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In retrospect: using long-term ecology to set current management issues in context in NW Sutherland and the Peak District

Dr Althea Davies, School of Biological & Environmental Sciences, University of Stirling, Stirling, Scotland FK9 4LA, a.l.davies@stirling.ac.uk

Rationale & Context

This project assesses how long-term (LT) ecological records can inform upland management. Sustainable management of the wide range of ecosystem goods and services that society derives from natural resources depends on informed, secure baselines and objectives. We are frequently asked to look to 2020, 2050 or even 2080 to consider how these natural resources, carbon emissions or climate change should be managed, but how do we build the knowledge required to predict and manage these impacts unless we have a secure understanding of ecosystem processes and responses over at least these timescales? In practice, most ecological studies span less than a decade, which is incommensurate with the timescales over which many ecological and environmental processes occur. For instance, some habitats may be responding to and reflect past management legacies more strongly than current conditions, leading to misconceptions if management is based primarily on current appearances. Assuming that recent observations are sufficient to understand the processes and networks underpinning ecosystem function and the goods and services we derive from them therefore generates increased risk and uncertainty.

Longer-term evidence indicates that many trends of current management importance originated well beyond the duration of observational records. Whilst accepting that the past is unlikely to provide a direct analogue for the future, a growing number of papers put forward compelling arguments for incorporating LT evidence (>50 years to millennia) into conservation and management to provide information about processes and trajectories of change, appropriate baselines, thresholds and acceptable limits of change, and offer opportunities to test predictive models developed to manage future change (*e.g*. Anderson *et al*. 2006, Froyd & Willis 2008). Such evidence derives from analyses of pollen, plant macrofossil, charcoal and other proxies preserved in sediment accumulations, in addition to tree-ring and written sources. Policy documents often mention the need to include longer-term evidence, but this is seldom put into practice. The present study adopts a case study-based approach to assess the potential contributions of LT insights to upland management, explore how different stakeholders respond to LT evidence and how it might be made more accessible.

Long-term perspectives: moorland dynamics and woodland regeneration

Two contrasting upland areas were selected as the basis for this work. The Peak District lies on the southern limits of blanket peat formation, has accumulated severe erosion problems and bears a heavy pollution burden as a result of the growth of surrounding cities since the Industrial Revolution. It lies within an hours drive for 16 million people. By contrast, NW Sutherland is relatively inaccessible, contributing to a ‘wild land’ perception, and oceanic conditions have given rise to extensive blanket peat. Where climate change may result in increased wetness in Sutherland, drought risk is likely to increase in the Peak District.

Within these areas, two broad habitat types, moor and woodland, are subject to UK, European and international conservation designations and form the focus of this research which is directed towards current conservation issues. In the Peak District, these include establishing what constitutes 'favourable condition' on the limits of UK blanket peat growth. For instance, should dry heath communities on deep blanket peat be seen as indicative of normal conditions here or could they indicate a potential imbalance? There are also concerns over the loss of heather communities across the UK due to historic factors, with efforts to restore heather on grass-dominated moors in areas including the Peak District (Anderson & Yalden 1981, Marrs *et al*. 2004, Smith & Bird 2005). Intensive conservation efforts are underway in the southern Pennines to stabilise the severe and extensive peat erosion. These include blocking grips and drains inserted under previous agricultural strategies, and encouraging the growth of *Sphagnum*, which was a key peat former before atmospheric pollution from c.1850 caused major losses. There is continuing debate in both areas as to what burning regimes are appropriate and where to set baselines (Yallop *et al*. 2006), particularly where heather, the usual target for muirburn, is growing on deep blanket peats which are more sensitive to burning damage. Sustainable grazing levels are also debated in both areas. In Sutherland, much of this revolves around the balance between sufficient deer densities for stalking on some estates, whilst allowing population regeneration without enclosing all woodland fragments.

The presentation focuses on the management implications of the LT evidence, rather than the details of the vegetation and land-use dynamics. The case study work undertaken during this project is distinct from many previous palaeoecological investigations in that the sites were chosen to reflect ecological change at local spatial and temporal scales, comparable to ecological and archaeological data, and to human generations, rather than the millennial, regional scales which many published palaeoecological sequences depict. The latter are used to place the fine-resolution studies into a broader context. Note that the chronologies for the Peak District are provisional as this work is still on-going. Site names are omitted for the Peak District since the information has yet to be discussed with land owners who kindly allowed access.

Moorland dynamics: cycles and extremes

To complement the existing palaeoecological work on eroded peatlands in the Peak District, the present study focuses on rotationally-burned heather moor and degraded grassmoor. The study sites span a gradient from heather moor which is managed for grouse by burning (Grouse Moor), through a drier, mixed grass/heath (Mixed Moor) to a degraded grass moor on deep blanket peat (Grass Moor). Previous work in NW Sutherland has established the longevity of the extensive blanket peat and heath, but far less is known about local-scale responses to historical patterns of grazing and burning in a landscape which had a dense network of small farming townships until their 19th century replacement by extensive sheep farms. In addition, very little is known of the ecology or 'normal' dynamics of communities around Inchnadamph, where the mix of limestone and acid quartzite gives rise to a unique heath/grass mosaic.

What is immediately evident is the extent of moorland variability over the last c.30-1200 years. Transitions between heather and grass dominance were especially marked in the Peak District, where all three sites examined in this study swing from heather to grass dominance (Table 1). While the composition of the grass moors was similar, the heather moors were more varied, forming a gradient from grass/heather to lower diversity heather-dominated communities. There is striking similarity in the timing of changes: shifts to grass dominance occur around 1850, coinciding with the appearance of soot particles indicative of the onset of the Industrial Revolution. Intensified grazing is evident at two of the three sites during this grass moor phase, perhaps reflecting accompanying agricultural changes, including drainage and pollution (see below). This trend is repeated across the Peak District over the last c.700-100 years, indicating widespread moorland change (e.g. Hicks 1971, Lee & Tallis 1973, Tallis & Switsur 1973, Livett *et al*. 1979). Much of the grass pollen probably derives from purple moor grass (*Molinia caerulea*) which now dominates grass moors and has spread to similarly unprecedented levels on degraded blanket mires in Exmoor, northern England and Wales (Chambers *et al*. 1999, 2006, 2007). The accompanying decline in heather moorland has been recognised in other upland blanket peat catchments across the UK from the 16-20th centuries, but particularly during the 18-19th centuries; grazing practices are most strongly implicated, although no single cause can be recognised at a national level (*e.g*. Stevenson & Thompson 1995, Tipping 2000, Hendon & Charman 2004, Yeloff *et al*. 2006, Davies & Dixon 2007).

Climatic change and atmospheric pollution were also influential in the Peak District where the peat may be inherently more sensitive owing to marginal location in terms of blanket peat formation. This includes the plateaux of deep blanket peat which have developed progressively deeper and more extensive erosion gullies since sensitised by dessication during more arid climatic conditions at c.1100-1300 (Tallis 1997). This was followed by high altitude erosion damage in many UK uplands from c.1500-1850 due to increased storminess and extreme rainfall events associated with the so-called Little Ice Age (see Davies 2008 for sources). Such perturbations combined with grazing disturbance to cause the loss of *Sphagnum* (bog moss), a major peat-former, from the Grass Moor around 1500, with similar 14-16th century losses elsewhere in the southern Pennines (Tallis 1994, Coulson *et al*. 2005). These pre-date extensive *Sphagnum* losses from the 19th century due to atmospheric sulphur pollution, indicating variability in local thresholds.

By contrast, the Sutherland moors show more gradual variations in heather abundance, reflecting the continuity of a range of functioning (i.e. un-degraded) blanket mire communities across the landscape. Agriculture, especially grazing and burning regimes, drove cycles of heather/grass growth, in contrast with the extremes of heather and grass dominance witnessed in the Peaks. Even the calcareous moorland site in Inchnadamph, where there was locally unprecedented heather loss within recent decades, does not reflect a widespread trend, since the same decline is not evident further up the valley (Charman *et al*. 2001). This may be indicative of differing ecological sensitivity, and scales and intensities of land-use between these dry and oceanic extremes of UK moorland.

Agricultural intensification at Glenleraig (farm and shieling) during the late 18th century and management shifts in the 19th are attributed to population growth and changing attitudes towards productivity, followed by the era of Agricultural Improvement, the rural counterpart of industrialisation which so affected the Peak District. This includes the removal of 24 families removed from Glenleraig during the infamous Highland Clearances, leading to marked diversity loss under extensive sheep grazing. Similar loss of diversity is evident around the Cheviot with the transition to sheep ranching (Tipping 2000, Davies & Dixon 2007).

Table 1. Summary of moorland and woodland changes discussed

Peak District: Grouse Moor - heather moor with peaty flushes, traditionally managed for grouse 1. Since c.1570, varying from heather dominance (c.1570-1850) to 2. grass dominance (c.1850-1950), to 3. mixed grass/heather, with spreading heather; 4. locally severe fire during transition from heather to grass, more burning during grass phase, 5. grazed throughout
Peak District: Mixed Moor - drier grass/heather mosaic 1. c.660-1600 mixed grass/heath with some woods (in valleys), 2. tree clearance to heather dominance, resulting in declining diversity c.1600-1850, 3. grass dominance c.1850-1980 with some loss of sedges, including cotton grass; most severe local fire during peak grass cover; 4. heather & diversity levels recovering over last c.20-30 yrs; 5. grazed throughout, particularly heavy during grass phase, with reduced burning since c.1980
Peak District: Grass Moor – grass moor on deep peat 1. Heather moor with birch/oak/hazelwoods in valleys from c.800 2. woods lost with spread of heather and some grass c.1300-1820; 3. grazed heather dominant with loss of *Sphagnum* around c.1460; 4. transition to current grass moor c.1880, possibly aided by a severe local fire
NW Sutherland: Inchnadamph - calcareous/acid heath/grass mosaic 1. Heather dominated throughout last c.500 yrs, but with three cycles of heather/grass shifts; this consisted of reduced heather at c.1580-1650, 1810-1840 & c.1980-2008; 2. these reflect combined grazing & burning dynamics; diversity lowest when heather most dense; 3. third decline is the largest heather contraction in the last 500 yrs, possibly following a short, intensive stocking phase
NW Sutherland: Loch Veyatie – SSSI Atlantic acid birchwood edge 1. Mix of birch & heather dominated blanket peat throughout last 500 yrs, 2. 2-3 small & short-lived birch fluctuations out from woodland edge at c.1640-1730, c.1890-1910 & perhaps since c.1980; 3. both grazing & fire disturbance may have assisted birch establishment
NW Sutherland: Glenleraig township - acid grass/birchwood/mire mosaic, cleared farming township 1. Grassy pastures & barley fields established before *c*.50 BC; 2. trees lost through agricultural expansions at c.1580-1640 & c.1790-1830, creating species-rich pastures; 3. poorer drainage from *c*.1810-1870; 4. marked changes at c.1830: burning, arable, tree cover & diversity fell, as grazing continued; 5. birch spread from c.1900
NW Sutherland: Glenleraig shieling - dry grass/heath 1. Dominated by open birch/alder/hazel woods until c.1340 expansion of pastures & establishment of cultivation; 2. spread of heather, managed by burning from c.1500, peaking at c.1660-1690, as trees became scarce & farming expanded; 3. burning increased after c.1770, peaking at c.1810-1840, but now favoured grasses; heather declined until recent decades; 4. local spread of birch from c.1900
NW Sutherland: Loch a'Mhuilinn - SSSI Atlantic birch/oakwood, peat mosaic, by former farm, which ceased in 1970s when wood was enclosed 1. Grazed grass & blanket peat replacing birch cover at c.1580; 2. reversed at c.1780 by reduced grazing & increased birch; 3. tree cover most extensive over last c.500 yrs since c.1890; 4. oak pollen scarce throughout, reflecting rarity &/or poor flowering; 5. below mean diversity since c.1790 reflecting reduced disturbance; 6. oak tree-ring counts of 150-220 years & estimates that some oaks may be 230->300 years old (Clifford & Clifford 2008) suggest current oaks became established as grazing declined

Rotational burning is considered characteristic of many UK heath and moorlands (Thompson *et al*. 1995). However, equating tradition with constancy may lead to misplaced confidence in burning as a tool primarily for management of heather growth. Burning levels were highest during the grass moor phases at two of the three Peak District sites. This suggests that increased burning on some Peak District moors since the 1970s (Yallop *et al*. 2006) may not be the norm throughout the region. The occurrence of local fires during periods of extreme change in the Peak District suggests that moors are more susceptible to fire damage during periods of instability. Muirburn objectives at the Sutherland shieling site also seem to have shifted through time, with burning favouring heather during the 16-17th centuries, but promoting grass growth during the 19th, perhaps in line with estate policy to replace heather moor with grass pastures which were perceived as more productive.

Despite attaining extremes unprecedented over the last c.40-1300 years, two of the Peak District study sites have regained varied moorland communities, with heather cover displacing some grass since c.1970 on the Mixed Moor and since c.1950 on the Grouse Moor. Some moors were thus able to recover from extremes, so the occurrence of unprecedented extremes does not necessarily indicate that moors have crossed an irreversible threshold. This apparent recovery contrasts with the negative ecological impacts inferred and observed from grazing intensification through the 20th century (Anderson & Yalden 1981). Based on a longer-term perspective, 20th century intensification post-dates the most radical ecological changes, although the data do suggest high grazing pressures during the last century: spore frequencies from fungi which live on dung are higher and many usual grazing indicators disappear (potentially grazed out or prevented from flowering), particularly around the Mixed and Grass Moor sites. The 20th century pollen data from the Grouse and Mixed Moors may thus reflect increased vegetation turn-over, proposed by Dallimer *et al*. (2009), rather than a simple trajectory towards more degraded moorland vegetation (*e.g*. typified by heather loss). By contrast, it is likely that the Grass Moor, in common with the other eroded moors, had already crossed a critical threshold and become relatively insensitive in ecological terms. Local moorland management histories are needed to investigate this further and discussions will be held with land managers and ecologists once data analyses are complete.

Woodland regeneration: protection versus disturbance

Woodlands are a scarce and valued resource in northern Scotland, where the bryophyte-rich Atlantic oak and birchwoods have been called ‘temperate rainforest’. Under the European Habitats Directive, the main conservation objectives for Atlantic woods are to increase connectivity and create woodland networks to allow movement of genes and associated wildlife, and thus improve habitat viability (Hall & Stone 2005). At present, many of these woods show poor regeneration and there is uncertainty over what levels of intervention are appropriate to ensure their viability; grazing exclusion remains common, despite both research (Palmer *et al*. 2004) and observational evidence (by local conservation staff and land owners) that this is ineffectual. This reflects tension between the perceived naturalness of the woods, based on 20th C experience, the long-held assumption that historical woodland loss was caused by mismanagement, and growing recognition of past management legacies, based on coppice and pollard forms.

A further issue for management lies in the fact that the ecology and dynamics of these woods are only known from data which span far less than a single generation of trees. This poses difficulties for making decisions about how to manage any long-lived organisms. Most existing palaeoecological data, which document the widespread loss of tree cover some 4200-3800 years ago, are simply too broad-brush to link long-term patterns with the status of current woodland fragments. New data from four sites adjacent to current woods with differing environmental settings and ages provides insights into the history of these pockets of tree cover, particularly management impacts.

On a regional scale, many of the current woodlands are survivors of major woodland contraction 4000 years ago. Comparison of an estate survey of 1774 with current woodland distribution suggests that existing many woods have not contracted significantly over the last c.200 years (Noble 1997). However, this snapshot comparison conceals longer-term and spatial variability as localised woods also survived until the last 1500 years, within further losses over the last c.200-700 years in treeless and partially wooded areas (Charman *et al*. 2001, Froyd 2001, Bunting & Tipping 2004). This includes the contraction of two of the four populations in this study over the last c.500 years. Three of the sites adjacent to surviving woods were able to expand within the last c.100-250 years. All of these changes appear to have been driven by changing agricultural pressures, especially grazing levels.

Birch appears to have been most able to respond to changes in disturbance and grazing pressures, especially on mineral soils, colonising both better-drained knolls (Loch a'Mhuillin, c.1780-1890) and old fields (Glenleraig, c.1900) in the wake of reduced grazing pressures. The colonisation of abandoned fields is the most obvious change in woodland from a resident and managers perspective. Alder populations have contracted over the last 400-2000 years owing to increased agricultural use of relatively fertile alluvial soils. It was previously able to compete successfully with birch, far more so than current limited distribution patterns would suggest, but has evidently been less able to recover than birch. This suggests that efforts to increase alder growth may be justified but will require intervention. At a landscape scale, hazel was a common component of these woodlands, but its distribution may always have been patchy. Hydrological conditions probably allowed birch and alder to compete more effectively on alluvial soils as well as on rocky outcrops where it is currently most common. Although frequently grouped with Atlantic oakwoods, oak populations were most abundant over 6000 years ago, and oak pollen frequencies have been low since then. This is the case even adjacent to birch-oak knoll woods at Loch a'Mhuilinn, suggesting that oak does not flower abundantly; this tallies with observations by the land owner over the last 50 years. Oak therefore has not and is unlikely to set abundant seed unless climate change brings warmer winters (with fewer frosts) or summer drought to help increase its competitive ability (Crawford 2001, Ray 2008).

Soil conditions and disturbance are prime drivers of these patterns of woodland growth and regeneration. The scattered pockets of mineral soil in a landscape dominated by peat provide the best locations for both farming and trees, which is why the most marked changes in woodland extent over the last 500 years occur on better-drained soils. Significantly, there is little evidence that woods are able to expand from current stances in more peaty areas: the eastern edge of the birchwood by Loch

Veyatie shows just 2-3 short-lived phases of expansion. Manipulation of soil fertility and drainage may thus be necessary to kick-start woodland growth on these less favoured, more acidic and peaty soils, since birch can improve and maintain soil fertility (Miles 1985).

Although browsing damage is detrimental to regeneration, grazing and fire disturbance contributed to seedling establishment in the past. At Loch Veyatie, birch expansion occurred during a phase of increased grazing disturbance around c.1640, and again as burning increased around 1890-1910, possibly aided by a fall in the local water-table around 1840. Disturbance and enrichment (by dung or ash) may have created openings in the heather and grass sward suitable for birch seedling establishment. Birch regeneration at Glenleraig (farm and shieling) and at Loch a'Mhuilinn may have occurred following release from grazing pressure. This is supported by a comparison of tree-ring counts from Loch a'Mhuilinn (Clifford & Clifford 2008) with the pollen record, as many of the mature trees became established following a reduction in grazing, thus possibly benefitting from ground disturbance and enrichment. The value of disturbance is evident to managers through observations of enclosed woods, which show a pulse of regeneration following grazing exclusion, before the ground cover has become too dense (*e.g.* Amphlett 2003).

While grazing exclusion remains a common management response, the shift away from purely commercial forestry objectives has brought growing recognition that many of these woods were managed in the past. This can be inferred from the relation between land-use and regeneration presented above and is evident in the documentary records for many woods outside Sutherland (Smout *et al*. 2005). The most direct (but undated) evidence derives from the trees themselves: pollard birch, alder, hazel and oak can be found in many of the woods, suggesting that they were managed to coexist with grazing. Management is thus not incompatible with regeneration objectives and may in fact be essential to ensure woodland viability (Palmer *et al*. 2004, Sansum 2005).

Conclusions

Evidence that moorland or woodland ecology varied in response to management regimes is unlikely to be a revelation to either ecologists or historians. However, representative baselines and the limits of habitat variability cannot be adequately inferred or predicted from ecological surveys or from historical records. To return to some of the current conservation issues mentioned initially, a LT ecological and management perspective indicates that the windows and snapshots into ecosystem function and dynamics provided by ecological datasets often conceal more than they show:

- Even moors in more 'favourable condition' show extremes of change which lie outside the historical limits of moorland variability: the dominance of heather and then grass seen during the period c.1600-1970 is unprecedented in the longer-term history of moors in northern England, the Pennines, Exmoor and Wales. This suggests that moors which appear 'healthy' do show resilience but are still in a recovery phase, and remain close to potentially critical thresholds.
- Although management has not been the norm over recent human generations, grazing exclusion is unlikely to encourage woodland desired levels of regeneration as shifting disturbance regimes created suitable seedbed conditions and have regulated regeneration over the last c.500 years at least, such that current

generations of trees originated from managed woods, often following release from grazing pressure.

This indicates a real need to move away from anthropocentric approaches and consider the timescales on which ecosystem processes operate in order to shape ‘good practice’.

Target-led conservation and vegetation classification systems are often criticised for failing to take account of ecological dynamics, and conservationists recognise some of the uncertainties which make it difficult to define ‘best practice’ (Holden *et al*. 2007). Reliance on type examples of ‘good’ condition may contribute to the homogenisation of ecological variability, compounding the loss of heterogeneity which is evident over millennial and centennial as well as recent decadal timescales in many habitats (e.g. Davies *et al*. 2006, Berglund *et al*. 2008, Britton *et al*. 2009, Keith *et al*. 2009). By revealing the extent to which different time perspectives give rise to different ‘norms’ and baselines, LT data can broaden management vision the range of potential restoration targets, where rigid adherence to contemporary vegetation classifications for setting management targets may exclude potentially relevant assemblages that contribute to habitat resilience (Chambers *et al*. 1999, Wilkinson 2001).

Despite originally developing from the disciplines of ecology and geography, there are few established forums for regular interaction between palaeoecologists and ecologists or practitioners. Opportunities for incorporating new forms of knowledge into established decision-making frameworks are also limited. There is thus a need for both theoretical-level and practical, applied work to increase the accessibility, relevance and availability of LT ecological evidence as a tool in ecosystem management.

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