fig.1), a limestone mountain relic species, *Clausilia dubia* (Fig.2) and *Helicigona lapicida* (Fig.3), an open crag and limestone wall species.

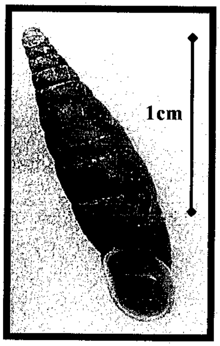

Fig. 1: *C. laminata*

Fig. 2: *C. dubia*

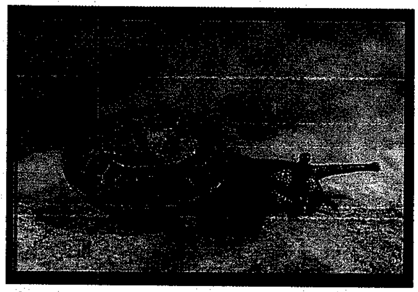

Fig. 3: *H. lapicida*

Data analysis gives similar results for both richness and diversity of mollusc species on limestone pavements. Mean grike depth accounts for 57% of the variation in mollusc species richness on limestone pavements with greater richness on pavements with deeper grikes. ANOVA of the regression analysis tells us that grike depth is a statistically significant predictor of species richness on limestone pavement stands (Pearson, $F = 12.07$, $p=0.007$). Grike depth also accounts for 51% of the variance in mollusc species diversity and 74% when combined with site elevation (altitude), mollusc species diversity declining as elevation increases. ANOVA of the regression tells us that both grike depth and grike depth/elevation combined are statistically significant predictors of species diversity on limestone pavement stands ($p<0.05$).

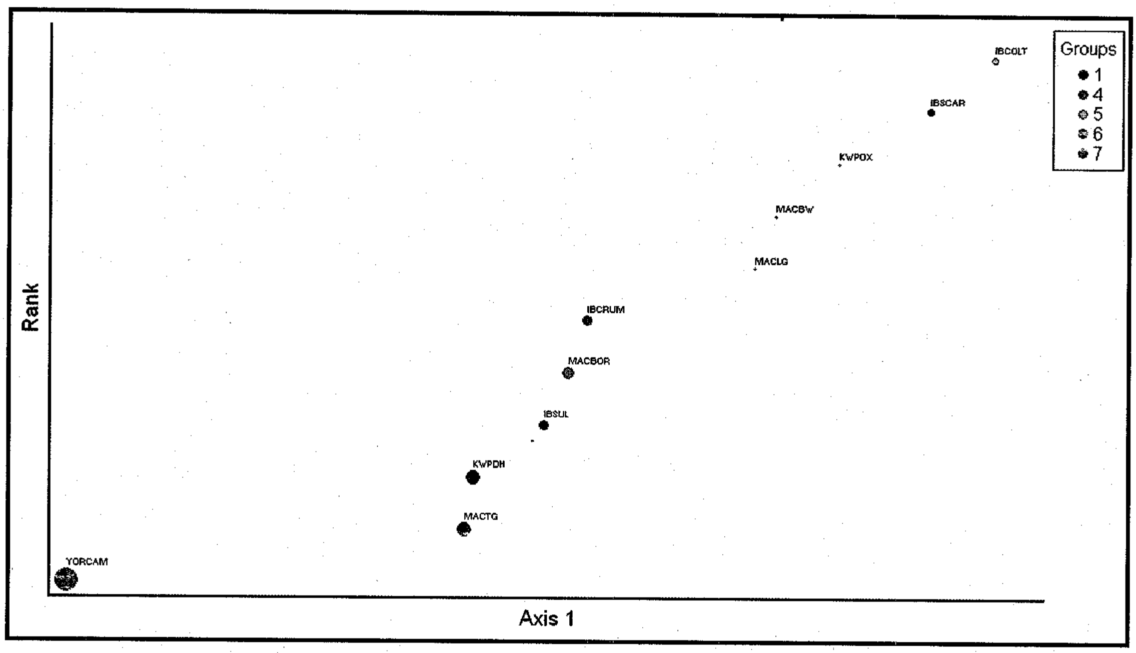

Figure 4: Ordination showing similarity between sites based on mollusc species abundance. Each symbol represents a limestone pavement and the colour of the symbols reflects pavement group membership (see legend).

Multivariate analysis using PC-ORD results in a one axis ordination (see Figure 4). Correlation of axis one scores with measured environmental factors indicates that the prime factors driving the gradient are landscape features i.e. elevation and wind exposure. These factors are also the most significant in the plant ecology of these limestone pavements.

Analysis of limestone pavement plant species data together with the mollusc data found a highly significant correlation between the ordinations of mollusc species abundance and ordinations of plant species present ($p<0.001$).

Discussion

Grikes provide habitats similar to those of woodland, protecting a wide range of plant species and collecting leaf litter, thus offering a variety of habitats for molluscs. Deeper grikes contain the greatest mollusc species diversity, mirroring results found in plant studies (Willis et al., 2009). Conditions on open, exposed pavements at higher elevations are the least hospitable for molluscs, and species diversity is predictably reduced. This is particularly notable where grikes are shallow, affording little or no protection from the weather, as seen at Cam High Road (YORCAM, figure 4). This pavement is markedly dissimilar to the other pavement stands in its mollusc population. At 592m (over 150m higher than other sites), and with the shallowest grikes, relatively few mollusc species were found and it lacked the characteristic woodland species seen on other limestone pavements.

Figure 5: White edges can be clearly seen on grike margins at Hutton Roof limestone pavement, Lancs.

During this research, interesting observations have been made on the limestone pavements concerning "white edges" evident around grike margins. Literature review and discussions with experts in this field of study have suggested a number of possible theories for the cause. They include mollusc grazing on lichens, vegetation retreat (where this is seen around vegetated solution cups), a fungal activity on the lichen, or insect grazing. Further investigation is unfortunately beyond the remit of this research.

Summary

This study establishes significant links between the geodiversity of limestone pavements and their mollusc populations, illustrating clearly that geodiversity underpins biodiversity (Burek, 2001). Patterns of mollusc species have been identified, relating to the limestone pavement classifications derived from geodiversity and biodiversity variables. Key drivers for mollusca assemblages echo those of plant species on limestone pavement, namely elevation, exposure and grike depth. Further work is indicated, both to extend this research beyond the limestone pavements of Yorkshire and also to identify the causal factors which create the white strips around limestone pavement grike margins and solution cups.

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Supervisors: Professor Cynthia Burek, Professor Roy Alexander (University of Chester) and Dr Tim Thom (YDNPA).

Limestone pavements in a changing climate

Cynthia Burek & Peter York

Introduction: What are limestone pavements?

First defined by Paul Williams in 1966 in the Burren as "A roughly horizontal exposure of limestone bedrock, the surface of which is:

- Approximately parallel to its bedding
- Divided into a geometrical pattern of blocks by the intersection of widened fissures."

However the statutory definition as embedded in the Wildlife and Countryside Act of 1981 (amended 1985) is "An area of limestone which lies wholly or partly exposed on the surface of the ground and has been fissured by natural erosion" .

Definition of climate change

Climate itself is defined for scientific purposes as 30 years of average weather. Climate has been changing rapidly recently as shown by the Intergovernmental Panel on Climate Change (IPCC) 4th report published in 2007, (Solomon et al, 2007) (Fig 1).

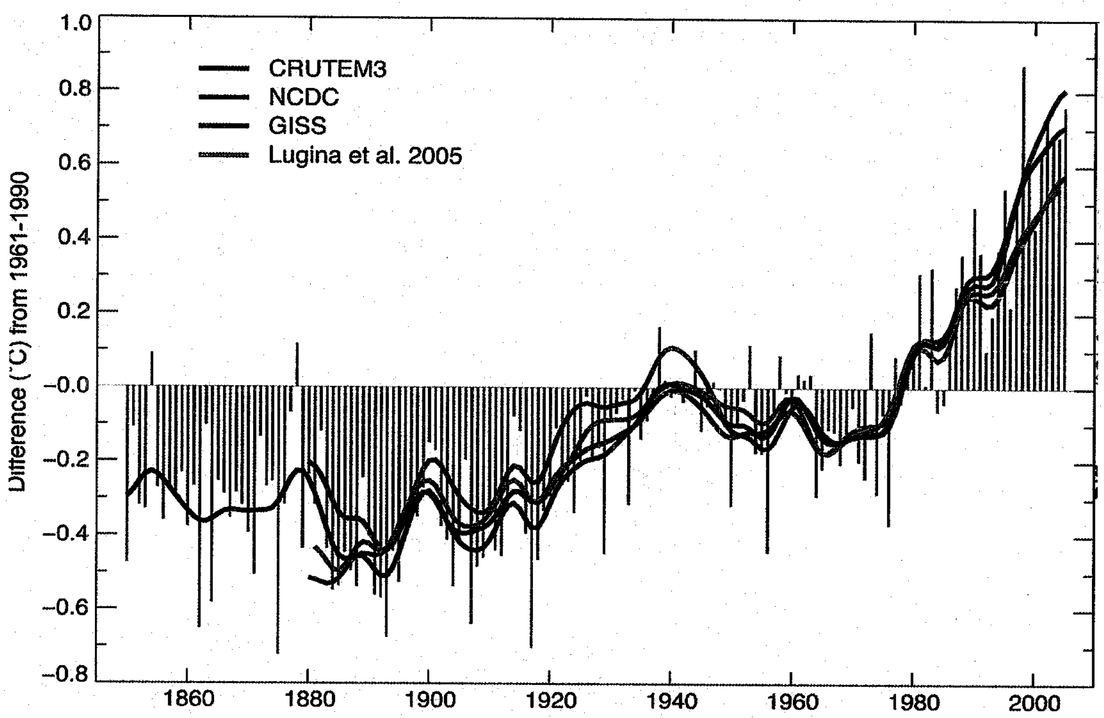

Figure 1 IPCC chart of temperature rise 2007 report

The change varies depending on the different scenario adopted from "business as usual to various carbon cutting emissions levels, Figure 2 shows the estimates for the present century.

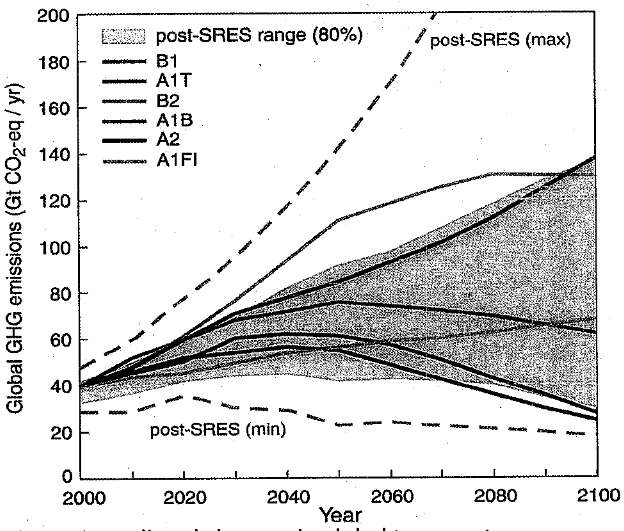

Figure 2 Predicted changes in global temperature

Microclimate

Limestone pavements are a unique and distinct habitat because of their grike microclimate. However the relationship between climate and microclimate is not known and needs further research. At present little long-term research has been carried out on microclimate of grikes (Silvertown,1983). Only 2 studies, both carried out at the University of Chester, are known and both relate to the orientation of grikes and the differences recorded in temperatures in relation to their flora and fauna (Burek & Legg 1999).

The first is a study of temperatures rainfall and relative humidity in 1997-8 at Y Taranau (Fig 3) in North East Wales and the second is a much longer study carried out in 2003-4 in Clawthorpe Hall Fell (Fig 4) in Cumbria. Here PAR as well as temperature and rainfall were recorded. Both studies therefore span several seasons (Alexander R, Burek C. & Gibbs H, 2007).

Figure 5 shows the difference in north-south oriented grikes as opposed to east-west ones. This data emphasises that between September to January, data covering the winter solstice the base of the grike rarely freezes except in the E/W grike and the temperatures are consistently more stable at 65 cms depth. However 1998-1999 was a mild but rainy winter.

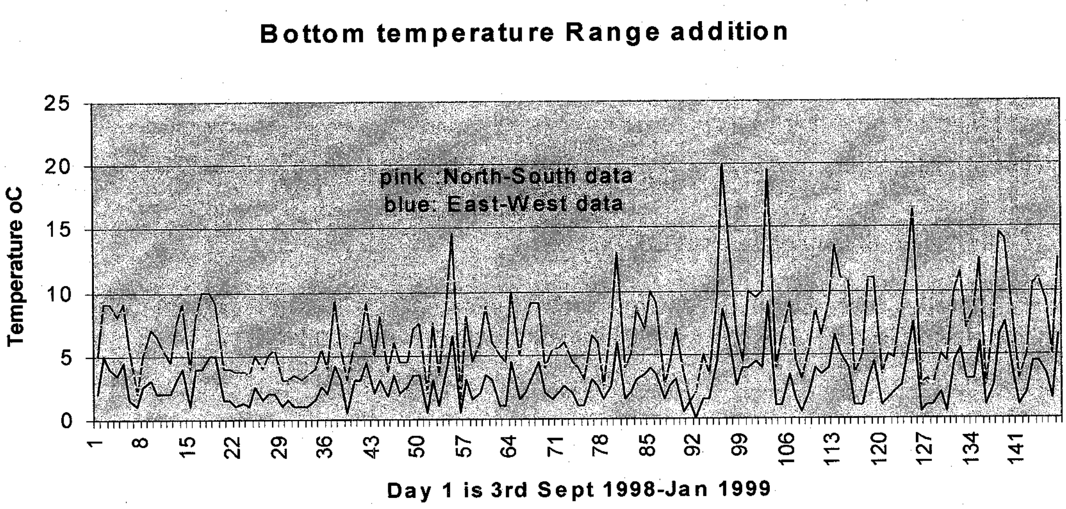

Figure 5 temperature data over 4 months during the winter of 1998.

Figure 6 shows the difference in the fall of maximum temperatures again plotted on orientation.

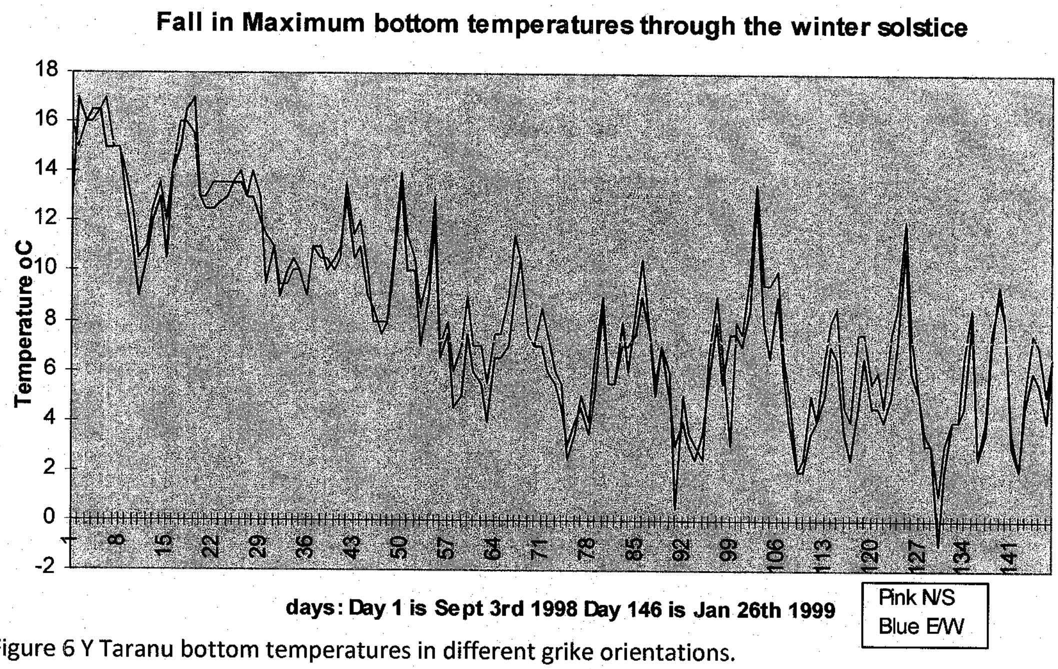

Figure 6 Y Taranu bottom temperatures in different grike orientations.

The second data set covers Clawthorpe Hall Fell quarry in Cumbria and the data here shows temperature ranges at different depths in north-south and east-west grikes over a 10 month period from July 2003-Aprill 2004. It highlights the clear decrease in temperature ranges as greater depth is gained with stability of temperatures occurring at greater than one metre (Fig. 7). The depth of this grike is 196cm.

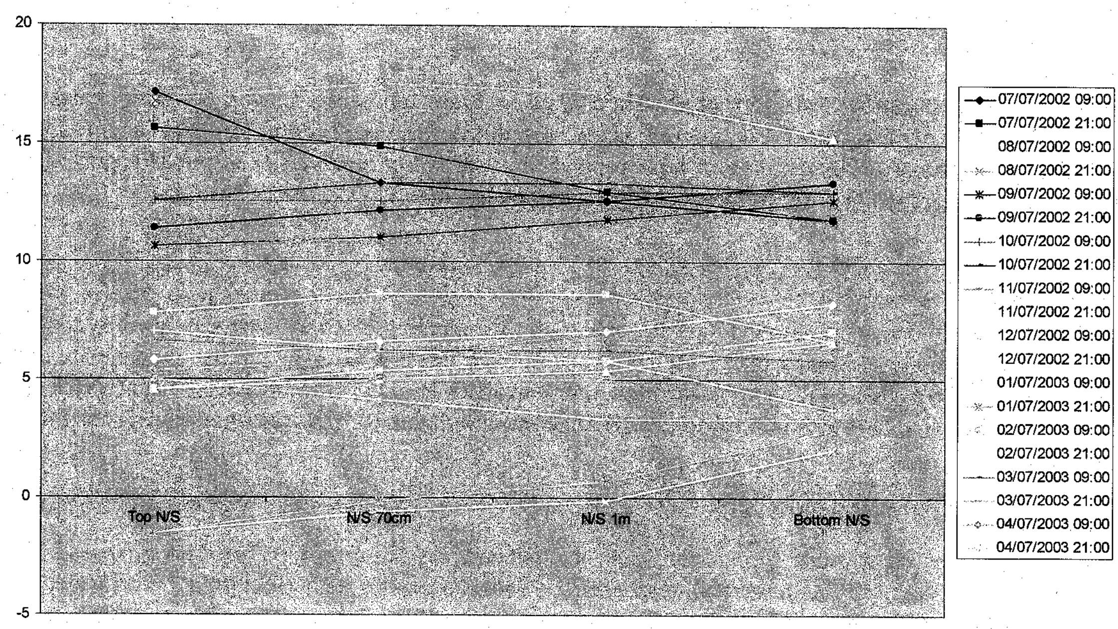

Figure 7 N/S grike temperature range. The bottom lines are January and the top July.

The east-west grike shows the same decrease in temperature range but here the depth is slightly less at 181 cms and has a slightly less bottom range of temperatures (Fig. 8).

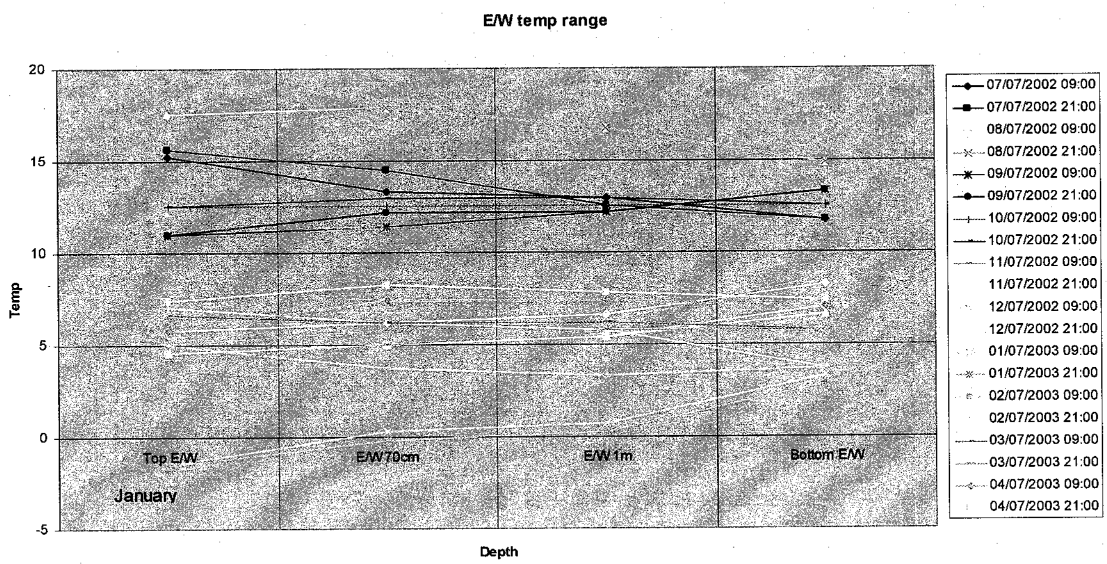

Figure 8 east-west grike temperatures at Clawthorpe Hall Fell, Cumbria

However both show the stability of the bottom of the grikes and in this respect resemble cave data which shows a greater stability of temperature the further away from the cave entrance. So perhaps grikes are merely reflecting a vertical example of temperature stability whereas caves are a horizontal representation (pers. comm. Hodgson, 2009).

As the base of these two differently oriented grike never freezes at greater than one meter it perhaps backs up the data from Y Taranau.

What are the implications therefore of climate change on these temperatures and will they change with rising global air temperature? We do not know, therefore the implications for flora and fauna are unknown. A greater understanding of how geodiversity will affect biodiversity in our changing climate needs to be researched in order to safeguard this special habitat.

Biodiversity

A wide range of flora and fauna is found in Limestone Pavements grikes including species of woodlouse, ant, snail and beetle and many plants are relic species from the last Ice Age (Fig. 9). Biodiversity differs between pavements due to geographic location, soil, elevation. Notable examples of rare species found on Limestone Pavements are Western mason bee (*Osmia parietina*) and Narrow mouthed whorl snail (*Vertigo angustior).*

Open Pavements

On open pavements without tree cover, lack of shelter is an important factor. The grikes on these pavements with their less harsh environment allow herbaceous species such as St. John's-Wart (*Hypericum montanum*) and Rigid Buckler fern (*Dryopteris submontana*). This flora supports fauna which is mostly woodlice and leaf beetles as well as other species. Interestingly leaf beetles are found in very small numbers on the wooded sites because they are ineffective in shade. This is supported by work from the US where they are used to control St. John's Wart (Ref) and it was found that they left the shade plants but controlled those in the open. Grike dwelling flora provides food but lack of shelter benefits some species

Wooden Pavements

On wooded pavements, cover is mostly provided by ash (*Fraxinus excelsior*) and sycamore (*Acer pseudoplatanus*) with some oak (*Quercus spp.*) and wych elm (*Ulmus glabra*). They are populated mostly by ants, snails and slugs. Woodland provides food and shelter.

What will be the expected effects of climate change on limestone pavement biodiversity?

Generally species distribution will progress north with those species whose ranges are already far north may become extinct in the UK all together. It is possible also that the number of invasive species will increase. Life cycles will become out of sync with one another. However in the limestone pavement grikes, the warmer climate as predicted will become inhospitable to relic species. The grikes will become havens for species whose ranges have progressed north. Eventually grikes might widen with increased weathering and result in a microclimate change. This will lead to colonisation by new species yet to be determined.

It is therefore vitally important that we track changes in microclimate over the past decade and project future effects of climate change upon the grike microclimate and the biodiversity. It will also be essential to monitor species encroachment into the grikes.

Woodlice

Woodlice are common on the open site of Eyarth Rocks but not on the wooded Y Taranau (York 2009). This is surprising as most research comes to the conclusion that as deterivores and crustaceans, woodlice should favour the rotting damp leaves of the wooded pavement. A possible theory (Zimmer, 2005) is that in summer and autumn the invertebrates in the trees are producing frass containing micro organisms. This drops onto the pavement and joins the woodlice and other deterivores breaking down the leaf litter. As winter draws in the woodlice retreat underground surviving on reserves until spring. The micro organisms at this time would normally also become dormant due to the cold however in a warm winter this will not happen and they will continue to break down the leaves. As spring arrives the woodlice emerge to find substantially less leaf litter and subsequently suffer.

How to plan for microclimate change in limestone pavement grikes

What can be done?

- Track changes in microclimate over the past decade using available databases
- Project future effects of climate change on grike microclimate
- Predict possible grike geodiversity change
- Monitor weathering of grike width to establish possible microclimate change
- Investigate solution rates of various limestone pavements in future climate
- Predict possible grike biodiversity change
- Establish if rate of change is too great to allow biodiversity adaptation
- Monitor species encroachment into grikes

Conclusions

The effects of climate change will prove a challenge to the optimum conservation and management of limestone pavements up and down the country.

Timescales and different rates of change must be taken into account for effective conservation of this unique habitat.

Fast action and planned management may allow limestone pavement's biodiversity to alter smoothly over the coming uncertain years, while the underlying geodiversity effectively remains the same as ever providing shelter for a new set of species.

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Figure 3 Y Taranau, Flintshire, North Wales

Figure 4 Clawthorp Fell National Nature Reserve, Cumbria

Figure 9 A vegetated grike in North Wales

Figure 10 a snail *(Cepea nemoralis)* on Bryn Alyn limestone pavement, North Wales

Palaeoecology and landscape history in upper Ribblesdale, North Yorkshire

Helen Shaw and Ian Whyte

Introduction

This abstract forms an introduction to a current Leverhulme funded research project "Post-medieval vegetation change and grazing management in an upland landscape". The project aims to examine land use history and vegetation change in upper Ribblesdale using integrated documentary and palaeoecological approaches.

Project rationale

Research and management strategies for upland landscapes in the middle to late 20th century have tended to separate ecological and economic functions. Nature conservation, managed in reserves, has focussed on the preservation and restoration of valued vegetative or zoological features whilst economic development opportunities focussed on improvement of agriculture and forestry. Unlike wilderness areas in other parts of the world European and British uplands have long histories and prehistories of human interactions with environment. This has led to the creation of complex, intricate landscapes which are both patchworks varying spatially, and palimpsests evolving through time. Separation of preservation and production functions may be of little relevance to the management of large tracts of upland for biodiversity. In recognition of this the last two decades have seen a shift towards study of cultural landscapes via interdisciplinary science, joined up policy and the integration of management strategies to try to take account of ecosystem function including that driven by human intervention.

Whilst the generalities of impacts in pastoral and extensive agricultural systems and their broad changes upon vegetation are now understood, the role, and importance, of small-scale past impacts in developing the patterns of biodiversity in present landscapes are only just being discovered (e.g. Gustavsson et al. 2007). Upland landscapes are the end product of small-scale alterations by farming communities over centuries and millennia. These individual histories can have a long-term implication for ecological resilience and potential, and for landscape evolution and management into the future. Although uplands policy and management now places more emphasis on valuing the socio-economic systems that occur in these remote areas, there has been a tendency to take the state of upland environments and economies c.1945 as a baseline representing a static 'normal' set of conditions. This has led to possibly erroneous views of sustainable land management within the context of a rural idyll.

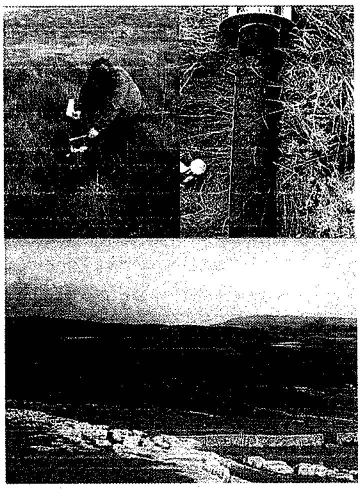
A major problem is that we have little detailed ecological knowledge of vegetation diversity and change from the historic period. Traditional Quaternary palaeoecological research, whilst valuable, has tended, with some notable exceptions e.g. North Gill (Innes and Simmons 1999, 2000) to be at a coarse temporal scale and/or to concentrate on the earlier postglacial periods; for example Piggott and Piggott's 1963 study of Malham, or that of the Craven Lowlands by Bartley et al. (1990). Where more recent or finer scale studies exist they show tantalising glimpses of the benefit of a more integrated research approach between understanding vegetation change via palaeoecology and understanding the human drivers of change through detailed historical study (e.g. MacKay & Tallis 1994).

The relative neglect of research on pastoral farming in medieval and post-medieval times has resulted in a lack of attention to many aspects of upland land use of relevance to long-term management objectives; particularly the nature and intensity of grazing management, (though see examples in Birks 1996, and Foster et al. 2003, Ross 2006, Dodgshon, 1998). It is in such areas that co-operation between palaeo-environmentalists and environmental historians, combining a palaeoecological approach with the use of evidence from historical records, can be particularly fruitful (e.g. Davies & Watson 2007).

Objectives
The Ribblesdale project will concentrate research effort on the recent few centuries and document change in vegetation, habitat diversity, correlating closely with historic shifts in land management to gain a deeper insight into post-medieval socio-ecological landscape.
The project has three specific objectives:

- To test the pollen-vegetation relationship in pastoral upland setting and to apply knowledge of this to new upland palaeoecological analysis to achieve robust vegetation reconstructions through space and time.
- To integrate, at a fine spatial scale, historical and palaeoecological data for the post-medieval period in an upland landscape to determine cause and effect between shifts in land management and biodiversity change.
- To test the relevance of prevailing views of sustainable pastoral management based on restricted but stable stocking densities.

Methods and site selection
The study will focus on Ribblesdale from its source near Ribblehead to the market town of Settle. It encompasses the large parish of Horton and the townships of Giggleswick, Langcliffe and Stainforth in Giggleswick parish. This area has been the subject of previous palaeoecological study (Gosden 1965: 1967 and Swales 1987), however these studies did not examine recent centuries in any detail.
Documentary evidence from a variety of local and national sources is being collated to form a timeline of land management practices and to identify shifts in cultural activity. Palaeoecological research, primarily pollen analyses, are being carried out on a network of sites where small peat basins provide substrate that record local rather than regional vegetation change (Jacobson and Bradshaw 1981). Sampling is being concentrated on near surface peat (to c.45cm) to gain insight into recent centuries of vegetation change at fine temporal scales.



Sites are being cored using a modified golf hole corer (see photos to left), which is good for extracting surface peat. Two sites have already been cored; at Wife Park (OS Grid ref SD 784 787) in peat deposits between drumlins, and at Sulber (SD 774 736) on a small raised bog overlying limestone. Further cores will be extracted at Whit-a-Green (SD 780 758) near to archaeological evidence of previous human settlement, and in at least three other locations.
Several surface samples have been taken from moss and peat around Ribblehead together with modern vegetation surveys. These will be used to test the relationship between deposited pollen abundance and plant abundance. Vegetation surveys will continue in 2010.

Challenges
There are several challenges in this project. From a palaeoecological perspective it will be important to find peat accumulations that have not been disturbed by peat cutting, and it will be important to ensure that dating of the peat is as thorough as possible. From an historical perspective it will be important to compile detailed landscape and farm records from a variety of sources to get try to achieve a record that is continuous through time and is spatially explicit. To ensure that full value of the joint study it will also be important to develop methods to integrate the datasets from the two disciplines. We will use GIS as well as timelines to achieve this.

We are grateful to Natural England and the Yorkshire Dales National Park Authority for helping with access to land, and to various local people for input and discussion into suitable field locations.

We hope to report on results of this work at the Malham research seminar in 2011.

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An update on work in surrounding caves in the last two years

David Hodgson

Scoska Cave, Littondale

Work has been carried out on noise levels in the cave as the Tissues seem more active when the cave is noisy. This is caused by an increase in the flow of water in the cave and also by a small waterfall that enters the passage. The highest noise level I recorded was 85 decibels so it does prove the cave can be noisy however whether it is the noise that makes the Tissues more active or an increase in the air movement due to the air disturbance by the water I am still not sure.

More work was done using the UV light on the cave walls and light green and brilliant red patches were noted. Calcite that has a manganese content fluoresces bright red but also some bacteria on decay forms a slime that can fluoresce under UV light.

Still on the quest for some form of sugar on the cave walls that the Tissues can obtain nutrients from micro-organisms that can live on bat guano form an enzyme called chitinase that is capable of converting the chitin exoskeleton of insects into simple sugars. As we have bats and insects (large numbers of *Culex pipiens* are present) I plan to do more work on bacteria at this site.

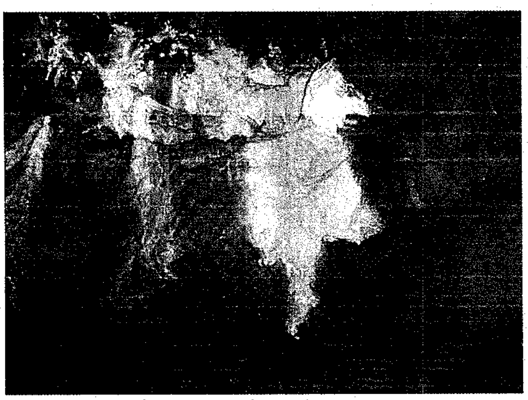
Robinsons Pot

Work carries on at this site and next year (2010) will be 35 years since I started work here. 1862 Cavern has at some time been completely flooded and this may give some indication to the ice in Cowside Beck and also how parts of the cave were formed and the way that the sand stalagmites formed. Georges Hole which I am sure is connected to this system has large deposits of silt very similar to Mc Colls rift in Robinsons Pot. The logger in the Worm series was removed in October 2009 and now I have to compare the results with the temperature and rainfall recorded at Malham Tarn.

Copper deposits

Visits were made to Wizards Chasm and Pikedaw to try and work how the faulting occurs between Lancliffe Tops and Pikedaw, a great deal of work is still needed in this area but both these sites show evidence of faulting and in Wizards the formations stand out as very white due to the presence of large amounts of mud.

Photos show evidence of copper veins in the surrounding rock.



Wizards Chasm (photo D Hodgeson)

Pikedaw II showing green and blue copper deposits.
(Photo Anthony Brown)

The cave spider (*Meta menardi*).
I have been re-checking several sites for this spider in the Dales and am finding that the spider has been lost at some caves and in others the numbers are diminishing. As lots of cave spider sites are in shallow caves I am wondering if the increase in short periods of heavy rain cause the caves to become wetter so damaging the egg sacs or if the condition of the floor litter in and around the entrance causing a decrease in the spiders food supply. Some, like Chapel cave that has been excavated, are now more or less biologically speaking dead as far as supporting a colony of spiders is concerned.

Thoragill Cave
The sump in this cave was dived in June 2008 and the following observations were made of geological interest; the entire cave is developed within abroad fault zone, the left wall is composed of fault breccia cemented together by hydrothermal calcite. This fault which must run (very roughly) north west-southeast is difficult to trace at the surface outcrop. More work to be done on water tracing and also to photograph the fault and the formations at the far side of the sump.

Cowside Beck
We are still looking for a way into what must be a potentially interesting cave system with links to Cherry Tree Hole. Diving continues.

Malham Cove
Diving still continues at this site with roughly a mile of passage beneath the cove. Underwater speleothems have been dated at 29000 BP compared to some at Keld Head, Kingsdale at 90000 BP so gradually a picture is being built up of land levels and drainage channels in the Dales. Diving continues.

Doukabottom Cave
Work has carried on sifting through documents of the early excavations as some of the reports do not tie in with our knowledge of the Dales in prehistoric times. More work is needed to try to establish the whereabouts of some of the bones to try to give us more information about these periods.
Surveying work carries on at this site and others in Lower Littondale to try to give us more understanding of how the caves have altered through the last glaciations.

Grike Erratics in the Limestone Pavements of the Silverdale AONB

Peter Standing

This study was inspired by a blank over Silverdale on the Britice map of evidence for glaciation in Britain (Clarke et al., 2004) and by Rose and Vincent's (1986) paper on pre and post Devensian grike populations at Underlaid and Longtail Woods. Research was conducted during an undergraduate geography dissertation at Lancaster University submitted in March 2010.

Late Devensian ice flow modelling by Hubbard et al. (2009) and dating of loess deposits in a doline at Warton Crag, suggest that ice left Silverdale no later than 17kaBP and possibly as early as 19kaBP (Telfer et al. 2009). The area's highest point today is 163m and low elevation would have meant that periglacial conditions prevailed during the Younger Dryas (12.8ka-11.5kaBP) rather than the further glaciation which affected the higher parts of the Lake District.

Geologically Silverdale is mainly composed of Lower Carboniferous limestones and pavements are formed in the Urswick formation (339-336Ma BP) which is represented in the Yorkshire's Dales by the Gordale Limestone formation. Urswick limestone has beds from 0.5 to 5m and is extensively jointed.
Although there are scattered surface examples in Silverdale of Borrowdale Volcanics and Shap Granite, most surface erratics are Silurian sandstone greywackes which are often incorporated into local walls. On limestone pavements, cobbles and small boulders have become lodged in grikes. 536 examples were mapped at six pavements at Sandside Quarry, Longtail Wood, Hale, Underlaid Wood, Gait Barrows and Warton. 95% were Silurian rocks from the Windermere Group, confirmed on field examination and thin section to be sandstone greywackes and the remaining 5% were Borrowdale Volcanics. These acidic erratics tend to attract distinctive lichen species that make them stand out from the surrounding limestone.

The distribution of erratics varied by a factor of 46 by pavement area and 8 by grike density, across the pavements studied. Erratics tended to be deposited in dominant wide grikes systems often orientated south and roughly coinciding with late Devensian ice flow direction. The chronosequence of deposition is part of an ongoing study but it seems likely that larger grikes were open before the Devensian LGM and that erratic cobbles and small boulders entered grikes by primary glacial emplacement. There was some secondary transport from adjacent clints of fines and weathered pebbles and relicts of these can still be found at Hale Pavement.

Grike morphometry at both sites where erratics were lodged, and at random sites, did not confirm any bimodal distribution of distinct populations of pre and post Devensian grikes. Denudation rates for limestone pavements in Silverdale are not known but are likely to be have been lower than in the upland pavements of Craven. In a study of erratic pedestal erosion rates in Northern England (Goldie 2005) the lowest recording was 3mm/ka from Silverdale.

Since grikes have two walls, Goldie (2009) postulates that under favourable conditions a 30cm wide grike could develop in 15ka but using the lower Silverdale erosion rate of 3mm/ka, that figure would become 6mm/ka, 6cm in 10ka or **10.2cm over 17ka**. Since grikes are often flared at surface level, widths recorded at a depth of 15cm are more reliable morphometric guides. At this level, 92% of grike widths at erratic emplacement sites were >10.2cm, further supportive evidence that the grikes were already formed before the Devensian LGM.

The only other study in the world literature that partly addresses the emplacement of grike erratic is by Feeney (1996) who had no doubt that pre Wisconsian grikes exist in the Chaumont Barrens pavements of upper NY State. He recorded erratics aligned along and within grikes and present in depressions where remaining till was subsiding over grikes. This Silverdale research broadly supports Feeney's model.
The chronology of grike formation in the pavements of NW England still offers many challenges for future research.

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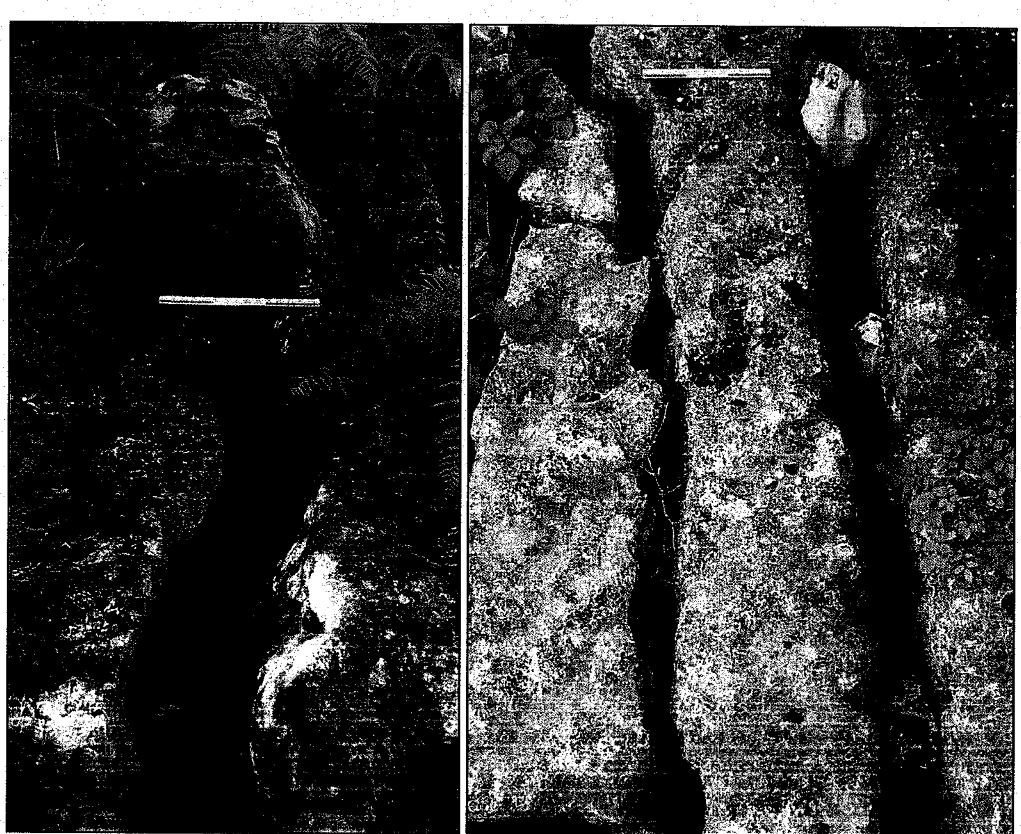

Plate 1 *- Erratics at Underlaid Wood with differing levels of grike association from resting astride a grike (left) to wedging in a grike top to lodgement between the walls of a grike (right) -scale 30cm rule.*

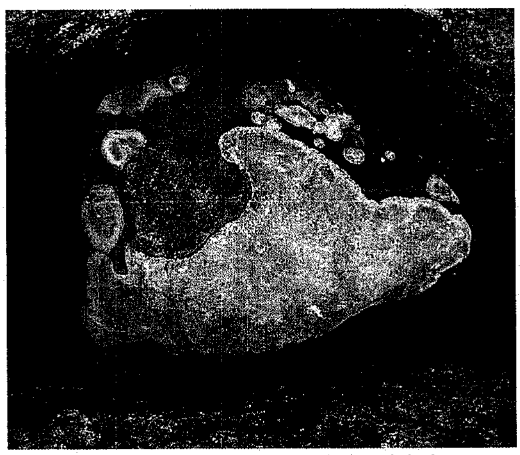

Plate 2 *– Porpidia tuberculosa, a common acidic rock lichen on a Silurian erratic.*

Plate 3 *– Underlaid Wood has a highly dissected pavement with clint areas <2m² and dominant north south grike orientation. It has the highest density of grike erratics of any Silverdale pavement.*

Large Karstic Depressions in the Yorkshire Dales

Margaret Marker

Background
The results reported are based on research by myself and Helen Goldie from 1997 onwards, starting in west Crummackdale. Results have been presented at every biannual Malham Tarn research Seminar since 2001.

Results
Limited numbers of large complex karstic polygenetic solution depressions had been reported from the 1960s, on the glaciated Dales karst but were considered to be a minor component of the landscape. At the start of our research 21 such sites on the Malham High Country and a few in Crummackdale area were recorded. The Feizor depression between Stainforth and Austwick was also mentioned. We visited that site first, It is a large example located on the Craven Fault System. (Many of the larger depressions are located on or near faults). We found other depression in that locality which had not been recorded.

Early field research had started below Sulber Nick and then been extended on the western flank of Crummackdale, a glaciated limestone pavement area between 390-410m altitude. Those results were published in Cave & Karst Science 2001. 36 depressions containing sediment were recorded within 6 km^2. All depressions (a term coined to distinguish these large solution landforms from the much smaller dolines/swallets developed since the last ice age) were established as frequent rather than scarce. The polygenetic large solution depressions were then considered few and localised.

By utilising stereoscopic air photos we extended the search and have recorded 496 depressions onto a database which covers an area of 360 grid squares between the Craven Fault System and Wensleydale. Between one quarter and one third have been field checked.

Depression significance
The large depressions are a significant landform component of the glaciated Yorkshire karst. As they are too large to have formed since the last Devensian glaciation (15ka), they have to represent a pre-glacial inheritance, possibly even Tertiary in origin. That is their significance.

The presentation was designed to emphasise the difference in size between swallet and depression (Chapel Fell site) and then the grid square map to show where depressions are located. Major large and deep depressions were illustrated: Feizor, the big depression on High Mark (depth 25m), Dowka Bottom (25m depth) and Lunch Hole (10m depth) on Clowder, structurally controlled examples from the west outlier and an angular series form an arc immediately west of Wharfedale. The contrast in terrain between the grassy Malham High Country with many deep large depression and the glaciated pavements of Crummack was emphasised. Crummack has smaller and shallower depressions probably due to glacial removal of upper beds of limestone.

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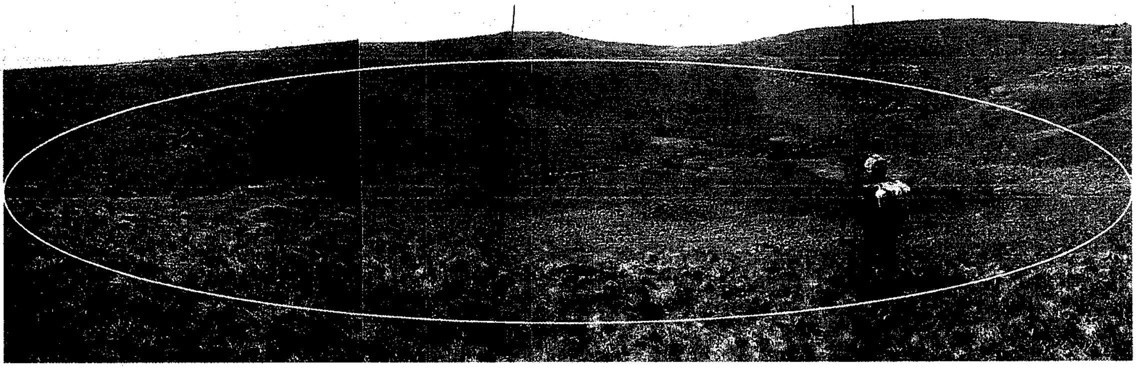
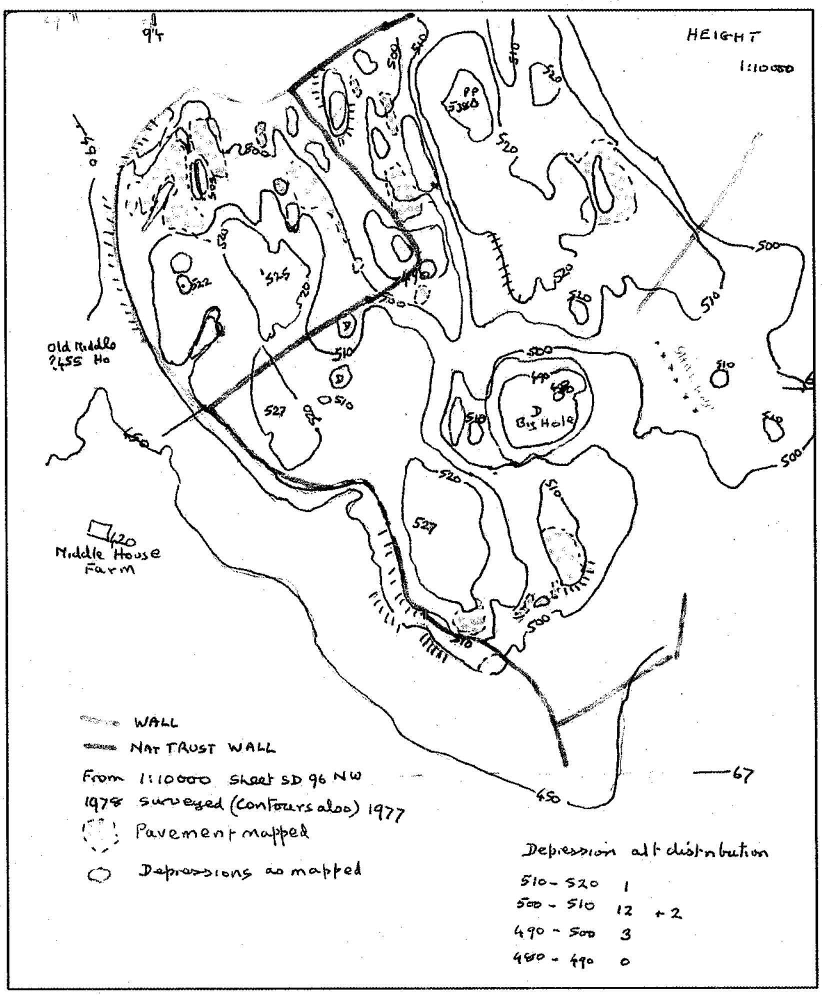


Hole on High Mark. GR 921680. Alt. c. 500 m



Map of depressions on Malham High Country.

Palaeoclimatic significance of two major recurrence surfaces in Tarn Moss, Malham

Graeme T. Swindles

Introduction

Two major recurrence surfaces are visible in the sections of Tarn Moss adjacent to Malham Tarn (Figure 1). Such stratigraphic features in ombrotrophic peatlands are interpreted as major shifts to wetter conditions in the past and are thus important for understanding long-term climate dynamics. Although there is some debate over what has driven the changes in bog surface wetness in the Holocene (Barber and Langdon, 2007; Charman, 2007), recent evidence suggests that precipitation, reinforced by temperature is the primary driver in mid-latitude Europe (Charman et al., 2004, 2009) and North America (Booth, 2010). Peat records may also prove to be particularly valuable records of past drought variability in the mid-to-high latitudes (Booth, 2010; Swindles et al., in press).

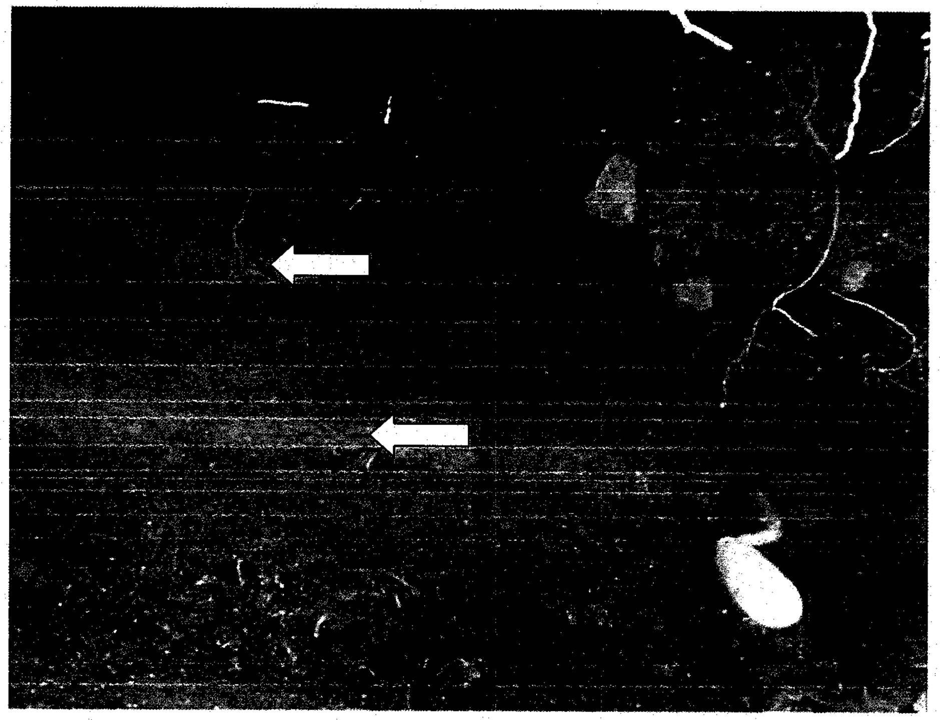


Figure 1: Photograph illustrating the two visible recurrence surfaces in the exposed peat face at Tarn Moss.

Methodology

A wide-capacity monolith sample was extracted from the face of Tarn Moss in 2008, maintaining the integrity of the samples and minimising contamination. The top of the monolith sequence does not represent a modern peat surface. The monolith was examined for visual contamination, surface cleaned where appropriate and stored in sealed aluminium foil and cling film, returned to the laboratory and stored in refrigeration at 4°C. It was carefully unwrapped and sub-sampled at contiguous 1cm intervals. Pollen, plant macrofossil, humification, testate amoebae, $\delta^{13}C$, loss-on-ignition and C:N analyses were carried out on the profile at contiguous 1cm intervals using established methods. One tephra layer was found in the profile which represents the first discovery of microscopic distal tephra in the Yorkshire Dales. It was analysed using electron microprobe analysis at the NERC facility in Edinburgh. Hand-picked *Sphagnum* remains have been submitted for AMS ^{14}C dating at ^{14}Chrono (Queen's University Belfast).

Initial Results

The lithostratigraphy of the sequence is composed of moderately-well humified *Sphagnum* and sedge peat interspersed by two major visible 'recurrence surfaces', characterised by relatively unhumified *Sphagnum* remains, and represent the wet shift events. An Icelandic tephra layer discovered in the sequence was identified as the Glen Garry tephra (2210-1966 cal. BP; Barber et al., 2008). Five AMS ^{14}C dates were submitted to the ^{14}Chrono centre (QUB) so that the earliest wet shift event can be wiggle-match dated. One date at has been returned at 2728 ± 27 (815-920 cal. BC; 2σ, INTCAL09), which dates the start of the earlier wet shift. Two major wet shifts are represented in the light transmission (humification), C:N and $\delta^{13}C$ data. These are also represented in the testate amoebae data, with the rise of the wet indicator *Amphitrema wrightianum* and associated shift in reconstructed water table, and in the plant macrofossil data with the increase in *Sphagnum* section *Cuspidata* (Figure 2). Interestingly, these two events are also replicated in the pollen data, with increases of wetland taxa such as *Sphagnum* and *Lycopodium*

Future work

All palaeoenvironmental analyses have been completed, but we are currently awaiting the results from the submitted AMS radiocarbon dates. The work will be written up for a major international peer-reviewed journal in 2010

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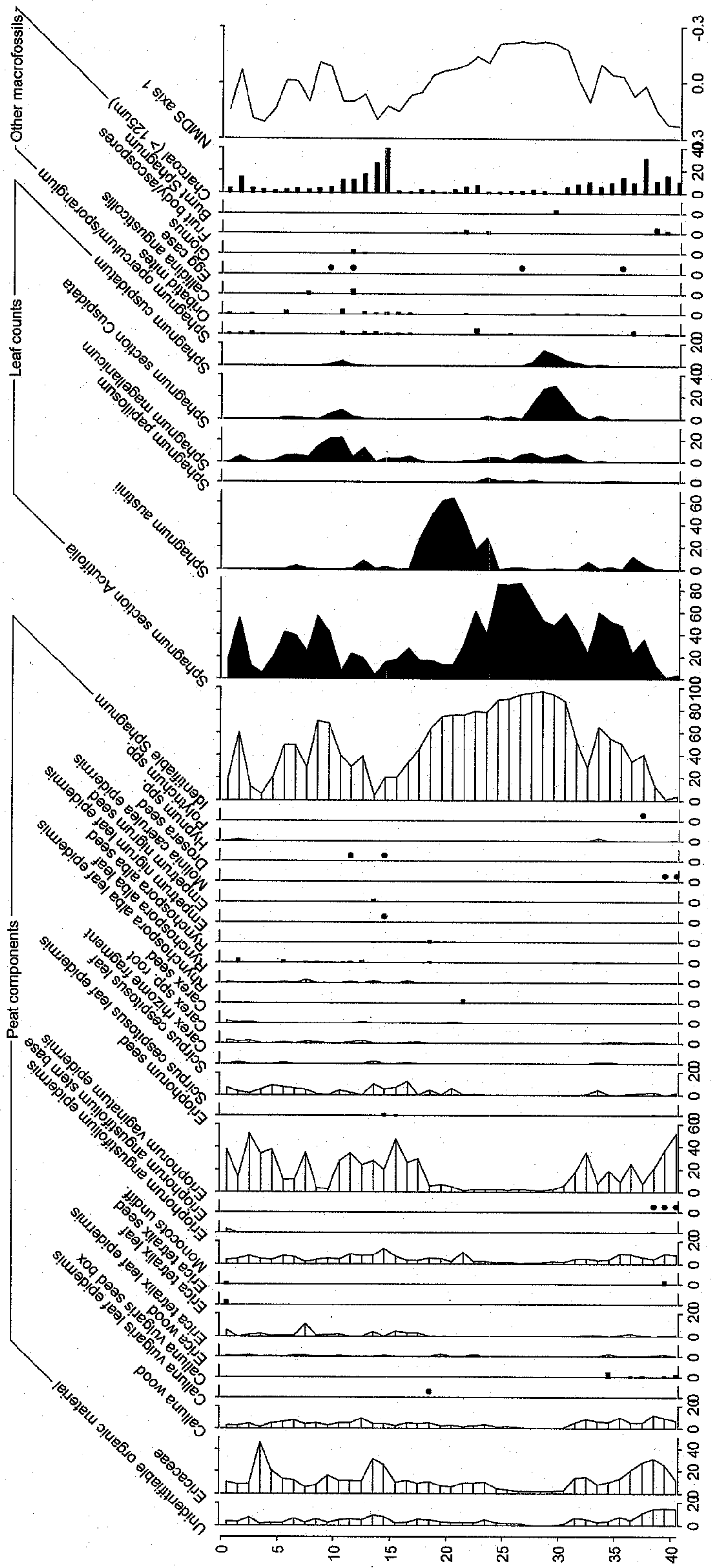

Figure 2: Percentage plant macrofossil diagram from Tarn Moss (bars indicate absolute counts). Non-metric multidimensional scaling (NMDS) has been used to present a one-dimensional summary of the data. Analyst: G Swindles.

Diatoms and Green Algae in the sediments of Malham Tarn, North Yorkshire

Allan Pentecost[1,*], Pietro Coletta[1,] and Elizabeth Y. Haworth[2]**

The investigation is part of a wider study of the recent sediments in Malham Tarn, a classic upland marl lake. In the Late Glacial, the sediments of Malham Tarn consisted of dark clays with a low carbonate content, but by the beginning of the Holocene, *Chara* marls began to form and continue to the present day (Piggott & Piggott, 1963; Nuñez et al., 2002; Pentecost, 2009). The most recent marls contain more organic matter than their predecessors and the change in sedimentation coincides approximately with the raising of the water level of the lake by about one metre over 200 years ago. Our aims in this study were threefold: to identify the main Tarn habitats for diatms and determine the species composition; to examine the fossil microalgal flora in a sediment core to seek changes over time, and to examine microalgal preservation in the sediments.

Two piston cores were taken from the Tarn, one in an area where the sediments were known through seismic measurements to exceed 5 m in thickness, and another penetrating marl and earlier sediments below the peat of Tarn Moss to the west. Standard methods were used to prepare the microalgae for identification and enumeration from 0-650 cm depths within the sediments.

An examination of the modern diatom flora occurring on submerged substrata of the Tarn demonstrated the existence of five broad habitats: inwash from streams and land; phytoplankton; epiphytes growing on larger algae or vascular waterplants; epipelic algae growing on fine sediments; epilithic algae growing on littoral rocks and stones. We found that inwash was an insignificant component of the diatom flora accumulating in the sediments but the remaining habitats all contributed to the sedimentary archive significicantly. Since many diatom species can be classified into habitat according to the species it was possible to estimate the relative contributions from these habitats in the most recent (0-5 cm depth) sediments. It was found that little apparent change had occurred in the habitat contributions over the past 8000 years, at least in broad terms. This contrasts with similar work undertaken in the Norfolk Broads where the phytoplankton diatoms have increased, while the epiphytic diatoms had fallen sharply over the past 100 years (Moss et al., 1996). This has been attributed to water enrichment leading to eutrophication and loss of water plants. The results for Malham Tarn are in line with other evidence suggesting that enrichment of the Tarn over recent years has not been sufficiently high to have had a deleterious effect on the aquatic macrophytes. However, some interesting changes were observed with individual species. For example, the planktonic diatom Asterionella formosa, appears to have increased over the past 50-100 years in its relative abundance and was not found in the deeper layers of sediment while Denticula numbers appeared to be relatively higher several thousand years ago. Of particular interest is the diatom Mastogloia smithii var. lacustris. This diatom was found throughout the lower section of the core and often in large numbers but declined in abundance over the past 100 years and no longer appears to be present. Its loss at Malham is intriguing as it still occurs in other British marl lakes of similar water quality to Malham Tarn and is being investigated further.

By counting diatom numbers in known masses of the sediment, absolute values were obtained at several levels and demonstrated a significant decline with age. Also, direct observation demonstrated frequent partical dissolution of the silica frustules of several diatom species. This is often observed in calcareous sediments, within which the amorphous silica is unstable, and it leads to problems in interpretation. Not all frustules are equally vulnerable and the weakly silicified frustules of Asterionella suggest that while it was increasingly abundant in the near-surface sediments, this may not be the result of enrichment, but dissolution. It is therefore apparent that conclusions concerning change in the diatom flora of the tarn must be viewed with caution.

In addition to the diatoms, the green alga Pediastrum boryanum was also found to be common in the core. This alga does not possess a silicified cell wall and is not found in diatom preparations, but was found in the pollen preparations. It occurred throughout the core (to ca. 8000 yr BP) but was relatively much more abundant in the recent sediments dating to 100 yr or less. This increase in abundance might be due to some increased enrichment of the Tarn water with nutrients, but again, preservation may decline with depth in these sediments so the conclusion must be considered tentative.

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The phenology of ice on Windermere

D.G. George

In the 1930s, the Freshwater Biological Association started their observations of ice on lake Windermere. They noted the date when ice first appeared in a sheltered bay and counted the number of days when some ice was present. Ice records of this kind are widely used as an indicator of the long-term change in the climate (Livingstone *et al.*, 2009). The observations on Windermere (George, 2007) represent one of the few records available for a lake that only freezes for a few days in the year. An analysis of these records shows that the main factor influencing the phenology of ice was the winter air temperature. The variations in the ice-cover were also strongly correlated with the atmospheric pressure gradient known as the North Atlantic Oscillation (NAO). When the NAO is in its positive phase, the winds tend to blow from the west and winters are mild. Figure 1 shows the year-to-year variations in the number of ice-days recorded on Windermere between 1933 and 2000. In the 1990s, when the NAO remained in its positive phase for several years in succession, very little ice was reported on the lake. Since then, the effects of global warming have led to a more sustained reduction in the ice-cover.

The decision to start an ice-monitoring programme on Malham Tarn is therefore most welcome. At this altitude, useful ice records can probably be acquired for decades to come, whatever the outcome of the climate talks in Copenhagen.

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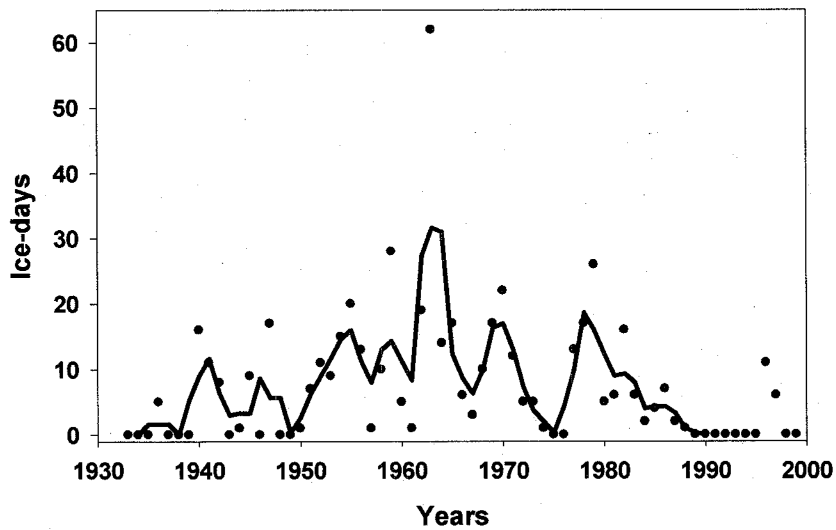

Figure 1. The year-to-year variation in the number of ice-days recorded on Windermere. The points are the observations and the line shows the three-point running mean. Note that the very cold winter of 1962/1963 was excluded from these calculations.

A Dairy on Malham Lings, 1344-62?

Mike Spence

A document in the Lancashire Records Office appears to be part of the financial records of a shepherd in Malham in the mid-fourteenth century. Details of the location are not specified in the document, which itself is a copy made in the sixteenth century, but the figures record the number of lambs produced each year from a breeding flock of up to 2000 sheep, based around 1200 ewes. Additionally they record the quantity of cheese produced from ewes' milk, and the price per pound.

The shepherd is not identified, nor is the location of the flock, beyond 'Malham', which at that time included the area of Malham Moor. Sheep were much in demand for their wool in the fourteenth century, and many flocks were kept in the area, by private owners and, predominantly, by two religious houses, Fountains Abbey and Bolton Priory. No records survive from secular sources: however, records from Fountains for the following century show they kept several flocks on Malham Moor: unfortunately, they seem to have been wether flocks, i.e. male sheep. Some Bolton Priory records cover a period only about twenty years earlier than the document in question: moreover they contain details of ewes' milk production, and specific references to Malham.

Circumstantial evidence may be provided from the labours of Dr Raistrick and his summer school volunteers at the Centre for Field Studies, who examined the Moor for some twenty five years in search of archaeology. Through these efforts Dr Raistrick was convinced he had identified a Bolton Priory sheep-house complex, located on Malham Lings. This location is within an area which is described in several medieval charters as the subject of boundary disputes, and seems to have been ceded by Fountains Abbey to Bolton Priory, and others, in the mid-twelfth century.

If this is indeed the site of the cheese production, two other factors merit consideration: firstly, from subsequent ground survey and aerial photos the enclosed area is shown to be have been much more extensive at some stage, although not necessarily contemporary with the sheep house; the implication is that it had been in use several centuries earlier, though whether it remained in continuous use or was abandoned and later reoccupied has not been determined. Secondly, within the site two low-value Northumbrian coins were discovered; these date from the tenth century.

There is an environmental enigma to this site: in essence it is a limestone pastureland, but an extensive portion - today perhaps up to one-third of several hundred acres- consists of bare limestone pavement, the characteristic clints and grikes of this area. When and how did this erosion of soil cover take place? If it resulted from overgrazing, was it from the tenth-century - or even earlier- stocking densities which seem to have been on a more intensive scale than the fourteenth-century breeding flock, or does the survival of a sixteenth-century abstract of a fourteenth-century document suggest that a new owner in the 1500s wondered how it had been possible to keep 2000 sheep on the tracts of bare limestone he then looked upon?

Eco-hydrology of the Malham Wetlands – a National Trust Report

Roger Meade & Alex Jones

A project was commissioned by the National Trust in April 2009 with financial assistance from a Biffa Award and from Natural England. The objective was to describe the structure and function of the plant communities found on the Malham wetlands in a way that is both technically sound and understandable to the non-specialist. It is based on earlier vegetation surveys by Proctor and Cooper, and on an early hypothesis of the vegetation and hydrological relationships proposed by Wheeler *et al.* (2005).

Surface levels were described using new ground-based LIDAR and used in conjunction with soil augering and geological map interpretation to underpin and build on Wheeler *et al.* (2005). New vegetation survey was also carried out to include that part of Ha Mire not surveyed by Cooper and Proctor (1998), and all Great Close Mire. A computer-based programme (MATCH) was used to classify the new quadrats into NVC communities (Rodwell *et al.*, 1991-2000), and their positions, together with aerial photograph detail, were used to help map the extent of the communities.

Topography, geology, hydrology and vegetation are incorporated into an account of the functioning of each wetland in its immediate environs and in their wider catchment context. The NVC communities are used to relate the vegetation to groundwater-dependent categories, using links with the Environment Agency's Water Framework Directive interpretations (UKTAG, 2004). Water chemistry analysis for plant macronutrients in the Tarn are used to assess the likely status of the wetlands under the Environment Agency's Review of Consents under the Habitats Directive Regulations. Professional judgements are used to comment on whether the individual mires achieve Favourable Condition, and how this might be affected by water supply mechanisms and livestock grazing pressure. The findings from this project will be used to help guide the future conservation management of the Malham wetlands by the National Trust.

The project steering group was composed of Martin Davies (National Trust), Katherine Hearn (National Trust), Stephen Morley (National Trust), Steve Rose (JBA Consulting Ltd) and Roger Meade (Roger Meade Associates).

Summary of the Eco-hydrological Conceptualisation of the 4 Wetlands

The work presents the Malham wetlands as a diverse group, each having a different balance between rain, surface water and groundwater as the main water supply source.

The solid geology in the Malham area is dominated by limestone which is highly permeable and often leads to a landscape devoid of surface water features. The four wetlands at Malham rely on the underlying low permeability drift deposits which line the main east-west valley, which isolates the base of the wetlands from the limestone; reducing the rate at which water can drain from these areas.

Tarn Moss

Tarn Moss is ostensibly a raised bog, but includes a groundwater-fed runnel across its centre, as well as around its lagg. The contour map provides a new perspective on the relative surface levels on Tarn Moss that can now be developed further and used as the basis to a programme for raising water-tables and retaining more rainwater on the bog to improve its current rather dry condition.

North Fen

The fen lies to the north of Tarn Moss and water is fed to it from a number of sources and mechanisms. Groundwater feeds the area from Tarn Moss, the limestone hills to the north (through springs) and from the glacio-fluvial deposits to the west. Tarn Beck runs through the fen providing water to the site when it overtops during flood events. There are a number of small raised mires within the fen which are rainfall feed and more isolated from influences from the wider catchment than the rest of the fen. Given the large catchment, North Fen is particularly vulnerable to high concentrations of the nutrients nitrogen and/or phosphorus that might originate from agricultural fertilisation, either as surface runoff or via the recharging of local aquifers.

Ha Mire

Ha Mire lies to the east of Malham Tarn. Its southern slopes are fed by a diffuse seepage emerging from the glacio-fluvial deposits which from the southern boundary of the wetland. The communities in the centre of the site are mainly rainfall fed and acidic in nature; however, within the small streams which criss-cross this area, the communities indicate an alkaline influence, suggesting the possibility of groundwater upwelling in this area. It is not clear whether the extensive area of ombrotrophic peat on Ha Mire is a remnant of a thicker deposit removed by peat cutting, or represents the limit of its development since the retreat of the ice cover. Limestone cliffs form the northern boundary of the wetland. Only a small number of springs emerge from these cliffs and their influence of the vegetation of Ha Mire is limited.

The juxtaposition of acidic, base-poor wetland with base-rich examples has been plotted in detail in this project for the first time.

Great Close Mire

This work provides a completely new set of data on the vegetation and water sources on Great Close Mire. It shows that the mire receives much water from both the limestone aquifer and the glacio-fluvial deposits. The long streams running across glacial till have resulted in the watercourses cutting into the deposits and limiting the influence of the base-rich water. It has led to a complex mosaic of extremely base-rich, base-moderate, and base-poor wetlands, though the last are not so extensive as on Ha Mire or on North Fen. There is some evidence from the flora around the spring heads that the limestone aquifer may contain greater than desirable concentrations of the nutrients nitrogen and/or phosphorus.

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