Calaminarian Grassland

Report for the North Pennines AONB Partnership

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1. Introduction

The term calaminarian is used for a range of plant communities, from the sparse vegetation of highly contaminated mine spoil to closed grass swards on less contaminated ground. In Britain it has a highly localised distribution in the North Pennines, Mendips, Derbyshire, the Yorkshire Dales and Cornwall. It is found on well-drained and often calcareous skeletal soils that are nutrient-poor with high levels of lead, zinc or copper and slow rates of soil development. Many calaminarian grasslands are anthropogenic in origin, being associated with heavy metal mining and particularly the disposal of contaminated mine waste.

The most easily recognised form is a short, open turf with exposed stones and areas of bare ground. There are scattered individuals of sheep's fescue, spring sandwort, alpine penny-cress and thrift, and patches of common bent, thyme and *Cladonia* and *Peltigera* lichens. The stones may be covered by a mosaic of crustose lichens, and there is often a soil crust of cyanobacteria and small, seasonal lichens. Stands of calaminarian grassland are often small and sharply delimited, with no transitional zone to adjacent communities. The common feature to all the forms of calaminarian grassland is the presence of metallophytes, in the North Pennines particularly spring sandwort, alpine penny-cress, thrift and mountain pansy. These have different ecological niches and don't necessarily occur together.

Calaminarian grassland is an important habitat in the North Pennines, on lead mine spoil and on the river shingles of the South Tyne and Allens. It is now a BAP habitat, and recent research has shown that the North Pennine plant communities are unique and unusually species-rich. They include a number of nationally scarce plants and lichens, and at least two lichens that are nationally rare.

Since the 1970s at least 60% of the calaminarian grassland in the North Pennines has been lost, and many of the remaining sites have lost some or all their conservation interest. This applies particularly to those below 215m altitude (roughly the altitude of the rivers at Alston and Allendale). Possible contributory factors have been identified as leaching of heavy metals away from the rhizosphere, scrub invasion in the absence of heavy rabbit grazing after the 1955 myxomatosis outbreak, reduced livestock grazing, a reduced frequency and intensity of flooding, and fragmentation and isolation (Simkin, 2007a).

Their flora and ecology has been investigated in some detail over the last 20 years, but although the results have been written up in a series of reports (Simkin 1999a, 1999b, 1999c, 2003a, 2003b, 2007b, 2007c, 2010, 2012, and in a PhD thesis (Simkin, 2007a), and presented in talks to academic and amateur groups, they are not yet available in any more publicly accessible form. This report is a summary of the current state of knowledge of the North Pennine calaminarian grasslands.

This report includes:

- a description of the habitat and characteristic species
- photoguide to the metallophytes and indicator species
- the conservation status of calaminarian grasslands in the North Pennines
- threats to the calaminarian habitat
- the potential impacts of remediation on spoil heaps and levels of soluble metals in the rivers
- conservation efforts undertaken to date.
- the most important sites

2. Calaminarian grassland in the North Pennines

2.1 Origin of sites

In the North Pennines calaminarian grassland is found in three situations:
- Over natural outcrops of lead or zinc-rich mineral veins
- On lead, zinc and cadmium-rich mine and smelter waste in the historic mining areas of Alston Moor and Allendale.
- On alluvial gravels containing fine material contaminated by lead, zinc and cadmium-rich waste from the mines upstream. These occur along the length of the South Tyne, Nent, Allens and Tyne.

Mining activity in this area was intensive for several centuries and it is doubtful whether any significant veins close to the surface remain unworked, so the first category may no longer exist. There are still large areas of mine spoil in the Pennine uplands. Much of this is uncontaminated country rock, supporting acid grassland, but each mine also left smaller heaps of contaminated material. These are gradually being overwhelmed by acid grassland as the heavy metals are leached away from the surface layers, but significant areas of calaminarian grassland remain. The most extensive are in the Nenthead and Flinty Fell areas, where the contamination includes high concentrations of lead, zinc and cadmium, with traces of silver, arsenic, strontium, thallium and other metals.

The river gravels (or river shingles) are the result of a particular combination of circumstances, unique to the North Pennines. The rivers that drain the mining areas to the north are steep, with gravel beds and prone to flooding. At present they are confined to narrow channels and are incising into the river bed, but at times in the past they have been more dynamic with braided channels that migrate across the valley floor (Passmore & Macklin, 2000, 2001). The poor climate of the 18th century, combined with the loss of riverbank vegetation poisoned by toxic waste from the mines upstream, initiated one of the these periods of instability. This process was described by the Rivers Pollution Commission in 1874:

> "All these streams are turbid, whitened by the waste of the lead mines in their course; and flood waters in the case of all of them bring down poisonous "slimes" which, spreading over the adjoining flats, either befoul or destroy the grass, and thus injure cattle and horses grazing on the dirtied herbage, or, by killing the plants whose roots have held the land together, render the shores more liable to abrasion and destruction on the next occasion of high water. It is owing to the latter cause as well as to the immense quantity of broken rock which every mine sends forth that the small rivers … present such surprising widths of bare and stony bed."

Massive gravel bars were deposited during the frequent floods. These gradually accumulated contaminated fines in the gaps between boulders, and were reworked by subsequent floods until the river channel moved away and they began to stabilise and vegetate.

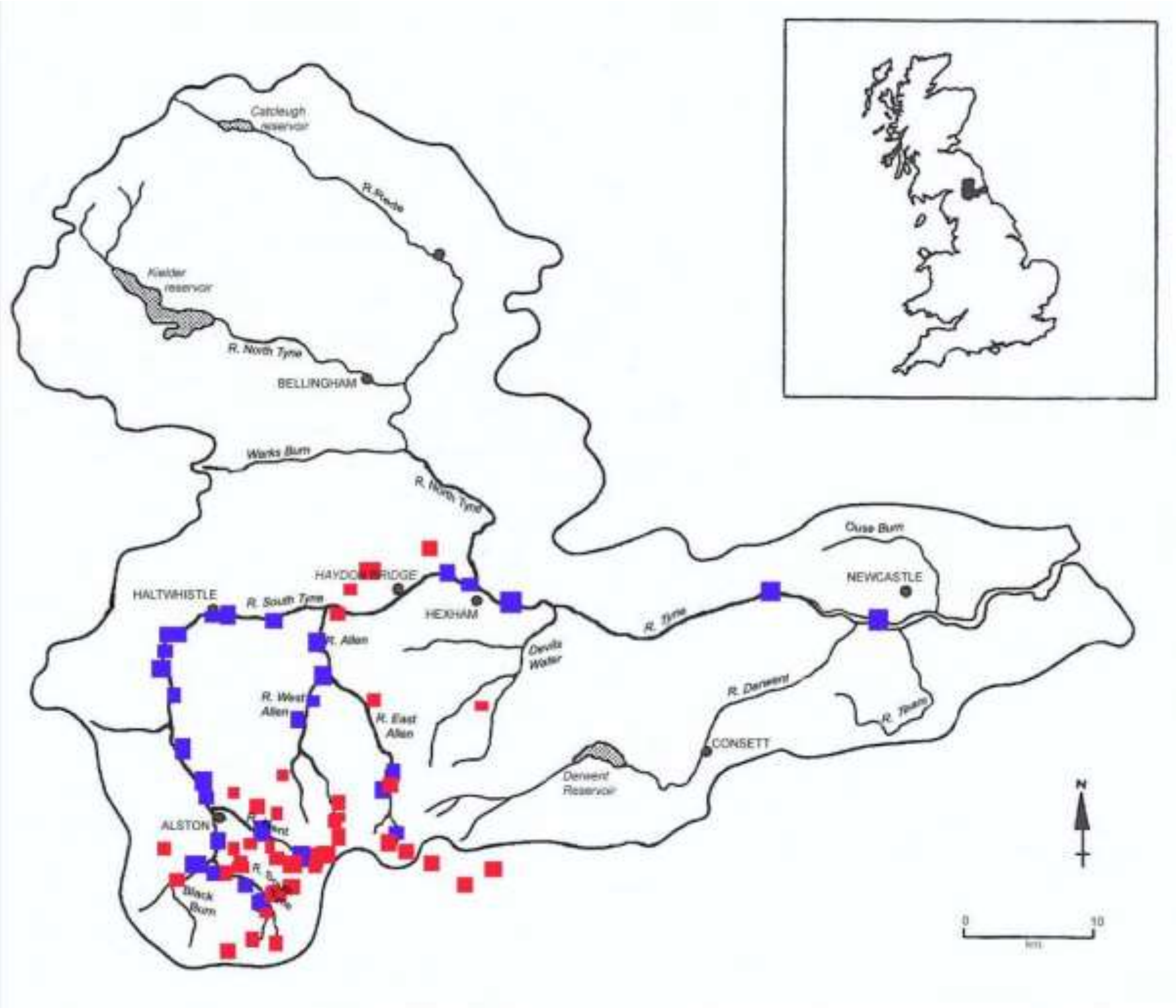
This continued until the early 20th century, when climate change, moorland drainage, and the closure of the mines led to changes in river behaviour. Now the rivers are cutting down into their beds and the surfaces of these gravel bars are above all but the highest floods. These occur every 5-10 years, but now they rise and fall quickly and have less erosive effect than the great floods of the 18-19th centuries. Instead they leave a deposit of fine, and relatively uncontaminated sediment over the gravel and this is changing the habitat and reducing the area of contaminated ground.

The distribution of mine spoil and river gravel sites is shown in Figure 1. All the sites studied by the author are marked on the map but there may be others, especially mine sites in Allendale and south of the Tyne watershed.

2.2 Description

The plant communities of mine spoil and river gravels are similar, but the river gravels are less exposed to the elements and subject to occasional flooding so they tend to be more species-rich and at a later stage of succession. The commonest form is a short turf with some exposed stone and bare ground and a high proportion of metal and drought tolerant species, including terricolous lichens and mosses. The metallophytes spring sandwort, alpine penny-cress and thrift are important, but metal-tolerant ecotypes of harebell, ribwort plantain, field woodrush and fairy flax are also characteristic. These areas of sparse or closely grazed grassland are often surrounded by taller closed grassland with alpine penny-cress, mountain pansy, knapweed and ragwort.

Figure 1. Extent of mine spoil and river gravels in the Tyne catchment. The inset map shows the location within the British Isles. Key: red– mines and smeltmills; blue – river gravels.



In the uplands there are occasional areas of damp soil with pyrenean scurvy-grass. At lower altitudes the calaminarian grassland grades into open birch woodland or patches of gorse scrub, often with mountain pansy and dune helleborine growing amongst grass in the transitional zone. Disturbed ground sometimes supports the semi-prostrate campion that is variously considered to be sea campion *Silene uniflora* or a metal-tolerant ecotype of *S. vulgaris*.

Table 1. Typical species of calaminarian grassland in the North Pennines. Metallophytes are marked *

Grasses

Aira praecox	Early hair-grass
Agrostis capillaris	Common bent
Anthoxanthum odoratum	Sweet vernal-grass
Festuca ovina	Sheep's fescue

Forbs

Achillea millefolium	Yarrow
* *Armeria maritima*	Thrift
Campanula rotundifolia	Harebell
Cerastium fontanum	Common mouse-ear
* *Cochlearia pyrenaica*	Pyrenean scurvy-grass
* *Epipactis dunensis*	Dune helleborine
Euphrasia nemorosa	Eyebright
Galium saxatile	Heath bedstraw
Leontodon hispidus	Rough hawkbit
Linum catharticum	Fairy flax
Lotus corniculatus	Bird's-foot trefoil
* *Minuartia verna*	Spring sandwort
* *Noccaea caerulescens*	Alpine penny-cress
Pilosella officinalis	Mouse-eared hawkweed
Plantago lanceolata	Ribwort plantain
Polygala serpyllifolia	Milkwort
Potentilla erecta	Tormentil
Rumex acetosa	Sorrel
Silene uniflora/vulgaris	Campion
Thymus polytrichus	Thyme
Trifolium repens	White clover
* *Viola lutea*	Mountain pansy

Ferns

* *Botrychium lunaria*	Moonwort

Mosses

* *Bryum pallens*
Climacium dendroides
Hylocomium splendens
Polytrichum juniperinum
Racomitrium ericoides
Rhytidiadelphus squarrosus
Weissia controversa

Lichens

Cetraria aculeata
Cladonia chlorophaea
Cladonia chlorophaea
Cladonia furcata
Cladonia pyxidata
Cladonia rangiformis
Micarea lignaria
Peltigera hymenina
Peltigera leucophlebia
Peltigera membranacea
* *Peltigera neckeri*
* *Peltigera venosa*
* *Sarcosagium campestre*
* *Vezdaea aestivalis*
* *Vezdaea leprosula*

Photographs of some of these, including all the metallophytes, are included in Appendix B.

2.3 Metallophytes

The term metallophyte can be applied to any plant which shows an association with, or is restricted to, metalliferous soils. Metallophytes are of conservation importance because of their rarity and the threat of habitat loss. Three categories are generally recognised:

- Obligate or absolute metallophytes - restricted to metal-rich environments throughout their distribution.
- Facultative or local metallophytes - found only on metalliferous soils in that area, but on non-metalliferous soils elsewhere.
- Pseudo-metallophytes - generally widespread but with distinct ecotypes on metalliferous soils.

Only one plant found in the North Pennines, alpine penny-cress, is considered to be an obligate metallophyte. Spring sandwort, thrift, mountain pansy and the dune helleborine are all facultative metallophytes. Most of the other calaminarian grassland plants fall into the last category, of metal-tolerant ecotypes.

Metalliferous soils have a low water-holding capacity and low concentrations of the essential nutrients N, P and K, so metallophytes also have to be tolerant of these factors. Many species that lack this tolerance germinate in disturbed ground but fail to become established.

Metallophytes have an important role in succession on metalliferous soils. Their root systems stabilise the soil, and their aerial parts protect the seedlings of other species from the extremes of frost and drought. They contribute organic matter and humus to the surface layers of the substrate, which eventually improves soil texture, raises nutrient levels, and reduces the bioavailability of potentially toxic metals.

Alpine pennycress (*Noccaea caerulescens*)
Alpine pennycress is Nationally Scarce. It hyper-accumulates zinc and cadmium, to concentrations of 4% zinc and 0.01% cadmium in the shoot, and is particularly associated with sites such as Nenthead that have very high levels of these metals. Other metals, including lead and copper, are immobilised in the roots.

Spring sandwort (*Minuartia verna*)
Spring sandwort is Nationally Scarce, with a RDB status of Near-Threatened. It is tolerant of disturbance, but although it has a tap root it is intolerant of severe drought and so does best damp ground or where the roots are shaded by rocks. It is a zinc hyper-accumulator and tolerant of extremely high levels of lead, zinc and cadmium, but is a poor competitor and is soon lost as the grass sward closes. It is known in some areas as leadwort, from its value to early miners as an indicator of the presence of a vein of galena.

Thrift (*Armeria maritima var. maritima*)
The thrift found here is considered to be an ecotype of the same variety that occurs on the coast. It is very tolerant of grazing and seems to have done well when stocking levels and rabbit numbers were both high, prior to 1955. It has two mechanisms of metal tolerance. Lead is immobilised in the roots but this only gives tolerance of moderate levels and thrift is not found on the most contaminated sites. Zinc and cadmium are accumulated in moribund leaves which are then shed.

Mountain pansy (*Viola lutea*)
This plant also occurs on limestone in the uplands, but the yellow form that is common in that habitat is infrequent in calaminarian grassland and becoming very scarce on the river gravels. There a dark purple form dominates, and the large flowers and intermediate characters suggest that it may be a hybrid between the mountain pansy (*Viola lutea*) and heartsease (*Viola tricolor*). These do not normally occur together and their flowering periods do not coincide, but both may have happened after the disturbance of river floods. Comparison of modern and historical specimens shows that flower size is reducing and the frequency of the purple form increasing, perhaps the result of back-crossing or of natural selection in favour of a different pollinating insect.

Dune helleborine (*Epipactis dunensis*)
The dune helleborine is endemic to Britain, Nationally Scarce and a RDB species. It is known from 32 sites, of which 21 are on the South Tyne or Tyne, and appears to be a recent hybrid. The earliest confirmed record is from Williamston in 1973 but earlier records from Featherstone in 1897 and Haltwhistle in 1924 could relate to the same species. The Tyne population may be derived from similar plants in southern Scotland and Lancashire but some authorities consider the local form sufficiently distinct to have arisen independently, and have proposed that it be separated as the Tyne Helleborine (*Epipactis tynensis*).

Pyrenean scurvy-grass (*Cochlearia pyrenaica*)
This species is only found on wet ground associated with mine spoil or river gravels, and is Nationally Scarce.

2.4 Metal-tolerant lichens and bryophytes

The classification of terricolous lichens (growing on soil) and bryophytes as metallophytes is difficult. They are not dependent on nutrient uptake from the substrate and only have contact with the surface of the soil where metal levels are lowest, but exposure to metalliferous dust can be significant, especially on open sites.

Bryophytes considered to be facultative metallophytes include *Bryum pallens*, a small moss with a distinctive red colour that is an early coloniser of disturbed contaminated ground. *Weissia* *controversa* var. *densifolia* (Nationally Scarce) is also thought to be associated with lead spoil, but it has not been reliably recorded in the North Pennines for some time.

Terricolous lichens strongly associated with heavy metal sites in this area include *Peltigera venosa* (Nationally Scarce, Vulnerable), *Baeomyces placophyllus* (Northumberland RDB), and the lichenicolous species *Epilichen scabrosus* (Nationally Scarce) and *Taeniolella rolfii* (Nationally Rare). The North Pennine populations of *E. scabrosus, T. rolfii* and *P. venosa* are nationally important. Other species of conservation concern include *Gyalidea subscutellaris* (Nationally Rare and Near-Threatened), *Gyalidea lecideopsis* (Nationally Rare), and *Bacidia viridescens, Cladonia cariosa, Peltigera leucophlebia, Peltigera neckeri, Sarcosagium campestre, Vezdaea leprosa* and *Vezdaea retigera* (all Nationally Scarce).

Saxicolous lichens (growing on stone) are defined as metallophytes if they are only found on metal-rich rock. Such stones are rare in the North Pennines, but walls contaminated by mine dust are more common. Species recorded include *Lecanora epanora, Lecanora handellii* (Near-Threatened) *Stereocaulon condensatum, Stereocaulon delisei* (Near-Threatened) and *Stereocaulon vesuvianum* var. *nodulosum* (all Nationally Scarce) and*Stereocaulon evolutum*. *Stereocaulon nanodes* was abundant around the remains of Nenthead smeltmill until the restoration of Nenthead Mines.

2.5 Plant communities

From an extensive survey of the North Pennine calaminarian grasslands six sub-communities have been identified:

C1a – open, stony ground, dominated by stands of terricolous lichens and often with a biotic crust over the soil. The substrate generally has very high levels of zinc and cadmium, and the only vascular plants able to grow well are spring sandwort and alpine penny-cress. Lichens include *Epilichen scabrosus* and *Cladonia cariosa*. These communities are found mainly around Nenthead and along the Nent.

C1b – sparse communities on open, stony ground, dominated by spring sandwort and sheep's fescue, with thrift, alpine penny-cress, lichens and small mosses. Pyrenean scurvy-grass grows on wetter ground. The lichens include *Epilichen scabrosus*, *Cladonia cariosa* and *Stereocaulon nanodes*. The substrate has high levels of lead, or zinc and cadmium, so this community is found mainly on mine spoil and the river shingles close to the mines.

C2 – short-grazed turf of common bent and sheep's fescue, with spring sandwort, thrift and alpine penny-cress. This community is species-rich and metal-tolerant ecotypes of harebell, common mouse-ear and other species are also frequent. Lichens and small mosses occur on patches of bare soil. These include a variety of *Peltigera* lichens, including *P. leucophlebia* and *P. venosa*. The substrate has toxic levels of lead, zinc or cadmium, or may be heavily contaminated but with a thin covering layer of humus and developing soil into which grasses can root. This community occurs at many sites, particularly mine spoil at lower altitudes and on many of the river gravels.

C3 – closed grassland with mountain pansy, alpine penny-cress, and an abundance of large mosses. This community is nearly as species-rich as C2 but lacks the lichens and small bryophytes. Many of the species of interest are less common and declining as a soil develops over the contaminated substrate.

C4 – closed grassland being invaded by birch, on a developing soil over contaminated ground. Mountain pansy and dune helleborine are characteristic, but self-heal, ragwort, creeping buttercup and germander speedwell are much more common.

C5 – closed grasslands that are subject to river floods and invaded by gorse and birch. The flood sediments are fine with high levels of zinc. Dune helleborine or campion occur in some of these sites but otherwise metallophytes and other species of interest are scarce.

2.6 Succession

Most of these plant communities have only developed over the last 100-200 years, since the mines were abandoned and the river gravels began to stabilise. Even the oldest sites, such as the mines on Flinty Fell, were probably being reworked and disturbed until some time in the 19th century. Initially the substrate must have been highly contaminated and subject to summer drought, and seed sources may not have been available nearby. Succession and soil development would both have been slow and may have followed an initial path similar to that we see now at Nenthead or Blagill. New sites are no longer being created so the evidence for this is limited to historical records and aerial photographs, and the results of a long-term field trial that includes restarting the succession by removing the surface soil.

<u>a) Pioneer communities</u>

Early colonisers of contaminated ground form a biotic soil crust that includes cyanobacteria, algae, crustose lichens such as *Vezdaea aestivalis*, *Sarcosagium campestre* and *Micarea lignaria*, and the mosses *Weissia controversa* and *Bryum pallens*. Some of the lichens are highly seasonal and only recognisable when they produce apothecia and spores, generally after rain or snow melt. The soil crust stabilises the soil surface and makes it possible for other plants and lichens to establish. If there is a source of spring sandwort seed, from nearby plants or the seedbank, this plant also establishes quickly. Early colonisers of exposed stones are also crustose species, particularly *Trapelia coarctata*, *Porpidia crustulata* and *P. tuberculosa*.

<u>b) Early successional stages</u>

These would have been similar to the communities still found on heavily contaminated ground, described here as C1a and C1b. Scattered plants of spring sandwort, sheep's fescue and common bent are associated with lichens in the soil crust and a variety of larger *Cladonia*, *Peltigera* and *Cetraria* species. Exposed stones are covered by a mosaic of saxicolous lichens. On the river gravels alpine penny-cress, thrift and mountain pansy may have been slow to colonise as they took a while to spread from the mines, but they were widespread by the late 19th century. These early successional communities may have persisted for decades, maintained by the combined stresses of toxic zinc and cadmium levels, drought and grazing.

<u>c) Later stages</u>

Eventually soil development on the more sheltered sites led to increased competition from grasses and the loss of the rarer lichens. A plagioclimax community similar to C2 was maintained by intense livestock and rabbit grazing until the 1960s or later, but when grazing ceased sites below 200m altitude were invaded by coarse grasses and scrub and this community was replaced by C3 and then if scrub invades by C4 or C5. The outbreak of myxomatosis in 1955 triggered this change on some sites, but others were grazed by sheep until more recently. River flooding and the deposition of less contaminated sediments over the gravel also have led to a rapid success on some sites. Above 200m exposure and the higher contamination levels ensured that the more open C1 and C2 communities persisted.

<u>d) Climax communities</u>

The succession beyond the grassland communities described here appears to go to scrub below 200m, and to acid grassland at higher altitudes. A different path is followed by sites grazed by cattle or horses, where enrichment leads to closure of the sward and the loss of species of interest as mesotrophic grassland develops.

Any of these communities can be maintained as a plagioclimax by appropriate controls on the invasion and spread of grasses and scrub, but while grazing levels can be maintained by appropriate management the same is not true of heavy metal levels. These will gradually fall in the surface layers into which plants root, and soil development and succession are then inevitable and irreversible.

Few of the North Pennine calaminarian grasslands have yet completed the succession to a climax community, but the older river gravels such as Williamston and Crow Hall are scrubbing over. Scrub clearance arrests this but does not restore the grassland to its original composition. Some of the less contaminated mine spoil is being encroached on by acid grassland.

Rates of succession vary with climate and situation, but there are indications that they have increased over the last ten years. Atmospheric deposition of nitrogen and climate change could be contributory factors.

3. National and international importance

3.1 National context

Estimates of the extent of calaminarian grassland remaining in Britain vary from 109 to 229 and even 10,000 ha, depending on whether just the area of metalliferous vegetation is taken, or the wider area that may be affected by the influence of heavy metals, or even the total area of sites that include calaminarian grassland. The following uses the narrowest measure and only includes vegetation of that broadly meets the definition of OV37 calaminarian grassland:

North Pennines	47 ha
Derbyshire	18 ha
Yorkshire	25 ha
Wales	14 ha
Mendips	3 ha
Scotland	2 ha
	109 ha

By any measure the North Pennine sites are a significant proportion of those in Britain, possibly nearly half. The extent of other types of metalliferous vegetation, such as that found on serpentine or the heaths of the mid-Wales rivers (Simkin, 2005) has not been measured, but is small.

3.2 National Vegetation Classification

British plant communities are classified according to the National Vegetation Classification (NVC). In this the only metalliferous community is OV37 *Festuca ovina–Minuartia verna* grassland (Rodwell 2000), characterised by the presence of spring sandwort. Three sub-communities are recognised:

OV37a Typical – an open sward on immature soils, dominated by spring sandwort, sheep's fescue and common bent.

OV37b *Achillea millefolium – Euphrasia officinalis* sub-community – a denser, grazed sward on soils with a developing profile and lower contamination levels, dominated by sheep's fescue, common bent and sweet vernal-grass. White clover, bird's-foot trefoil, fairy flax, yarrow, eyebright, ribwort plantain, kidney vetch, glaucous sedge, and the moss *Rhytidiadelphus squarrosus* are all frequent.

OV37c *Cladonia* spp. Sub-community – lichen-rich communities at high altitude where the surface soil has been leached by rainfall. Heather and species of *Cladonia*, including *C. portentosa and C. arbuscula,* are common.

These NVC definitions are based on survey data from lead mines in the Mendips, Derbyshire and the Yorkshire Dales. The North Pennine calaminarian grasslands are similar to those further south in the Pennines and fit into the broader definition of OV37, but they are more species-rich and there are significant differences in species composition in the forms found on zinc mine waste and on the lower altitude river gravels.

The North Pennine sub-communities have been proposed as additions to OV37 (Simkin, 2007a). Reasons for the differences include the harsher climate of the North Pennines, and the geology which here is a mix of sandstones, shale and limestone that gives rise to a soil that is pH neutral rather than strongly calcareous.

3.3 International context

The British calaminarian grasslands are floristically similar to those in Ireland, Belgium and the Netherlands, but with significant differences that make them unique in the world.

European plant communities are classified according to a phytosociological system. In this the British communities are classified to the Minuartio-Thlaspietum association within the western European Thlaspion calaminariae. The forms found in Belgium and Holland have several species differences, particularly the pansy *Viola calaminaria* instead of *V. lutea*, thrift *Armeria maritima* subsp. *halleri* rather than subsp. *maritima*, and thyme *Thymus pulegioides* rather than *T. polytrichus*. The closest match is the vegetation of lead mine spoil on the Burren in Ireland, a calcareous grassland community with frequent spring sandwort but without the common bent, sheep's fescue, alpine penny-cress, thrift and other species that are common in the British equivalent.

Eastern Europe and other continents have forms of metalliferous vegetation that are very different from those in Western Europe.

4. Ecology

4.1 Environmental influences

An understanding of the ecology of calaminarian grassland is essential to its conservation, and particularly to the avoidance of further damage to the habitat. It is also of wider interest as an example of a series of plant communities at an early stage of succession.

Correlations between environmental influences and the distribution of the different plant communities and species of conservation interest were studied as part of the wide-scale ecological study that forms the basis of this report (Simkin, 2007a). The range of these environmental factors is given in Table 2.

Table 2. Environmental factors on mines, upland and mid-reach river gravels (means)

	Mines	Upland river gravels	Mid-reach river gravels
Altitude (m)	474	301	124
Date	1937	1938	1916
Cobbles (%)	30	20	17
Fines (%)	30	53	66
pH	6.2	6.7	6.5
Organic content (LOI %)	11	10	10
Phosphorus (mg kg^{-1})	8	7	6
Total Pb (mg kg^{-1})	22,118	4,837	1,935
Total Zn (mg kg^{-1})	12,216	11,085	3,471
Total Cd (mg kg^{-1})	18	24	8

Multivariate analysis (using DCA and CCA) shows that there is a continuous range of vegetation, from the sparse communities of stress-tolerant lichens and plants at high altitude to scrub-invaded grasslands with more competitive species on river gravels at lower altitudes. The grouping of sites together in the plots shows the strong similarities between sites in the same geographic area.

The strongest factor (Figure 6, axis 1) explaining the variation in the vegetation is altitude, a combination of climatic factors such as temperature, rainfall, frost days, snow lie, and summer drought.

The next strongest factors are pH and biologically available zinc and cadmium levels (Figure 6, axis 2). These are linked in the data because the highest zinc levels are on sites rich in limestone, so the analysis is unable to separate them. Grazing intensity is the third factor (Figure 7, axis 3), and age of deposit the fourth (not shown). Others, including lead levels, are less significant.

4.2 Soil development

These are mineral substrates with a very low organic content, and much of the organic matter is still recognisable as leaf litter and not decomposed. Phosphorus (P) levels are also very low and limiting to plant growth, and only one earthworm was found in 50 soil pits. All this is consistent with very slow soil development, and with the soil invertebrate and microbial activity being inhibited by heavy metal toxicity.

Nitrogen levels have not been measured, but the plants found in calaminarian grassland are typical of soils of low or intermediate fertility. In this habitat nitrogen is derived mainly from nitrogen fixation by legumes such as clover and bird's-foot trefoil. Gorse is also a legume and the nitrogen-fixation that occurs under gorse accounts for much of the irreversible change to the vegetation that follows its invasion, even if it is subsequently cleared. Atmospheric deposition rates are increasing and may also be significant.

Figure 5. Multivariate analysis of survey and environmental data: CCA plot, axes 1 and 2

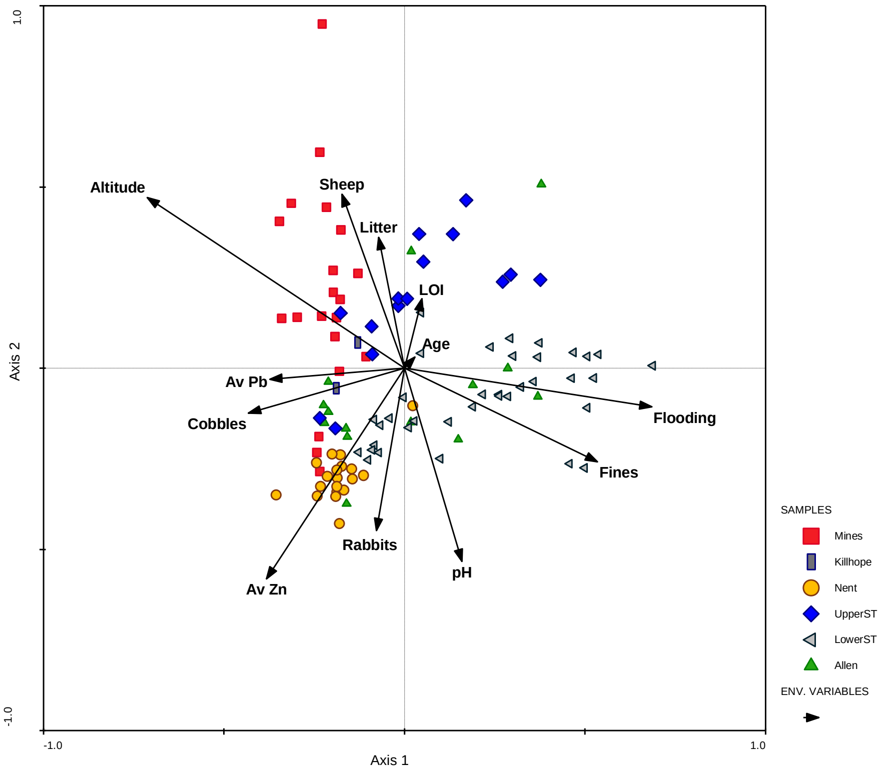
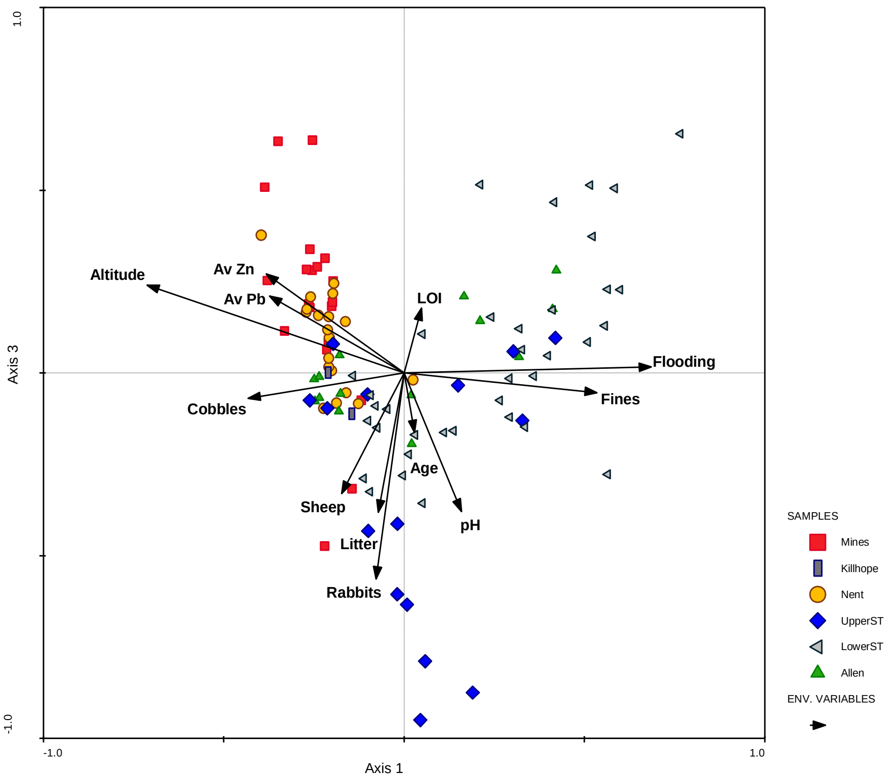


Figure 6. Multivariate analysis of survey and environmental data: CCA plot, axes 1 and 3



4.3 Drought

Many of the plants, mosses and lichens of calaminarian grassland are drought tolerant. The stoniness and low organic content of the substrate lead to a poor water-holding capacity and prolonged summer droughts. This is especially so in Allendale and Tynedale, where the rain shadow effect leads to lower rainfall than to the west.

4.4 Heavy metals

Although lead (Pb) was once thought to be the main determinant of the presence of calaminarian grassland, it is relatively immobile and only toxic to plants at high concentrations (>10,000 mg kg-1). It is above that level in some mine spoil, and in the river gravels on the Nent and upper South Tyne, but otherwise not. The highest concentration, 134,683 mg kg^{-1}, was found in the remains of the smeltmill flue at Nenthead.

Zinc (Zn) is phytotoxic at lower concentrations (>2,000 mg kg^{-1}), and is above that level in most of the mine spoil and river gravel substrates analysed. The highest concentrations are in waste from Nenthead smeltmill, up to Zn 65,997 mg kg^{-1}.

Cadmium (Cd) is closely associated with zinc in the North Pennine mineralisation, and is toxic to plants at very low concentrations (>15 mg kg^{-1}). It is above this level in mine spoil around Nenthead, up to 82 mg kg^{-1}, and in the river gravels of the Nent, 121 mg kg^{-1}.

The presence of heavy metals, especially zinc and cadmium, at phytotoxic levels is clearly a determinant of the presence of calaminarian grassland. For many of the metallophyte plants and lichens, including spring sandwort, alpine pennycress, Pyrenean scurvy-grass, and lichens such as *Stereocaulon nanodes*, *Baeomyces placophyllus* and *Epilichen scabrosus*, there is also a strong association between their distribution and zinc and cadmium levels. For other species the influence of climate is stronger than that of metal levels. Lead and barium are less mobile and no species were found to be particularly associated with high concentrations.

Most of the calaminarian grassland plants are very shallow-rooted, avoiding the higher metal levels found below the surface. This has only been investigated in the river gravels, where soil pits were dug to a depth of 50cm. The increase in zinc and cadmium levels with depth indicates that leaching down the soil profile is slow but significant over time.

Table 3. Heavy metal levels at the surface and at depth (means)

	0-5cm depth	40-50cm depth
Total Pb	1,793 mg kg^{-1}	2,632 mg kg^{-1}
Total Zn	3,070 mg kg^{-1}	7,705 mg kg^{-1}
Total Cd	9 mg kg^{-1}	29 mg kg^{-1}

Much of the leached metal is attached to organic matter or clay particles and is held within the matrix of the gravel bar. Groundwater flows in or out are thought to have very little influence on metal levels in the gravels or in the rivers, but direct measurements are needed to confirm this.

4.5 pH

The mean pH values are similar but these mask some variation, from pH 7.55 on the River Nent, where the rock in the river gravels includes a high proportion of limestone, to 4.69 at Williamston on the South Tyne. Williamston is probably the oldest of the river gravels, first formed in the great flood of 1771, and has recently suffered from gorse invasion, so soil development is well advanced and the surface layers are becoming more acidic.

4.6 Flooding

Although the North Pennine rivers are tending to incise deeper into their beds, the gravels are still subject to regular flooding. River flooding may be erosive or depositional, and sometimes both at different stages in the same flood. Sedimentation generally occurs on the outside of river bends as the flood falls, and the fine sediment left behind by the floodwater may be 5-10cm thick. The flood sediments tend to have a high pH which reduces heavy metal mobility and toxicity in the soil, but contamination levels vary depending on the nature of the deposits eroded upstream.

Even thin layers of uncontaminated sediment have a marked effect on the vegetation, smothering the lichens and slower growing plants. Others are able to grow up through the sand, with the result that common bent and the lawn moss *Rhytidiadelphus squarrosus* quickly replace sheep's fescue and the smaller mosses and lichens. If the sand is then dispersed by the wind or animals this effect is partially reversed, with the vascular plant flora recovering much more quickly than the lichens and bryophytes (Simkin, 2010). In the longer term repeated flood sedimentation leads to a change from species-rich calaminarian grassland to a more uniform, grassy community with few species of interest.

Erosion seems to be getting less frequent, but when it does occur it disrupts the soil crust and removes the litter layer to create bare patches that can be colonised by new species. If the exposed substrate is also heavily contaminated this strongly favours the metallophytes and restarts the process of calaminarian grassland succession. Heavy rainfall can have a similar effect, and surface ponding and run-off may be a significant influence on sparsely vegetated mine spoil.

Floods may also carry plant and lichen fragments downstream and this appears to be important in the dispersal of species such as *Hylocomium splendens* and *Peltigera venosa*.

4.7 Disturbance

Rabbit burrowing is a significant influence on some of the lower altitude river gravels which have large warrens nearby. The effect on the vegetation is similar to that of flood sedimentation, and favours grasses such as common bent over slower growing species. The effects of human disturbance have not been studied in any detail, but they appear to be similar.

4.8 Grazing

Many grasslands are dependant on grazing for nutrient cycling, seed input, and the control of fast-growing grasses and scrub. This applies to calaminarian grassland once the sward has closed, but few of the North Pennine sites are now grazed by livestock. Rabbit and sheep grazing have similar effects, maintaining a species-rich plagioclimax community, but sheep prefer the grassier edges of the gravel bars and so are less effective. Both are selective feeder and graze close to the ground, and this favours the low-growing species characteristic of calaminarian grassland. Intense rabbit grazing, as at Ninebanks and Wydon, can even reverse the succession to a more open, metallophyte dominated sward. Cattle and horses have different grazing habits and do not suit this habitat.

Not all the species of interest are favoured by grazing, and the metallophytes alpine pennycress, Pyrenean scurvy-grass, mountain pansy and dune helleborine are all absent from heavily grazed sites. Rabbits tend to nip off the flower heads before they have a chance to set seed.

5. Conservation issues

5.1 Habitat damage

Throughout the North Pennines these communities are threatened by damage and habitat loss.

Gravel extraction, landscaping, and the reworking or stabilisation of spoil heaps can all lead to total loss of habitat from a site, and it is generally the best sites, from an ecological viewpoint, that are vulnerable to these. River protection works that confine the river channel and prevent its movement across the valley floor may protect river gravel habitats in the short term, but the long term effect is to isolate the calaminarian grassland from the river and the larger ecosystem. More localised damage can also be significant, for instance the soil surface is easily disrupted by vehicles, and terricolous lichens are very vulnerable to trampling by walkers.

Changes in grazing may also be damaging. Intensive grazing by cattle or horses and supplementary feeding of any livestock, lead to nitrogen enrichment, soil development, and the spread of competitive grasses. Nitrogen levels are also being raised by atmospheric deposition, affecting all the sites. Severe overgrazing, as at Wydon and Ninebanks where there are very large rabbit warrens, can suppress species diversity but it also maintains early successional stages of calaminarian grassland as they are and may cause later stages to revert to these earlier forms.

Under-grazing is more of a risk, leading to increased competition from grasses and the loss of less competitive species. This may occur when livestock are excluded, or after a disease outbreak in a rabbit warren. In the absence of grazing annual strimming of the sward in late summer or autumn has a positive effect on short turf species, including spring sandwort, thrift and alpine pennycress, but it suppresses populations of mountain pansy and dune helleborine by reducing leaf area and preventing flowering. It is important to remove the cuttings from the site to prevent suppression of germination, and if they are burnt to avoid dispersal of ash onto the calaminarian grassland area.

5.2 Sward closure

On many of the river shingles, including all three study sites, there has been a trend since 1990 towards closure of the sward by vigorous growth of grasses, particularly common bent, and the large pleurocarpous mosses *Hylocomium splendens*, *Rhytidiadelphus squarrosus* and *Pleurozium schreberi*. This has increased the rate of soil formation, creating a thin layer of humic soil over the metal-rich mineral substrate into which non-metal tolerant plant ecotypes can root, and has led to the loss of much of the diversity recorded in the 1980s on river gravels such as Willliamston, Lambley and Beltingham. At Wydon, Ninebanks and Coanwood, where surface soil metal levels are higher and the plants are heavily grazed, closure is more patchy and there are still some areas of bare ground. Where these are disturbed by rabbit burrowing and the consequent disruption to the soil crust leads to a similar loss of diversity and conservation interest. Some species are initially favoured by the loss of bare ground, particularly alpine penny-cress and mountain pansy, but study of other sites where the succession is more advanced (Simkin, 2007a) indicates that they will also be lost as coarse grasses increase.

The reasons for sward closure need further investigation. Possible factors include:

- Pedogenesis, with humification and acidification of the surface horizons
- Leaching of heavy metals down the soil profile, at an increased rate due to pedogenesis
- Flooding, leaving a layer of relatively uncontaminated sandy sediment over the soil surface
- Nitrification, from atmospheric deposition or perhaps in the ground water.

Soil processes are complex, with positive feedbacks that increase the rate of change once it starts, and at many of the sites several of these factors are probably acting together to cause the change.

5.3 Isolation

Calaminarian grassland used to be widespread in the mining areas and then along the rivers, but at least 60% of this area has been lost since 1970. Many of the remaining sites are small and isolated. This increases the risk of local extinctions and makes it less likely that new species will colonise, so there is a gradual loss of diversity over time. The species of interest are often only present as one or two individuals and are poor dispersers, so they are particularly vulnerable to the chance events that lead to local extinction.

Another impact of fragmentation is the reduced scope for small scale variations in nutrient levels, soil dampness and disturbance. These, together with short term changes such as the seasonal accumulation of surface litter and changes in soil moisture and groundwater flows, create micro-sites suitable for plant colonisation, and often determine whether a seedling can establish and set seed. Spring sandwort persists in the soil seedbank for decades and so can recolonise by germinating in bare patches after disturbance. Mountain pansy does the same, although it does not persist for so long. In a trial on the North Pennine river shingles the other metallophytes were not present as viable seed in the seedbank.

Many of the study sites have a mosaic of different forms of calaminarian grassland, often with open stony ground surrounded by a closed sward and, at lower altitudes, patches of encroaching scrub. These mosaics are dynamic as the vegetation responds to very local changes in grazing intensity, flood effects, and climate. The long-term survival of each species depends on the continued availability of suitable microhabitats somewhere within the mosaic, although that may not always be in the same place. Succession leads to the loss of some of these microhabitats, and if they are not replaced by others there will be a consequent loss of species diversity. The stress-tolerant but less competitive, and often rarer, species tend to the ones whose microhabitats are lost from the mosaic at an early stage.

When spatial and temporal variability are high, as in calaminarian grassland, a wide range of species that respond differently to environmental perturbations is needed to ensure ecosystem stability. Site management such as scrub clearance and grazing may arrest the succession in the short term, but the gradual loss of species will lead to other and unpredictable long term changes. To be successful in the long term restoration techniques must maintain the mosaic of microhabitats as well as providing opportunities for successful recolonisation.

There are also implications for the designation of protected sites. The tendency has been to focus on the C2 communities, being the richest in flowering plants. Many of the designated sites are very small and isolated from each other, and succession has changed the lower altitude sites from C2 to C3, C4 and C5 communities, with a consequent loss of conservation interest. There is an urgent need to designate more C1 and C2 communities, and these need to be larger or interconnected sites at a landscape scale to ensure that they are large enough to maintain ecosystem stability with a mosaic of vegetation types. In the mining area this could be achieved by extending the existing SSSIs so that they connect, and in particular by designating the key areas of Nenthead Mines, Killhope Moor and Flinty Fell. For the river gravels designation of lengths of a river system should be considered, especially on the South Tyne.

5.4 Spoil heap stabilisation

Landscaping and the stabilisation of spoil heaps leads to a loss of the open habitats that support many of the lichens and metallophytes of conservation concern. This has happened on a wide scale around Nenthead, and elsewhere on Alston Moor.

There is also a secondary effect in that the river gravel calaminarian grasslands are dependent on regular “topping up” of zinc and cadmium levels to offset the effects of leaching away from the soil surface. Flood events that leave a covering of zinc-rich sediment have been observed to reduce the growth of competitive grasses in subsequent years, and to favour spring sandwort and alpine pennycress. It is now a rare event for a contaminated spoil heap to collapse into the river so most floods leave a relatively uncontaminated sediment which changes the vegetation irreversibly. Spoil heap stabilisation upstream appears to be increasing rates of succession and species-loss downstream. Freshly created substrates in the river flood plains tend to be much less contaminated than those of historic age and do not develop calaminarian grassland.

5.5 Mine water remediation

Mine water remediation schemes reduce the concentrations of heavy metal rich soluble and suspended matter in the rivers. Some of the suspended matter is deposited as the flood retreats, and if it has a high concentration of zinc and cadmium this replenishes the leached horizon of the surface soil. Remediation schemes that reduce this effect can be expected to increase rates of succession and species loss downstream.

The effect of reducing dissolved metal levels in the rivers is uncertain as we know little of the interconnection between ground-water flows in the gravel bars and river flows. Water can sometimes be seen emerging from a gravel bar under pressure, so there appears to be some flow from gravel to river, but whether the reverse occurs is unknown.

5.6 Habitat management

Several techniques are available for physical management of calaminarian grasslands, including scrub clearance, grazing and annual strimming, but the choice of method, and indeed the decision of whether to intervene at all, must be based on a detailed assessment of conditions at each site. Each of the species of conservation interest has different ecological requirements, and any physical intervention will favour some but disfavour others.

The objectives of habitat management vary. Many sites are so degraded that their recovery to optimal condition must include the restoration of species richness to a site that has lost most of its metallophyte and lichen populations as a result of disturbance or scrub invasion. This is difficult to achieve, as recolonisation is dependent on the availability of seed and lichen propagules from another calaminarian grassland nearby, or on regeneration from the seed bank. More realistic objectives for management are to increase populations of species still present, or at least to arrest their decline, and to extend the range of micro-habitats present. In the long term the latter may result in recolonisation by species that have been lost, but this will depend on dispersal opportunities which may be neither predictable nor manageable.

Only three calaminarian grassland sites are managed solely for conservation, all on the river gravels, the NWT reserves at Beltingham and Williamston and the larger Burnfoot-Broomhouse-Wydon complex that is owned by the National Trust. Management of these sites includes scrub control and, at Williamston and Beltingham, autumn strimming of the long grass. Several of the other sites are SSSIs or in HLS, and these have management plans that take some account of the conservation of calaminarian grassland. Some are more successful than others.

Scrub clearance is the easiest and most effective technique. It results in an increase in plant and lichen diversity, and particularly favours many of the species of conservation interest. However, if dune helleborine is present it is important to ensure that light shade from birch is maintained, and that the clearance is carried out at a time of year when the helleborines are not showing. As well as clearing scrub from the grassland itself, the clearance of trees and large bushes to the south and west increases its exposure to the sun and wind, while clearance to the north and east has less effect. The reduction in shade and shelter has the effect of drying the soil surface, and this leads to a thinning of the bryophyte mat and loss of the “green slime” of cyanobacteria and other micro-organisms that covers the soil surface in damp conditions. Sedimentation during river floods is reduced by removing the woody stems that trap debris and obstruct water flow. If a rabbit warren is nearby the removal of cover that might conceal predators encourages the rabbits to graze on the calaminarian grassland, and this leads to a reduction in coarse grasses and an overall increase in plant species diversity.

Restoring plant diversity by the application of seed is becoming an accepted technique in grassland restoration (Smith, 2002; 2003; 2008), especially in productive hay meadows. Its potential for calaminarian grassland has not yet been tested. It is not practical to obtain sufficient locally provenanced seed of thrift or alpine penny-cress, but spring sandwort and mountain pansy are more suitable for experiment. Spring sandwort is being considered as part of a mine spoil restoration project at Nenthead, to be planted in as plug plants to increase the chance of successful establishment.

5.7 Habitat restoration

A long term field trial to investigate strategies for calaminarian grassland management and species conservation on alluvial gravels on tributaries to the River Tyne in the North Pennines has been ongoing since 2002. The main objective was to determine whether intervention could reverse the process of succession and re-establish stable plagioclimax calaminarian grassland communities. Three study sites were selected for differences in grazing and flood frequency, and the treatments applied include scrub clearance, raking, moss-killer, and stripping of the soil surface. Soil conditions and the seedbank were assessed in the first few years after treatment and changes to the vegetation have been monitored annually from fixed quadrats. 25% of the plots were left untreated as controls, and these have provided an opportunity to monitor the overall trends of change on these sites, where closure of the sward and the loss of rare species are a significant problem.

The initial results confirmed that soil conditions after scrub clearance and treatment were within the range suitable to support calaminarian grassland, but that the availability of seed from the seed bank was limiting on the early reinvasion of treated plots. Of the treatments:

- Removal of dead wood from individual plots, by cutting it at the base, had no long term effect compared to the controls where it was allowed to fall and decompose naturally.
- Moss-killer reduced the dominance of large mosses initially, but they recovered rapidly and after three years there was no significant difference.
- Raking is effective in the short term if there is a thick mat of pleurocarpous mosses, but they recover after 2-4 years and the seedlings that germinated during that time fail to survive in the long term. There was some replacement of the species of interest by bird’s-foot trefoil, self-heal, crossword, creeping buttercup and other plants favoured by disruption to the soil surface.
- Stripping the soil surface has the greatest effect, creating a fresh soil surface with exposed stones, a high pH and high levels of lead, zinc and cadmium. This was colonised initially by ribwort plantain, common bent, spring sandwort, and the mosses *Weissia controversa* and *Bryum pallens*. Sheep’s fescue, mountain pansy, harebell and other species came in later. Lichen colonisation is slower and is still at an early stage. Not all the early colonists succeeded in becoming established, and the only metallophytes to colonise are spring sandwort, at the sites where seed was still viable in the seedbank at 10cm depth, and mountain pansy at those where plants were flowering nearby.

Substrate renewal by stripping off the surface soil is the only treatment that restarts the succession, but it is labour intensive and destroys the existing vegetation. If metallophytes are still present in the grassland it should only be carried out in patches, so that they can spread back onto the freshly exposed substrate. The soil that is removed has been subject to leaching, so the mineral substrate that is exposed has a higher pH and higher zinc and cadmium levels. If spring sandwort and other species are present in the seed bank they establish quickly, but sheep's fescue, alpine penny-cress, thrift and the lichens are slow to invade. In the meantime gorse and birch seedlings may become established if they germinate between stones or are otherwise protected from grazing. On a site where gorse is abundant but rabbits are scarce this can lead to such an abundance of gorse seedlings in the stripped areas that other species are suppressed, and a new cycle of gorse invasion is started.

River flooding affected all three sites in January 2005, and the deposition of a thin layer of flood sediments contributed to the loss of lichens and closure of the sward at this time. The diversity of forbs increased slightly in the summer following the flood, but the increase was short-lived and may be explained by the germination of casuals from seed deposited with the flood sediments which then failed to establish. At Wydon, the site most affected by the flood, the terricolous lichens, acrocarpous mosses, and most of the vascular plants were initially overwhelmed by sand, but in the subsequent months the overlying sediment was redistributed and since then some vascular plants, including spring sandwort, and the pleurocarpous mosses recovered well. The composition of the grassland changed, with sheep's fescue largely replaced by the faster growing common bent, and rosette-forming forbs that were completely covered by the sand greatly reduced, but these trends are now being reversed. Terricolous lichens are particularly sensitive to inundation by water or sand, and most were lost from this site or left in very poor condition. By 2010 there were some signs of recovery, but long term monitoring is needed to see whether this is restricted to just a few species.

The initial results of the field trial suggest that species diversity and populations of rare species can be encouraged by active site management, especially scrub clearance and surface stripping, but that these methods should be applied in patches to create a mosaic of microhabitats. It is important to monitor the effects of management over a period of several years and to amend the management plan if necessary.

5.8 Habitat creation

It would be possible to create new calaminarian grassland habitat by spreading heavy metal contaminated waste over an area with no intrinsic conservation value. It must be mixed with stone, to create the necessary free drainage and sheltered microhabitats, and the contamination levels must include at least one heavy metal at phytotoxic levels (Pb >10,000 mg kg^{-1}, Zn >2,000 mg kg^{-1}, Cd >15mg kg^{-1}). This could be done on an upland or river gravel site. An obvious habitat would be a river gravel formed since 1920 that has insufficient heavy metal levels to be phytotoxic but has not yet scrubbed over. Land associated with a lead mine that has recently been cleared of buildings would be another, as would mine spoil that has been reworked to extract any remaining ore. Any soil on the site would have to be stripped off first, so that the contaminated material and stone was spread over a mineral substrate, preferable one that is naturally stony and well-drained.

5.9 Other considerations in habitat creation and restoration

For any scheme in this habitat that may disrupt an existing waste tip or gravel bar it is essential that the hydrology and drainage of the site is assessed carefully for any potential effect on water courses. On river gravels the risk of erosion and river channel movements must be taken into account.

To ensure colonisation by metallophytes the site should be close to an existing calaminarian grassland site, and if it is necessary to stabilise the soil surface quickly this could be expedited by adding seed or plants of metal-tolerant ecotypes, particularly spring sandwort and the grasses common bent and sheep's fescue.

6. Important sites in the North Pennines

The conservation interest of each site has been assessed from the overall species richness and the presence of metallophytes and other scarce species, and calculated as an index of biotic integrity (IBI). On that basis the top sites, with an IBI of 14 or more, are as shown in Table 1. Of the 24 highest ranked compartments, only 11 were subject to any conservation management or statutory protection. The highest scores were associated with the intact habitats, which are themselves associated with high altitude, age of deposit, stoniness and the absence of flooding.

The most important are discussed below, and the full list with further details of each site is attached as an appendix.

Table 4. Calaminarian grassland sites with the greatest conservation interest

Location	Type	Status	Grid ref	IBI
Williamston	River gravel - South Tyne	SSSI; cSAC; NWT	NY681519	26.6
Ninebanks (Whamlands)	River gravel - West Allen	SSSI; cSAC	NY781542	25.4
Killhope Moor mines	Mine		NY790436	25.3
Blagill	River gravel - Nent	SSSI; cSAC	NY743468	22.4
Garrigill	River gravel - South Tyne	SSSI	NY739418	22.1
Killhope	River gravel - Killhope Burn		NY828429	22.0
Whitesyke Mine	Mine		NY750424	21.8
Leadgate	River gravel - South Tyne		NY715433	21.3
Broomhouse	River gravel - South Tyne	SSSI; cSAC	NY695628	20.0
Allenheads smeltmill	Smeltmill		NY850465	19.1
Bardon Mill	River gravel - South Tyne		NY780643	18.6
Skydes	River gravel - South Tyne		NY734423	17.9
Alston (The Islands)	River gravel - South Tyne	SSSI; cSAC	NY715451	17.8
Coalcleugh Mine	Mine		NY800451	17.2
Coanwood	River gravel - South Tyne	SNCI	NY674587	17.2
Lambley	River gravel - South Tyne	SSSI; cSAC	NY677583	16.3
Allenheads	River gravel - East Allen		NY850465	16.1
Nentsberry Haggs Mine	Mine		NY766451	15.9
Hodgsons Level	Mine		NY786428	15.8
Wydon	River gravel - South Tyne	SSSI; cSAC	NY693627	14.9
Nenthead smeltmill	River gravel - Nent		NY781433	14.8
Flinty Fell mines	Mine		NY758422	14.3
Nenthead smeltmill	Smeltmill	SAM	NY781433	14.3
Ninebanks (Blackett Bridge)	River gravel - West Allen	SSSI; cSAC	NY780537	14.1

Williamston

This site comprises as single massive gravel bar on the eastern side of the present river channel, just south of Slaggyford. The assessment is based on plant and lichen records since 1999, and should now be revised down as much of the lichen interest has since been lost. Gorse invaded during the 1990s, after the rabbit population was removed, and this increased the rate of soil development, with acidification and nitrogen enrichment of the surface layers and some leaching of heavy metals down the soil profile. As a result much of the open stony ground was overwhelmed by moss and grass, and although the gorse was cleared in 2002 and has been cut back every year since, this has not been reversed. Rabbit numbers are still very low so the grass is now strimmed every autumn. This has helped maintain species richness and has favoured some plants, but there has been an adverse effect on the mountain pansies for which the site was well known and devil's-bit scabious has spread to take over a large area.

Williamston is also important for the large population of dune helleborine on the edge of the birch woodland. This persists but is suffering from the competitive growth of other plants in the ground layer, apparently in response to an input of nitrogen rich ground water from the adjacent pasture.

Ninebanks (Whamlands)

The northern part of Ninebanks SSSI is undisturbed and (when last visited c. 2010) was in excellent condition. Intense rabbit grazing prevents flowering in many species so it appears at first sight to lack the species richness of other sites, but on closer inspection spring sandwort and a rich variety of lichens are still present and doing well. The heavy and selective grazing keeps the vegetation sparse, with large areas of bare ground supporting soil crust species and stands of *Cladonia* lichens, and with an abundance of exposed stones. Alpine pennycress and mountain pansy are frequent in the grassy areas surrounding the open stony ground.

This is how many of the river gravels appear in photographs taken before the outbreak of myxomatosis in 1955, but it is not known whether this site was maintained in this state by livestock grazing or has reverted to such open vegetation since rabbit numbers recovered.

Killhope Moor

The shafts on the hill above Nenthead have left extensive areas of spoil and tailings that, although exposed and often wet, still have high concentrations of lead, zinc and cadmium. Little grows on the most contaminated ground close to the road, apart from spring sandwort and lichens. Alpine pennycress and mountain pansy occur in the grassier areas around the shafts, and Pyrenean scurvy-grass is common in the wet flushes that drain the tailing spreads. This area is grazed by sheep but is otherwise undisturbed, and has been able to develop mature and stable metallophyte communities since the mines were abandoned.

Blagill river gravels

Extensive river gravels have been deposited along the Nent between Foreshield and Blagill bridges, and because they have accumulated waste from the mines and smeltmill upstream at Nenthead they have extremely high levels of zinc and cadmium. This is a superb lichen site, with a well-developed soil crust and vast stands of *Cladonia* and *Cetraria* lichens. Several of these are only fertile here and not found in such good condition anywhere else in the North Pennines. Nationally rare species include the lichenicolous lichens *Taeniolella rolfii* and *Epilichen scabrosus*. Mountain pansy and alpine penny-cress are common in the grass on the older gravel bars, and spring sandwort is abundant on more open ground. Pyrenean scurvy-grass and grass of parnassus frequent wetter ground. All these communities are vulnerable to disturbance and trampling, and for a time a gate was put up to prevent access to leisure vehicles but this has now gone.

Zinc and cadmium levels in the river Nent at Blagill are falling and the riverbanks are now vegetating, but the river is still dynamic and braided for much of its length through the basin between Foreshield and Blagill bridges. It has recently become active and erosive again at the Foreshield end after decades of stability. These natural river movements have recently led to the loss of some of the best habitat on the south side of the river, and they threaten the archaeology of the Foreshield Shaft, one of the access shafts to the Nent Force Level (this also threatens river levels in the Nent as it may divert down the shaft to exit at Alston).

Garrigill river gravel

This site has deteriorated over the last 10 years, mainly due to river channel movements that have eroded the most species-rich part of the site. This was reworked spoil from Tynebottom Mine on the opposite side of the river which had only travelled a few metres and still included fragments of galena, sphalerite and fluorspar, had very high levels of zinc and cadmium in the finer material.

The rest of the site is a massive river gravel, similar to others on the South Tyne. The vegetation has been disturbed by campers and bonfires. The single specimen of *Peltigera venosa* near the footbridge, the highest of the series of populations along the South Tyne, was unfortunately collected (by person unknown) some years ago and this lichen has not been seen here since.

Killhope river gravels
This small site is at a higher altitude than the other river gravels and very close to the mines that are the source of heavy metal contamination. It is relatively undisturbed and has a good range of metallophytes and lichens, all in good condition.

Whitesyke Mine
This abandoned mine has important populations of metallophytes and some interesting lichens. Much of the plant community on the dressing floors was damaged by floods and has changed since previous surveys, but the structure has now been stabilised to prevent further damage and there is still a large area of calaminarian grassland on the banks above the dressing floors that is in good condition.

Leadgate river gravels
This large river gravel is subject to erosive flooding and still has large areas of open stony ground with metallophytes and lichens, including at times the short-lived lichen *Peltigera venosa*. Grassy areas on slightly higher ground include large populations of mountain pansy and alpine penny-cress, and unusually for this area there are stands of the large lichen *Cetraria islandica*, known as Iceland moss. The habitat is in good condition, and the large size of the site and the mosaic of habitats present make it one of the most ecologically stable and likely to retain its conservation interest.

Broomhouse river gravels
Part of the large Burnfoot SSSI, the river gravel on the bend of the river below Broomhouse Farm is a large area of open stony ground with good populations of metallophytes and lichens. The grassy area used to support a large population of mountain pansy, with an unusual variety of colour forms, but this has disappeared since the January 2005 flood. This site benefits from being inaccessible and undisturbed, and from the presence of a large rabbit warren that prevents scrub invasion.

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Appendix A - Calaminarian grassland sites in the northern North Pennines

The study area covered is from Tynedale south to Killhope and Garrigill, but there may be more mine sites on Alston Moor and in East Allendale than are shown here. Only sites known to have some metallophyte plants or lichens are included.

Status: CP - country park, SAC - candidate Special Area for Conservation, SAM - Scheduled Ancient Monument, SNCI - Site of Nature Conservation Importance, SSSI - Site of special scientific interest.
Phytotoxic concentrations are for total metals (nitric acid extractable) in the surface 5cm of soil, Pb >10,000 mg kg^{-1}, Zn >2,000 mg kg^{-1}, Cd >15mg kg^{-1}. Only known for my study sites.
Indicator species: A - *Armeria maritima* (thrift), C - *Cochlearia pyrenaica* (pyrenaean scurvy-grass), D - *Cladonia cariosa* (lichen), E - *Epipactis dunensis* (dune helleborine), L - *Epilichen scabrosus* (lichenicolous lichen), M - *Minuartia verna* (spring sandwort), P - *Peltigera venosa* (lichen), R - *Taeniolella rolfii* (lichenicolous fungus), T - *Noccaea caerulescens* (alpine penny-cress), V - *Viola lutea* (mountain pansy).
IBI: Index of Biotic integrity, a measure of habitat quality derived from the vascular plant, bryophyte and lichen species richness, overall diversity, and the presence of indicator species. Only known for my study sites.

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Alston Moor mines								
Tynebottom Mine	SSSI	Spoil heap	NY739419	330		M		Rare lichen areas destroyed, Scrub and nettle clearance and removal of rubbish and stock feeders urgent but probably now too late
Browngill mines		Spoil	NY763423	535		CMTVL		Survey needed
Flinty Fell mines		Shafts and spoil	NY758422	505	Pb Zn	MLR	14.3	Recent damage by vehicles has led to loss of rare lichens. Survey needed to assess the damage
Whitesyke Mine		Tailings heaps	NY750424	420-430	Zn Cd	ACMVTL	21.8	Lichen sites have been damaged by leisure uses and flooding, but still has large populations of metallophyte plants. Included in the OREsome project.
Bentyfield Mine		Dressing floor and spoil	NY755425	450-460		M		Survey needed. Included in the OREsome project.
Middle Fell mines		Shafts	NY739440	450		MTV		Survey needed
Rotherhope Mine		Dressing floor and spoil	NY700428	320-380		MP		Survey needed. *Peltigera venosa* not seen since 1970s but could still be present.
Dowgang Hush		Shafts above hush	NY774430	535	Pb Zn	-	7.7	No metallophyte interest
Dowgang Mine		mine spoil	NY776427	535		M		Survey needed
Nent mines								
Killhope Moor mines		Shafts and tailings	NY790436	545-610	Pb Zn Cd	CMLVLR	25.3	
Nentsberry Haggs Mine		Spoil heap	NY766451	400	Zn	MTLD	15.9	Habitat changes due to removal of sheep? Survey needed.

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Hodgsons Level		spoil	NY786428	495	-	CMTD	15.8	
Smallcleugh Mine		dressing floor	NY786430	480		L		Included in the OREsome project but already well surveyed.
Nenthead smeltmill	SAM	Smeltmill, wastes, flue and associated structures	NY781433	450-485	Pb Zn Cd	AMTLDR	14.3	Highly contaminated. Much of the metallophyte and lichen interest, including large populations of *Stereocaulon nanodes* and *Cladonia cariosa*, was been lost during "restoration" but is beginning to recover. Important population of *Taeniolella rolfii* on *Cetraria aculeata*. Included in OREsome project but has recently been surveyed so won't be done again. Opportunity for a long term study of recovery, against 1999-2000 baseline data
Nenthead/Rampgill mines		Spoil, shafts, leats etc.	NY785433	435-490	Zn Cd	CMTDL	13.5	Much of the lichen interest was lost during "restoration", including large populations of *Stereocaulon nanodes*, *Cladonia gracilis* etc. Opportunity for a long term study of recovery, against 1999-2000 baseline data.
Nenthead Firestone Levels		Firestone level and spoil	NY787435	490-500		CMTLD		Damaged by reprocessing in 20th century but may be recovering
West Allendale mines								
The Rake		Shafts and spoil, including Rough and Ready shaft and roadsides	NY795446	570-590		M		Survey needed
Coalcleugh Mine		Shafts, spoil, trackways and dressing floor, inc. Alston Cleugh	NY800451	510-540	Pb Zn Cd	CMTL	17.2	Survey of Alston Cleugh area needed
Carrshield		Barneycraig Mine and tailings	NY803474	400		TDL		Has been damaged by flooding and restoration activities but still has good areas of calaminarian, especially on the west side of the river. Recently surveyed as part of EIA for proposed stabilisation and diffuse pollution control works.
Wellhope Moor		Shafts and spoil	NY787461	560-570				Survey needed, large area
Wellhope Mine		Spoil	NY780480	420				Survey needed
Keirleywell Bank		Mine road	NY770515	350				Survey needed
East Allendale mines								
Allenheads smeltmill		Spoil, flue and mine roads	NY850465	365	Pb Zn	MTVLP	19.1	Excellent *Viola lutea* site. *Peltigera venosa* has not been seen for many years.
Tynedale mines								
Langley Barony Mine		Dressing floor, spoil	NY827659	150		D		Survey needed
Langley Barony Mine		upper spoil	NY830665	180				Survey needed
Stonecroft Mine		Dressing floor, spoil	NY854688	125	Pb Zn Cd	E		Survey needed

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Killhope Burn alluvial								
Killhope		Gravels	NY828429	450	Zn	MVLD	22.0	
Nent alluvial								
Nenthead smeltmill		Gravel	NY781433	445	Pb Zn Cd	MTLD	14.8	Heavily contaminated and species-rich, threatened by trampling, disturbance and changes in water levels. *Stereocaulon*s recently much reduced.
Nenthead, Overwater		Gravel	NY780435	445	Zn Cd	CMTV		Much of the metallophyte interest has recently been lost, reasons unclear.
Blagill	SSSI; SAC	Gravels north and south of the river, between Foreshield and Blagill bridges	NY743468	325	Zn Cd	CMTVLD	22.4	A superb metallophyte and lichen site, very large and with high Zn and Cd levels, quite unique. Threatened by disturbance, river channel changes, and by a proposed minewater scheme upstream. The Foreshield Shaft (and hence river flows in the Nent) is threatened by riverbank erosion and stabilisation is urgently needed (EA aware)
Upper South Tyne alluvial								
Garrigill	SSSI	Gravels associated with Tynebottom Mine	NY739418	330	Pb Zn	MTVLPD	22.1	Severely damaged by Jan 2005 flood and river channel movements, *P. venosa* and much of the calaminarian interest lost.
Skydes		Gravels	NY734423	320	-	TLPD	17.9	Very small patches of calaminarian within a hay meadow
Rotherhope Mine		Gravel	NY705432	320	Pb Cd	D		survey needed
Leadgate		Gravel	NY715433	295	-	AMTPVD	21.3	Large, species-rich site, with *Cetraria islandica*
Alston (The Islands)	SSSI; SAC	East gravels	NY715451	275	Zn	AMTLPD	17.8	Severely damaged by cattle and river defences since survey, some tree removal would help.
		West gravels	NY715448	275				Severely damaged by cattle, no recent survey
Lower South Tyne alluvial								
Underbank			NY702492	225		V		Survey needed
Kirkhaugh	SNCI	Gravel	NY698498	220	Zn Cd	AM	9.3	Cattle damage
Barhaugh		Gravel	NY690512	210				Survey needed
Williamston	SSSI; SAC; NWT	Gravels	NY681519	200	Zn	AEMTVPD	26.6	Much of the lichen interest was lost during recent scrub invasion, but metallophytes recovering well in response to annual clearance and strimming. Important *Epipactis dunensis* site (c.200 spikes 2004-2006).
Knarsdale		Gravels	NY678534	180				Survey needed, a large area but grazed by cattle
Eals	SNCI	Gravels	NY679555	170	Zn	AMTD	13.9	Gorse protects small areas of metallophytes from cattle, but is now overwhelming them. Cattle feeders on gravels causing severe damage.
Tows Bank	SNCI	Gravel	NY681572	165				Survey needed

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Lambley	SSSI; SAC	Gravels	NY677583	155	Zn	AEMTVPD	16.3	The main area of shingle has been severely damaged by recent flooding, sand deposition and birch encroachment. Used to have a large population of Epipactis dunensis but after a brief reappearance in 2006 this has now been lost. Birch thinning, vegetation stripping and soil removal down to the level of the gravel are urgently needed in the areas that used to support calaminarian, it will soon be too late to save this important site.
Coanwood	SNCI	Gravels	NY674587	150	Zn Cd	AMTD	17.2	A large area in pasture but not harmed by light cattle grazing. Some scrub clearance needed
Burnfoot	SSSI; SAC	Gravels	NY688623	125	Zn	MTPVE	13.9	Large site, almost entirely lost to woodland despite recent work to clear scrub from the main gravel area and strip off vegetation and soil to expose the gravel. More of this is needed, concentrating on areas with some chance of recovery. *Peltigera venosa* has now been lost to increasing shade, and the large *Epipactis dunensis* and *Viola lutea* populations are much reduced.
Bellister	SSSI; SAC	Gravels	NY695628	115	Zn	AMTLPD	20.0	An important and undisturbed species-rich site with large populations of metallophytes and lichens, including many Peltigera venosa. Now threatened but another invasion of gorse (the previous invasion was effectively controlled by arson!)
Wydon	SSSI; SAC	Gravels	NY693627	115	Zn	AMTVPD	14.9	The main area of shingle has been severely damaged by recent flooding, with the extent of exposed gravel greatly reduced by silt deposition. Gorse senescence and scrub clearance have been very effective in opening up the site, and recent small-scale grass and soil stripping should be effective. The population of *Epipactis dunensis* is increasing.
Haltwhistle		Gravels	NY706637	110		AMTVD		Small areas disturbed by dog walkers, survey and scrub clearance needed
Partridge Nest		Gravel	NY780643	90	Zn	AMT	18.6	Wide-scale scrub clearance has been carried out by the SOMM project, with some recovery of the calaminarian since. A small area from which the soil has been stripped and into which metallophytes have been reintroduced should be monitored.

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Beltingham	SSSI; NWT	Gravels	NY785640	85		AMTVE	12.1	Scrub clearance and strimming are working well by the road but the area of metallophyte grassland is still shrinking and the *Viola lutea* population is very much reduced. The main area (for which the site was designated) is completely lost to trees, but developed a small population of *Epipactis dunensis* (not seen recently).
Crow Hall		Gravel	NY793644	80				Survey needed. Site of the first records of metallophytes on the South Tyne but none seen recently. Potential *Epipactis* site.
Wharmley	SSSI; SAC	Gravels	NY892672	45	Zn	EMTV	8.8	*Epipactis dunensis* and metallophytes declining.
Baddox	SSSI; SAC	Gravels	NY900666	40	-	AMTVD	13.4	An interesting flora is developing on an artificial gravel opposite Warden Paper Mill, but without metallophytes. Older gravels along riverside are being overwhelmed by scrub, scrub clearance ad strimming would help but check for *Epipactis dunensis* first. This may interfere with angler parking.
East Allen alluvial								
Allenheads		Gravels	NY850465	365		MVL	16.1	Survey of west gravels needed
Sipton		Gravel	NY845497	310		MV		Survey needed
Black Bank		Gravel	NY841513	270		MTVD		Recently disturbed by hay meadow recreation project, resurvey needed.
Old Man's Bottom		Gravel	?	?		V		Survey needed
West Allen alluvial								
Ouston		Gravel	NY781526	235				Survey needed
Blackett Bridge	SSSI; SAC	Gravels	NY780537	225	Zn	MTVLD	14.1	Unstable site, disturbed by flooding and cattle but with a spectacular population of *Parnassia palustris*
Whamlands	SSSI; SAC	Gravels	NY781542	215	Zn Cd	MTVLD	25.4	Excellent, undisturbed site. Intense rabbit grazing is preventing development of displays of flowering metallophytes, but is also preventing scrub and coarse grass invasion.
Parmently Hall		Gravels opposite Whamlands	NY782547	215				Survey needed
Allen alluvial								
Allen Confluence	SSSI	Island gravel	NY800587	150	Zn	-	7.7	Scrub clearance needed. No metallophytes when last surveyed (notified for invertebrates)
Briarwood Banks	SSSI; NWT	Briarwood banks gravel	NY795619	95	Zn	TV		Survey needed. Recent scrub clearance has extended the area of calaminarian considerably. ,

Location	Status	Metalliferous deposits	Grid ref	Alt. (m)	Metals	Indicators	IBI	Notes
Plankey Mill	NT	Allen Banks gravel	NY795623	95	-	V	3.2	*Viola lutea* populations fluctuate but are generally declining, some thinning of the encroaching woodland would help.
Tyne alluvial								
Watersmeet	SSSI	Gravel	NY918661	35				Survey needed
Hexham	CP	Gravel	NY945642	30		E		Recent large *Epipactis dunensis* population (in 2005), Survey needed
Close House	SSSI; NWT	Gravel/dredgings	NZ125649	10	-	TED		Ongoing mowing and scrub clearance are working well. Increasing *Epipactis dunensis* population (182 spikes in 2006) under beech.
Newburn	CP	Gravel	NZ180638	5		E		Large *Epipactis dunensis* population in 2004, threatened by scrub closure. Survey needed

Appendix B Photoguide to calaminarian grassland species

All photos are © Janet Simkin. Indicator species (metallophytes) are marked with *.

* Thrift (*Armeria maritima*)

* Pyrenean scurvy-grass (*Cochleria pyrenaica*)

* Spring sandwort (*Minuartia verna*)

Dune helleborine (*Epipactis dunensis*) *

Thyme (*Thymus polytrichus*)

Grass of Parnassus (*Parnassia palustris*)

* Alpine penny-cress (*Noccaea caerulescens*)

* Mountain pansy (*Viola lutea*)

* Mountain pansy (*Viola lutea*)

Sheep's fescue (*Festuca ovina*)

Common bent (*Agrostis capillaris*) with spring sandwort

Ferns

* *Botrychium lunaria*

Mosses

* Pale thread-moss (*Bryum pallens*)

* Stubble-moss (*Weissia controversa var. densifolia*)

Juniper hair-cap (*Polytrichum juniperinum*)

Tree moss (*Climacium dendroides*)

Glittering wood-moss (*Hylocomium splendens*)

Springy turf-moss or lawn moss (*Rhytidiadelphus squarrosus*)

Lichens

* ‘brillo pad’ (*Cetraria aculeata*)

* Epilichen scabrosus (on *Baeomyces rufus*)

** Cladonia cariosa*

Cladonia chlorophaea

Cladonia furcata

Cladonia rangiformis

* ‘red barrels’ (*Sarcosagium campestre*)

* ‘fish bones’ *Ochrolechia frigida*

** Vezdaea aestivalis*

Baeomyces rufus

Peltigera leucophlebia

Peltigera membranacea

Peltigera neckeri

Peltigera hymenina

Peltigera venosa

Stereocaulon dactylophyllum