1. Introduction

The extensive heathland, characterised by dwarf shrubs dominated by ericaceous species, of present times are a semi-natural habitat, present largely as a result of interference by man. They once covered vast areas of Britain and Europe but now, also as a consequence of the actions of man, much of this habitat has been lost or degraded. Since the 1940s around 30% of heathland has been lost in England and Wales, 11% has also been lost in Scotland with about 25% of total loss due to overgrazing resulting in the establishment of *Agrostis-Festuca* grassland (Usher and Thompson, 1993).

Heathland vegetation types were once naturally limited mainly to coastal and upland locations and also temporary forest glades. In the coastal and upland locations combinations of poor soils, humid climate and wind exposure created unsuitable conditions for tree growth (Environmental Advisory Unit, 1988) therefore halting typical succession at this dwarf shrub stage. Heathland vegetation present due to the creation of temporary glades in the extensive forests which once covered vast areas of Britain and Europe. These were caused where trees may have died or fallen on free draining sandy soil which, as the soil is unable to retain nutrients such as nitrogen and phosphorus due to leaching, it is fairly infertile therefore leaving open areas for these smaller shrubs and herbaceous species to thrive. These glades began to be expanded as early as Neolithic times, although there has been some disagreement over whether the expansion was completely due to mankind or as a result of climate (Gimingham, 1972). It is, however, generally accepted that heathland developed from the destruction of woodland in prehistoric times and has been conditioned and maintained by persistent burning and grazing and because of this is liable to successional changes when these regimes are altered or stopped. There is evidence of human settlements on and around the Stiperstones which may account for the once extensive heathlands found here. Evidence of activity during the Bronze Age can easily be found (Figure 1.1) and although the expansion of heathlands began to tail off during this period there still remains this anthropogenic link between the Stiperstones heathland and human settlements. The Stiperstones is an intriguing area of extensive heathland which is further enhanced by the strong anthropogenic links with the past.

Figure 1.1 Bronze Age burial cairns stretching between Manstone Rock to the Devil's Chair along the Stiperstones ridge. Source: www.bbc.co.uk

The heathland habitat as it is today is an intrinsically unstable environment (Miles, 1985), a changing mosaic in a cycle of limited succession. Different aged stands of heather increase the potential biodiversity of the habitat, particularly for birds e.g. stonechat – *Saxicola torquata*, and also protect against the risk of wildfire. Heather has a four phase life cycle: pioneer - small pyramidal shaped growth lasting about 3-6 years (Figure 1.2a); building - lasts until the plant is about 15 years old this stage is also the most dense allowing very little light penetration to the ground (Figure 1.2b); mature – growth and vigour both slow down the plant is aged between 20 - 25 years the oldest part of the plant, the top central part tends to spread apart allowing greater light penetration to the ground (Figure 1.2c) and the regenerating phase – a gap appears in the centre of the plant which expands at age 25 – 30 with only the outer branches remaining alive and generally spread flat out on the ground (Figure 1.2d). The older stages begin to allow more light penetration

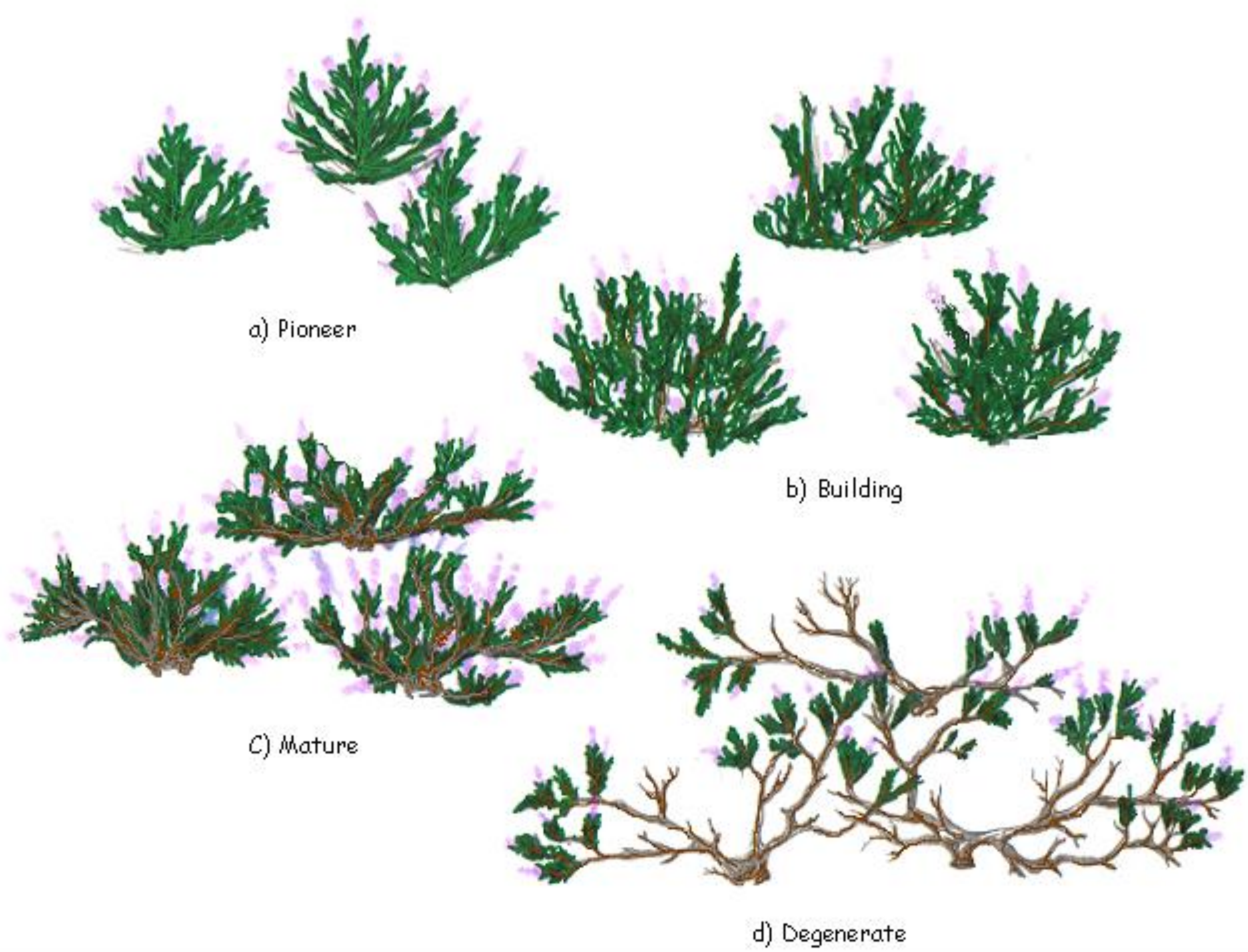

Figure 1.2 Structural diversity of heather, the four main phases associated with typical growth.

which in turn allows heather seedlings to grow in the newly re-opened spaces. As heathland plants are not a climax vegetation type management techniques hold the cycle of succession to these stages preventing further development to woodland. Whether the original expansion of the habitat type was or was not as a direct result of the activities of mankind (Gimingham, 1972) the maintenance of this intermediate stage in a natural succession certainly is, through grazing and burning practices.

The Stiperstones once supported a continuous ridge of heathland habitat for about 10 miles. Records showing this continuous vegetation indicate that this area demonstrated the transition in vegetation from southern lowland heath to the northern upland heath communities found on the spine of the ridge (Pywell *et al*, 2002). Due to afforestation by conifer plantation and changes in agriculture, predominantly since the 1950s, the unbroken ridge has become seriously fragmented and habitats degraded. Changes in agriculture and agricultural policy since World War Two have had a serious impact on heathland communities. Intensification in agriculture to create a self-sufficient Britain caused increases in the overall area of improved grassland, primarily as a result of government subsidies encouraging the use of fertilizers to intensify the use of infertile lands (Davidson and Lloyd, 1979); this can alter the species composition of heathland shifting from *C. vulgaris-V. myrtillus* dominated vegetation to *Molinia coerulea* grassland but also as the result of over-grazing on heathland causing a shift towards *Agrostis* sp -*Festuca* sp grassland (Usher and Thompson, 1993).
During the late 1990s English Nature developed a project- *Back to Purple,* in partnership with Shropshire Wildlife Trust and Forest Enterprise, with the aim of arresting habitat reduction and fragmentation by restoring heathland and

surrounding habitats to the Stiperstones (Figure 1.3). The reversal of fragmentation by expanding even very small areas of heathland may be considered worthwhile (Piessens *et al*, 2005). The specific aims of this ongoing project were to restore and re-create more than 40 hectares of heathland within 5 years and to improve the surrounding habitats for the conservation of wildlife. This included: the restoration of heathland from bracken – *Pteridium aquilinum* invasion present largely as a result of both over- and under-grazing; the complete re-creation of large areas of heathland from conifer plantation, planted at various times over the last 150 years; and a change from low diversity improved grassland to a more floristically-rich, low fertility, diverse grassland habitat. The funding for this project came from a variety of sources, the most significant of which is the Heritage Lottery Fund which was gained through the Tomorrows Heathland Heritage project set up by English Nature as a 10 year programme to restore mostly lowland heathland habitats around the UK in 26 separate projects, funding has also come from the European Union and Tarmac, through Landfill Tax Credits.

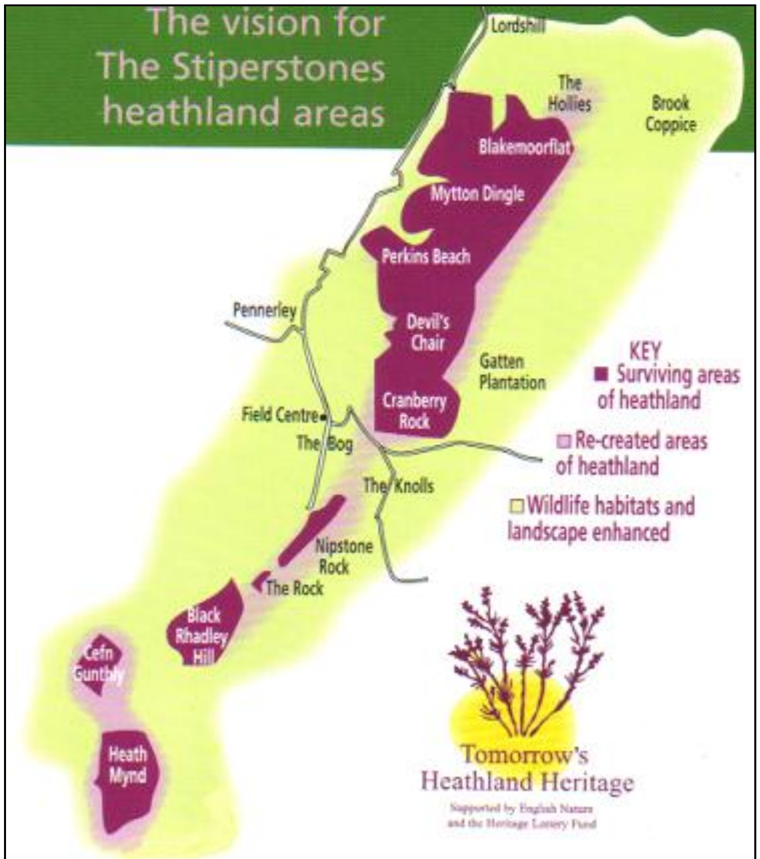

Figure 1.3 Plan for heathland and associated habitat restoration along the Stiperstones, Shropshire. Source: English Nature, 2003.

The aims of this report are firstly to analyse heathland restoration along a time sequence. By investigating changes in vegetation composition and diversity, and the soil chemistry at five sites in different stages of restoration, any significant relationships or processes of succession would be established by using canonical correspondence analysis (CCA). The second aim is to determine if management at the sites has been and will continue to be successful in the restoration from conifer plantation to typical heathland and thirdly to provide advice for the future management of heathland restoration projects.

2 Field site

2.1 The Stiperstones

The Stiperstones, situated to the south west of Shrewsbury, south Shropshire, (grid ref. SJ 370000) are part of the Stiperstones and The Hollies Site of Special Scientific Interest (SSSI) (original notification 1953 last revised 1971) which cover a total area of 587.8 hectares, 437 of which are part owned and managed as a National Nature Reserve (NNR) by English Nature. The site is situated within the Shropshire Hills Area of Outstanding Natural Beauty (AONB) Environmentally Sensitive Area (ESA). The Stiperstones, rising to an altitude of 536m, consist of a prominent quartzite ridge with pronounced tors, which rise up to 20 metres, along the length of it, the best known of which are the Devil's Chair and Cranberry Rock (Trueman, 1971). The underlying geology of this rugged formation consists of Arenig sedimentary Ordovician rocks underlain by Mytton and Tankerville Flags, with Stiperstones quartzite creating the characteristic ridges, also due to igneous activity in the area there are present lead veins which have been worked for centuries, since the Roman times. The mines and shafts are currently derelict but provide important winter roosts for several species of bat including the rare lesser horseshoe bat – *Rhinolophus hipposideros*. There is evidence of extensive human activity in this part of Shropshire from as far back as the Iron Age and it is likely that the large swathes of heathland present in this area are as a result of the actions of ancient man.

2.2 Study sites

The sites included in this report lie mainly on along the southern end of the ridge, with site 4 (Gatten Plantation) situated between Cranberry Rock and just beyond the Devil's Chair on the east facing hillside. They are situated in close geographical proximity to each other, running in a broken sequence to the north-east for about 3.5 miles (figure 2.1) and as such should all experience a similar climate. The only site completely segregated from the other four is the Gatten Plantation, which is separated

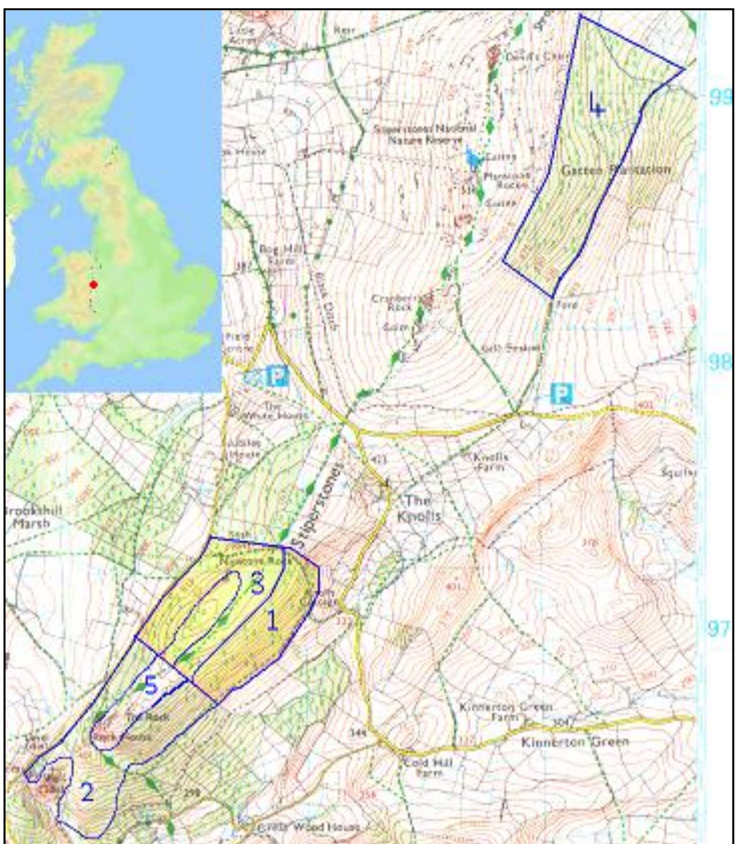

Figure 2.1. Map indicating five survey sites situated along the Stiperstones. Source: www.ordnancesurvey.co.uk

from the other sites by a conifer plantation, heathland and a lightly used public road. Management at the sites consists of light grazing by Hebridean sheep and Exmoor ponies. There have been no management burns at any sites since conifer clearance.

The sites where chosen for this study to produce a chronosequence of restoration: (Mitchell *et al*, 1997; Mitchell *et al*, 1999) three areas where conifers have been removed at different times will be compared with a pristine heathland and a very old conifer plantation. Site information is detailed (Table 2.1).

Table 2.1 Site details and descriptions

Site	**Site type**	**Grid ref.**	**Year felled**	**Notes**
1	Conifer plantation	Big Wood SO358968	-	9ha, small conifer plantation covering the base of the eastern slope of Nipstone Rock. Possible third rotation plantation planted c.1900, c.1930, 1962 (Pywell *et al*, 1997 *unpublished*).
2	Recent restoration	Within the Linley Estate SO355970	2004	24ha area, most recently felled, previously known as Ritton Woods's first rotation plantation was planted during 1962.
3	Older restoration	Nipstone Rock	1999	12ha area, first rotation plantation *Pinus nigra* and *P. sylvestris* planted

		SO358973		in 1971.
4	Older restoration	Gatten Plantation SO373986	1998	34ha area, second rotation conifer plantation where the ridge and furrow conifer plantation can still be seen. The area was first planted in 1850 and felled in the 1960s; it was then left bare for 30 years before being afforested once more in 1968 to 1970.
5	Pristine heathland	Nipstone Rock SO358969	-	5ha area, pristine heathland known to maintain NVC community H12, *Calluna vulgaris, Vaccinium myrtillus, V. vitis-idaea*. (Pywell *et al*, 2002)

2.3 Site management

There is no current management work on site 1 this will not begin until the removal of the conifer plantation which have been established on this site for over 100 years and it is unknown how many rotations have been planted. Site 5 currently has no grazing or burning regime applied to manage and maintain the heathland there. On sites 2, 3 and 4, following the clear felling of the conifer plantation from each site, management strategies between sites varied slightly. A seed bank survey was conducted on site 4 the results of which found insufficient seed in the south-western corner of the site. An application, by air, of extra seed was applied to this area this consisted mainly of suitable seed from a source in the Peak District. The brash and some litter was removed by burning in regular bonfires throughout the site. There have been no other burns on this site as yet and the ongoing management consists of a light grazing regime by four Exmoor ponies and sheep. Brash from site 3 was removed by burning on site this was carried out mainly in a low lying area in the north-western corner of the site. No extra seed was applied to this site. Grazing was introduced 5 years following felling this consists of 50 Hebridean sheep and three Exmoor ponies (Figure 2.2). The ponies are feed a supplementary feed of oats by their owner. There is currently no burning regime implemented at the site. Site 2 has experienced little or no litter disturbance

Figure 2.2 Hebridean sheep and Exmoor ponies graze the area around Nipstone Rock.

other than the deep disturbance, which penetrates into the topsoil, from the action of heavy machinery on site. There are a few main pathways and a large turning area of severe soil profile destruction mainly found along the north-westerly facing hillside. The brash has been piles into bonfire stacks ready for burning but the fires have not yet been set, most likely waiting for the autumn burning season to reduce the risk of wildfire of which parts of this site could be very susceptible to.

3 Method

Surveying and sampling at each site was carried out during July 2005 and consisted of the analysis of $2m^2$ quadrats randomly placed within representative areas of the chosen sites. It was necessary to specify representative areas due to very uncharacteristic areas of disturbance in site 3 from the previous use of heavy machinery during conifer clearance. The number of samples varied from 10 for the smaller sites increasing according to total site area on a *pro rata* basis to around 20 for the larger sites. The position of each quadrat was recorded using a Global Positioning System (GPS) which was accurate to within 5m. Sampling at each random quadrat included the collection of floristic data, vegetation surveys, and soil sampling, for further chemical analysis. The data gained from this work was then statistically analysed by multivariate methods.

3.1 Vegetation survey

Sampling at each random quadrat site consisted of identifying a full species list, nomenclature using Rose (1991; 1989) for higher plants, ferns and sedges, Hubbard (1992) for grasses and Dobson (2000) for lichens. Floristic data was collected on visual estimates of percentage cover for each species and bare ground. The use of $2m^2$ quadrats was deemed most suitable for the heathland habitat, being probable that this size would include an accurate sample of the typical plant population present at each site on both grasslands and dwarf heaths (Kent and Coker, 1998).

3.2 Soil sampling

Samples were taken from the top 0-15cm of soil from the centre of each quadrat site using a trowel cleaned between quadrats with deionised water. Each sample was stored in individual bags below 4°C before chemical analysis for pH, extractable phosphorus (Bradshaw, 1980), exchangeable potassium, magnesium and calcium.

3.3 Soil analysis

Fresh soil was shaken with deionised water and was measured for pH using a standard pH meter with buffers of pH4 and 7, the remaining soil samples were air-dried and sieved through a 2mm sieve. 4g of dry soil were shaken with 100ml ammonium acetate for 1 hour then filtered using Whatman 44 filter paper. Exchangeable potassium, magnesium and calcium were then analysed within these samples using the atomic absorption spectrometry with absorbance spectrometry for Mg and Ca, emission spectrometry was used for K. The mg/l results from this analysis were then calculated to determine accurate concentrations in mg/g. Extractable phosphorus was measured by shaking 5g of air dried soil with 100ml of Olsen's extraction for 30mins (Allen *et al*, 1974) with addition of de-colourising carbon to enable analysis through a colorimetric procedure. Concentration (µg/g) was then determined by the correct calculation.

3.4 Data analysis

The data was analysed using a variety of techniques to establish any relationships between vegetation and environmental variables. The methods used specifically for vegetation were to establish accurate diversity at each site by using the Shannon index (H'), also known as the Shannon-Wiener Index, which was calculated from the formula:

$$\text{Diversity } H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where s = the number of species
p_i = the proportion of individuals or the abundance of the ith species expressed as a proportion of total cover
In = log base$_n$

Vegetation and soil chemistry data were analysed with site age by canonical correspondence analysis (CCA) using CANOCO computer software (ter Braak, 1986). CCA is a direct ordination technique in which the species/sample data in the ordination are constrained to optimize their linear relationship to the environmental variables (Mitchell *et al*, 1999). The advantage of using this method exists in that it focuses on the relationships between species and environmental variables and provides an automated interpretation on the ordination axes (ter Braak, 1986).

Two ordination diagrams were created using CANOCO, CCA model 1 was to show all variables and CCA model 2 was to show the distribution of sample points on the axes developed from model 1. CANOCO was chosen over DECORANA as it is currently considered by some to be the superior method of vegetation/ environmental data analysis (Kent and Coker, 1998).

3.4.1 CCA Model 1

The program was carried out using all species (% cover), environmental variable and site data. The number of active samples was 67, with 33 active species and 5 nominal variables (sites). Species data (% cover) was transformed by a In (Ay+B), A= 1.000 & B= 1.000, bare ground was included in the species data as it was an important component of the habitats examined. The program was run without detrending with statistical validity being tested by an unrestricted Monte Carlo permutation test. The information inputted to the CANOCO program was plotted onto ordination diagrams. Environmental variables were represented by arrows (vectors), the length of which was proportional to the rate of change in the direction of the arrow (ter Braak, 1986; 1987). The vectors were scaled to be displayed at twice there actual length in order to be able to fit all sample data onto the chart due to environmental variables, vegetation and site data being at different orders of magnitude. The direction of the arrows indicates the correlation of that variable to the axes.

3.4.2. CCA Model 2

The data input used to create CCA model 1 was identical for model 2 the display was altered however to show each individual sample point. This was deemed necessary to more precisely identify trends and also to include all these points on one chart would be too cluttered to be useful.

4. Results

4.1 Vegetation and site description

Sites 1 – 4 were all disturbed habitats with varying species composition, diversity and percentage cover tree stumps were not removed from any restored sites as it was thought the financial cost outweighed any aesthetic advantage. Throughout all sites two species remained constant *V. myrtillus* and *D. flexuosa* both of which are typically associated with Stiperstones heathland habitats. Overall species richness varied significantly between sites with the lowest diversity found in the pristine heathland (site 5) and conifer plantation (site 1). Species richness increased through the time sequence from 13 individual species being found at site 2 through to 19 at site 4 and just 8 at site 1 and 9 at site 5. By using the Shannon Wiener Index to estimate diversity site 2 was indicated to be the most diverse, H = 2.04, for site 4 H = 1.86, with sites 3 and 5 showing a similar lower diversity, H = 1.56 & 1.50 respective. The lowest diversity H = 1.20 was found in site 1.


Figure 4.1 Deep needle litter covering the ground within Big Wood, conifer plantation.

Big Wood conifer plantation, site 1, covers part of a south-easterly facing hillside below Nipstone Rock (Figure 4.1). The ground between the well established conifers was mostly un-vegetated other that towards the edges and in areas opened due to fallen trees, possibly as a result of wind throw judging by the trunk damage. The canopy cover, having closed many years before the time of this survey, was complete (other than due to wind throw) as a result very little sunlight penetrated even a few metres into the plantation. The floor of the plantation was covered with a thick (~8cm) mostly undisturbed needle litter layer. General observations from site 1 showed certain species (ferns) were missed by random quadrat sampling these were mostly found in wet flushes down the site. The range of ground flora present was narrow with a total of 8 species found. The most frequently identified species was *Vaccinium myrtillus* the most dominant species were two different mosses (moss 1 & 2) present at a mean percentage cover of 11.3 and 17.9 respectively, with either one or both of them being found in 80% of the quadrat samples, however the total area of bare ground far exceeds that of vegetated areas, except for ground nearer to the edges of the plantation and in more open parts percentage vegetation cover was notably increased.

Site 2 supported very little vegetation overall with over half of the sample quadrats having <5% vegetation cover. This site covers two hillsides (Figure 4.2); there was some difference in vegetation cover and diversity between the north-westerly and south to south-east facing slopes, with the greater amount of vegetation being found on the northerly aspect. The dominant species at this site were *D. flexuosa, V. myrtillus*, and moss 1, there was also a high cover of bracken – *Pteridium aquilinum* and rosebay willow herb - *Chamaenerion angustifolium*. Grasses were frequent in small amounts within this site with *D. flexuosa* being the most abundant and also creeping soft grass - *Holcus mollis*, not found elsewhere. There were also many seedlings and young trees around the site particularly holly - *Ilex*

Figure 4.2 Site 2 situated within the Linley Estate covering two sides of the hill (a) south to south-east facing and (b) north-west facing.

aquifolium and rowan - *Sorbus aucuparia* with the occasional conifer Scots pine - *pinus sylvestris*. During an early walk through survey of this site many individual plants of wood sorrel – *Oxalis acetosella* were found but none were present at the time of this survey.

There was very little bare ground at site 3 (Figure 4.3) which covered part of a hillside including both a steep north-west aspect and more gently angled south-east aspects. Brash bonfire sites, roughly circular areas supporting non-typical heathland vegetation, were mostly limited to the bottom west corner of site 3 and therefore did not interfere with typical heathland restoration (vegetation colonisation and growth, % cover) over the main body of the site. Nipstone Rock had a high dominance of *C. vulgaris* with a constantly high presence of *D. flexuosa* increasing where *C. vulgaris* was sparser. Moss cover varied greatly around the site ranging from complete absence to areas of ~50% cover. There were frequent

Figure 4.3 Calluna vulgaris in flower on the south-eastern hillside at Nipstone Rock, site 3.

appearances of *V. myrtillus* (half of surveyed quadrats) although these were fairly small, covering no more than 15% total cover in any one quadrat. The overall diversity of this site was quite high in comparison to the other sites surveyed. The majority of plants responsible for this diversity were present in small amounts, infrequently scattered throughout the site. There was evidence of declining quantities of bramble - *Rubus fruticosus* on site as often across the site were found long, dead branches, with only a few remaining living examples left. Soft rush – *Juncus effusus* was found in the largest amounts within this site with large clumps, ~30cm diameter at base, growing frequently around the eastern aspect.

Positioned regularly around site 4, Gatten Plantation an east to south-easterly facing hillside (Figure 4.4), were many areas of brash bonfire sites, the vegetation present within these areas was different to unburned ground there was an overall dominance of *C. angustifolium* and the vegetation was not typical of heathland. The majority of the site was not burnt and was dominated by *C. vulgaris* and *D. flexuosa* and overall the cover of *D. flexuosa* was much greater in this site than any other. Following seed bank trials on this site extra seed was dispersed by air to an area deemed to hold an insufficient seed bank for natural re-colonisation of the site. However the area of seed application remained the least colonised by heather for many years (personal communication Tom Wall, 2005). The diversity and species richness was highest here, a total of 19 species found, several of which, *Juncus squarrosus, Antennaria dioica, Digitalis purpurea, Rumex acetosella, Eriophurum vaginatum* were not found in other sites but could be attributed to wet flushes present throughout the Gatten Plantation. There was also fairly high cover of *Ulex europaeus* and *Galium saxatile* which leads the site to most closely resemble NVC community H9 *Calluna vulgaris-Deschampsia flexuosa* heath with a *G. saxatile* sub-community.

Figure 4.4 Site 4 the Gatten Plantation, line of old tree stumps visible among large areas of C. vulgaris and D. flexuosa.

Site 5 (Figure 4.5) was the only undisturbed, pristine heathland community defined, according to the National Vegetation Classification (NVC) (Rodwell, 1998), as a H12 *Calluna vulgaris – Vaccinium myrtillus* heath. The diversity at this site was very low, as is typical of heathland habitats, a total of nine species were found, the most dominant of which were *C. vulgaris* and *V. myrtillus*. There was also a presence of cowberry - *V. vitis-idaea* throughout the site which was not found elsewhere in the areas surveyed for this report. One species found solely at this site, within more open areas of ground, were large quantities of the lichen - *Cladonia portentosa*.

Figure 4.5 Untouched heathland growing on 'The Rock', the pristine heathland extends along the ridge of the hill onto this rocky outcrop at site 5.

4.2 Soil results

The results for all cations analysed showed site 1 to contain the least concentrations of any nutrients and also the results for this site appeared the most uniform. In general there appeared to be an increasing trend within sites 2, 3, and 4 for Ca, Mg and pH (although sites 2 & 3 were very similar in pH). The results for potassium were fairly uniform between sites with site 4 again containing the maximum concentrations. Phosphorus differed from the general trend in that the mean concentration for site 4 was very low, lower than site 5. The results are further detailed below and are summarised in Table 4.1.

Table 4.1 Chemical properties of soil samples, mean concentrations, ions are expressed as mg/g; P is expressed as μg/g.

Site	pH	Ca	Mg	K	P
1	4.09	38.73	48.93	146.43	1.09
2	4.16	63.70	55.94	186.43	19.0
3	4.15	84.29	81.00	156.40	24.3
4	4.35	137.90	97.17	198.95	4.2
5	3.89	53.13	67.23	193.95	9.3

All soil samples taken were strongly acidic, ranging between pH 3.57 to 4.89 (Figure 4.6), with site 5 being the overall most acidic. The pH increased through the restored sites with site 4 being the least acidic. As stated above site 5 maintained

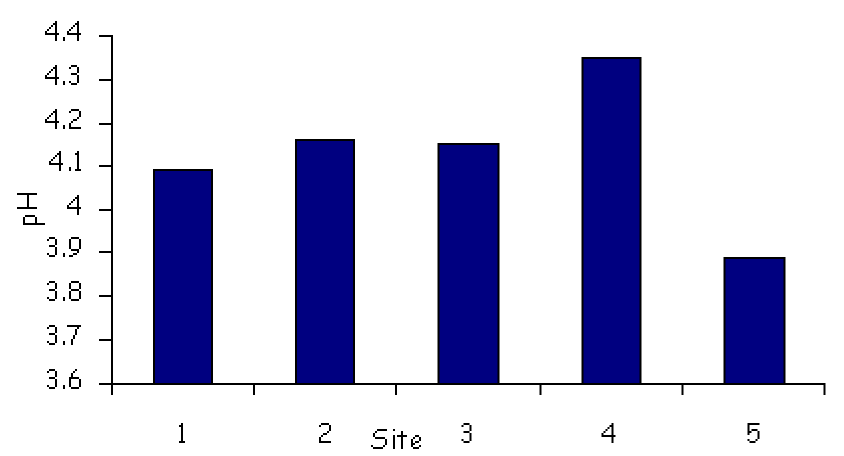

Figure 4.6 Mean pH value for sites 1 - 5

the lowest constant pH averaging pH 3.89, with a range of 3.57 - 4.17, site 1 was also low, averaging pH 4.09 with a range of 3.76 - 4.28, this was the most narrow range. Sites 2 and 3 were very similar in pH 4.16 & 4.15 respectively, however the range for site 3, pH 3.58 - 4.60, was about twice as large as that for site 2, pH 3.93 - 4.49. The highest results were found in site 4, averaging pH 4.35, the largest range was also located here, pH 3.78 – 4.89.

There appears to be a steady increase in mean soil Ca, Mg and K from sites 1 – 4, levels which then drop considerably at site 5. The levels of Ca, Mg and K at site 5 are similar to that at sites 1 and 2. There also appears to be a general trend in concentrations of these nutrients at each site, where great similarities are found between sites 1 and 5 (Figure 4.7). Site 4 was held the highest levels of all soil nutrients other than P which was very low at this site, lower than mean the mean level of P for site 5, with many individual samples being recorded as 0.0µg/g of soil (see Appendix).

The results for exchangeable calcium show an overall steady increase through the restored sites. The lowest results were found in the conifer plantation, site 1, which averaged 38.73mg/g with a minimum concentration of 8.33 mg/g and maximum of 79.05mg/g and the pristine heathland, site 5. The mean concentrations for calcium are displayed in Figure 4.7 with Mg and K, P is shown in a separate figure.

Magnesium displayed a similar trend of gradual increase through the time line of restored sites as shown for calcium (Figure 4.7). Site 1 had the lowest mean concentrations, however site 5 was found to be slightly higher than site 2 as was

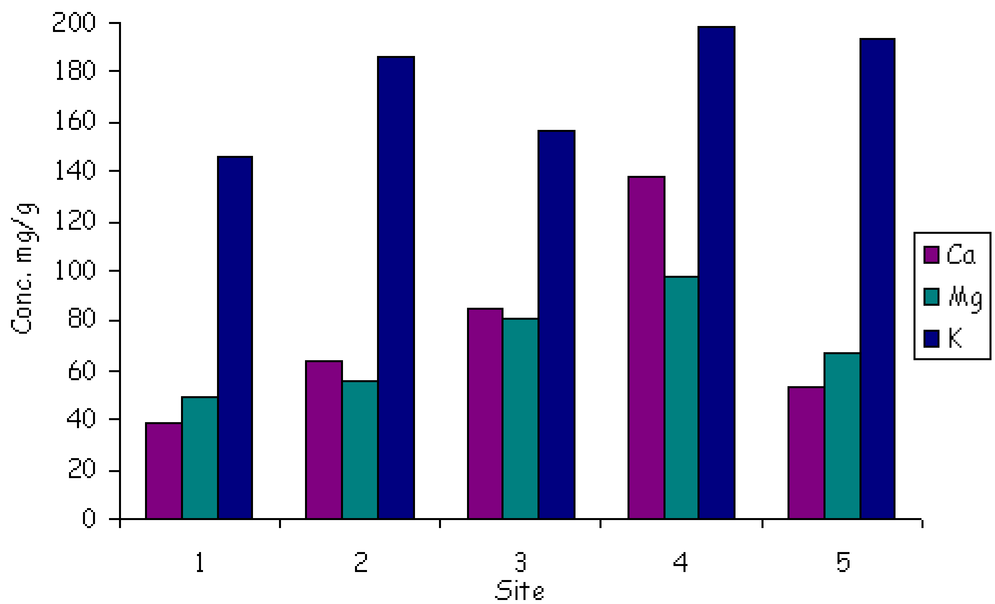

Figure 4.7 Mean concentrations of calcium, magnesium and potassium mg/g for sites 1 - 5.

not the case for Ca. The range of concentrations found in the Mg samples was larger than Ca, the samples showed much greater variety within a site, with site 1 appearing the most uniform with a range of 29.75mg/g to 74.50mg/g.

Potassium for all sites fell into a fairly narrow range for the mean results, similarly the results for the complete range within a site was also quite narrow. Site 1 again appeared the most uniform with a range from 116.50mg/g to 192.25mg/g whereas site 4 ranged from 83.75mg/g to 539.25mg/g however 539.25mg/g seemed anomalously high (see appendix 1) and without the inclusion of this sample the mean would be 186.44mg/g which would give site 5 the highest mean concentration of K. Overall phosphorus was very low, in many individual samples the concentration was too low to be identified or absent. This was the case in 90% of samples from site 1 and 75% of samples from site 4 which recorded 0.0μg/g for P. Most of the samples in site 5 had identifiable concentrations of P present but these were generally very low most falling below 10μg/g with a couple fairly high above the average, 21.4μg/g and 15.5μg/g. the mean concentrations showed site 1 to be the lowest in soil P with, unusually, site 4 also displaying a very low mean P, sites 2 and 3 were highest in mean P (Figure 4.8) with extremes of 70.8μg/g and 49.0μg/g, these sites also had some blank samples as such the range in concentrations was wide. The mean for site 5 came mid-way between the extremes for all sites.

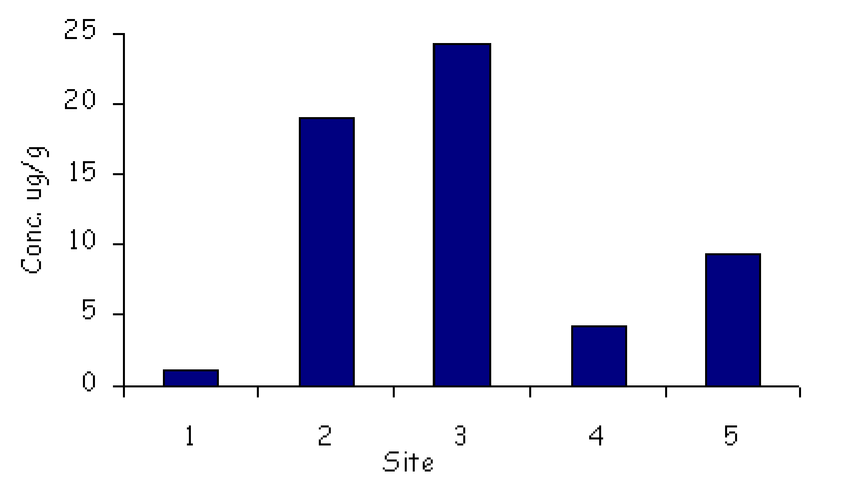

Figure 4.8 Mean concentrations of phosphorus (ug/g) for sites 1 - 5.

4.3 The CCA model

The first axis accounted for 36.4% of species-environment relation with axis 2 accounting for 60.8%. The eigenvalues for axis 1 and 2 were fairly high (see Table 4.2) the highest overall value of 0.512 was for axis 1, indicating that correlations associated along axis 1 hold the most significance. Statistical analysis found the eigenvalue for axis 1 to be significant to p-value = 0.002.

Table 4.2 Eigenvalues, species-environment correlations and cumulative percentage variance for four axes for CCA analysis.

Axes	1	2	3	4
Eigenvalues	0.512	0.342	0.156	0.111
Species-environment correlations	0.949	0.887	0.716	0.700
Cumulative percentage variance:				
of species data	12.1	20.2	23.8	26.5
of species-environment relation	36.4	60.8	71.9	79.8

4.3.1 CCA Model 1

The ordination diagram for vegetation species (% cover), environmental variables and site age (age of restoration) (Figure 4.9) shows a significant relationship between the age of a site and the vegetation composition and cover within that site. The vector lengths are totally dominated by pH which is more than twice the length of the other environmental variables, K, P, Ca, and Mg. the order of importance of soil nutrients according to vector length show Mg to be the dominant nutrient followed by Ca, K and P.

The dominant patterns in community composition are represented jointly by species and site points. The site points are positioned about the diagram in a clockwise pattern roughly according to the chronosequence of site restoration. Sites are marked on the diagram by the year of restoration: site 1 – 2005, site 2 – 2004, site

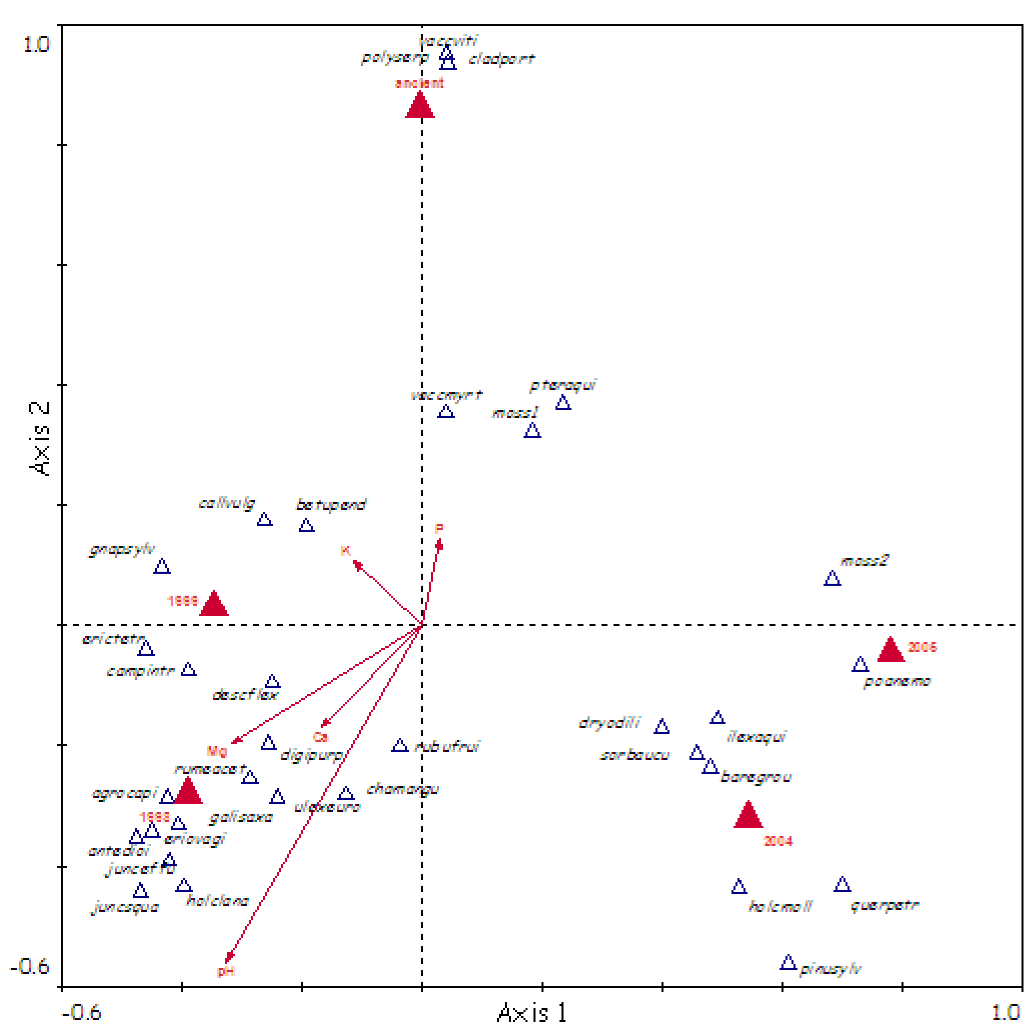

Figure 4.9 Ordination diagram from CANOCO for all data showing the relationships between vegetation species, site and soil chemistry. Full length species names can be found in appendix 1.

3 – 1999, site 4 – 1998 and site 5 – ancient. Sites 1 and 2 are situated near each other to the bottom right of the diagram. Site 1, on the far right, has two species most closely correlated to it *Poa nemoralis* and moss 2, which also according to vector position correlate to both low Mg and K concentrations with slightly more influence coming from Mg. Moving forward in the time sequence to the next site

(site 3) the pattern is slightly disturbed as site 4 appears next, however sites 3 & 4 are quite close together indicating a certain amount of similarity and overlap between the two. The highest species richness is located around the point for site 4. According to vector location the species present at this site correlate to the highest magnesium, calcium and pH levels with similar but weaker correlations with site 3.

Species associated with the pristine heathland habitat are situated towards the centre and top of the diagram. Progressing clockwise through the diagram from the left side through an area of increased K towards increasing P correlations species become scarce and more typical of heathland habitats. This area of the diagram also generally correlates to lower soil Ca and Mg and lower pH, as is typical of heathland. The most closely associated species with the ancient site were shown to be *V. vitis-idaea*, *Polygala serpyllifolia* and *Cladonia portentosa*. Phosphorus was also noted to be the most influential soil nutrient upon the heathland vegetation.

4.3.1 CCA Model 2

In order to show the true representation of sample sites along the axes the CANOCO program was run with a sites only display (Figure 4.11). The ordination diagram from this shows individual sample sites clustered in site specific groups, as previously indicated from CCA model 1 in the previous ordination diagram (Figure 4.10), there is some overlap between sites 3 and 4 which further explains the similar correlations for these sites in CCA model 1.,

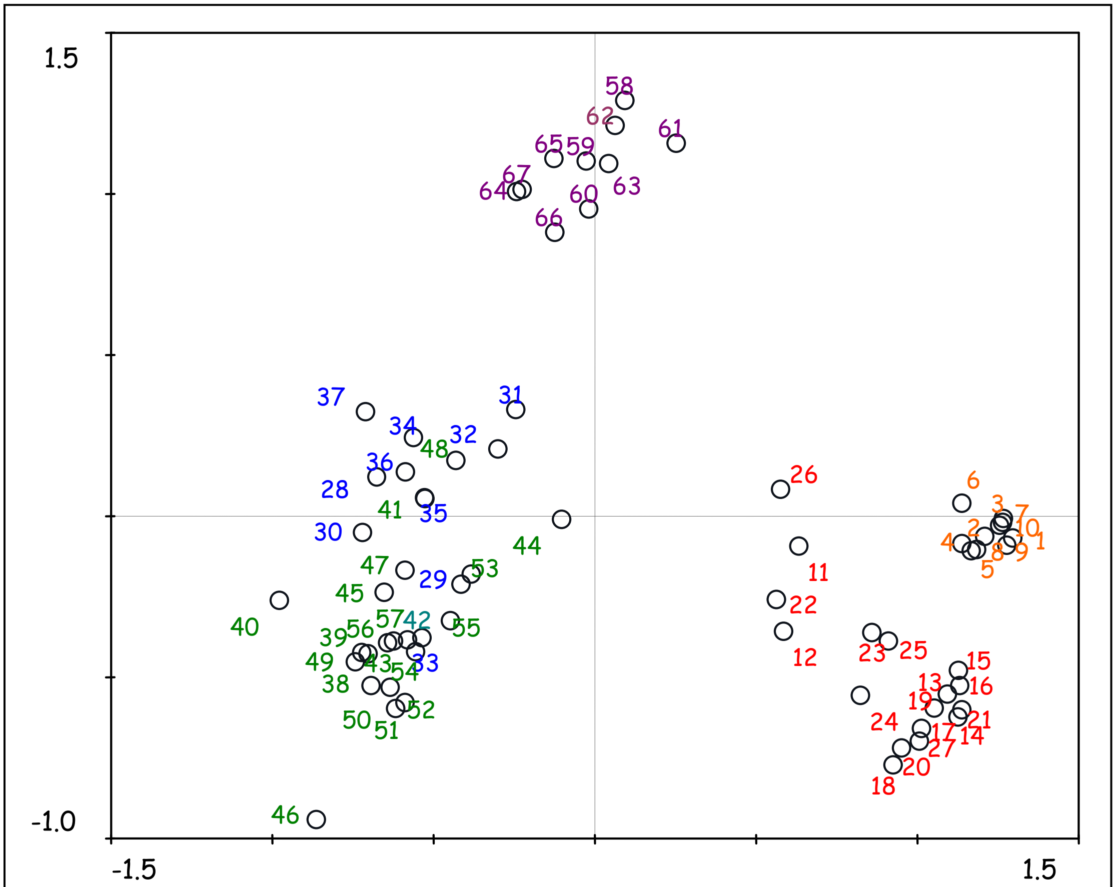

Figure 11. Ordination diagram from CANOCO with sample number only data indicated, colour coded by site: site 1; site 2; site 3; site 4; site 5.

4.4 The Shannon index

The results calculated for the Shannon Index show diversity to be highest on site 2, H' = 2.043, where many species were found associated with a range of habitats woodland - *Quercus petraea*, heathland - *Vaccinium myrtillus* and scrub - *Chamaenerion angustifolium*. Diversity was more reduced on site 4 where H' = 1.86, at sites 3 and 5 the diversity was shown to be quite similar, site 3 H' = 1.56 and site 5 H' = 1.50. The site with the lowest diversity according to this method of calculation was site 5 with a value of H' = 1.20.

5. Discussion

5.1 Chronosequence of restoration

Sites 1 and 5 were chosen to represent start and end points in the chronosequence of restoration, with intermediate stages covered by sites 2, 3 and 4. Restoration appears to be progressing well in those sites but although the vegetation cover is high with appropriate species present the soils are still in an unstable state when compared to those of sites 1 and 5. The soils and vegetation of sites 1 and 5 appear to be in a steady state, diversity is low and the range for all environmental variables is the lowest of all sites, indicating fairly homogenous chemistry throughout the site, these observations could also be said of site 5 chosen due to its pristine nature. The CCA models showed similarities between the correlations of sites 1 and 5 with negative Ca, Mg and low pH. When the conifer plantation are cleared there appears to be an increase in pH and available soil nutrients, this may be due to the pH increasing without the acidifying impact of conifers. There was shown to be a positive correlation between the pristine heathland and increasing P by CCA model 1, a condition previously recorded (Mitchell *et al*, 1999). Site 4 showed a very low mean concentration for this nutrient possibly to the rather lush and diverse vegetation growth on that site which had a greater demand on the soil P for survival.

Soil chemistry can be altered by the actions of plant species growing upon it by the decomposition of the litter and the varied uptake of nutrients. The litter produced by some species can alter the chemical composition of soil in both plant nutrient and secondary chemicals. Soil pH increases due to the absence of positive feedback mechanisms from conifers or *C. vulgaris*, both of which are strong acidifiers of soils the latter creating marked acidification within a decade (Miles, 1985). This type of feedback can also be known as a Type 1 (one-sided) switch where plant species X acidifies the soil creating more favourable conditions for species X. This type of mechanism can occur with soil nutrients e.g. species X uptakes calcium into the roots when growing on calcium rich soils this results, put very simply, in there being less Ca present in the soil therefore species X has changed the soil chemistry by altering the concentration of Ca present. Where this type of switch occurs the plant may begin in a small patch which would then expand by changing its surrounding environment, altering the conditions outside its range to be more suitable for itself, which would allow the species to further expand (Marrs and Bannister, 1978; Usher and Thompson, 1993).

The increase in pH increases the mobility of some of the soil plant nutrients (Ellis and Mellor, 1995) creating an environment more suitable for a wider range of species and bare ground is quickly colonised by rapid growing plants such as grasses and particularly rose-bay willow herb - *Chamaenerion angustifolium*. In particular the areas of burn appear to be the least advanced towards the desired heathland vegetation, being dominated by *C. angustifolium*. This is particularly noticeable on the Gatten Plantation where from a distance the burn sites appear as bright green stripes down the hillside. These areas, while creating a more diverse habitat, are unwanted and future brash burning should be minimised, it is appreciated that it may be difficult to dispose of the large amounts of brash generated from plantation clearance but it may be better for the more rapid development of heathland to allow burning in fewer places to minimise the extent of the damage to the soil and seed bank. Burning is a traditional part of heathland management however uncontrolled burns on even well developed mature heathland can be seriously detrimental to the recovery of the plants in a similar manner as found on sites 3 and 4. Figure 4.9 displays the CCA diagram which clearly indicates that in order to restore the typical low plant diversity to the Gatten Plantation the pH is the key. By reducing the pH this would limit the species capable of growing there, however English Nature may be reluctant to add agents to the land, such as sulphur, and may prefer to allow nature to continue what they have started, although this will result in the complete restoration of the heathland being a much lengthier process.

There were significant differences in species composition between sites this varied both with age and management technique implemented at each site. There appeared to be an increase in species richness with restoration time. The use of the Shannon diversity index showed fluctuating diversity between the sites. However the Shannon Wiener Index (Shannon Diversity Index) presumes knowledge of a complete species list for each habitat (site) and this may not be accurate in this study as species were found on some sites which were not found in any quadrat and so were overlooked. This mainly refers to the fern species noted at site 1 among wet flushes through the site which unfortunately failed to fall within a random quadrat position. This was most likely due to the immediate availability of space, nutrients and (possibly most importantly) light, a serious limiting factor to plant growth under conifer stands and dense heather growth. Through this work it appears that the rapid influx of many species must stabilise and reduce to reach the goal of re-creating a low diversity heathland such as a NVC H12 *Calluna vulgaris* – *Vaccinium myrtillus* heath. Site 5 provides the template for desired vegetation community type for this area. It has been observed that with the successful re-establishment of heather from seed these less desirable weed species do eventually become shaded out following the dense growth of heather. The reversal of the fragmentation of heathland along the Stiperstones will hopefully see the natural expansion in the range of cowberry - *V. vitis-idaea* which has become present simply as a relic population isolated in site 5. This population should now be capable of expanding its territory into the Nipstone rock site as the C. vulgaris has done from site 3 to 2.

Site 2 was comprised of a hillside area covering 2 different aspects, north and south facing. There were found to be significant differences between the percentage cover of vegetation of the two hillsides and it is believed aspect may have played a vital role in this. The southern slope was cleared shortly after the northern side this is a factor which may have allowed for earlier colonisation and expansion of existing species, therefore giving the northern aspect a 'head-start'. Although there are no temperature or soil moisture records included in this report it was noted that the southern aspect was considerably warmer and dryer than the northern aspect, as would be typically expected. Deciduous trees planted around the base of this hillside were observed as suffering seriously from the lack of sufficient water, with many individuals appearing quite dead. Drought and desiccation of any vulnerable seedlings, this is particularly relevant to *C. vulgaris* seedlings (Britton et al, 2003), may therefore also account for the lower percentage vegetation cover present on this side of the hill, with the majority of plants found already well grown indicating they became established beneath the tree canopy before felling. It may be necessary to establish a watering strategy for this particular site to aid with initial plant growth.

The position of a donor seed bank provided a useful source of seeds for the re-colonisation of cleared ground. This was particularly noticeable on site 2 where gorse seedlings rapidly colonised an area of bare ground from an untouched area of growth approximately 2m away. Upon a later visit to the site following survey work *C. vulgaris* seedlings (Figure 5.1) were abundant in areas close proximity to an existing population but increasingly absent with distance from the donor population. It is unlikely that these germinating seedlings could be sourced from the dormant soil seed bank as the litter was left undisturbed and, due to the thickness of the litter layer ~8cm, it is unlikely that sufficient light would penetrate to initiate seedling growth from that source (Pywell *et al,* 1997 *unpublished*). The possibility of transplanting heathland turf may exist here as the Stiperstones supports, despite current problems, large areas of pristine heathland and the observed success of germination from a donor seed bank suggests this would be a successful technique for re-establishing heathland, particularly on site 2.

Figure 5.1 *C. vulgaris* seedling at site 2, the largest example measured a height of 6cm.

The existence of a viable seed bank is considered essential to any heathland restoration scheme. The absence of sufficient seed can in some cases create a situation where seed must be imported to the site from an external existing heathland and this additional expenditure could prove too much when there may be more suitable sites for cheaper restoration elsewhere. Due to time restrictions it was not possible to analyse the dormant seed bank it the soils studied in this report, it is acknowledged that this would have been particularly useful in assessing the potential for natural re-colonisation of heathland species following conifer removal and possible litter disturbance, particularly for sites 1 and 2. It has been well documented that for the regeneration and re-creation of heathland former land use on the site has a major influence on the survival rates of seeds in the dormant seed bank which must not be disregarded. It has been found that of all possible previous land uses conifer plantation allows for the best re-colonisation results by preserving the largest most viable seed bank (Walker *et al*, 2004). Heathland seed banks tend not to survive well under arable land use and grassland as result of predation, disease, soil erosion and germination following exposure during cultivation (Pywell *et al*, 1997), but can survive under bracken for some time however the viable quantity may become seriously reduced with longer periods of time >50 years (Pakeman and Hay, 1996). The long-term persistent heather seed bank survives well under conifer plantation this is due to the low pH which creates a hostile environment for soil fauna the absence of which combined with the lack of any other soil disturbance results in the accumulation of large numbers of seed at the soil surface (Putwain and Gillham, 1990). The seed can become covered in a thick layer of needle litter where it remains viable for many year, some trials a have found sufficient relic seed banks, ±500 – 1000 viable seeds m^{-2}, beneath conifer plantation from 70year old stands. There is some conjecture over the actual survival times as there are no definite records for the dates when the plantation canopy closes, therefore blocking light which eventually kills off seed producing heather. Also where plantations are in a second rotation the heathland may have had sufficient time of light exposure to regenerate and produce more seed before the canopy eventually closes again. So in this manner even areas of long standing plantation cover may still maintain a viable seed bank if it is second, third etc rotation planting. There has been previous work on the existent seed banks on various sites at the Stiperstones. These were carried out by Pywell *et al* (1997, *unpublished*) the results of which showed quite a variety in the size of viable seed banks. The estimated range from this work for *C. vulgaris* was 1840-15560 germinable seeds (m^{-2}). This range indicates that natural regeneration of *C. vulgaris* should begin following plantation clearance.

Litter disturbance to encourage seedling germination was practised over some parts of some sites involved in this study, however these are not recorded. The vegetation surveys of sites 3 and 4 found no particular areas of poorer percentage cover that may indicate no litter disturbance, it was therefore concluded that in the long term needle litter did not inhibit germination from the dormant seed bank. As site 2 is a first rotation plantation established ~40 years ago it is reasonable to assume the presence of a strong relic seed bank, therefore if re-colonisation does not appear on this site consideration should be given to extensive litter disturbance across the site.

Despite the relatively high diversity at the sites of later restoration the percentage cover of typical heathland species *C. vulgaris, V. myrtillus* and *D. flexuosa* is high. The aim of restoration work by English Nature was to re-create the lost heathland habitat so in this sense the restoration work has been a success in terms of the visual appearance. However the restoration of the soil doesn't appear to have been as successful as the soil nutrients have increased over time with an increasing range within the sites, and in this respect are dissimilar to the soils of pristine heathland in this area. This is not so significant a problem however as the vegetation has, and continues to, re-colonise the restored sites and therefore nutrient stripping would not be a consideration in site management for future work. The fact that the vegetation appears to be succeeding well on these soils is good and in fact the soils will themselves become altered by the influence of the vegetation growing on them. The soils can be indirectly tended by managing the vegetation upon them (Miles, 1985) this is so far handled by grazing as the heathland is too young to withstand any burning just yet. The main problem occurs on patches of severely burned earth, as discussed, and it would be recommended that instead of having many areas of brash bonfires that these are limited and where ever possible brash be taken off site or to a safe location to burn.

5.2 Management techniques

Grazing has always been an important part of moor and heathland management since ancient times. English Nature has realised this and under advice from outside organisations reinstated grazing to the recovering sites 5 years following heather germination. This time period was designed to protect vulnerable, young seedlings and to allow the *C. vulgaris* and *V. myrtillus* sufficient time to become established (Environmental Advisory Unit, 1988). However there was some concern that 5 years was too long, particularly at site 3 where bramble - *Rubus fruticosus* had become quite well established throughout the site (personal communication Tom Wall, 2005) it may therefore have been prudent to introduce grazing after 3 or 4 years as is also recommended by experts. Although the *R. fruticosus* may have been considered a problem in the past it appeared to be much more under control during the time of field work for this report, with many long stems being dead. It is commonly understood that the modern breeds of large domestic herbivores, sheep and cattle, require too high an energy intake and grazing technique together with physical poaching of delicate soils and high dung input to the site have a detrimental affect on heathland. This area has been well studied and it has been found that sheep feed selectively and although a lot is down to grazing pressure due to density dependence (Gimingham, 1972; Gorden *et al*, 2004; Pakeman *et al*, 2003; Steinheim *et al*, 2005) choosing the right breed can assist in heathland recover, cattle are not suitable as there is no strong selectivity to their grazing regimes. It was for that reason Hebridean sheep and Exmoor ponies were chosen to graze restored sites.

Hebridean sheep are a 'primitive' breed of sheep that can survive well on poor grazing with no need for high energy food input. They are a small, dark-brown, hardy breed that have no real commercial value due to their small size and the black skinned meat, which is apparently unpopular among consumers (pers. Comm. Tom wall, 2005). It is because of the size and digestive anatomy that they are suitable to graze heathlands and were chosen here. There is a 50 strong flock of Hebridean sheep on site 3 which do seem to be maintaining the heathland in good condition. There are also three Exmoor ponies that occasionally graze site 3 and four have been present on site 4. Exmoor ponies again were chosen mainly due to their suitability to the sites which are exposed to extreme conditions and as such require hardy breeds to survive there; supplementary feeding was supplied for the ponies. The recommendation for using grazing as a method of controlling unwanted invasive species from heathlands, following the study of the Stiperstones restoration sites, is site specific. Each individual site of heathland restoration should be considered individually, and has been shown here at the Stiperstones, should be reviewed and judged throughout the early years rather than sticking rigidly to a plan, by this it is meant that if a site appears to be suffering from invasion of aggressive weed species grazing may be implemented early than originally planned for possibly at a lighter rate i.e. smaller flock increasing with increased *C. vulgaris* dominance.

6. Conclusion

The re-establishment of heathland on the Stiperstones following conifer removal does not need to be an elaborate display of scientific genius as the Stiperstones forms an ideal site for this type of work. The methods applied by English Nature under instruction by restoration ecologists are straight forward non-complex strategies. The use of CCA and the CANOCO program were considered a success in establishing correlations along a time sequence in site restoration and has shown an overall increase in many significant (significant to heathland) soil nutrients and pH with time during restoration which are not associated with pristine heathland. It would, however, be an unnecessary waste of resources to further interfere with the soil processes other than allowing the vegetation to natural stabilise the soil chemistry over time. As can be seen from vegetation data from sites 3 and 4 heathland vegetation is flourishing and is well on the way to dominating the whole of those sites, where it will eventually out shade the less desirable species. It is therefore concluded that the management techniques thus far implemented appear on the whole to be successful, although more emphasis may be needed on reacting to situations in the field rather than simply following instructions. The use of Hebridean sheep appears to be a huge success on the area around Nipstone Rock with most of the area having at least the appearance of a typical heathland, although the soil chemistry still appears in a state of flux.

It would be interesting to monitor the chosen sites in the future to attain if in fact the vegetation does have a stabilising affect on the soils and to establish the expansion of the more isolated heathland species, cowberry - *V. vitis-idaea*, from previously isolated zones.

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