

# Ecosystem effects of woodland exclosures





Scottish Natural Heritage  
Dualchas Nàdair na h-Alba

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# RESEARCH REPORT

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**Research Report No. 971**

## **Ecosystem effects of woodland exclosures**

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# RESEARCH REPORT

# Summary

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## Ecosystem effects of woodland exclosures

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### Keywords

Grazing; over-grazing; fence; herbivore; deer; woodland structure; soil.

### Background

Over the last 150-200 years, herbivores have had a big impact on the vegetation throughout Scotland. Much has been documented about above-ground impacts, but impacts (both direct and indirect) on below-ground communities, soil properties and ecosystem function are largely unknown. Long-term exclosures allow us to assess the long-term impacts of herbivores by comparing soils and vegetation inside and outside the exclosures and analysing differences in composition, structure, etc.

SNH have a database of long-term (30-50 years) woodland exclosures that is curated by the Scottish Forestry. This database was used as the basis to select paired grazed/ungrazed birch woodland sites on brown earth soils to assess long term differences between grazed and ungrazed areas.

Six sites were selected for sampling in May 2014. At each site there was a fenced plot and a paired unfenced plot which was located as close as possible to the fenced plot with the same aspect, slope and soil type. The aim was to establish a set of 6 paired plots which would enable an assessment to be made of the impact of herbivore removal on soil and vegetation. The six sites were grouped into 3 areas, with 2 sites at each of Ardura, Coille Thogabhaig and Morrone.

### Main findings

- Assessment of herbivory at the plots showed that grazing was now occurring at many fenced ('ungrazed') plots and some unfenced plots either had lower levels of grazing or higher levels of grazing than the fenced plots. Thus although the plots are coded throughout this report as fenced (F) and unfenced (U) this does not mean that the fenced plots were ungrazed, nor that the unfenced plots were heavily grazed, which of course greatly limits the assessment of the impact of the removal of herbivores on vegetation and soils.
- Initial 'removal' of grazing resulted in an increase in the number of trees present, particularly trees 2-6 m tall and over 6 m tall. However there were no differences between fenced and unfenced plots in the number of younger trees present, possibly because the fences at many of the plots were now permeable and grazing is now occurring within many of them.

- There was a significant difference in the ground flora present with the grazed plots containing more grazing tolerant species such as grasses and the fenced plots being more bryophyte dominated.
- There were differences in the Ellenberg moisture values between fenced and unfenced plots with fenced plots having greater cover of plants that required greater moisture.
- There was no clear change in soil profile morphology due to herbivore exclusion, that is, there was no consistent development of Ah or L horizons in the fenced sites.
- Although there were inevitably some differences in individual soil properties (carbon content, carbon stock, nitrogen, bulk density, pH, base saturation) between fenced and unfenced sites, the differences were not statistically significant.
- Although the topsoil A horizons were thought to be the horizons where there was most likely to be differences in soil properties between samples taken from the soil profiles both inside the fenced area and outside the fenced area, there was no significant difference in the main soil properties thought the most likely to change (carbon content, carbon stock, nitrogen, bulk density, pH, base saturation).
- There was no significant difference in profile C stocks to 1m depth (or shallower if constrained by rock) though, as the sample numbers were low, the threshold for having a statistically significant difference was relatively high.
- There was no significant difference between most of the main soil properties of interest (carbon content, carbon stock, available nitrogen, available P, available K, bulk density, pH, base saturation, moisture content) as measured in the 0-15 cm bulked soil cores from each site between samples from inside the fenced area compared to those outside.
- Available K as measured in the 0-15 cm bulked soil cores was found to be significantly greater ( $p=0.04$ ) in the unfenced area in comparison to the fenced area. At present this result is difficult to explain.
- There were no consistent differences in the composition of the soil microbial community, as assessed using PLFAs (phospholipid fatty acids), between fenced and unfenced plots, although there were differences at individual sites (Ardura).
- All results (vegetation, soil and PLFA) should be treated with a degree of caution for the following reasons: a) the low number of replicates, b) the fact that grazing occurred in most fenced areas, c) within the multivariate analysis of the quadrat data there is a degree of pseudoreplication with multiple quadrats being recorded from within one plot, d) the three fenced plots at Morrone are not strictly independent and e) natural soil heterogeneity.
- These results should not be used to infer that herbivores do not have an impact on soil properties; rather that due to natural variability as well as the above limitations of the data/plot set-ups, no consistent pattern was discovered in relation to herbivore 'removal'. Indeed within any one site there were differences between the fenced and unfenced plots.
- Future work to look at the impacts of herbivores on ecosystem function would require a greater number of samples (as advised at the point of tendering) and 'ungrazed' plots that had really not been grazed.

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We thank the landowners of the sites for permission to survey the sites and take soil samples.

**Note:** Subsequent to the publication of the Soil Survey of Scotland classification (Soil Survey of Scotland Staff, 1984), brown forest soils and brown forest soils with gleying were renamed brown earths and brown earths with gleying respectively to avoid any implication of land use associated with these soils. This modified designation will be used throughout this report when referring to the 1984 classification system.

## **1. INTRODUCTION**

Herbivores are known to impact on the vegetation composition, structure and regeneration capacity of woodlands (e.g. Palmer and Truscott 2003, Rooney and Waller 2003, Palmer et al. 2004, Palmer et al. 2005, Edwards and Mason 2006, Didion et al. 2009, Amar et al. 2010). These changes in woodland composition and structure then have a cascading impact on the wider species composition within the woodland, e.g. birds (Amar et al. 2010). While the above ground impacts of herbivores in woodland are well studied, the impacts below-ground have received less attention (Hester et al. 2006).

Grazing will influence not only above-ground tree growth but also below-ground tree growth (Hester et al. 2004, Hodar et al. 2008); this in turn may influence carbon storage and resources below ground which may influence the soil microbial community, nutrient cycling and soil chemical properties. Grazing will also alter the ground flora vegetation both directly through grazing and indirectly through altering the competitive balance between plant species (Millett et al. 2008). Changes in the ground flora may also drive changes below-ground through changes in litter quality and quantity, for example (Mitchell et al. 2007 & 2010). In addition there may be interacting effects between understory vegetation and trees which could affect soil community composition (Mitchell et al. 2012).

Over the last 150-200 years, herbivores have had major impacts on the vegetation throughout Scotland. Much has been documented about above-ground impacts, but impacts (both direct and indirect) on below-ground communities, soil properties and ecosystem function are largely unknown. Long-term exclosures allow us to assess the long-term impacts of herbivores by comparing soils and vegetation inside and outside the exclosures and analysing differences in composition, structure, etc which have developed over time since herbivore exclusion.

SNH have a database of long-term (30-50 years) woodland exclosures that is maintained by the Scottish Forestry. This database was used as the basis to select paired grazed/ungrazed sites across a range of common, upland soil types from which to assess long term differences between grazed and ungrazed areas.

Ideally a study assessing the impact of herbivore exclusion on vegetation and soils should cover a range of woodland types and soil types to assess if there are consistent impacts of the removal of herbivores across all woodland types. In addition the more paired fenced/unfenced plots that can be studied, the stronger the evidence will be about changes which are likely to be attributable to herbivores versus changes caused by other factors. Such a study would require a large number of sites to be sampled and was beyond the resources of this project. This project therefore narrowed its focus with the aim of studying herbivore impacts on one woodland type on one soil type through studying the impacts of herbivore removal at six sites which ideally should be the same woodland type (vegetation) and the same soil type.

### **1.1 Objectives**

The objectives of the project were:

1. Review the information available for the sites with exclosures and select 6 sites for comparison of fenced/unfenced plots. Ideally the 6 sites should be the same woodland type and on the same soil series such that they may be treated as replicates. In addition the sites should cover a wide geographical spread.
2. Develop appropriate field sampling methodology for the project.

3. At the selected sites (both inside and outside the exclosures) document contextual site information, vegetation, soil profile and take soil samples for chemical/microbiological analysis.
4. Undertake laboratory analysis of soil samples for soil moisture, pH, organic carbon content, soil carbon/nitrogen ratio, fungal/bacterial PLFA ratio, base cation/aluminium ratio, available N/P/K and bulk density.
5. Produce a technical report analysing the results.

## 2. SELECTION OF SITES

### 2.1 Introduction

The original Scottish Forestry database had a list of 72 woodland sites where exclosures had been set up. A further 24 sites were added to the list by SNH providing a total of 96 sites with exclosures that were established between 1949 and 1990. The size of these exclosures ranged from 0.034ha to 6ha. From this list six sites had to be chosen to be sampled. The bullet points below describe the decision process that was followed to select the sites, with the number of sites remaining on the selection list given in parenthesis after each step.

1. Information on the current condition of the fences was obtained where possible. Exclosures that no-longer existed or were known to be no longer deer proof were removed [26 sites removed, 70 sites remained on the list].
2. Sites listed as only stock proof or rabbit proof but not deer proof were removed from the list [A further 10 sites removed, leaving 60 sites on the list].
3. Sites for which no grid reference was provided were removed [8 sites removed, 52 remaining on the list]
4. The soil series at each location (as defined using the national grid reference provided by the data base) was derived from 1:25 000 or 1:63 360 scale soil maps and, where these did not exist, from 1:250 000 scale soil maps.
5. Those exclosures known to be deer proof or only slightly porous were selected (for many sites the current condition of the deer fence was unknown) [12 sites were known to be deer proof a further 7 were known to be slightly porous, 19 sites remaining on the list, 33 sites removed from the list].
6. The information on woodland type in the database was simplified to broad woodland types on the basis of the dominant tree species listed. This was done because there was no consistent method of recording the woodland type within the database. Therefore sites were classed as birch, Scots pine, oak or open. The open site was removed as this did not fit the criteria for the project [18 sites remaining on the list, 1 site removed]
7. The sites were then grouped by woodland type to assess the number of sites within each group (Table 2.1).

Table 2.1 Sites remaining for selection by step 6 in the selection process, classified by their woodland type (step 7) with their dominant soil types also shown.

Fence condition	IDENT	Location	NGR	Vegetation (information from database)	Woodland type (step 7)	Dominant soil type		
						Soil 1	Soil 2	Soil 3
Porous	EX160	Ariundle Oakwood NNR	NM847648	oak	Oak	Peaty gleyed podzols	Dystrophic semi-confined peat	Peaty gleys
Porous	EX169	Morvich (Strathfleet SSSI)	NC755010	oak	Oak	Brown earths	Humus-iron podzols	
Deer proof	EX_P2	Coille Phuiteachain	NN095841	pinewood native	Scots pine	Peaty gleyed podzols	Dystrophic semi-confined peat	Peaty gleys
Deer proof	EX170	Alladale	NH387882	native pine	Scots pine	Peaty gleyed podzols	Peaty gleys	
Deer proof	EX178	Glen Tanar	NO463911	scots pine	Scots pine	Noncalcareous gleys	Peaty gleys	
Deer proof	EX179	Glen Tanar	NO479903	scots pine/birch	Scots pine	Peaty gleyed podzols		
Deer proof	EX201	Liatric Burn SSSI	NH252338	native pine	Scots pine	Peaty gleyed podzols	Dystrophic semi-confined peat	Peaty gleys
Deer proof	EX216	Black Wood Of Rannoch	NN563556	native pine	Scots pine	Brown earths	Humus-iron podzols	
Deer proof	EX001	Artilligan Wood	NR858769	oak/birch	Birch	Brown earths		
Deer proof	EX_P13	Glen Feshie	NN857900	upland birch	Birch	Peaty rankers	Lithosols	

Fence condition	IDENT	Location	NGR	Vegetation (information from database)	Woodland type (step 7)	Dominant soil type		
						Soil 1	Soil 2	Soil 3
Deer proof	EX_P7	Langwell Water SSSI	ND057 229	upland birch	Birch	Peaty gleyed podzols	Dystrophic blanket peat	
Deer proof	EX_P8	Langwell Water SSSI	ND084 226	upland birch	Birch	Peaty gleys	Dystrophic blanket peat	Peaty gleyed podzols
Deer proof	EX177	Fealar Gorge (Beinn A' Ghlo SSSI)	NN998795	birch	Birch	Peaty gleyed podzols	Peaty gleys	Dystrophic semi-confined peat
Porous	EX180	Morrone Birkwood NNR	NO013909	mixed birch	Birch	Subalpine podzols		
Porous	EX181	Morrone Birkwood NNR	NO142904	mixed birch	Birch	Brown earths		
Porous	EX182	Morrone Birkwood NNR	NO139904	mixed birch	Birch	Brown earths		
Porous	EX183	Morrone Birkwoods NNR	NO133904	mixed birch	Birch	Humus-iron podzols	Humus-iron podzols	
Porous	EX184	Morrone Birkwoods NNR	NO135905	mixed birch	Birch	Humus-iron podzols	Humus-iron podzols	

The selection process continued:

8. As there were only two oak sites these were removed from the list [2 sites removed, 16 sites remaining on the list].
9. At this point in the selection procedure there were three options:
  - a) 6 sites that are all birch woodlands and all with podzolic soils (subalpine podzols, humus-iron podzols and peaty gleyed podzols). This was not seen as ideal as differences between soil types would make it hard to find consistent effects of herbivore exclusion.
  - b) 6 sites on peaty gleyed podzols, three sites that are birch woodlands and three sites that are pine woodlands. It was thought unlikely that there would be much change either botanically or in the soils under pine, and three sites per woodland type was considered poor replication.
  - c) 6 sites that are all birch woodlands but 3 sites that have a peaty surface layer (peaty gleyed podzols) and 3 sites with a mineral surface layer (brown earths). This would have enabled a contrast between these two soil types although with limited replication. However at least one more birch, brown earth site was required to fulfil this mix of sites as two of the brown earth sites are very close together both being at Morrone.
10. The database was searched again for sites known to be birch woodlands and with brown earth soils but where information on the fence condition was missing. Sites fitting these criteria were selected and the site owners contacted to find out the current condition of the fence. In the course of this process 5 additional sites were added to the list of birch sites on brown earth soils: 3 sites at Ardura Auchnacraig SSSI on the Isle of Mull and 2 sites at Coille Thogabhail NNR on Skye. Although these exclosures were listed as separate sites, it should be noted that essentially it is actually only two sites with either three (Mull) or two (Skye) exclosures in each area.
11. With the additional information gained in step 10 this provided 8 birch woodland exclosures all on brown earths from which 6 sites could be chosen. The sites were chosen to provide as wide a geographical coverage as possible. Only one of the two sites on Skye were chosen with the other one held in reserve as the soil maps showed a very small area of brown earths and it was uncertain if both the exclosures would have brown earths. Similarly only two of the three sites on Mull were chosen so if the soils at one of the sites were unsuitable, the reserve site could be sampled.
12. Site descriptions of the chosen sites are given in Chapter 3.
13. The final selection of sites met the original aim of 6 sites all with the same broad woodland type and same soil type. This option was chosen in preference to sampling 6 birch woodlands with 3 sites on brown earths and 3 on peaty gleyed podzols as this provided greater replication of sites on the same soil types increasing the likelihood that consistent patterns resulting from herbivore exclusion could be found.

### 3. DESCRIPTION OF SITES

Details of the site characteristics for the six chosen sites are given in Tables 3.1 and 3.2.

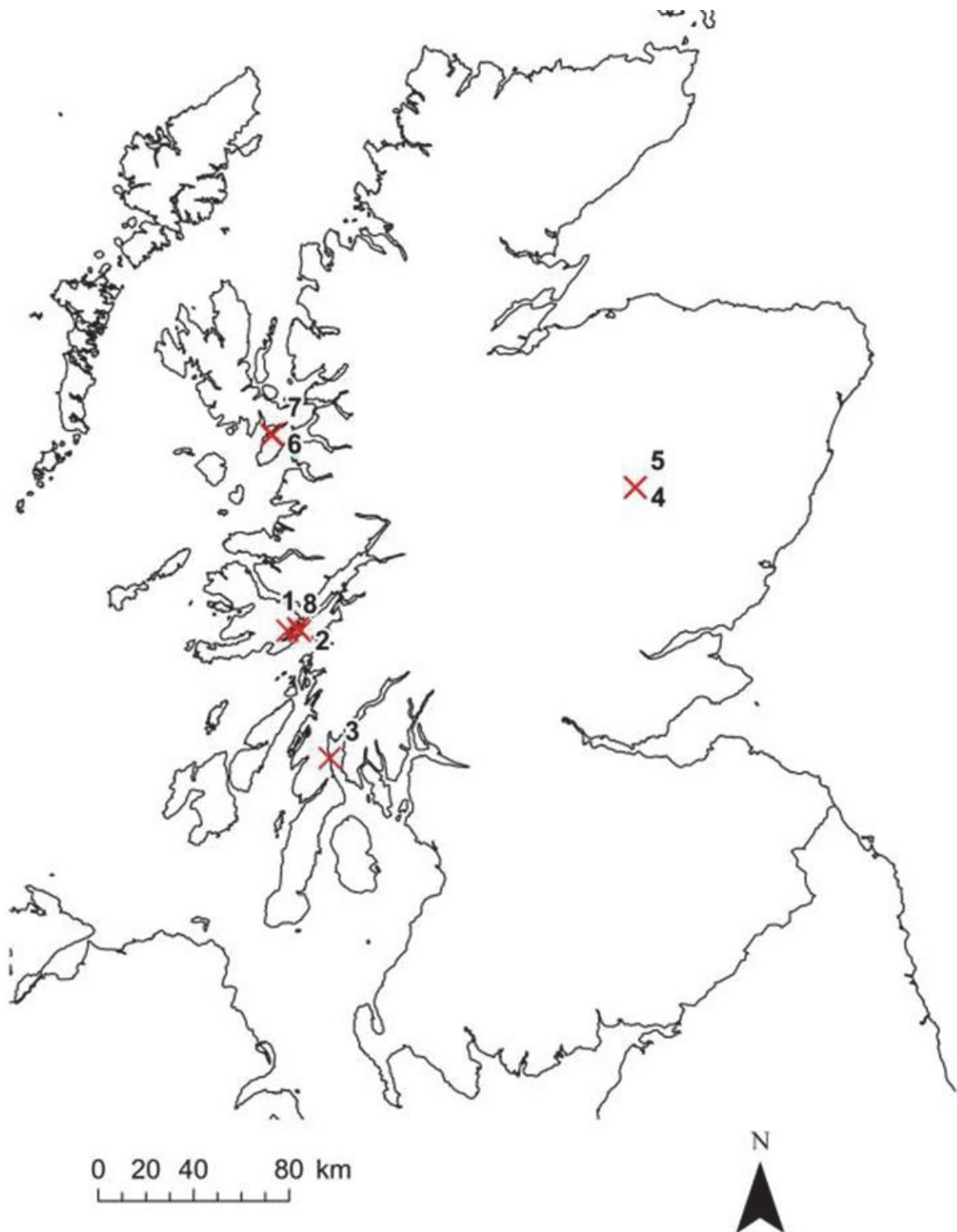


Figure 3.1 Location of chosen sites. See Table 3.1 for site names.

Table 3.1 Selected six sites: location and vegetation details as supplied by SNH

Site Number	Site name	IDENT	NGR	Region	Date established	Area (ha)	Elevation (asl)	Vegetation
1	Ardura Auchnacraig SSSI 1		NM725315	Isle of Mull	1970s/80s	2.2	110	Upland birch/oak
2	Ardura Auchnacraig SSSI 2	EX_P14	NM733302	Isle of Mull	1970s/80s	4.6	70	Upland birch/oak
3	Artilligan Wood	EX001	NR858769	Argyll	1989	1.0	80	Oak/birch
4	Morrone Birkwood NNR 1	EX181	NO142904	Aberdeenshire	1978	9.9	450	Mixed birch
5	Morrone Birkwood NNR 2	EX182	NO139904	Aberdeenshire	1978	2.8	450	Mixed birch
6	Coille Thogabhail NNR 2	EX161	NG615122	Skye	1978	20.0	100	Ash/birch
7	Coille Thogabhail NNR 2 <sup>1</sup>	EX162	NG617127	Skye	1983	20.0	80	Ash/birch
8	Ardura Auchnacraig SSSI 3 <sup>1</sup>		NM681303	Isle of Mull	1970s/80s	22.2	70	Upland birch/oak

<sup>1</sup>These sites are selected as reserve sites in case other sites on Mull or Skye were not suitable once visited

*Table 3.2 Selected six sites with brown earths: details of associated soil types and parent material taken from soil maps. The soil Association of the sampled soil profiles were also classified on-site and occasionally differ from those shown below.*

Site name	Soil Association	Component soils		Landform	Parent material
		Soil Series or complex	Associated soils		
Ardura Auchnacraig SSSI 1	Sourhope	Stotfold Complex	Brown earths, brown rankers, humus-iron podzols, rock outcrops & screes	Hill slopes	Drift derived from andesites
Ardura Auchnacraig SSSI 2	Darleith	Knockan Complex	Brown earths, brown lithosols & brown rankers	Terraced hill slopes	Drifts derived from basalt
Artilligan Wood	Strichen	Fungarth Series	Brown earths	Hill and valley sides with strong to very steep slopes: slightly and moderately rocky	Drifts derived from arenaceous schists and strongly metamorphosed argillaceous schists of the Dalradian Series
Morrone Birkwood NNR 1	Deecastle	Deecastle Series	Brown earths	Undulating lowlands and hills with gentle and strong slopes: slightly rocky to rocky	Drift derived from Dalradian limestones and calc-silicate rocks
Morrone Birkwood NNR 2	Deecastle	Deecastle Series	Brown earths	Undulating lowlands and hills with gentle and strong slopes: slightly rocky to rocky	Drift derived from Dalradian limestones and calc-silicate rocks
Coille Thogabhail NNR 2	Inchnadamph	Series not named	Brown earths & brown rendzinas	Valley sides and undulating lowlands with gentle and strong slopes: moderately to very rocky	Drifts derived from limestones of Cambrian and Ordovician age
Coille Thogabhail NNR 2 <sup>1</sup>	Inchnadamph	Series not named	Brown earths & brown	Valley sides and undulating lowlands with	Drifts derived from limestones of Cambrian

Ardura Auchnacraig SSSI 3 <sup>1</sup>	Inchkenneth	Balmeanach Complex	rendzinas Brown earths & Brown earths with gleying	gentle and strong slopes: moderately to very rocky Weakly terraced low hills usually below 150m	and Ordovician age Mesozoic - sandstone/shales and limestones
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<sup>1</sup>These sites are selected as reserve sites in case any of the other six sites were not suitable once visited

## 4. METHODS

### 4.1 Choosing location at the site

On arrival at the sites the following steps were taken to identify the location of the main soil pit both inside and outside the enclosure. The layout of the sampling for both the vegetation and soils was then conducted at set distances from this main soil pit.

1. The enclosure was located
2. The enclosure was walked round (where possible) to assess its size, how deer proof it was and the vegetation/slope/aspect of the land just outside the enclosure. This aided in choosing a site outside the enclosure to match that inside the enclosure as closely as possible.
3. Inside the enclosure an area which had a brown earth soil and the correct vegetation type (birch woodland) was located. In both cases broad definitions of the soils and woodland type were used as there was limited scope for using alternative sites at this stage. The following criteria were used: a) the woodland should at least be a broad leaved woodland with occasional birch although the percentage of birch canopy was likely to vary between sites and b) the soils should be freely drained brown earths though on the more acid parent materials, the soils may have some weak podzolic features.
4. When there was a large area of suitable soils and vegetation the soil pit soil pit was located in the centre of this area and the plot marked with canes.
5. Outside the enclosure an area as similar as possible to the main soil pit inside the enclosure was located. Surveyors aimed to establish the unfenced plot on the same soil type and with a similar aspect, slope and altitude as the soil pit on the fenced plot. In addition the surveyors aimed to establish the unfenced plot in birchwood but the difference between the vegetation inside and outside the enclosure varied depending on the impact of herbivore removal.

Once the location of the two main soil pits (fenced and unfenced) was decided, detailed soil sampling and vegetation recording began.

### 4.2 Vegetation methodology

#### 4.2.1 Introduction

Vegetation sampling was conducted by Richard Hewison, Debbie Fielding and Ruth Mitchell. The vegetation survey work followed similar methods to that in the National Vegetation Classification for woodlands (Rodwell 1991) as this method allows sampling of the ground flora, field layer and trees and shrubs while at the same time taking account of the different scales required to sample these components of the woodland. For structural and herbivore impact assessments, methods akin to those used in the Scottish Forestry national forest inventory<sup>1</sup> and the herbivore impact assessment field guide<sup>2</sup> were used. This enabled us to know whether we were comparing ungrazed sites (and verify that they were indeed ungrazed) with sites that may have experienced low, medium or high rates of grazing over recent decades.

#### 4.2.2 Detailed plot layout

Once the location of the soil sampling pit had been chosen within a relatively homogenous stand of woodland, one large 40m x 40m plot (i.e. approx. 1600 sq m), divided into four 20m

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<sup>1</sup> National Forest Inventory

<https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/>

<sup>2</sup> Herbivore impact assessment field guide <https://forestry.gov.scot/images/corporate/pdf/herbivore-impact-assessment-method.doc>

x 20m sub-plots (for ease of recording), in each quarter of the plot (NW, NE, SE and SW) was established both within the fenced and unfenced areas. The four corners of the plot were laid out by measuring 28.28m NW, NE, SW, SE from the soil pit (28.28m is half the diagonal of a 40m x 40m square). The main soil pit was located in the centre of this 40m x 40m plot. The sub-plots were laid out using a 100m retractable tape for the boundary with ranging poles marking three of the corners and the fourth being marked by the soil pit. The canopy, understorey, structural characteristics and any herbivore impacts within the woodland were recorded in these sample areas.

Each sub-plot was laid out and recorded sequentially beginning with the NW followed by the NE, SE and finally SW. The plot as a whole was centred on the location of the main soil sampling pit and each sub-plot was photographed (with a prepared sample code number board) from this central location towards each sub-plot corner which were accurately recorded by GPS.

When for any reason (e.g. topographic constraints or habitat heterogeneity) it was proven problematic to layout the plot in this manner, then an elongated version was used instead, such that they still covered the same area i.e. 1600 sq. m.

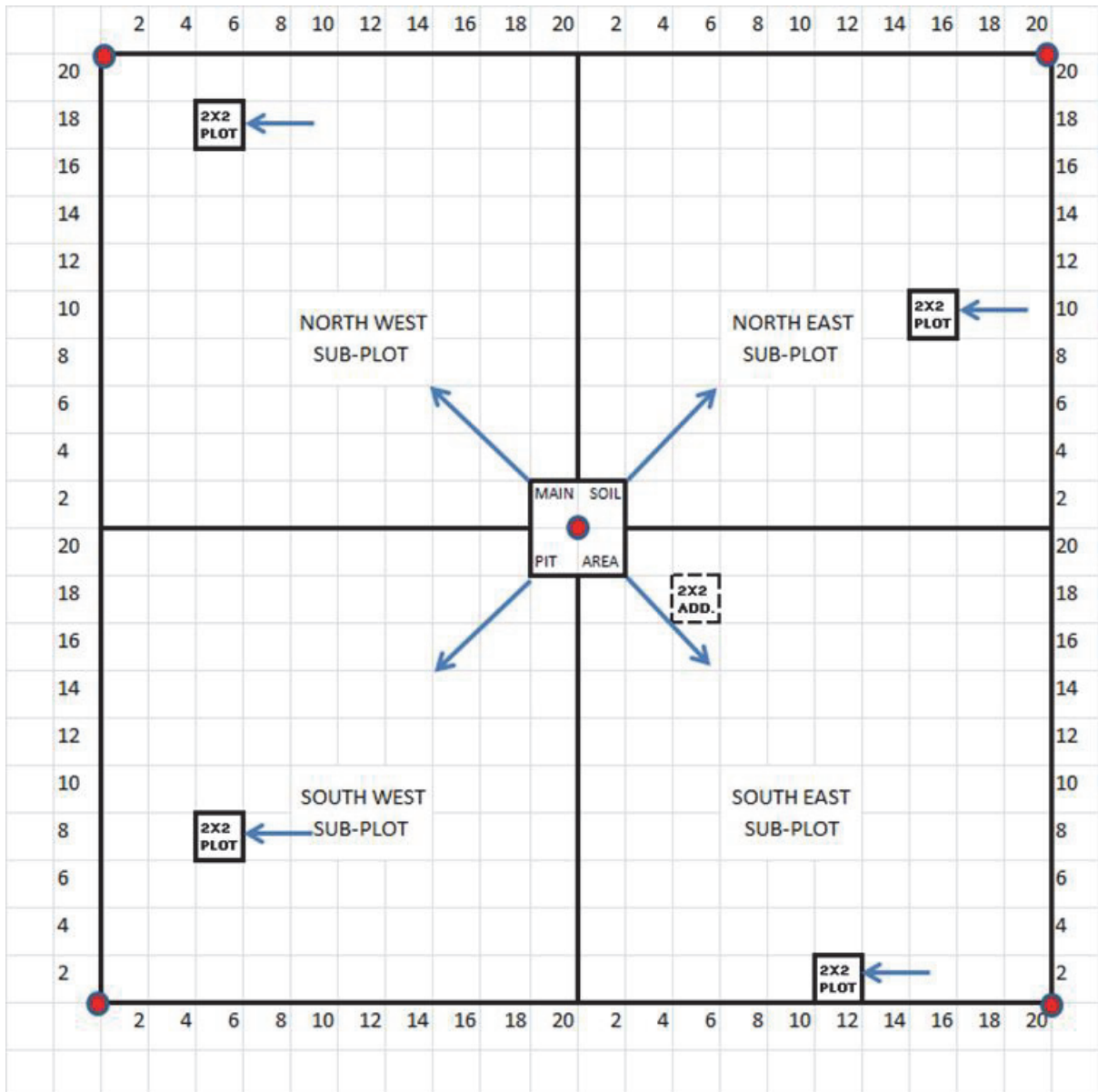


Figure 4.1 Plot layout (distance in m) showing the plot centred on the soil pit and locations of 2 x 2m ground and field layer plots

GPS records   
 Photographs 

#### 4.2.3 Structural stand characteristics: Trees

Within each of the four sub-plots the number of trees of each species within each of four size classes was counted. The size classes were <0.5m, >0.5 m - <2 m, >2 m - <6 m and >6m. The recording form had space for four different tree species to be recorded<sup>3</sup>, if more than four tree species were present a separate recording form was used. When there was a huge amount of young regeneration (e.g. of birch) and it was very difficult to count, an estimate of the numbers in a small area was made and scaled up to estimate the numbers at the plot scale.

<sup>3</sup> See separate Excel file sent to SNH with blank recording sheet for vegetation structure.

TREES - A woody plant growing to 6m (20ft) or more and usually single stemmed																
													NW	NE	SE	SW
NUMBER of mid age-mature age trees > 6m																
NUMBER of young-mid age trees > 2m and < 6m																
NUMBER of saplings > 0.5m and < 2m																
NUMBER of seedlings < 0.5m																

Figure 4.2 Section of recording form showing how for each tree species present in the woodland the number of trees at each age was recorded.

#### 4.2.4 Structural stand characteristics: Shrubs/scrub

The cover of different aged shrub species (mature/young) was also recorded for each shrub species within each sub-plot. The recording form had space for three shrub/scrub species, when more than three species were present then a separate recording form was used.

SCRUB/SHRUBS - A woody plant whose normal growth habitat is multiple stemmed																
													NW	NE	SE	SW
COVER of mature scrub/shrubs																
COVER of young scrub/shrubs																

Figure 4.3 Section of recording form showing how for each age of each shrub species present in the woodland the cover was recorded.

#### 4.2.5 Herbivore Impact Assessment

Within the plot as a whole, herbivore impact assessments were made by reference to the Herbivore Impact Assessment field guide in the Woodland Grazing Toolbox (see Annex I). This provided an assessment on:

- Browsing of basal shoots
- Browsing of epicormic/lower growths
- Bark stripping
- Level of browsing on seedlings/saplings
- Level of browsing on preferentially browsed species
- Level of browsing on sward
- The amount of ground disturbance.

In addition the level of dung deposition was recorded as absent, low, medium, high, or very high.

#### 4.2.6 Field and ground vegetation

The field and ground layers were recorded from five 2 x 2m quadrats. One quadrat was positioned within each of the four sub-plots at the positions shown in Figure 4.1 (these positions had already been randomly selected, if the location fell on an unsuitable site e.g. large boulder the quadrat was moved first to the north by 2m then to the west, south or east until a suitable location was found). A fifth quadrat was located at the discretion of the surveyor in order to cover any important variation not deemed to have been recorded from

within the four quadrats (Figure 4.1). The 2 x 2m field/ground layer quadrats were photographed from the most appropriate side in relation to shadows and topography.

All terricolous species were recorded including all bryophytes (small specimens were collected when they could not be successfully identified in the field). The species recording sheet used already had a number of common woodland species of such habitats indicated<sup>4</sup>. Abundance was recorded by visually estimated percentage cover. Species of < 1% were given DOMIN values of DM1, DM2 or DM3 for increasing value of abundance. For species estimated at between 1 and 10% cover, values to the closest integer were used. For abundances in excess of 10%, the closest 5% value was used.

#### 4.2.7 Other ancillary information recorded<sup>5</sup>

- Site name and a unique site code.
- The general slope and aspect of each unit in degrees.
- The date and surveyors initials

### 4.3 Soil sampling methodology

The soil sampling used methods employed during the recent NSIS resampling (Lilly et al, 2010), and the EU funded Biosoil sampling of European Woodlands (European Union, 2006) as well as other local and UK-wide sampling schemes to maximise the information gained at each site and to allow comparisons to be made with these other sampling schemes, as well as setting a baseline of soil information that may be used for future sampling at these sites.

At each of the locations a soil pit was dug sufficiently deep to allow sampling of the C horizon (the relatively unaltered parent material) and an auger used to determine the depth (and characteristics) of the soil up to 1m. The soil was classified according to both the Soil Survey of Scotland (JHI) soil classification systems (1984 and 2013 classifications) and that used by the Scottish Forestry. The site and soil characteristics were recorded following the protocols developed for the resampling of the National Soil Inventory of Scotland (NSIS) 2007-2009 (Lilly et al, 2010) which covered all the requested soil profile and contextual information. Profile sampling used a hybrid (but compatible) sampling scheme based on NSIS and Biosoil to derive the maximum amount of information most efficiently. Each organic-rich, near-surface layer (L, F, H, O & A) was sampled wherever possible over their full thickness (rather than the normal NSIS sampling protocols where samples are taken from a thin band in the centre of each horizon) along with bulk density measurements to determine carbon and nutrient stocks similar to the Biosoil protocols. Deeper subsoils were sampled from an approximately 10 cm band in the middle of each horizon similar to the NSIS protocols and also included bulk density measurements to allow total stocks to be calculated. This method ensured that any potential changes in the soil profile development are also taken into account (e.g. organic enrichment in upper layers, increased nutrient leaching) and also establishes a datum from which the differences in thickness of organic-rich layers can be measured (i.e. the top of the mineral layer) and provides a datum for future monitoring.

Two profile pits were excavated at each site, one inside the fenced area and one outside but still within the woodland. It was anticipated that these sites were likely to be heterogeneous in terms of soil profile development, so four satellite pits orientated along the 4 intercardinal directions and in the centre of each main vegetation sub-plots (approximately 28m from the main pit) were also dug in both the enclosed and open areas to establish the thickness and nature of any organic-rich layers and to assess the spatial variability at each site. At each of

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<sup>4</sup> See separate Excel file sent to SNH with blank recording sheet for field and ground vegetation

<sup>5</sup> See separate Excel file sent to SNH with blank recording sheet for vegetation structure.

these satellite pits and in the centre of the main pits, a 15 cm soil core in a plastic sample tube inserted from the soil surface was taken. These sample cores were subsequently bulked, smoothing site variability. These samples, along with samples from the main profile pits inside and outside of the enclosure were used to assess differences in soil properties from inside and outside of the enclosure. These samples will enable comparison with those taken for Natural England's long-term monitoring network and from the Countryside Survey.

As biological changes are only likely to occur in the top horizons of the soil, PLFA analysis was only conducted on one bulked sample from the top 0-15 cm of soil taken from around the main soil pit in each fenced/unfenced area. This sample comprised 12 sub-samples (more in highly organic horizons) and gave a total of 12 composite samples to be analysed for PLFAs (2 from each of 6 sites). This method follows that used for Natural England's long-term monitoring network and from Countryside Survey and thus provides comparative data. Archived spare soil from the soil pit could be used to investigate biological changes in the lower horizons at a later date if required.

Summary of the soil sampling scheme:

1. Established which soil type was dominant at the site.
2. Identified a candidate profile.
3. Excavated a pit to within the C (parent material) horizon and describe soil profile.
4. Established depth of the profile to at least 1m and noted the soil characteristics.
5. For organic-rich layers, sampled the whole horizon (where possible) and took a representative sample from mid-point of each horizon for subsoils.
6. Took 12 cores (at least 500g of soil) 0-15cm deep using a marked, long thin trowel or screw auger from around the edges of the soil pit. These samples were bulked for PLFA analysis.
7. Located 4 satellite pits in the centre of the vegetation subplots, measured and recorded thickness of the organic-rich horizons and took a 0-15cm (5cm diameter) intact core at each and a separate soil sample immediately adjacent to the core for analyses of available N.
8. Took an additional 0-15cm (5cm diameter) intact core from the main pit and bulked with those from the satellite pits to form one bulked sample per enclosed/un-enclosed area.
9. Material not used in subsequent analyses will be stored within the National Soil Archive held at the James Hutton Institute and can be used for additional analyses in the future if required.

Further details of the soil sampling protocols are provided in Annex 3.

## 5. SITE DESCRIPTIONS

### 5.1 Sites surveyed

On visiting the field sites the experimental design was adapted to suit the sites on the ground in the following ways:

#### Artilligan

On visiting Artilligan the soils were found not to be suitable. They were gleyed or peaty gleyed soils with *Molinia* and bracken with only very small patches of brown earths. As the enclosure is not very large it was not possible to find the right soil within the enclosure. Therefore the reserve site at Coille Thogabhail (Site 7) was visited instead.

#### Ardura

At Ardura site 1 the unfenced part of the SE corner of the plot was in the loch, this area was not sampled.

At Ardura site 2 the fence was being taken down during the two days of fieldwork. The fenced area had recently had cattle within it and hence had recently been heavily grazed.

#### Morrone

At Morrone site 5 (both fenced and unfenced areas) and site 4 fenced had all been combined into one large fenced area 19 years ago, although it was still possible to see where the older fences had been. Plots were therefore established as follows:

- 5F19 – the unfenced area that had been fenced 19 years ago and hence not grazed since that time
- 5F36 – the original fenced plot from site 5 – fenced for circa 36 years
- 4F – the original fenced plot from site 4 – fenced for circa 36 years
- 4U – the unfenced plot from site 4 which was close to both sites 5F19, 5F36 and 4F and was used as a control for all 3 fenced plots at Morrone.

This means that the three fenced plots at Morrone are not strictly speaking statistically independent samples as they have been fenced as one large fenced area for the last 19 years.



*Figure 5.1 The boundary between the original unfenced area (right hand side) and fenced area (left hand side) at Morrone site 5 was still clearly visible despite both areas being fenced as one large enclosure for the past 19 years.*

#### Coille Thogabhail

Due to the size and shape of the exclosures and the areas of suitable soil type available it was not always possible to lay the plots out as a 40 m x 40 m square. The fenced plot at site 6 was 36 m on the N and S sides and 44 m on the W and E sides, the unfenced plot at site 6 was 32 m along the N and S edges and 48 m along the W and E edges. At site 7 the fenced plot was 52 m long on the N and S sides and 30 m long on the E and W sides, the unfenced plot was the standard 40 m x 40 m.

## 5.2 Plot descriptions

Table 5.1 Plot codes, descriptions and date of survey. F = fenced, U = unfenced

Site Name	Site code	Date established	Years fenced*	Aspect (degrees)	Slope (degrees)	Date
Ardura	1F	1970/1980's	34	302	30	13/05/2014
Ardura	1U	n.a.	n.a	140	30	14&15/05/2014
Ardura	2F	1970/1980	34	278	26	15/05/2014
Ardura	2U	n.a.	n.a	100	22	16/05/2014
Morrone	4F	1978	36	350	15	14/05/2014
Morrone	4U	n.a.	n.a	324	12	15/05/2004
Morrone	5F36	1978	36	0	13	13/05/2014
Morrone	5F19	1995	19	334	8	12/05/2014
Coille Thogabhaig	6F	1978	36	215	13	14/05/2014
Coille Thogabhaig	6U	n.a.	n.a.	265	16	13/05/2014
Coille Thogabhaig	7F	1970's/1980's	34	350	10	20/05/2014
Coille Thogabhaig	7U	n.a.	n.a.	315	15	21/05/2014

\*Approximate number of years since herbivores were excluded.

*Table 5.2 National Grid references of soil pit and corners of the plots*

<b>Site code</b>	<b>Main soil pit</b>	<b>NW corner of plot</b>	<b>NE corner of plot</b>	<b>SW corner of plot</b>	<b>SE corner of plot</b>
1F	NM7251031471	NM724931496	NM7252931498	NM7249331453	NM7252831460
1U	NM7265631538	NM7264731554	NM7267531551	NM7263931521	NM7267031525
2F	NM7340530197	NM7339130233	NM7342930219	NM7337330195	NM7342130178
2U	NM7321630364	NM7319930393	NM7323730394	NM7319530357	NM7323630360
4F	NO1385490279	NO1383490299	NO1387490299	NO1383490259	NO1387590259
4U	NO1377290237	NO1374990258	NO1379190259	NO1375290219	NO1379390221
5F36	NO1395290402	NO1393090427	NO1397190426	NO1393090385	NO1397090385
5F19	NO1401990460	NO1399290181	NO1403290486	NO1399290444	NO1403290443
6F	NG6139612144	NG6138712170	NG6142712165	NG6139312121	NG6142812122
6U	NG6135712136	NM6134412144	NG6137612162	NG6134512114	NG6137412113
7F	NG6160912705	NG6158612724	NG6163612721	NG6158612692	NG6163812693
7U	NG6156512725	NG6157212755	NG6158812750	NG6154312710	NG6156012701

### 5.3 Herbivory levels

The aim of this work was to assess differences between fenced and unfenced woodland enclosures and hence assess the impact of herbivores on vegetation and soils. However on arrival at the sites it was discovered that many of the fences were 'porous' to some degree with a high to medium level of dung recorded in some cases (Table 5.3).

At Ardura site 1 there was no dung deposition either within the fenced area or outside it and the other herbivory impact assessment criteria (Table 5.3) indicate that grazing levels outside the fence were very low. At Ardura site 2 the enclosure had intentionally been grazed by cattle recently, resulting in a high level of dung deposition compared to a medium level outside. In addition, other herbivory indicators suggest that the grazing pressure in the fenced area at the site may have been as great as or greater than in the unfenced area.

At Coille Thogbhail the herbivory assessment did indicate that there was a genuine difference in the levels of herbivory inside and outside the enclosure (Table 5.3). At Morrone there was low to medium dung deposition in the fenced areas compared to high deposition in the unfenced areas; the other herbivory indicators also indicated that there was a moderate level of grazing occurring within the fenced plots at Morrone.

Thus, although the plots are coded throughout this report as fenced (F) and unfenced (U) this does not mean that the fenced plots were ungrazed, nor that the unfenced plots were heavily grazed, as detailed above. In reality 'fenced' means that there was light or no grazing and unfenced means that there was generally heavier grazing than inside the fenced area. The exception to this was the fenced plot at site 2 at Ardura which had recently been grazed by cattle, therefore the herbivore impacts here (such as dung) were higher than outside the fence. However dung is a very short term measure of grazing impact and it is unclear whether or not the cattle had been in there long-term. We therefore continued to keep the analysis for each site as fenced (low or no grazing) versus unfenced (higher grazing), although the relative difference between grazing impacts in fenced versus unfenced differed between sites (e.g. Ardura site 1 where there was little difference in grazing impacts between inside and outside the fence, compared to Coille Thogbhail where the herbivory assessment did indicate genuine differences in herbivory levels inside and outside the enclosure).

Table 5.3 Herbivore impact assessment for the 6 woodland sites

Site	Site code	Structure Class	Basal shoots	Epicormic/ lower growths	Bark stripping	Seedlings /saplings	Preferentially browsed species	Sward	Ground disturbance	Dung deposition assessment
Ardura	1F	4	Low	Absent	Absent	Absent	Absent	Absent	Low	Absent
Ardura	1U	6	Medium	Medium	Absent	Medium	Low	Low	Low	Absent
Ardura	2F	4	High	High	Medium	Medium	Medium	Medium	Medium	High
Ardura	2U	10	Medium	Medium	Low	Low	Not app.	Low	Low	Medium
Morrone	4F	5	Medium	Medium	Absent	Medium	Low	Low	Low	Low
Morrone	4U	8	Not app.	Not app.	Absent	Very High	High	Low	Low	High
Morrone	5F36	6	Not app.	Medium	Absent	Not app.	High	Low	Low	Medium
Morrone	5F19	8	High	High	Absent	Medium	High	Low	Low	Low
Coille Thogabhaig	6F	4 & 7	Medium	Medium	Low	Not app.	Medium	Low	Low	Absent
Coille Thogabhaig	6U	8	High	High	Medium	Not app.	High	Medium	Medium	Medium
Coille Thogabhaig	7F	7	Low	Low	Low	Not app.	Low	Absent	Absent	Absent
Coille Thogabhaig	7U	8	High	Medium	Low	High	Medium	Medium	Medium	Medium

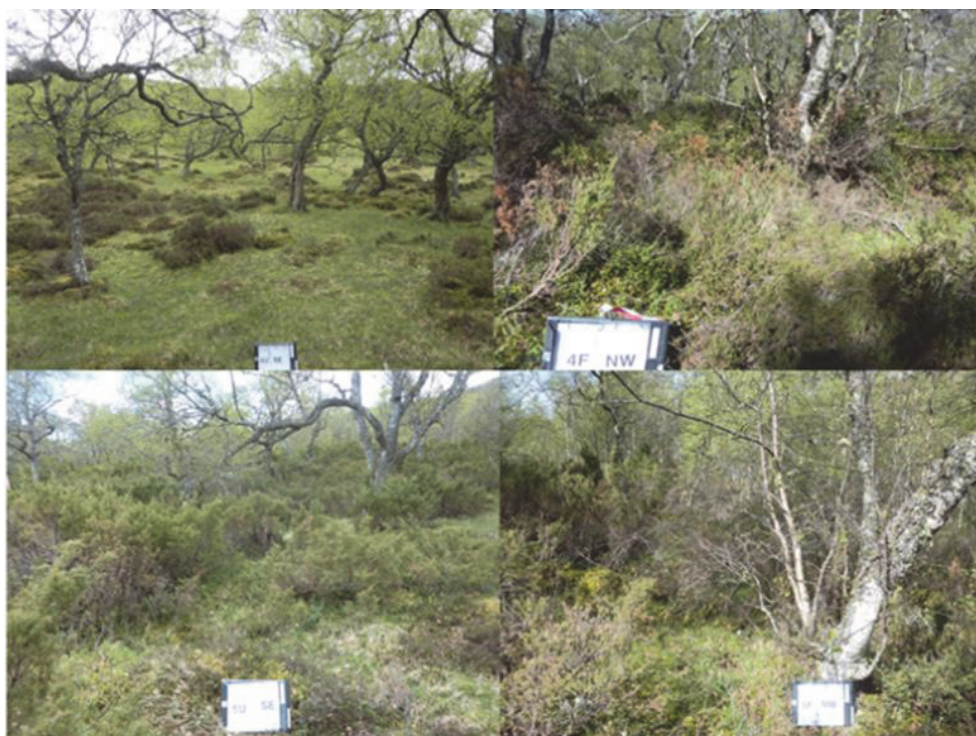
## 6. VEGETATION RESULTS

### 6.1 Vegetation structure

Visually there were big differences in the woodland structure between the fenced and unfenced plots (Figs 6.1-6.3) and these visual differences were confirmed by analysis of the vegetation structure data.



*Figure 6.1 Differences in woodland structure between unfenced (left hand side) and fenced (right hand side) plots at Ardura. The top row photos are from Site 1 and the bottom from Site 2.*



*Figure 6.2 Differences in woodland structure between unfenced (top left hand side) and fenced plots at Morrone. The top row photos are from Site 4 and the bottom from Site 5. Both plots at site 5 were fenced, the left hand one for 19 years and the right hand for circa 36 years.*



*Figure 6.3 Differences in woodland structure between unfenced (left hand side) and fenced (right hand side) plots at Coille Thogabhaig. The top row photos are from Site 6 and the bottom from Site 7.*

Generalized Linear Mixed Models using the 'proc mixed' procedure in SAS (SAS 2010) with area (Ardura, Morrone and Coille Thogabhail) as a random effect were used to assess whether there were differences between the fenced and unfenced plots in the number of trees present.

At all sites there were more trees in the fenced than the unfenced plots ( $F_{1,9} = 5.44$ ,  $P < 0.05$ , Fig. 6.4). This corresponds in general to the levels of herbivory recorded at the sites with generally a higher herbivore impact in the unfenced than the fenced sites (Table 5.3). The biggest difference between the fenced and the unfenced plots was in the number of trees with a height of 2-6 m ( $F_{1,10} = 6.0$ ,  $P < 0.05$ ) and greater than 6m ( $F_{1,10} = 6.0$ ,  $P < 0.05$ ) which were significantly greater in fenced than unfenced plots (Fig. 6.4). This is most likely to indicate an initial flush of regeneration when the herbivores were originally removed from the sites (34-36 years ago) resulting in trees that are now 2-6 m tall or more than 6 m tall. The exception to this is site 5F19 which only had grazing removed 19 years ago and did not have such a high density of medium height birch.

There was no difference between the fenced and unfenced plots in the number of trees less than 0.5 m tall and 0.5 m – 2 m tall. This is of some concern for the long-term survival and structure of these woodlands; as most of the fenced plots were 'porous' and some had considerable herbivore impact (Table 5.3). It is possible that the lack of younger trees is due to them being heavily grazed even within the fenced plots, the exception to this was 2F at Ardura which had 147 trees at less than 0.5 m. The grazed plots were characterized by having a few old (tall trees) and at some sites (e.g. 1U) a large number of small trees (<0.5m) which, judging by the small number of trees in the >0.5-<2 m and 2-6 m classes, appear to be failing to grow into these taller categories, presumably due to browsing pressure.

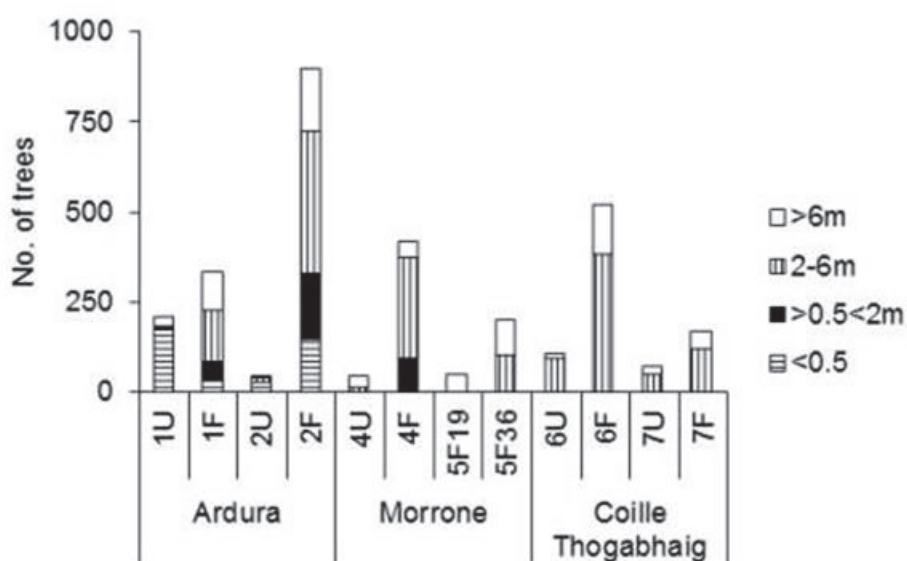


Figure 6.4 Number of trees at different height intervals at 6 woodland sites with fenced (F) and unfenced (U) plots.

## 6.2 Tree species composition

As expected, given that the project targeted birch woodlands, all six sites were dominated by *Betula* sp. (Table 6.1). The sites at Morrone were the most species poor with one to three tree species present, the other sites had up to six tree species present. There was no consistent pattern in relation to number of tree species present and whether the plot was fenced or not (Table 6.1). Within each tree species there was generally a greater number of

trees present in the fenced plots than the unfenced plots (Table 6.1). Due to the small number of trees of most species present, this could only be tested for three species and a significant effect was only found for *Betula* sp. More *Betula* sp. occurred inside the fenced areas than outside ( $F_{1,10} = 7.5$ ,  $P < 0.05$ ); there was no significant effect of fencing on the number of *Corylus avellana* ( $F_{1,8} = 4.4$ ,  $P > 0.05$ ) and *Sorbus aucuparia* ( $F_{1,8} = 1.4$ ,  $P > 0.05$ ) trees. However, these results should be treated with some caution due to the very low levels of replication.

Table 6.1 Tree species and number of trees present at each plot

Species	Ardura				Morrone				Coille Thogabhaig			
	1U	1F	2U	2F	4U	4F	5F1 9	5F 36	6U	6F	7U	7F
<i>Betula pendula</i> <i>/pubescens</i>	33	21 9	8	53 4	44	41 3	48	19 2	71	36 9	26	70
<i>Corylus avellana</i>	37	27	24	7					34	23	40	30
<i>Crataegus monogyna</i>	1	2		3						2		
<i>Fraxinus excelsior</i>	1								2	10	1	2
<i>Prunus padus</i>												55
<i>Quercus petraea</i>	36	37	6	12								
<i>Salix aurita</i>				59								
<i>Salix caprea</i>		9				4		4				
<i>Salix cinerea</i> <i>ssp oleifolia</i>										3		
<i>Sorbus aucuparia</i>	99	37	3	28 1				1		11 0	1	8
Total number of tree species	6	6	4	6	1	2	1	3		6	4	5

The proportion of each age class within each species for each site is shown in Fig 6.5. One might expect there to be more young palatable species in the fences plots than the unfenced plots, but this was not the case. However this result should be treated with caution due to the low sample numbers and different mixtures of tree species occurring at each site.

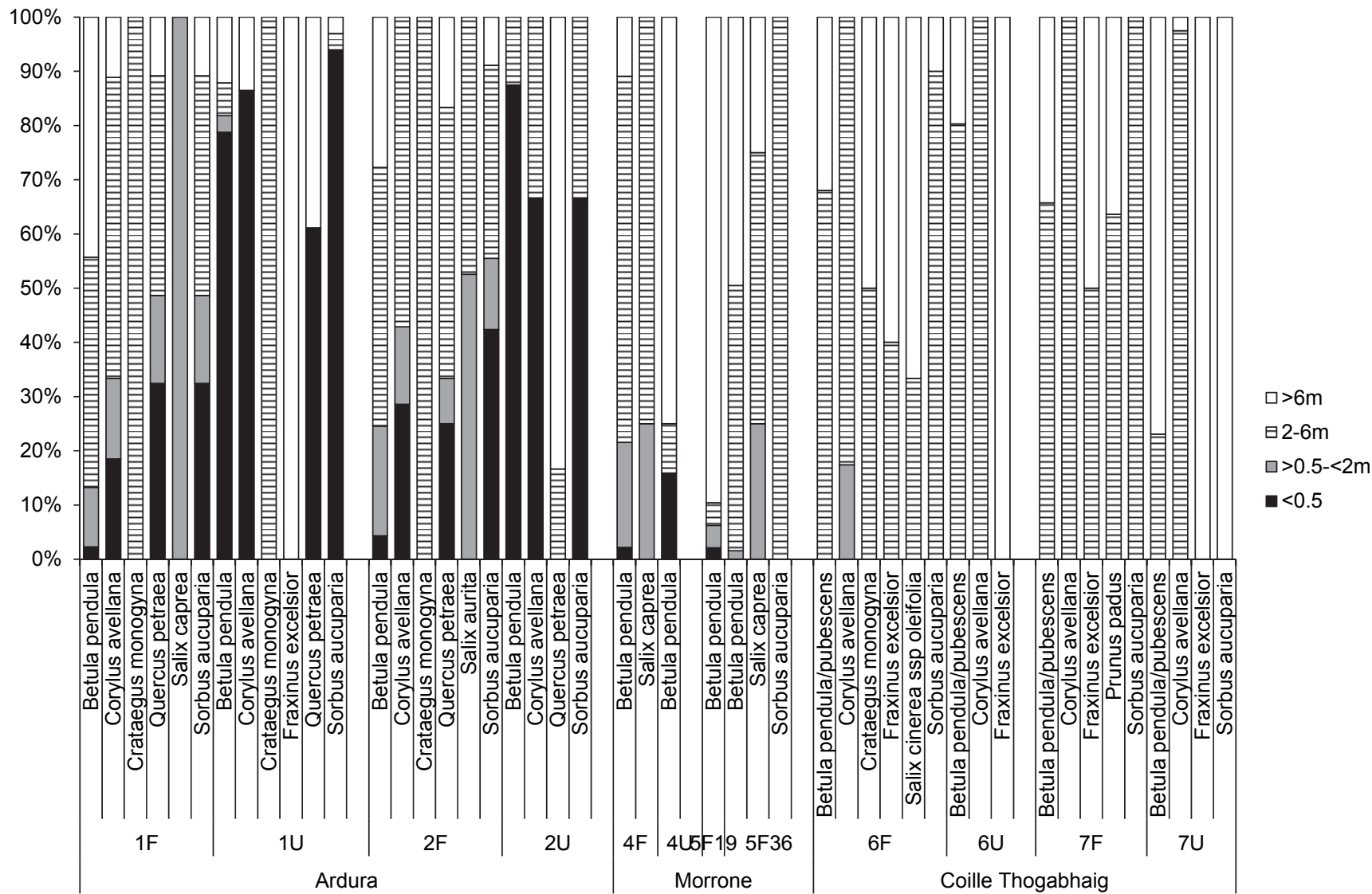


Figure 6.5 Proportion of each tree species in each age category at each site

### 6.3 Shrub structure and cover

There was no shrub cover at Coille Thogabhaig, low shrub cover (<10%) at Ardura and high shrub cover (30-60%) at Morrone (Fig. 6.6). At both Ardura and Morrone there was greater shrub cover in the fenced than the unfenced plots. At Morrone the shrub cover was largely composed of *Juniperus communis* some of which was dead in the fenced plots. It is thought that this was due to shading caused by the trees increasing in height and density following the 'removal' of grazing.

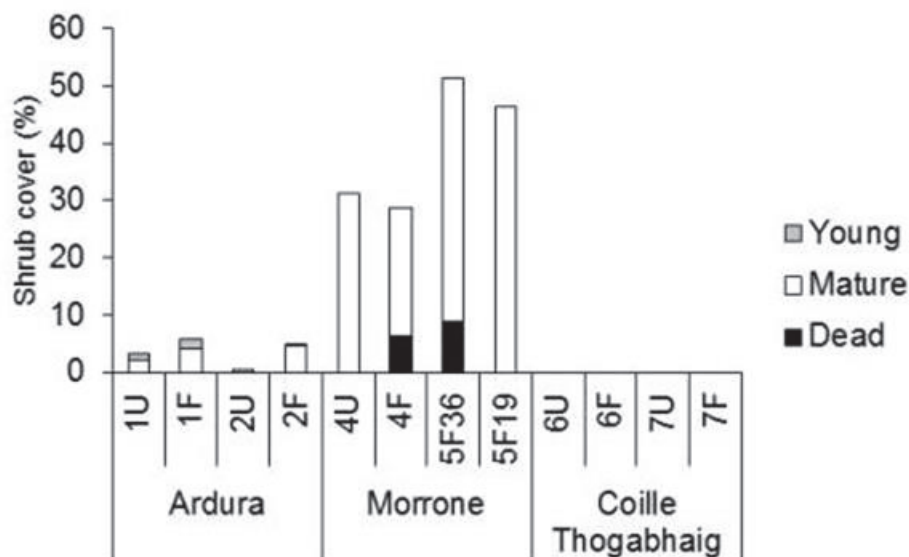


Figure 6.6 Percentage shrub cover and age of shrubs at 6 woodland sites with fenced (F) and unfenced (u) plots

### 6.4 Shrub species composition

The composition of the shrub cover varied between the sites, with no shrubs recorded at Coille Thogabhaig, *Juniper communis* recorded at Morrone and a wider mixture of shrubs at Ardura including *Rubus fruticosus* and *Lonicera periclymen* (Table 6.2).

Table 6.2 Shrub cover at Ardura and Morrone, no shrubs were recorded at Coille Thogabhaig

	Ardura				Morrone			
	1U	1F	2U	2F	4U	4F	5F36	5F19
<i>Calluna vulgaris</i>	0.1	0.1	0	0.1				
<i>Juniperus communis</i>					31	23	43	46.3
<i>Juniperus communis</i> - Dead						6.3	8.8	
<i>Lonicera periclymen</i>		0.1		1.8				
<i>Rubus fruticosus</i>	3.3	5.3	0.4	0.3				
<i>Vaccinium myrtillus</i>		0.1		2.5				

### 6.5 Ground flora species composition

In total 142 species were found in the ground flora quadrats across the 6 sites. At each site there were obvious visual differences in the vegetation composition between the fenced and unfenced plots (Figs. 6.7-6.9).



Figure 6.7 Differences in plant community composition between unfenced (left hand side) and fenced (right hand side) quadrats at Ardura. The top row photos are from Site 1 and the bottom from Site 2.



Figure 6.8 Differences in plant community composition between unfenced (top left) and fenced quadrats at Morrone. The top row photos are from Site 4 and the bottom from Site 5. Both plots at site 5 were fenced, the left hand one for 19 years and the right hand for circa 36 years.



Figure 6.9 Differences in plant community composition between unfenced (left hand side) and fenced (right hand side) quadrats at Coille Thogabhaig. The top row of photos are from Site 6 and the bottom from Site 7.

The ground flora species composition was analysed using the multivariate technique Principal Components Analysis (PCA) in CANOCO 5 (ter Braak & Šmilauer 2012). The three areas (Ardura, Morrone and Coille Thogabhaig) were included as co-variables within the analysis and a partial PCA analysis performed; this takes account of differences explained by the co-variables (the three areas) before carrying out the PCA. Differences between the three areas accounted for 32% of the variation in species composition. The first axis of the PCA explains 17% of the variation in the species composition and separates out the fenced and unfenced plots (Fig. 6.10). Increasing cover of grassland species such as *Plantago lanceolata*, *Festuca ovina*, *Agrostis capillaris*, *Anthoxanthum odoratum*, *Primula vulgaris*, *Ranunculus acris*, *Ctenidium mollusum*, *Luzula campestris/multiflora*, *Campanula rotundifolia*, *Persicaria vivipara*, *Ranunculus repens* were most closely positively correlated with first axis and hence the unfenced or grazed plots (Fig. 6.11). *Hyacinthoides non-scripta* and *Pteridium aquilinum* and the bryophytes such as *Thuidium tamariscinum* *Plagiochila asplenoides*, *Ptilium crista-castrensis*, *Kindbergia praelonga*, were most closely negatively correlated with the first axis and hence the fenced plots.

The effect of fencing in explaining variation within the plant community composition was then explicitly tested by including fenced/unfenced as a categorical explanatory variable within the ordination (a partial RDA analysis). Fencing explained 7% of the variation in plant species community composition which, although a relatively small amount, was significant ( $P=0.0001$ , Monte Carlo permutation test). However, this result should be treated with some caution due to pseudoreplication (multiple quadrats from within one fenced area, and at Morrone all three fenced areas now being within one large fenced area for the last 19 years).

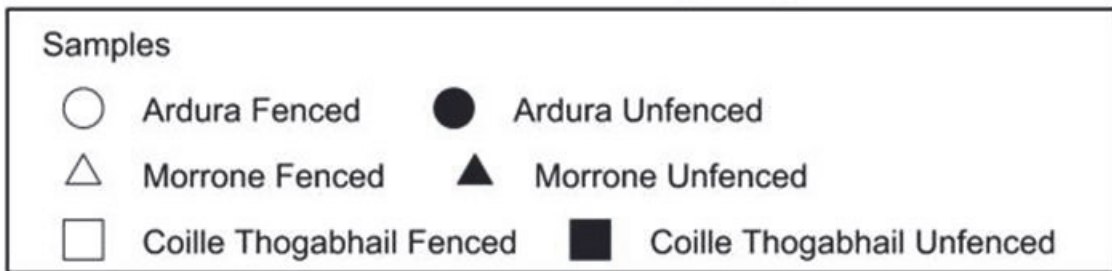
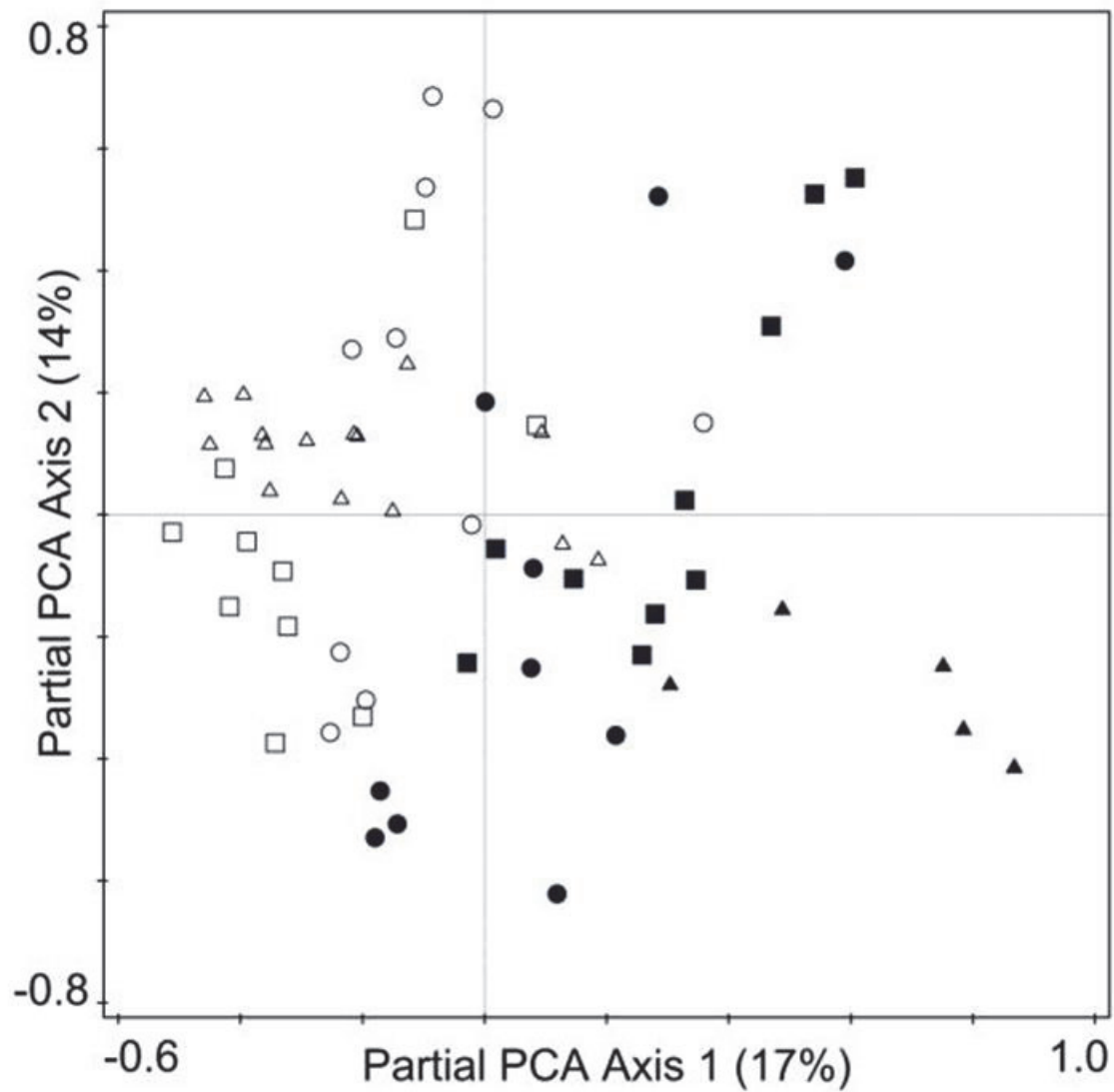


Figure 6.10 Ordination diagram from PCA analysis of vegetation quadrats in fenced and unfenced woodlands at 6 sites. This figure can be interpreted as showing a difference in plant community composition between the fenced (white symbols) and unfenced (black symbols) plots.

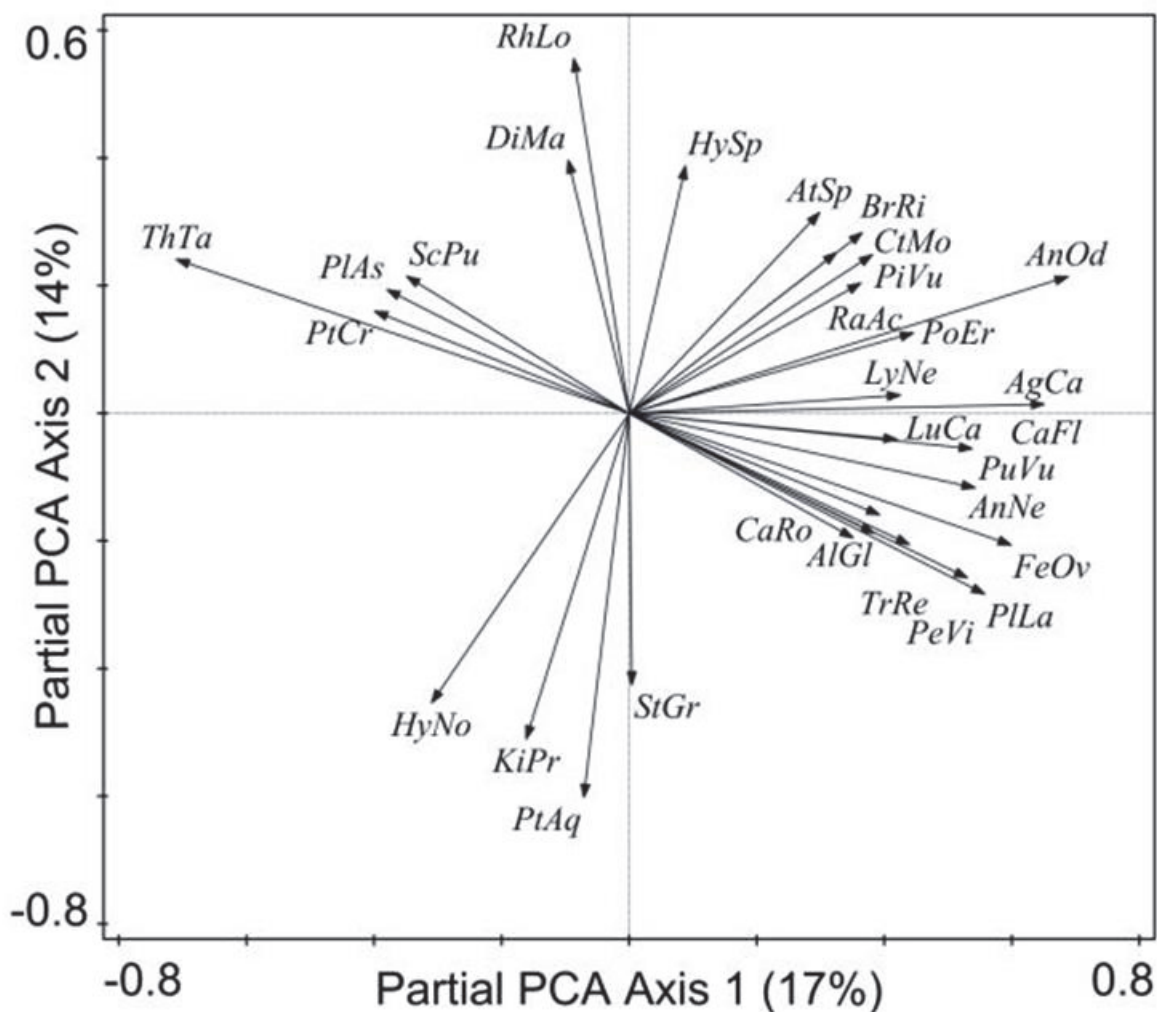


Figure 6.11 Species ordination diagram from PCA analysis of vegetation quadrats in fenced and unfenced woodlands at 6 sites. Only the 20 species that explain the greatest amount of variation within the ordination are shown. The figure should be interpreted in light of figure 6.9: Fig. 6.10 shows that unfenced plots occur in the right hand half of the ordination diagram and fenced plots occur in the left hand half. Plant species with arrows increasing towards the right hand side of this diagram are found at higher cover in unfenced plots; plants with arrows increasing towards the left hand side of the diagram are found at greater cover in the fenced plots. AgCa = *Agrostis capillaris*; AlGl = *Alchemilla glabra*; AnNe = *Anemone nemorosa*; AnOd = *Anthoxanthum odoratum*; Atsp = *Athyrium sp*; BrRi = *Brachythecium rivulare*; CaRo = *Campanula rotundifolia*; CaFl = *Carex flacca*; CtMo = *Ctenidium mollusum*; DiMa = *Dicranum majus*; FeOv = *Festuca ovina*; HyNo = *Hyacinthoides non-scripta*; HySp = *Hylocomium splendens*; KiPr = *Kindbergia praelonga*; LuCa = *Luzula camp/multi*; LyNe = *Lysimachia nemorum*; PeVi = *Persicaria vivipara*; PtAs = *Plagiochila asplenoides*; PILa = *Plantago lanceolata*; PoEr = *Potentilla erecta*; PiVu = *Primula vulgaris*; PuVu = *Prunella vulgaris*; PtAq = *Pteridium aquilinum*; PtCr = *Ptilium crista-castrensis*; RaAc = *Ranunculus acris*; RhLo = *Rhytidadelphus loreus*; ScPu = *Scleropodium purum*; StGr = *Stellaria graminea*; ThTa = *Thuidium tamariscinum*; TrRe = *Trifolium repens*.

## 6.6 Ellenberg scores

Ellenberg values (Hill *et al* 1999) for light, moisture, reaction and nitrogen describe the realised ecological niche in which the plant is found (i.e. if the plant is found in light or shady, wet or dry, acid or alkaline, fertile or nutrient poor habitats). For each of these four variables there is an ordinal scale. Ellenberg light scores range from 1 (deep shade) to 9 (full light); moisture scores from 1 (extreme dryness) to 12 (submerged plant); reaction scores from 1 (extremely acidic soils) to 9 (basic soils) and nitrogen scores range from 1 (extremely infertile) to 9 (extremely fertile). There is also a similar set of Ellenberg values for bryophytes (Hill *et al* 2007). Comparing Ellenberg values between plants allows comparison of the type of environment in which they grow. Ellenberg values were used to assess whether there were significant differences in the realised ecological niches of the plants between fenced and unfenced plots.

Weighted Ellenberg scores for each quadrat were calculated: for each Ellenberg value (light, moisture, reaction, nitrogen) for each quadrat, the sum of the Ellenberg scores multiplied by the percentage cover of the plant species was calculated.

A partial PCA was carried out on the weighted Ellenberg scores. Differences between the three areas (Ardura, Morrone, Coille Thogabhaig) explained 18% of the differences in Ellenberg scores. Of the remaining 81% in variation, 92% of this was explained along the first axis of the PCA which was negatively correlated with increasing scores for all four Ellenberg values (Fig. 6.12). The ordination of the quadrats did not show any clear separation between fenced and unfenced quadrats (Fig. 6.13). However when fencing was included as a categorical explanatory variable within the ordination (constrained partial RDA analysis) fencing was found to explain 8% of the variation and was significant ( $P=0.01$ ). Thus, there was a very weak effect of fencing on the ecological niches of plants (Ellenberg values). Fenced plots had plants with requirements for greater light, moisture and nutrients and less acidic soils. However this result should be set in the context of the unconstrained ordination (PCA) where the first axis explains 91% of the variation compared to the constrained ordination (RDA) which only explains 8%, thus there is a very large amount of variation in the Ellenberg scores that is not explained by the fencing treatment. In addition it should be remembered that there is a degree of pseudoreplication within the data (multiple quadrats from within one fenced area, and at Morrone all three fenced areas now within one large fenced area for the last 19 years) making robust statistical testing of this result impossible.

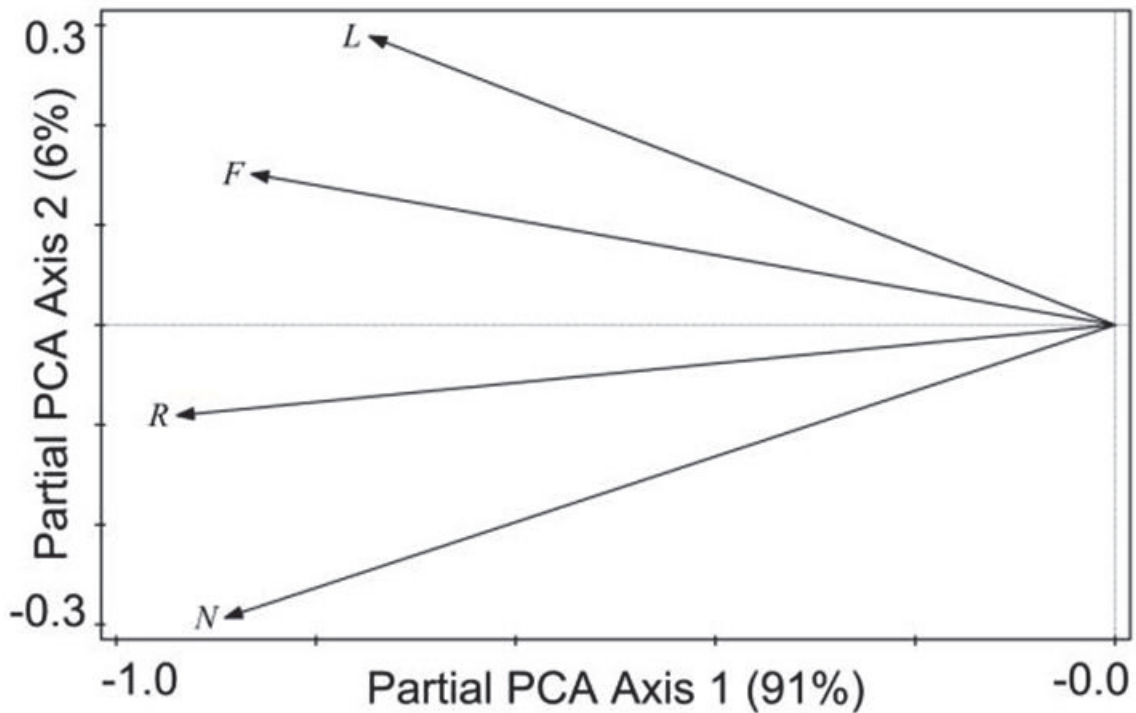


Figure 6.12 Ordination diagram from PCA analysis of Ellenberg scores: L = light, F = moisture, R = reaction (soil pH), N = nitrogen (soil fertility).

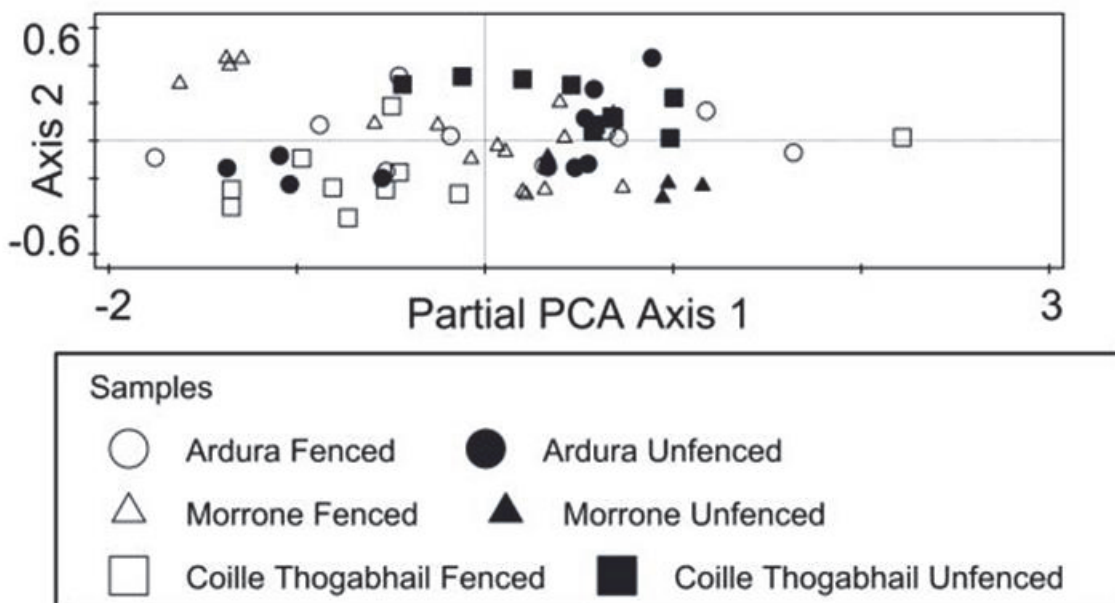


Figure 6.13 Ordination diagram of quadrats from PCA analysis of Ellenberg scores

In order to test the possible differences in Ellenberg scores between fenced and unfenced plots further, the mean Ellenberg score for each fenced/unfenced plot was calculated. This was done so as to avoid issues of pseudoreplication within the plots, although the issue of pseudoreplication at the three fenced plots at Morrone still remained. The four different sets of Ellenberg scores (light, moisture, reaction, nitrogen) were then analysed separately with Generalized Linear Mixed Models using the 'proc mixed' procedure in SAS (SAS 2010) with

area (Ardura, Morrone and Coille Thogabhail) as a random effect. There was no significant difference in the scores between fenced and unfenced plots for any of the four Ellenberg values, (with limited replication this might be expected). However, there was a slight trend ( $P < 0.1$ ) of greater cover of plants with a higher Ellenberg moisture score in fenced than unfenced plots, indicating that plants that require higher moisture levels occurred at greater abundance in the fenced plots.

## 7. SOIL RESULTS

All soils sampled are classified as brown earths (formerly brown forest soils) according to the Soil Survey of Scotland classification systems 1984 and 2013 (Soil Survey of Scotland Staff, 1984; <http://www.soils-scotland.gov.uk/publications/classification>) and the soils at all sites are classified as basic brown earths according to the Scottish Forestry soil classification system (Kennedy, 2002) due to the presence of calcareous or basaltic parent materials. Annex 4 has the soil profile descriptions and analytical results for all sites.

The horizon sequences in the main profile described at the paired sites were the same both inside the enclosure (fenced) and outside for all sites apart from Coille Thogabhaig 6 and Morrone Birkwood 4 (Annex 5). At Coille Thogabhaig 6 the profile outside of the fenced area had an additional L (Litter) and a Ah (humose topsoil) at 0-2 and 2-10 cm from the soil surface while at the Morrone Birkwood 4 site, it was the profile inside the fenced area that had an additional 6 cm thick L horizon (Figure 7.1).

The main soil properties of interest were C:N ratio, percentage carbon (C) content, percentage base saturation (ratio of base cations to Hydrogen and Aluminium), soil pH, bulk density (of the fine earth, < 2mm soil fraction) and horizon C stock (calculated as the product of horizon depth, carbon concentration and bulk density with a correction for stone content). Soil profile C stock was also calculated as the sum of horizon C stock.

Due to the low sample numbers, non-parametric statistics (Mann-Whitney U test) were used to compare results from the paired profiles at each site and Analyses of Variance (ANOVA) were used to compare results from the main topsoil horizon from all profiles inside the fenced area with those from outside. However, the low number of pairs means that the Mann-Whitney U test is not sufficiently robust to determine the significance of any differences in soil properties between profiles inside the fenced area and those outside.

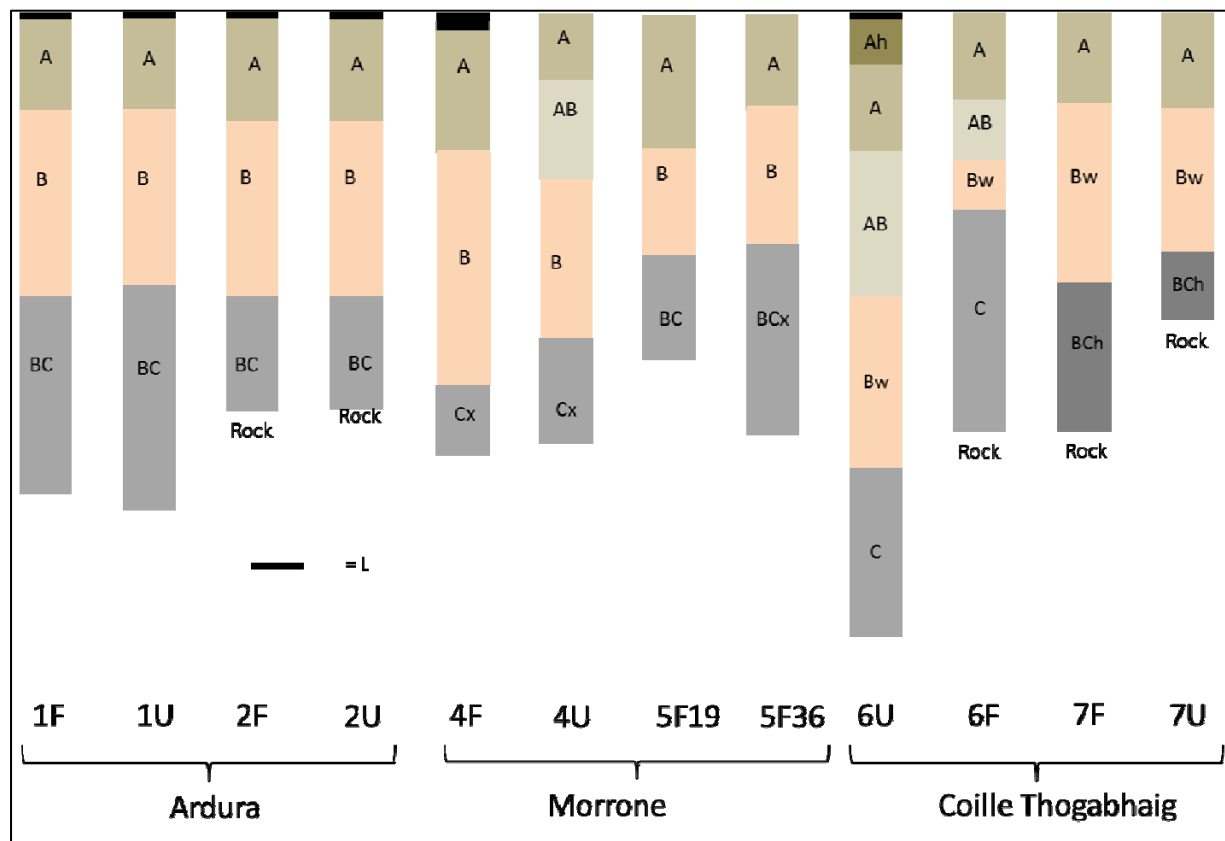


Figure 7.1 Scale schematic of soil horizons found in each profile pit

## 7.1 Profile pairs

### 7.1.1 Ardura 1 (Site 1)

The C:N ratio and percentage C were consistently greater in the horizons of the profile outside the fenced area and the bulk density was similar or noticeably greater inside the fenced area (Figure 7.2). The pH was either similar or greater inside the fenced area. The different pattern in bulk density and percentage C means that the individual C stocks for the horizons were quite similar (Annex 5) though the BC horizon seems to have a greater stock in the profile outside the fenced area but is partly explained by this horizon being thicker than the corresponding horizon inside the fenced area. The overall profile C stock to 1m depth was greater in the profile outside the fenced area (24.6 kg m<sup>-2</sup> compared with 23.02 kg m<sup>-2</sup> inside, Table 7.1). Both profiles had the same horizon sequence throughout (Annex 5 and Figure 7.1).

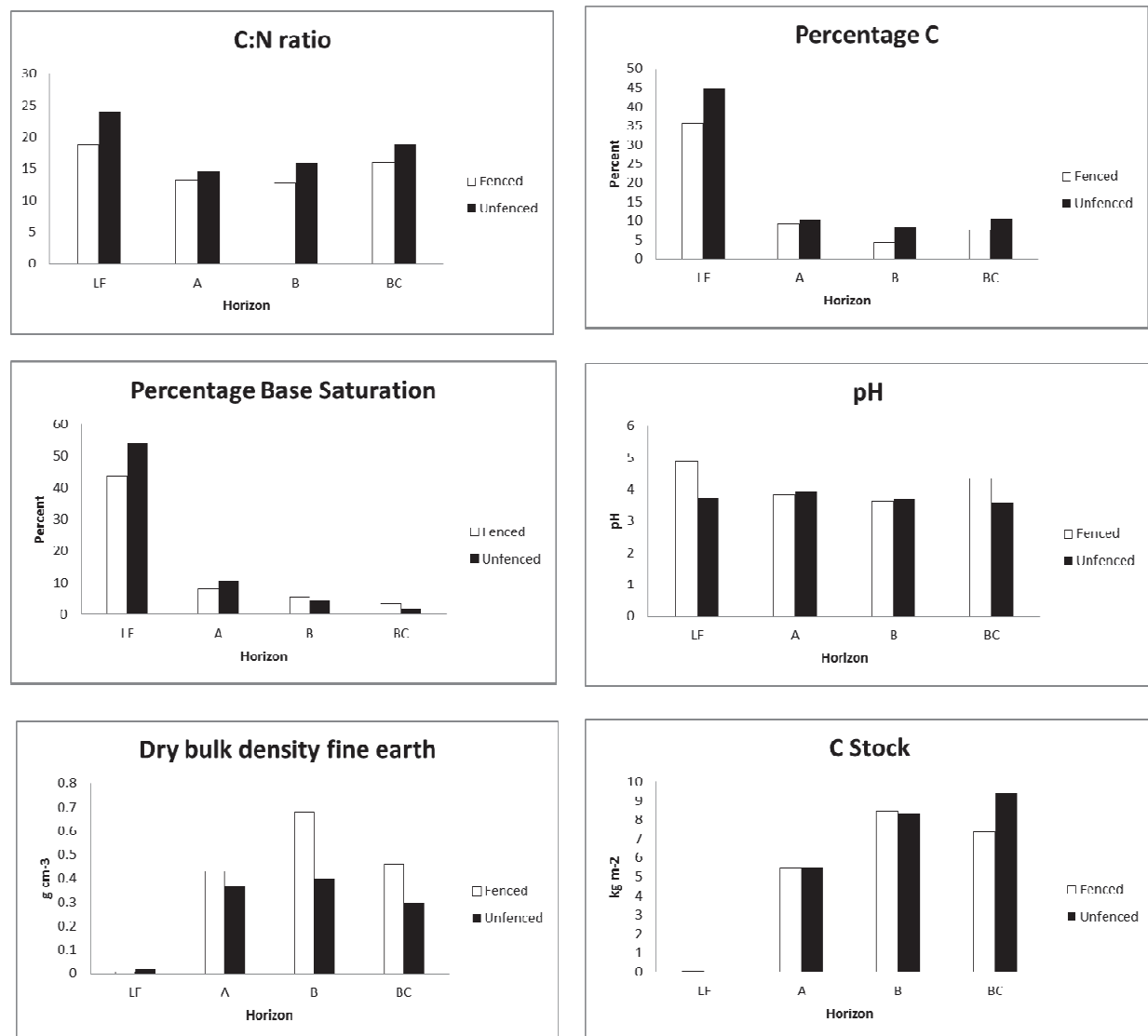


Figure 7.2 Graphical representation of selected soil attributes from Ardura 1 (Site 1).

### 7.1.2 Ardura 2 (Site 2)

The C:N ratio and percentage C appeared to be greater or similar for the profile horizons inside the fenced area compared to those outside (Figure 7.3) but this was reversed for pH and bulk density (apart from the litter layer). The horizon C stocks showed no trend and the profile C stock to 1 m was greater for the profile inside the fenced area than the profile outside (25.13 and 22.73 kg m<sup>-2</sup> respectively, Table 7.1). Again, both profiles had the same horizon sequence throughout (Annex 5 and Figure 7.1) and both had rock within 1 m of the soil surface (curtailing the C stock calculation to 75 and 76cm).

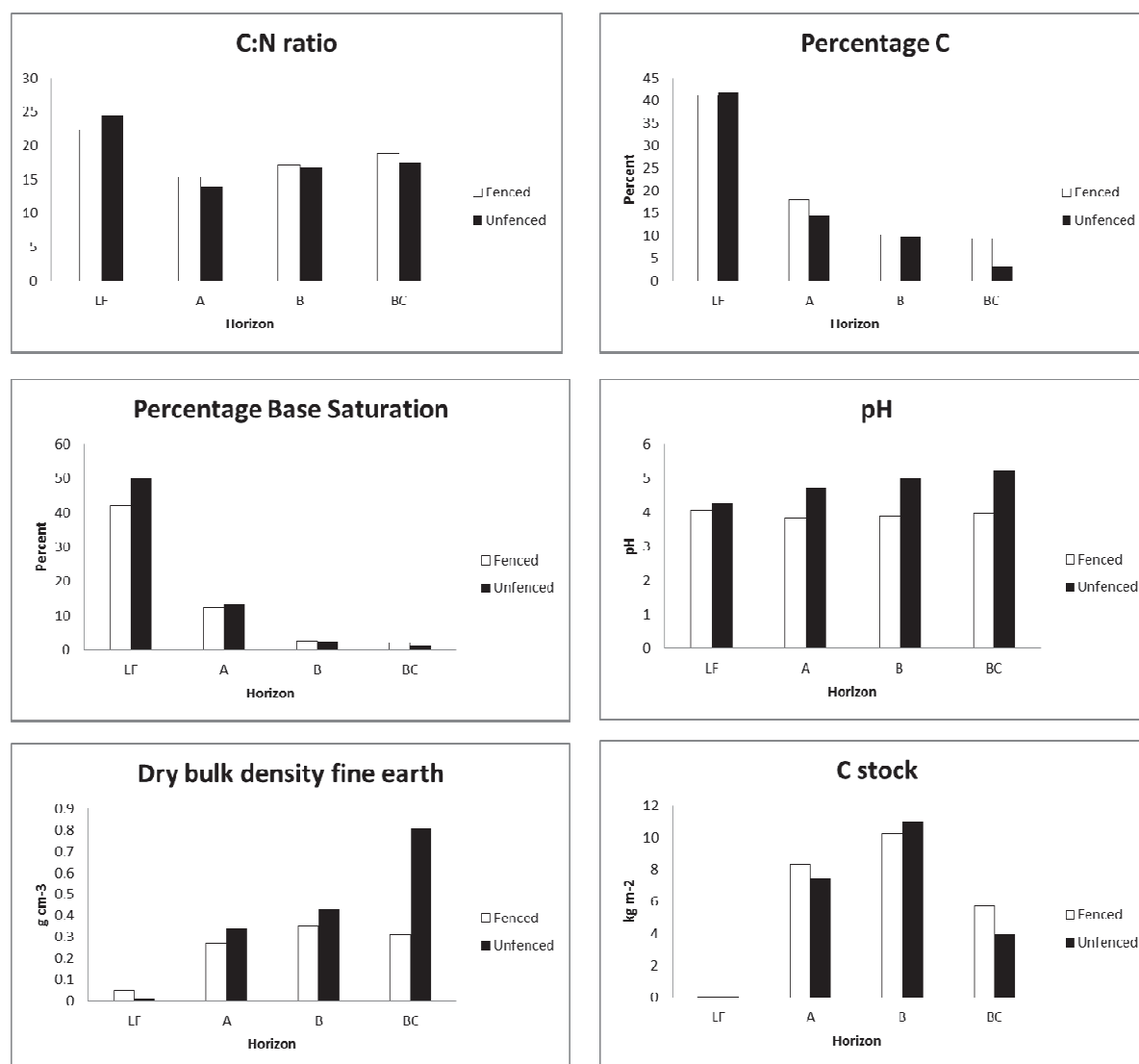


Figure 7.3 Graphical representation of selected soil attributes from Ardura (Site 2).

### 7.1.3 Morrone Birkwood (Sites 4 and 5)

As there was only effectively one profile at Morrone where herbivores were excluded and 3 where they had been excluded for either 19 or circa 36 years, the data for all four profiles were examined together. All profiles had a similar set of horizons (Annex 5 and Figure 7.1) with the unfenced site having an additional AB horizon (intermediate between a topsoil A and subsoil B horizon typical of brown earths). One of the older fenced profiles and the profile in the area enclosed for 19 years had LF (litter and fermentation horizons) overlying the topsoil A horizon (Figure 7.1).

The Morrone soils comprised mica-schist and hard limestones in varying proportions which affected the base saturation. The C:N ratio was fairly consistent across all similar horizons (Figure 7.4) and the percentage carbon content was not dissimilar within each of the comparable horizons. The soil pH seemed to be less affected by the varying proportions of basic and acid rocks and showed a general upward trend with depth and the bulk density also generally increased with depth. The horizon C stocks showed a similar pattern for each of the 4 subsoil and 4 parent material horizons apart from the Morrone Birkwood 1 profile (5F19) where the A horizon C stock was the greatest. However, the profile C stocks to 1m were greatest for the Morrone Birkwood 3 profile (4F) which has also been enclosed for circa 36 years but had an additional LF horizon on top of the A horizon.

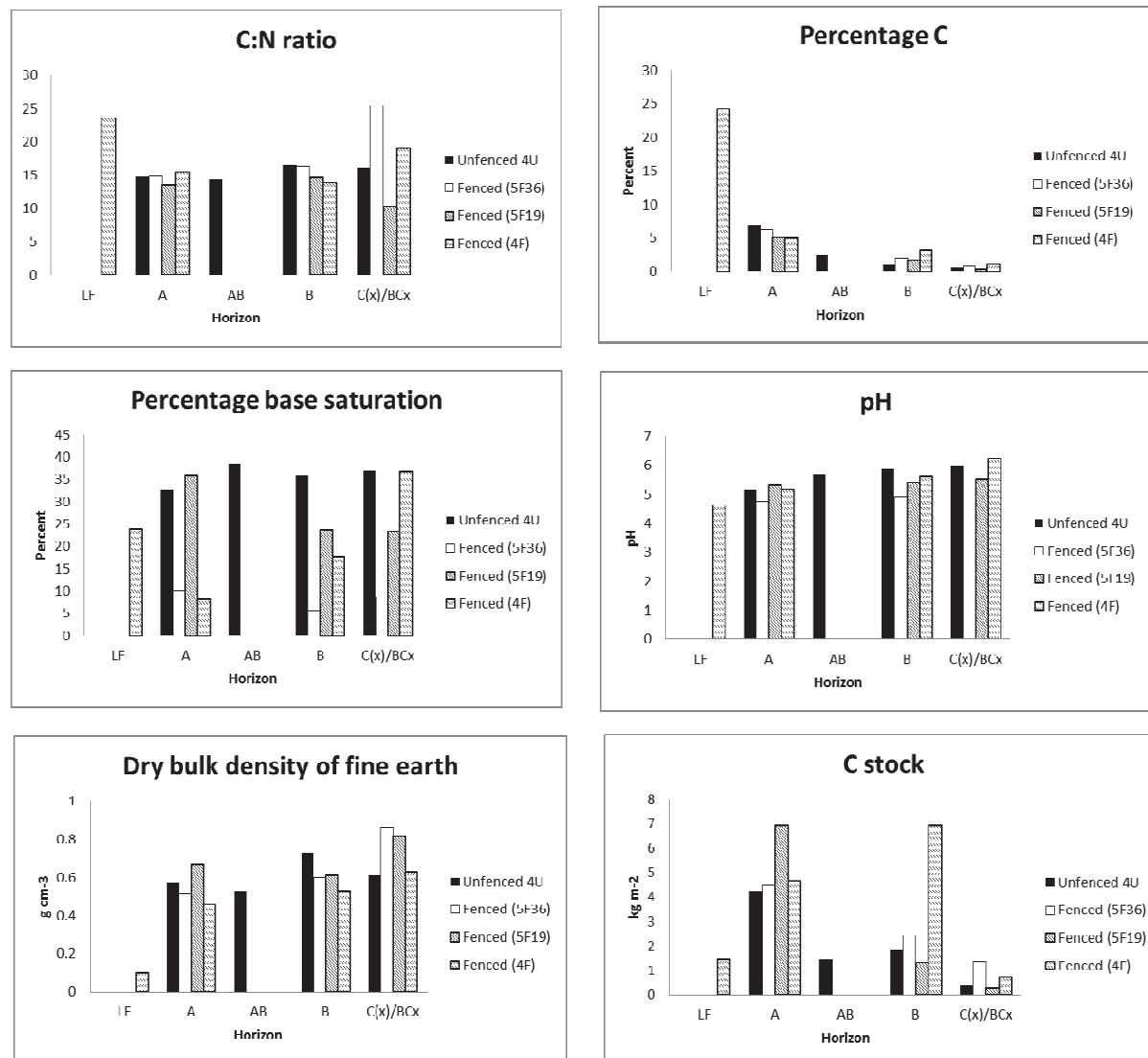


Figure 7.4 Graphical representation of selected soil attributes from Morrone Birkwood (Sites 4 & 5).

#### 7.1.4 Coille Thogabhaig (Site 6)

Figure 7.5 shows data for selected soil attributes from the main profile pits inside the fenced area and outside (unfenced). The C:N ratio and soil pH showed little differences between the samples from inside and outside the fenced area. The bulk density was generally lower or the same in all the horizons in the profile outside the fenced area apart from the topsoil A horizon (see Annex 3) where the bulk density was greater inside the fenced area, which was

unexpected. The carbon stock of the A horizon is greater inside the fenced area than outside, but as the profile outside also had additional L and Ah horizons, the C stock of these carbon-rich surface horizons is greater. This remained true when the C stocks were calculated to 1m depth (10.78 and 8.6 kg m<sup>-2</sup>, Table 7.1). It may be that some leaf-fall was trampled in to the soil by herbivores outside the fenced area resulting in the development of a more carbon-rich layer (Ah). However, care should be taken not to place too much emphasis on this result due to soil heterogeneity at the site.

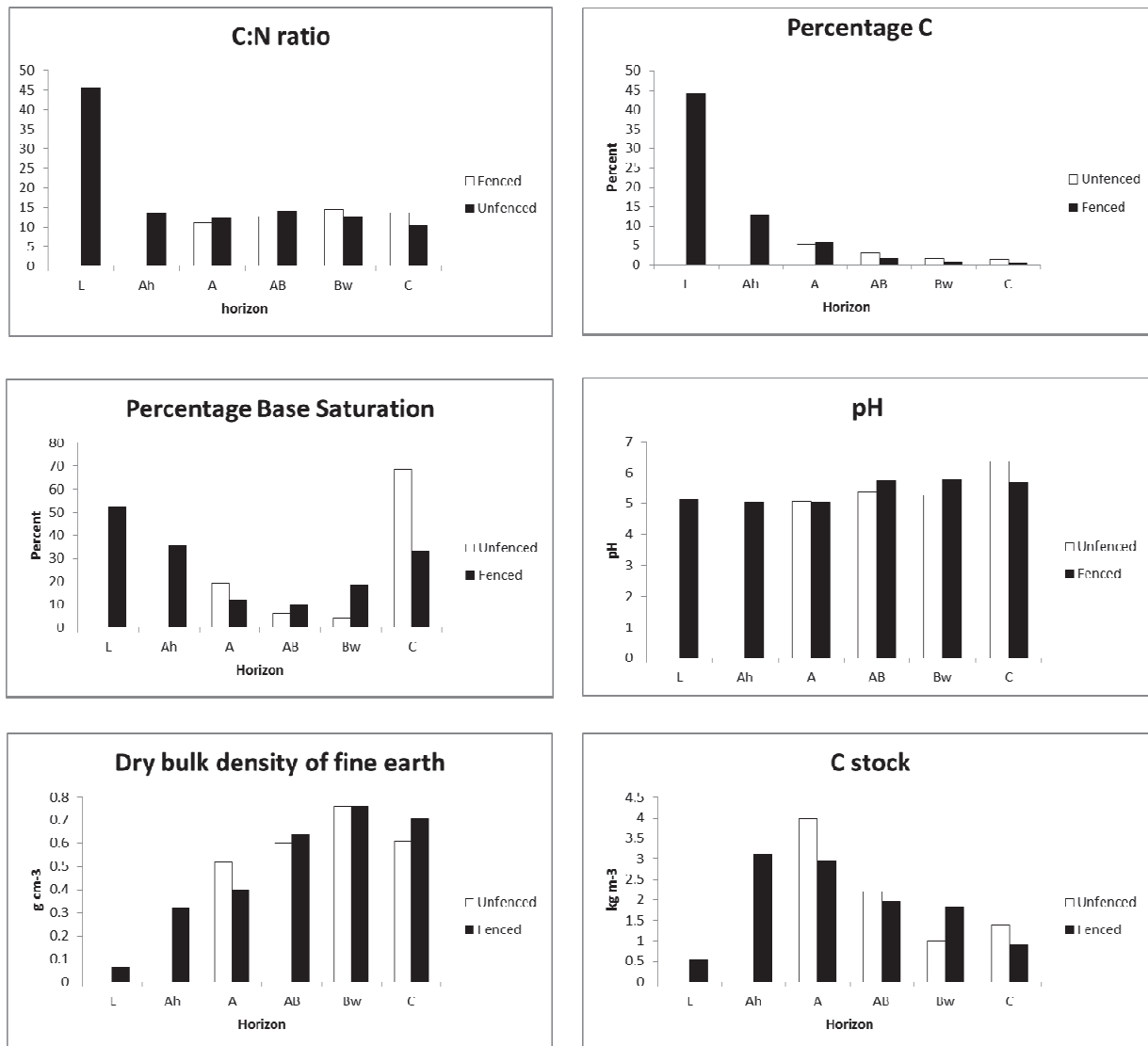


Figure 7.5 graphical representation of selected soil attributes from Coille Thogabhaig (Site 6).

### 7.1.5 Coille Thogabhaig (Site 7)

The two profiles examined at site 7 had the same horizon sequence throughout (Annex 5 and Figure 7.1) with a humose rich BC horizon (BCh) that may be due to the *in situ* decay of roots on top of the rock. The C:N ratio, percentage C, percentage base saturation, pH and (surprisingly given the greater C content) dry bulk density were all greater in this layer in the profile outside of the fenced area (Figure 7.6). Both percentage C and C stock of the topsoil (A horizon) were greater outside of the fenced area and the stock to the base of the profile (80 cm inside and 58 cm outside) was reversed 13.94 and 12.03 kg m<sup>-2</sup> (Table 7.1) with the greater amount in the profile inside the fenced area though this profile was 22cm thicker.

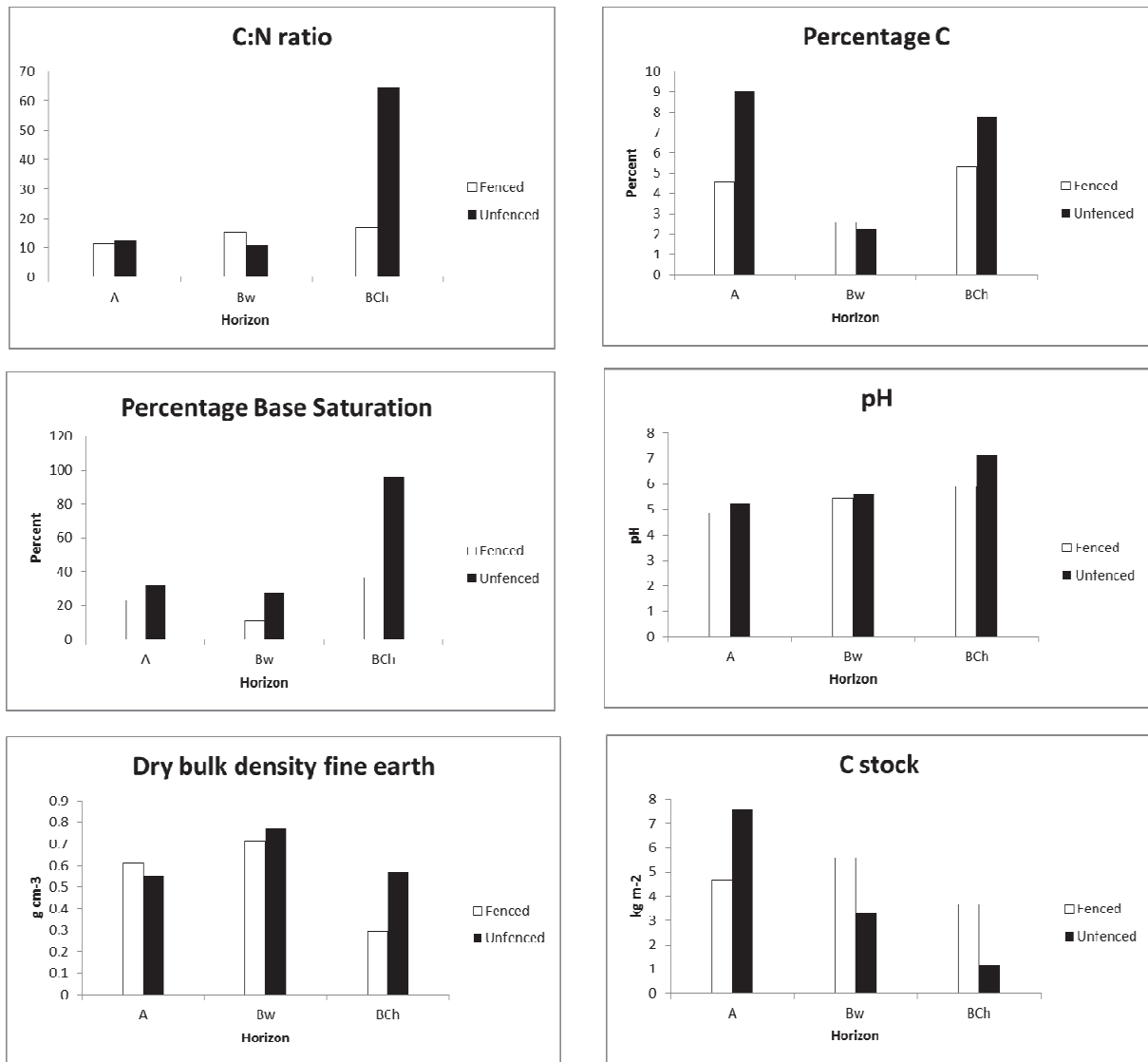


Figure 7.6 Graphical representation of selected soil attributes from Coille Thogabhaig (Site 7).

## 7.2 Comparison of topsoil (A horizon) properties

Given that the changes in soil properties due to the exclusion of large herbivores from a site are most likely to be seen in the surface soil horizons, selected properties from A horizons from all profiles inside the fenced area were compared to those outside. As three of the Morrone Birkwood sites had been enclosed for 19 years (5F19) and 36 years (4F and 5F36) all three were treated as being fenced (shaded white, grey and striped in Figure 7.7). The results were analysed by ANOVA and showed that there was no significant difference between the soil properties of the A horizons of the profiles inside the fenced area compared with those outside (Figure 7.7). As there are few sample numbers, a greater threshold is required for any differences to be significant.

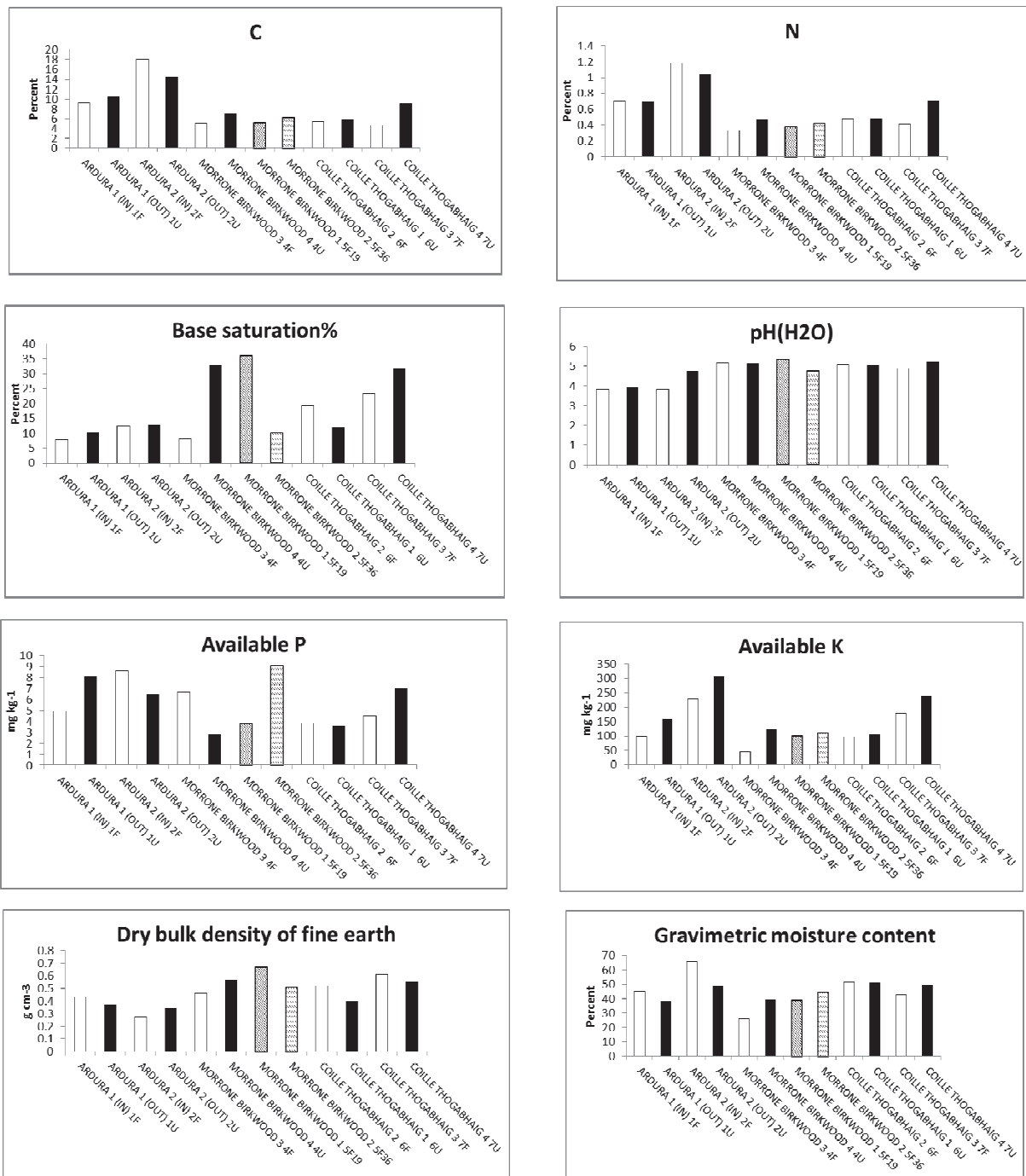


Figure 7.2 graphical representation of selected soil attributes from all topsoils (A horizons).

### 7.3 Profile C stocks

Figure 7.8 and table 7.1 show the C stock in each of the 12 sampled profiles to 1 m depth (unless the depth of the profile was constrained by rock at shallower depths). Again Analyses of Variance showed no significant differences between the profiles inside (white and striped/grey shading) and those outside the enclosures (black).

Table 7.1 Profile Carbon stock to 1m (or to rock if shallower than 1m) for profile inside and outside of the exclosed area and as mean of 5 cores 0-15cm.

Profile name	Site code	Profile C Stock (kg m <sup>-2</sup> )		Depth
		to 1 m	to 15 cm	
ARDURA 1 (IN)	1F	22.920	2.712	100+
ARDURA 1 (OUT)	1U	24.4	1.141	95+
ARDURA 2 (IN)	2F	24.432	3.393	76
ARDURA 2 (OUT)	2U	22.555	2.801	75+
MORRONE BIRKWOOD 3	4F	14.650	3.72	84+
MORRONE BIRKWOOD 4	4U	8.270	3.795	82+
MORRONE BIRKWOOD 1	5F19	9.090	3.176	66
MORRONE BIRKWOOD 2	5F36	9.090	3.291	88
COILLE THOGABHAIG 6	6F	8.597	3.394	80
COILLE THOGABHAIG 6	6U	10.780	3.91	120+
COILLE THOGABHAIG 7	7F	13.944	4.551	80
COILLE THOGABHAIG 7	7U	12.026	3.431	58

+ indicates that the lowest horizon continues to at least 1 m

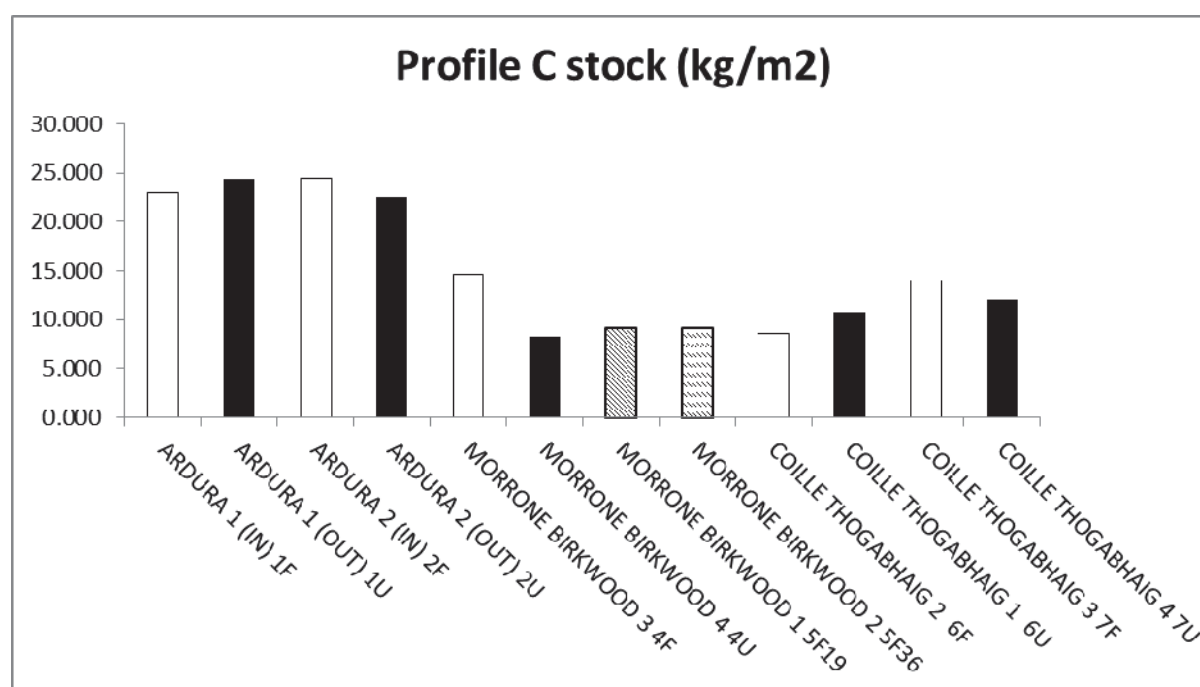


Figure 7.3 Graphical representation of profile C stock to 1m depth unless constrained by rock at shallower depths.

#### 7.4 Within site profile variability

Annex 6 shows the horizon sequences, depths and soil types at each of the satellite pits dug within each woodland. Plastic rings (15 cm long) were pressed into the soil from the surface at each of these sites to obtain a 0-15cm soil core. A separate, 0-15 cm soil sample was also taken for analyses of available N immediately adjacent to the core. This method allowed the

dry bulk density of the intact cores to be determined rather than having to take a subsample from this core prior to drying in order to determine the available N which requires a fresh and field moist sample.

Due to the near-surface horizons being relatively thin in most cases, the 0-15 cm soil cores mostly comprised a mixture of horizons. These often were a mixture of highly organic L and F layers and mineral A horizons. Clearly the differences in horizon sequences within the satellite pits means that these core samples are not directly comparable to the data obtained from analyses of the samples from the soil profile pit, especially where the randomly located satellite pits fall on another soil type.

In all sites there were some subtle differences in horizon sequences in these satellite pits, for example, the presence or absence of litter layers (L horizons) or Ah layers. These subtle differences would most often not affect the soil classification and so most of the satellite pits were also classified as brown earths.

The most heterogeneous site was Ardura 2 fenced area which had a different soil type at each of the four satellite pits including basin peat, brown earths (one with gleying) and a peaty ranker. The least variable site was Coille Thogabhaig 6 but even here the surface horizons of the satellite pits varied from mineral to organic.

## **7.5 Within site soil analyses**

Despite the heterogeneity at some sites compared to others, Analyses of Variance of the selected soil attributes deemed to be of greatest interest (C, N, C stock to 15 cm, available N, Base saturation, pH in water, available P, dry bulk density of the fine earth and gravimetric moisture content) showed no significant differences between those sites inside the fenced area and those outside (Figure 7.9). This was also true for C stocks calculated to 15 cm and corrected for horizon stone content and for available N (as nitrate). The measured stone content of the core was used to correct the C stocks rather than the estimated stone content as used to determine the horizon stocks. This doesn't take account of the larger stones as these would have been avoided allowing the sampling of the soil over the full 15cm thickness and possibly this will lead to an overestimate of the C stocks in the bulked core samples. Although there was no significant difference in C stocks at these sites in the upper 15cm, three of the 6 sites did show greater stocks in the fenced area compared to the unfenced area (Figure 7.9) and comparable stocks in another site. With only 11 degrees of freedom, these results need to be treated with caution but, for the most part, there is no statistically significant difference between fenced and unfenced sites apart from available K which did show a significant difference between the fenced sites and the unfenced sites ( $p=0.042$ ) with the greater concentration found in the unfenced sites. There is no clear explanation or mechanism as to why there would be a significant difference in potassium content.

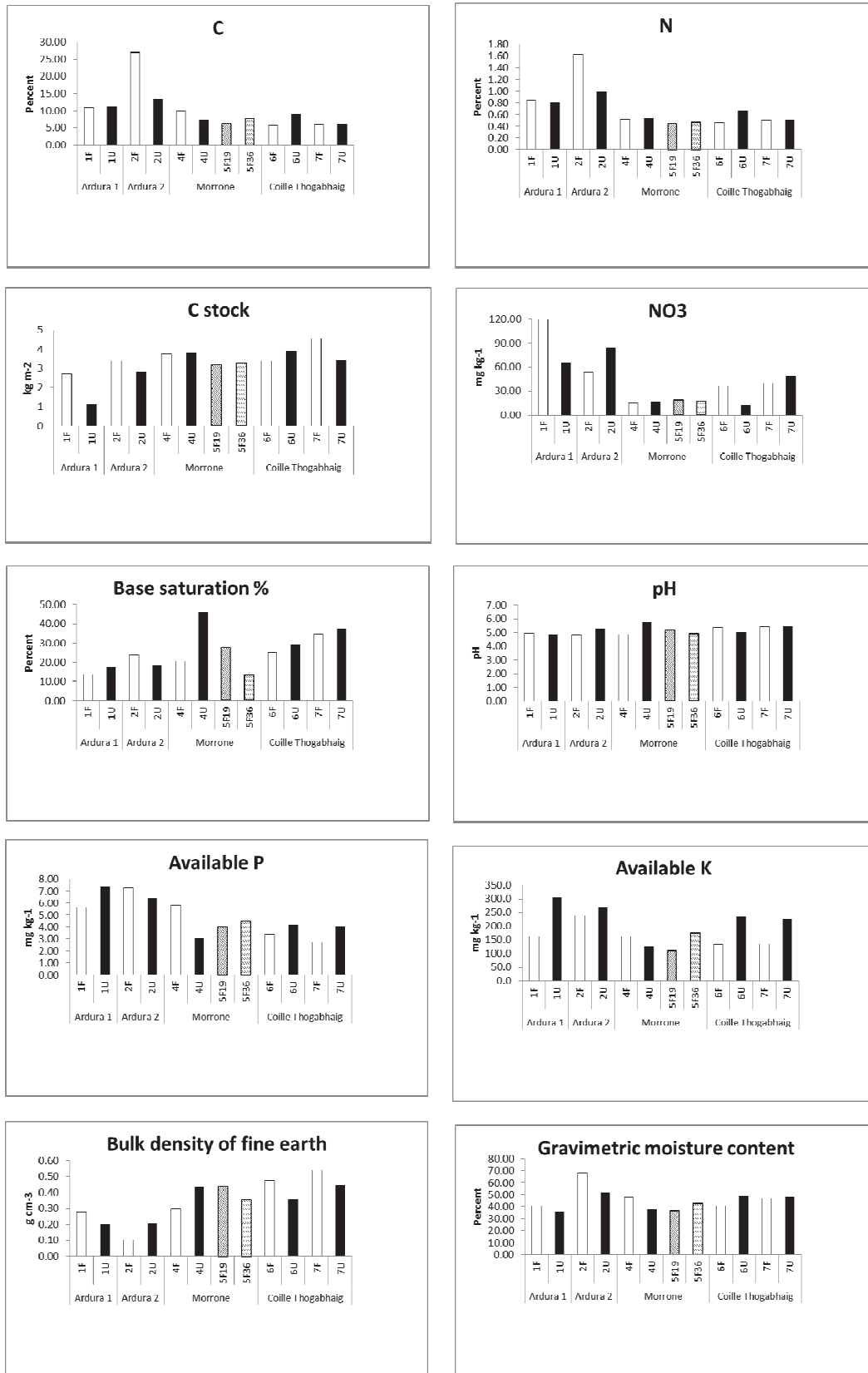


Figure 7.4 Graphical representation of selected soil attributes from all 0-15 cm cores taken at the main and four satellite pits (white and stripped/grey shading are for fenced sites)

## 8. PLFA RESULTS

Phospholipid fatty acids (PLFAs) provide an indication of the composition of the soil microbial community. They do not provide a detailed species composition but can be used to provide broad indications of the differences occurring in the soil. Some PLFAs occur in many different types of organisms, called unclassified PLFAs; others are specific to fungi or a particular type of bacteria such as Gram positive, Gram negative or Actinobacteria.

Generalized Linear Mixed Models using the 'proc mixed' procedure in SAS (SAS 2010) with area (Ardura, Morrone and Coille Thogabhail) as a random effect were used to assess whether there were differences between the fenced and unfenced plots in the amounts of PLFAs present.

Total PLFA (a measure of the total soil microbial community) showed no significant differences between fenced and unfenced plots across the different sites (Fig. 8.1;  $P>0.05$ ). However at any one site there were indications of differences between the fenced and unfenced plots. The largest differences occurred at Ardura (sites 1 & 2), but within the two sites at Ardura there were different patterns - with greater total PLFAs in the unfenced than the fenced plot at site 1 but the opposite pattern occurring at site 2. At Coille Thogabhail both unfenced sites had greater total PLFAs than the fenced sites, whereas at Morrone there were slightly greater PLFAs in the fenced than the unfenced sites.

When the PLFAs were classified by the group they represented (e.g. bacteria or fungi) (Fig. 8.1) there were no significant differences between fenced and unfenced plots ( $P>0.05$ ), but once again there were indications of differences at the site level between fenced and unfenced plots. However these differences at site level should be treated with caution as the analysis was done on a bulked sample providing no replication within each fenced or unfenced plot.

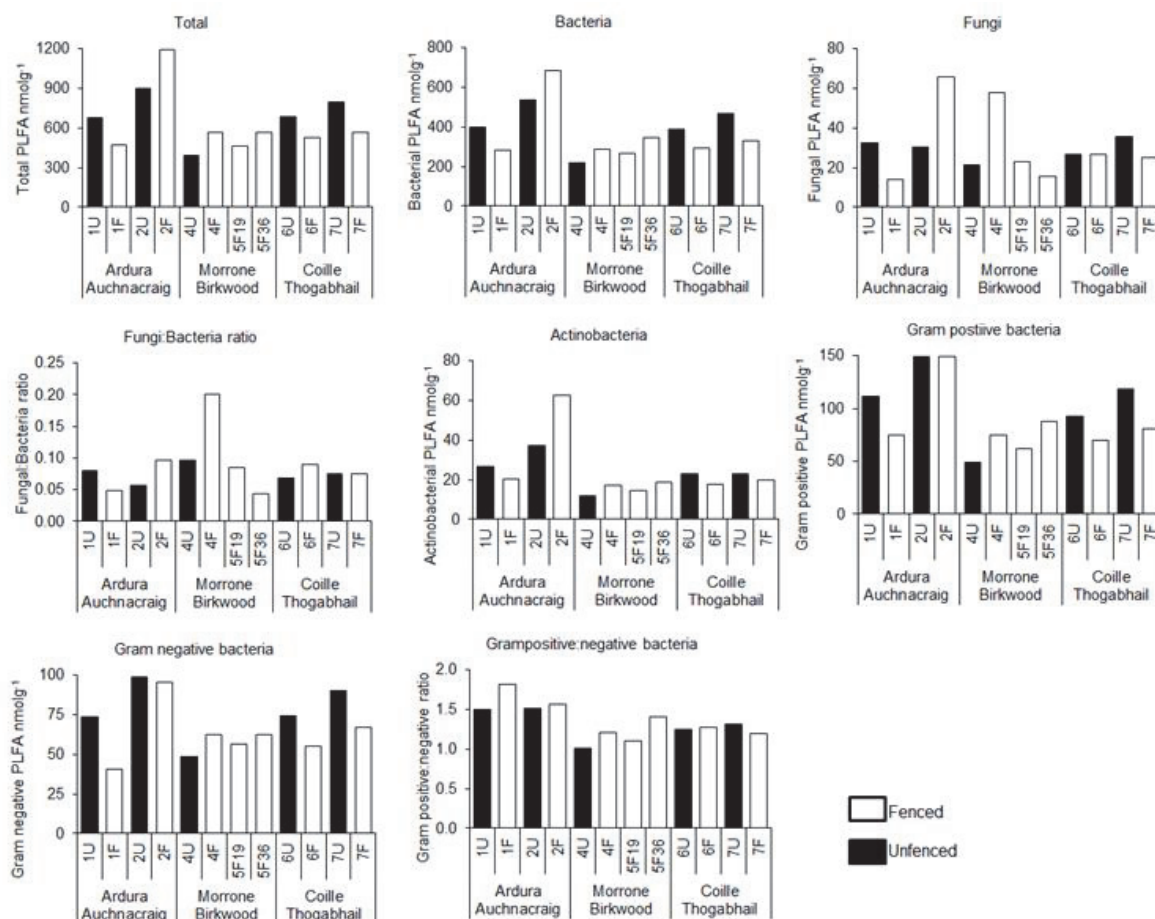


Figure 8.1 Differences in PLFAs in fenced and unfenced plots from 6 woodland sites

The 48 individual PLFAs were analysed using the multivariate technique Principal Coordinate Analysis (PCA) with the three areas (Ardura, Morrone and Coille Thogabhail) included as covariates to remove the variation in PLFAs that could be explained by these three areas (ie geographic variation rather than differences due to the fencing treatment).

Differences between the three areas account for 43% of the variation in PLFAs. Of the remaining variation the first axis of the ordination explained 37.4% and the second axis 20%. The first axis showed some separation between samples from fenced and unfenced plots but this was not very clear (Fig. 8.2). When fence was included as a categorical explanatory variable within the ordination (partial constrained RDA) fencing explained 8% of the variation in the PLFAs but this was not significant ( $P=0.27$ , Monte-Carlo permutation test).

The Ardura sites showed a clear difference in microbial community composition between fenced (1F and 2F) and unfenced plots (1U and 2U), with the position of the plots being quite separate in ordination space. There was very little difference in the microbial community between fenced and unfenced plots at Coille Thogabhail, with the fenced and unfenced plots from sites 6 and 7 being close to each other in ordination space, however there did appear to be quite a lot of within area variation as site 6 was very different from site 7. The samples from Morrone Birkwood (sites 4U, 4F, 5F19, 5F36) were spread throughout the ordination diagram and showed no clear pattern.

The differences in community composition between samples did not correspond to clear separation in differences in the microbial community – for example the Gram positive and

Gram negative bacteria were equally distributed over Axis 1 in the ordination diagram (Figure 8.3 and 8.4).

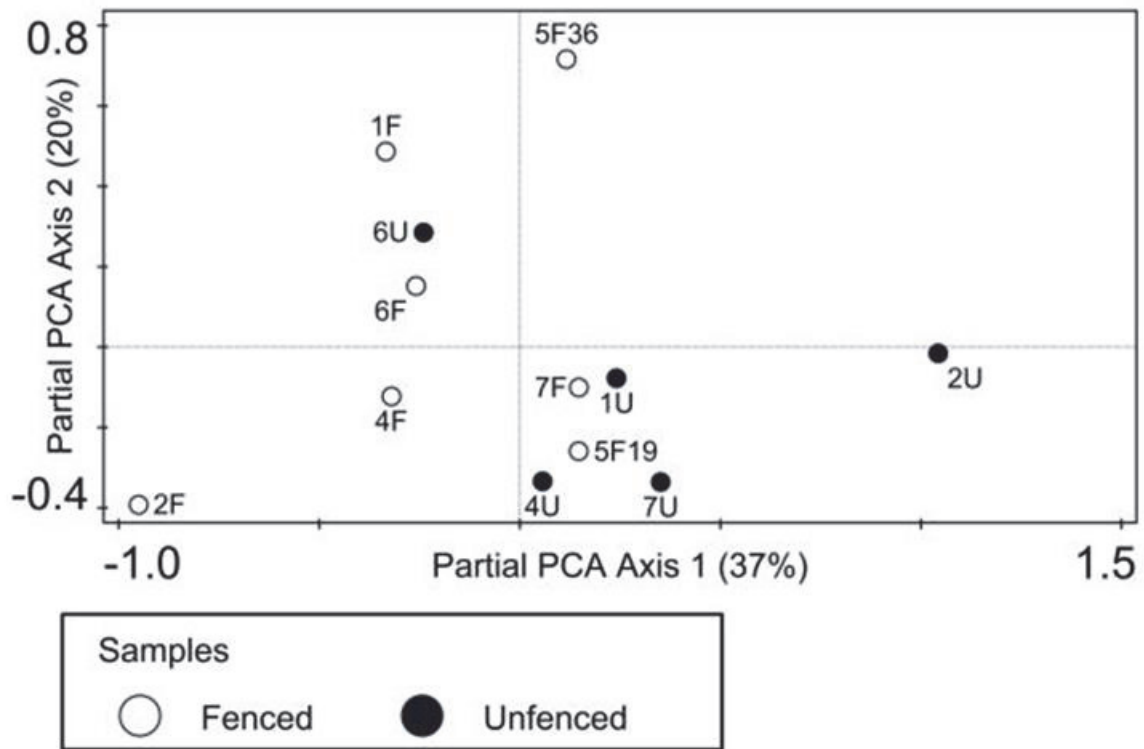


Figure 8.2 Ordination diagram of PLFA samples from 6 woodland sites with fenced (F) and unfenced (U) plots (See Table 5.1 for site codes)



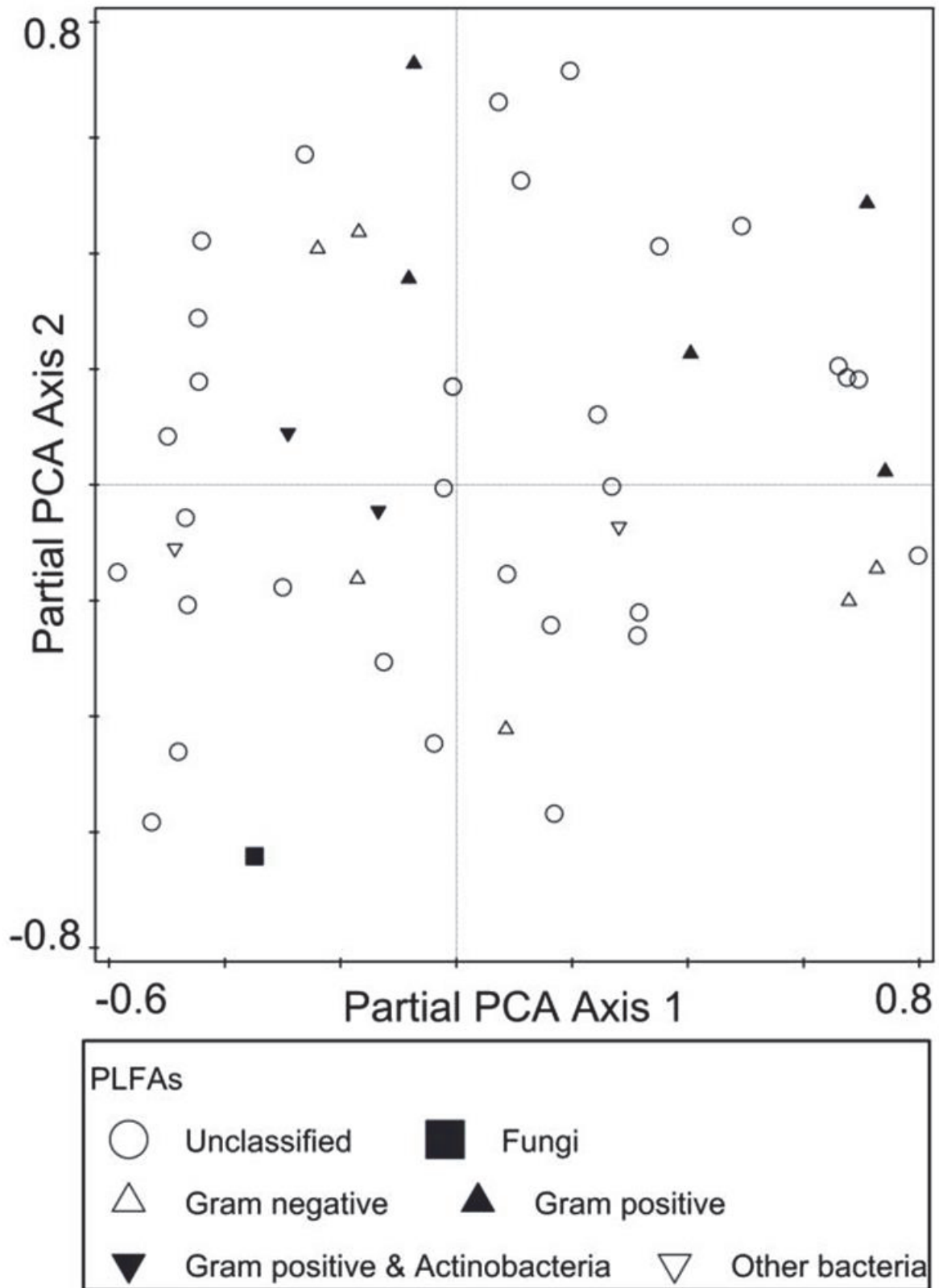


Figure 8.4 Ordination diagram of PLFAs from 6 woodland sites with fenced and unfenced plots. Each point is one of the arrows in Figure 8.3 classified as fungi, Gram negative, Gram positive, Gram positive & Actinobacteria, other bacteria and unclassified.

## 9. CONCLUSION

The impact of herbivores on woodland vegetation has been frequently studied and the potential for heavy grazing to reduce woodland regeneration is well known. However the impact of herbivores on below ground soil processes has not previously been studied in this type of woodland (upland birch woodland on brown earth soils). This small study aimed to gain an understanding of the changes that might result if herbivores were removed from birch woodlands on brown earth soils.

The main conclusions from this study were:

- Fencing to remove grazing (unsurprisingly) results in an increased number of trees present although there are indications of a lack of younger trees, possibly because the fences are very porous and some grazing is now occurring within them.
- There was a significant difference in the ground flora present with the unfenced plots containing more grazing tolerant species such as grasses and the fenced plots being more bryophyte dominated.
- There were differences in the Ellenberg moisture values between fenced and unfenced plots with fenced plots having greater cover of plants that required greater moisture.
- There was no clear change in soil profile morphology due to herbivore exclusion, that is, there was no consistent development of Ah or L horizons in the fenced sites.
- Although there were inevitably some differences in individual soil properties (carbon content, carbon stock, nitrogen, bulk density, pH, base saturation) between fenced and unfenced sites, the differences were not statistically significant
- Although the topsoil A horizon were thought to be the horizons where there was most likely to be differences in soil properties between samples taken from the soil profiles both inside the fenced area and outside the fenced area, there was no significant difference in the main soils properties thought the most likely to change (carbon content, carbon stock, nitrogen, bulk density, pH, base saturation).
- There was no significant difference in profile C stocks to 1m depth (or shallower if constrained by rock) though, as the sample numbers were low, the threshold for having a statistically significant difference was relatively high.
- There was no significant difference between most of the main soil properties of interest (carbon content, carbon stock, available nitrogen, available P, available K, bulk density, pH, base saturation, moisture content) as measured in the 0-15 cm bulked soil cores from each site between samples from inside the fenced area compared to those outside though the C stocks for 3 sites were greater in the fenced area and at one site, they were comparable.
- Available K as measured in the 0-15 cm bulked soil cores was found to be significantly greater ( $p=0.04$ ) in the unfenced area in comparison to the fenced area. There is no clear mechanism by which available K should be significantly different in the unfenced areas compared to soils inside the fenced areas especially as no other soil properties showed this. It may be simply due to natural soil heterogeneity and more samples would be needed to confirm if this is a valid result.
- There were no consistent differences in the composition of the soil microbial community, as assessed using PLFAs (phospholipid fatty acids), between fenced and unfenced plots. However multivariate analysis indicated that at Ardura there were differences in soil microbial composition between fenced and unfenced plots, but no consistent differences at Morrone or Coille Thogabhail.

While the above results do not show a clear indication of herbivore impacts on soil properties, all results (vegetation, soil and PLFAs) should be treated with a degree of caution for the following reasons: a) the low number of replicates, b) the fact that grazing occurred in most fenced areas, c) within the multivariate analysis of the quadrat data there is a degree of

pseudoreplication with multiple quadrats being recorded from within one plot. In addition, the three fenced plots at Morrone are not strictly independent as they have all been within one large fenced area for the last 19 years. These results should not be used to infer that herbivores do not have an impact on soil properties; rather that due to natural variability and low sample sizes, no consistent pattern was discovered in relation to herbivore 'removal'. Within individual sites there were differences recorded between the fenced and unfenced areas but these were not consistent across all sites. Future work to look at the impacts of herbivores on ecosystem function would require a great number of samples and fenced plots where large herbivores were fully excluded.

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## **ANNEX 1: WOODLAND STRUCTURE CLASS TABLE**

All tables in Annex 1 are taken from an earlier version of the Scottish Forestry guide to Assessing Herbivore Impact in Woodlands:  
A Subjective Method : Tables 1 – 5

<https://forestry.gov.scot/images/corporate/pdf/herbivore-impact-assessment-method.doc>

[Accessed February 2014].

<b>Table 1: Woodland Structure Class table</b>	
<b>Woodland Structure Class</b>	<b>General structure description</b>
<b>Class 1:</b> Open ground, simple	Any open ground vegetation with a simple structure. May be open because of high herbivore impacts, because seed trees are absent or because the ground is very wet, very poor or rocky.
<b>Class 2:</b> Open ground, complex	Any open ground vegetation progressing towards woodland. Includes sparse tree regeneration and a low shrub layer that includes very palatable species (e.g. bramble) – suggests a period of low herbivore impacts within the last decade.
<b>Class 3:</b> Dense regeneration, on previously open ground	Clumped patches of regeneration up to 3m. in height – suggests recent herbivore impacts low or absent.
<b>Class 4:</b> Young woodland up to early maturity, thicket and stem exclusion	Young woodland with a closed canopy >3m. in height, containing dead suppressed stems. It may contain small seedlings but normally these die due to a lack of light. Current herbivore impacts may vary. Recent or historic impacts low or absent.
<b>Class 5:</b> Mature woodland, understorey regeneration	Older woodland with small canopy gaps or where competition between canopy trees is minimal. The field layer is likely to be rank. A woody shrub layer, understorey and/or tree seedlings and saplings becoming established – suggests a period of low herbivore impacts within the last decade.
<b>Class 6:</b> Mature woodland, no understorey regeneration	Older woodland with small canopy gaps or where competition between canopy trees is minimal. A single storey of mature trees with a sparse or absent understorey and a short field layer or a rank field layer of unpalatable species such as bracken or <i>Molinia</i> . Few or no woody species - suggests historically moderate to heavy herbivore impacts.
<b>Class 7:</b> Post-mature woodland, dead canopy trees, complex	Open canopy with senescent and dead canopy trees. A woody shrub layer and understorey are present, including tree seedlings and saplings – suggests a period of low herbivore impacts within the last decade.
<b>Class 8:</b> Post-mature woodland, dead canopy trees, simple	Open woodland with senescent and dead canopy trees, no understorey and a lack of woody growth in the field layer – suggests heavy current or recent herbivore impacts and a decline in woodland cover.

<p><b>Class 9:</b> Open canopy, open-grown trees, complex</p>	<p>Wood pasture. Scattered, open-grown trees that are mature or post-mature, with tree regeneration and a rank field layer that includes palatable species – suggests a period of low herbivore impacts within the last decade.</p>
<p><b>Class 10:</b> Open canopy, open-grown trees, simple</p>	<p>Wood pasture. Scattered, open-grown trees that are mature or post-mature, with a short field layer or a rank field layer of unpalatable species such as bracken or <i>Molinia</i>. Little or no tree regeneration – suggests ongoing herbivore impacts and the potential for long-term decline in the woodland component.</p>

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<p><b>Basal shoots</b></p> <p>Use the “<i>Not applicable</i>” column on the field sheet if there are no trees with basal shoots at the stop</p>	<p>Accessible shoots of all species very heavily browsed.</p> <p>NB. Where large herbivore have been excluded in recent years and then suddenly increased, there may be basal shoots that are too large to browse.</p>	<p>Shoots of palatable species very heavily browsed, unpalatable species heavily browsed</p>	<p>Shoots of palatable species heavily browsed, unpalatable species moderately to lightly browsed</p>	<p>Shoots of palatable species lightly to moderately browsed, shoots of unpalatable species generally unbrowsed, some lightly browsed.</p>	<p>All species unbrowsed</p>
<p><b>Epicormic shoots and lower shoots</b></p> <p>Include shoots on fallen trees or lower branches in reach of herbivores</p>	<p>A very obvious and well maintained browseline on all trees, with plenty of evidence of recent browsing to shoot tips.</p> <p>Shoots below the browse-line difficult to find on palatable tree species (e.g. ash and oak) because they are browsed close to the trunk. Even woody shoots of birch and alder are moderately to heavily browsed</p>	<p>An obvious browse-line on all trees with live lower branches – most or all shoot tips browsed</p> <p>All but the most unpalatable epicormic shoots (e.g. old woody birch shoots) moderately to heavily browsed.</p>	<p>A maintained browse-line (i.e. evidence of some recent browsing to shoot tips) on most or all tree species. The presence of some unbrowsed lower branches may interrupt the horizontal browse-line.</p> <p>Most epicormic shoots lightly browsed, a few browsed back moderately to heavily</p>	<p>Shoot tips within the reach of large herbivores unbrowsed on all but the most palatable species</p>	<p>No sign of <i>recent</i> browsing on live lower/epicormic shoots</p>

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<p><b>Bark stripping &amp; stem breakage</b></p> <p>Use the “<i>not applicable</i>” column of the field sheet if the stop contains no trees susceptible to bark stripping or stem damage</p>	<p>There may be &gt;50% of live stems and recently fallen branches with severe fresh bark stripping.</p> <p>&gt;20% live stems of young trees (saplings/thicket) may be snapped (e.g. when traditional breeds of cattle are present)</p>	<p>There may be recent bark stripping damage of 20-50% of live stems. One species (e.g. Rowan) can have all live stems stripped by deer, There may be frequent stem snapping by cattle and/or deer.</p>	<p>A few trees show signs of bark stripping damage. Sometimes one individual tree badly damaged.</p> <p>Occasional to frequent stem snapping by cattle or red deer. One species, e.g. rowan, may be heavily targeted.</p>	<p>Bark stripping generally hard to find. There may be one stripped or frayed tree.</p> <p>Occasional stem snapping by cattle or red deer.</p>	<p>No bark stripping or stems snapped by large herbivores.</p>

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<b>Seedlings &amp; saplings</b> (seedlings <50cm)	<p>Old “seedlings” very heavily browsed into a topiaried form.</p> <p>Otherwise seedlings only present as new germinants in their first growing season (browsed the following winter).</p> <p>Saplings battered by very heavy browsing, many woody side shoots browsed back or snapped</p>	<p>Seedlings of palatable and browse- sensitive species absent (apart from possibly first year seedlings in the growing season), seedlings of unpalatable species heavily browsed.</p> <p>Saplings and old palatable “seedlings” heavily browsed. Leaders of saplings undamaged only if they cannot be reached by herbivores.</p>	<p>Seedlings of unpalatable species unbrowsed or lightly browsed. Those of palatable species moderately or heavily browsed</p> <p>Saplings moderately browsed.</p> <p>Groups of birch, alder and willow saplings may have some unbrowsed leaders. Otherwise, leaders undamaged only if they cannot be reached by herbivores.</p>	<p>Seedlings of unpalatable species generally unbrowsed – maybe some lightly browsed. Seedlings of palatable species lightly browsed – maybe some moderately browsed.</p> <p><i>Some</i> saplings of palatable species unbrowsed. <i>Most</i> saplings of unpalatable species unbrowsed.</p>	<p>Frequent, seedlings, provided that there is an adequate seed source and suitable ground conditions - unbrowsed by large herbivores.</p> <p>Saplings of all species (if present) unbrowsed</p>

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<b>Preferentially browsed or grazed plants</b> (other than trees)	All accessible shoots are heavily to very heavily browsed/grazed.  There may be some growth of this years shoots in the growing season.	Accessible shoots of preferentially browsed species generally heavily browsed/grazed but there may be higher (very high) impacts on some species than on others depending on relative preference	Accessible shoots of preferentially browsed species moderately to heavily browsed /grazed. Some preferentially browsed species may be heavily browsed but others ignored e.g. bramble browsed but blaeberry or honeysuckle unbrowsed	Accessible shoots of preferentially browsed species generally lightly browsed/grazed but there may be some shoots or individual species moderately browsed/grazed or unbrowsed/ungrazed.	No large herbivore impacts on preferentially browsed species. Depending on the time since exclosure, there may be long unbrowsed runners/climbers or a dense tangled field layer obscuring views through the wood.

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<b>Sward</b>	<p>Unpalatable species such as rushes and tussock-forming grasses (e.g. tufted hair-grass, purple moor-grass) heavily grazed</p> <p>Palatable species very heavily grazed.</p> <p>In the growing season, spring flowering herbs may be ungrazed even where winter impacts were very high.</p>	<p>Unpalatable species moderately grazed, not tussock forming.</p> <p>Palatable species heavily grazed.</p> <p>N.B On fertile, sheltered sites with high light levels, where evidence of current grazing is not obvious but where the grass sward is less than 5 cm high, it is safe to assume that the grazing impact is high.</p>	<p>In the absence of more palatable species, unpalatable species lightly grazed, except where livestock have been put into the wood at the start of the spring when they may be heavily grazed.</p> <p>Palatable species moderately grazed</p>	<p>Unpalatable species ungrazed. They may form a rank field layer more than 10 cm tall that shades the ground layer vegetation beneath</p> <p>Palatable species very lightly grazed</p>	<p>An ungrazed, and probably rank and tussocky sward with abundant leaf litter. There may be a high proportion of woody herbs (e.g. bramble) or heathy species in the sward, depending on site characteristics such as soil, exposure and light availability.</p>

<b>Table 2: Current Herbivore Impacts Table</b>					
<b>Indicator</b>	<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>	<b>Absent</b>
<p><b>Ground disturbance</b></p> <p>Use the “<i>not applicable</i>” column of the field sheet if the ground at the stop is composed of boulders or scree.</p>	<p>Wet, shaded sites completely poached.</p> <p>On drier sites, &gt; 50% of ground heavily poached if cattle present.</p> <p>Where deer are the main herbivore, there are frequent “motorways”. In wet open ground, there will be kicked out clods of turf and <i>Sphagnum</i> and well-defined deer wallows.</p>	<p>On wet ground with cattle, &gt;50% of the ground may be heavily poached. Without cattle grazing, the ground may be only moderately poached.</p> <p>Drier sites are lightly poached. There may be heavy poaching around feeding areas.</p> <p>Frequent deer tracks.</p>	<p>On wet ground with cattle, up to 50% of the ground may be heavily poached.</p> <p>Drier sites lightly poached or unpoached except around feeding areas where moderate or heavy poaching may occur.</p> <p>Occasional deer tracks</p>	<p>Very limited signs of poaching or tracks.</p>	<p>No sign of poaching or tracks.</p> <p>N.B. litter is very quickly mineralised in moist, very rich woodlands and soil may be bare in spring. The lack of vegetation in these cases is not due to animal disturbance.</p>

<b>Table 3: Browsing rates</b>				
	<b>Very Heavy</b>	<b>Heavy</b>	<b>Moderate</b>	<b>Light</b>
Browsing on tree basal shoots* (impacts within the last 12 months) <i>(estimate % removed based on the ratio of shoot diameter to length).</i>	> 90% of growth removed in last 12 months. Short stubby stems, difficult to see on some species. Most woody shoots browsed.	>50% and <90% of this year's growth removed. Some woody shoots browsed.	>10% and <50% of this year's growth removed.	Only stem tips removed (<10% of this year's growth).
Browsing on other tree shoots (i.e. seedlings/saplings, epicormics)	All outer shoots removed (including many woody shoots) and remaining growth old and woody with short internodes.	>80% of the current year's growth removed. Older, more woody growth removed from some shoots	30-80% of the current year's growth removed. Older, more woody growth removed from some shoots	<30% of the current year's growth removed
Browsing/grazing rates on preferential plants and sward	Runners and climbers reduced to woody central stems and very short side shoots.	>75% of leading shoots browsed	25-75% of leading shoots browsed	<25% of leading shoots browsed

<b>Table 4: Preferentially browsed or grazed plants (excluding trees)</b>			
	<b>Very palatable</b>	<b>Moderately palatable</b>	<b>Unpalatable</b>
Winter grazed/browsed	Bramble, Honeysuckle, Ivy, Blaeberry, <b>Greater Wood Rush</b>	<i>Greater Wood Rush, Hard Fern, Bog Myrtle, Heather, Bell Heather</i>	Tufted hair-grass, Soft & Sharp-flowered Rush, Cross-leaved heath
Spring - Summer grazed/browsed	As above + <i>buckler ferns</i> , Valerian, Meadow Sweet, Angelica, Raspberry	<b>Purple moor grass, Soft &amp; Sharp-flowered Rush Lemon Scented Fern, Lady fern</b>	Primrose

<b>Table 5: Relative palatability of different tree species</b>			
<b>Palatability</b> ( <i>Innate attraction of the species to being browsed</i> )		<b>Resilience</b> ( <i>ability to survive being browsed &amp; continue to grow</i> )	
1 – Most preferred	Aspen, Willow	1 – Most resilient	Eared Willow, Birch, Alder
2	Ash, Holly	2	Holly, Juniper
3	Hazel, Rowan, Oak, Douglas Fir, Larches	3	Hazel, Oak, Rowan, Ash
4	Scots Pine, Juniper, Western Hemlock	4 – least resilient	Scots pine* and non-native conifers
5	Birch, Hawthorn, Lodgepole Pine		*NB Scots pine and other conifers are less able to survive repeated browsing than broadleaves
6	Beech		
7 – least preferred	Alder, Rhododendron, Sitka Spruce		

## ANNEX 2: INDICATORS OF HISTORIC HERBIVORE IMPACTS

All tables in Annex 2 are taken from an earlier version of the Scottish Forestry guide to Assessing Herbivore Impact in Woodlands:

A Subjective Method - Table 6 Historic Herbivore Impacts:

<https://forestry.gov.scot/images/corporate/pdf/herbivore-impact-assessment-method.doc>

which was accessed during February 2014.

### Indicators of historic herbivore impacts for acidic dry woodland

<p><b>High</b></p>	<p>Open canopy with senescent and dead canopy trees and fallen large diameter deadwood. Dominated by herbs and grasses such as tormentil, tufted hair-grass, sweet vernal-grass, common bent and/or bryophytes. A low sward, rocky areas bare apart from bryophytes. No or very limited understorey. Preferentially browsed species (predominantly dwarf shrubs) restricted to inaccessible crevices.</p> <p>A very prominent browseline on the sparse understorey where broadleaves or juniper are present and where overstorey trees have abundant epicormic shoots.</p>
<p><b>Moderate</b></p>	<p>Greater diversity including a little blaeberry (and cowberry in pinewoods) and low-growing honeysuckle. Height of vegetation still low.</p> <p>In oakwoods and birchwoods, there may be a sparse understorey with browseline. Generally a full canopy cover or a canopy with few gaps.</p>
<p><b>Low</b></p>	<p>Dense and tall blaeberry and, where the canopy is more open, rank heather.</p> <p>In oak/birchwoods, there can be frequent but not abundant honeysuckle and bramble (the latter typically limited to rocky areas).</p> <p>Understorey trees can include holly, some hazel and juniper. Understorey trees with low growing branches. Canopy trees (oak/birch) with abundant basal shoots &lt;1m in length.</p>
<p><b>Absent for 20 years plus</b></p>	<p>Where dense tree regeneration has occurred (e.g. in a deer fenced enclosure), light levels can be reduced considerably and field layer – ground layer vegetation reduced to sparse blaeberry/cowberry and bryophytes.</p> <p>Where the canopy is less dense (e.g. on very poor soils), light underwood of birch and rowan with very tall blaeberry. Occasional well-developed, climbing honeysuckle.</p>

**Indicators of historic herbivore impacts in neutral dry woodland types  
(oakwood, birchwood and lowland mixed broadleaved woodland)**

<p><b>High</b></p>	<p>Open canopy with senescent and dead canopy trees plus fallen, large-diameter deadwood.</p> <p>Very species poor ground flora dominated by grasses such as sweet vernal-grass, common bent, cocksfoot and <i>Holcus</i> species. Can be dominated by bracken. Otherwise, no field layer or shrub layer. In NVC: W11b sub community, primrose may be the only obvious herb as it is unpalatable.</p> <p>A very prominent browseline on the sparse understorey and where overstorey trees have abundant epicormic shoots.</p>
<p><b>Moderate impact</b></p>	<p>Sparse to moderate understorey with prominent browseline. Preferentially browsed species present but largely restricted to rock-outcrops.</p> <p>The field layer may be dominated by bracken with abundant wood hyacinth (bluebell) in the spring, otherwise a short, grassy sward or a sparse to moderate field layer depending on herbivore species present (i.e. no deer, <i>Dryopteris</i> ferns may be occasional to frequent – no livestock and woodrush may be frequent).</p> <p>In old coppiced woodland, there may be widely spaced stools with a grassy sward or bracken stands in-between.</p>
<p><b>Low impact</b></p>	<p>Tall field layer including abundant ferns (typically <i>Dryopteris dilatata</i>) and honeysuckle. Can be dominated by rank woodrush with deep litter layers. Frequent preferentially browsed species including bramble, ivy and honeysuckle.</p> <p>Understorey trees (e.g. hazel and holly) with branches down to the ground.</p>
<p><b>Absent for 20 years plus</b></p>	<p>Dense understorey of hazel or holly is possible, branches to ground, very low light levels and very limited ground flora.</p> <p>In woods where grazing has been absent for longer, canopy gaps are occupied by saplings and a rank field layer</p>

**Indicators of historic herbivore impacts for base-rich dry woodland  
(upland mixed ashwoods, Atlantic hazelwoods, lowland mixed broadleaved woodland)**

<p><b>High impact</b></p>	<p>Open canopy with senescent and dead canopy trees and fallen large-diameter deadwood.</p> <p>There may be evidence of past heavy bark stripping.</p> <p>Ground flora dominated by a rich, probably productive, grass sward, with evidence of more graze-sensitive species such as meadowsweet restricted to low vegetative growth. Absent or very sparse understorey (hazel or bird cherry) with prominent browseline. In Atlantic hazelwoods, single stemmed hazel survive with very sparse crowns and no vegetative reproduction.</p> <p>Where deer are abundant, Dryopteris ferns restricted to crevices. There may be nettle patches where grazing animals lie up, e.g under open grown tree canopies. Disturbed sites at the wetter end of this category can have frequent to abundant tufted hair-grass [non-tussock forming].</p> <p>Boles of mature trees often with basal swelling, (particularly ash). Long-established topiared trees</p>
<p><b>Moderate impact</b></p>	<p>Thorny understorey (especially in lowland woods) of holly, blackthorn and hawthorn, with weak browseline; other, more palatable species, e.g. hazel, with more obvious browseline and heavily browsed basal shoots. Diverse range of ground flora, including dog's mercury, wood or water avens, occasional wood cranesbill. Field layer includes Dryopteris ferns and meadowsweet. [All or many of the above showing signs of grazing]. Where only deer present, woodrush may be abundant with deep litter layers. Bramble occasional to frequent (but browsed). Tufted hair-grass may be abundant (but in tall, ungrazed tussocks.)</p>
<p><b>Low impact</b></p>	<p>Tall herb and fern community (particularly Dryopteris ferns and meadowsweet), well developed where there is sufficient light. Bramble may be abundant, forming a dense underscrub with honeysuckle.</p> <p>Shrub layer and understorey trees frequent with branches down to the ground</p>
<p><b>Absent for 20 years plus</b></p>	<p>Complex woodland structure, even where there is a full overstorey, with shade-tolerant tree and shrub species present. Hazel capable of producing abundant basal shoots that grow into canopy despite low light levels. NB exclosure of herbivores of 5 years or more causes death of large diameter single stemmed hazel and abundant regrowth of basal shoots.</p> <p>Very difficult to see far through the wood. Herbs such as water avens or wood avens and meadowsweet still frequent despite dense canopy. Long, trailing runners of bramble, developing into thickets in any canopy gaps. Where there is an open canopy, ash has very large basal stems (&gt;5cm diameter and exceeding 2m in length). In lowland woods there may be a ground cover of ivy.</p>

**Indicators of historic herbivore impacts in acidic wet woodland types  
(Wet birch woodland)**

<p><b>High impact</b></p>	<p>Open canopy with senescent and dead canopy trees. Fallen large-diameter deadwood may be present but birch and willow rot quickly. Molinia grazed too heavily to be tussock forming, similarly, trampling inhibits the development of Sphagnum mounds. Eared willows have sparse and heavily browsed back canopies.</p>
<p><b>Moderate impact</b></p>	<p>Very limited understorey. Overstorey birch with no basal shoots or shoots browsed down to the bole and prominent browse line to lower branches.</p> <p>Molinia in well-defined clumps though not tussocky. Sphagnum moss shows signs of trampling damage.</p>
<p><b>Low impact</b></p>	<p>Willow may have well-browsed lower branches.</p> <p>Molinia grows rank and in obvious clumps with abundant leaf litter, maybe tussocky. Well-developed cushions of mosses, mainly Sphagnum mosses.</p>
<p><b>Absent for 20 years plus</b></p>	<p>Tall Molinia tussocks with Sphagnum mounds. Drier communities contain occasional bramble, forming localised thickets with long runners, also frequent broad buckler ferns.</p> <p>Birch have abundant basal shoots, although they are never long or thick. Willows can form thickets with branches down to ground level.</p>

**Indicators of historic herbivore impacts in neutral to base-rich wet woodland types (including slope alderwoods)**

<p><b>High impact</b></p>	<p>Unpoached parts of drier communities have a short sward, dominated by grazed tufted hair-grass and rushes. Woodland structure can range from topiared stands of eared willow to open alder woodland. In the latter case, tree bases are often broad, with closely browsed basal shoots. Swards with repeated winter poaching contain thistles, dock and cocksfoot in the summer.</p> <p>Wood pasture often have phoenix trees and air trees, although with sustained heavy grazing these can be bark stripped and roots eroded.</p>
<p><b>Moderate impact</b></p>	<p>Drier communities may have abundant, grazed broad buckler fern and male fern. Air trees and phoenix trees not restricted to extremely inaccessible sites</p>
<p><b>Low impact</b></p>	<p>Alder and/or sycamore saplings may be frequent as an understorey. Where present, ferns and tall herbs will be well-developed. Opposite-leaved golden saxifrage may be widespread.</p>
<p><b>Absent for 20 years plus</b></p>	<p>A variable woodland structure. Also a variable field layer, depending on light availability and the degree of wetness. Species may include angelica, opposite-leaved golden saxifrage, remote sedge, common valerian, iris, meadowsweet, marsh thistle and marsh hawksbeard. Patches of dense nettle may occur.</p> <p>Impenetrable willow carr may be present.</p>

### **ANNEX 3: DETAILS OF SOIL SAMPLING METHODS – FIELD PROTOCOLS**

At each of the sites small trial soil pits or a soil auger will be used to identify matched pairs of similar soils. The national grid reference, as indicated by Global Positioning Satellite (Garmin GPS map62 or Garmin 12), will be recorded for each soil pit. The attributes recorded in the field, methods and definitions will follow the NSIS protocols (Lilly et al, 2010) with the addition that the soils will be classified according to the Soil Survey of Scotland 1984 & 2013 classification systems and the Scottish Forestry soil classification system. The profile information and site characteristics will be entered on water-proof forms in the field and subsequently entered into the soil database.

#### **Digging of Pit**

The soil pit, rectangular in shape, will be dug by spade sufficiently large to facilitate sampling of horizons for chemical, physical and microbiological analyses and will be sufficiently deep to allow the description and sampling of the parent material, and where possible, to at least 80cm depth. An auger should be used to determine the nature of the soil to at least 1m depth if this cannot be achieved by digging. The pit will be orientated, where possible, such that the face to be described and sampled will face the sun or the direction of maximum light to permit the best photographic conditions.

Information will be entered on water-proof forms in the field and subsequently entered into the soil database.

#### **Photography**

The soil profile face to be described and sampled will be cleaned and photographed prior to sampling. The photographs should attempt to clearly show the horizons and any important features of the soil. Other photographs will also be taken of the site in general, prior to and after the digging of the pit, vegetation, and any relevant management and land use features which may aid future relocation or illustrate important characteristics of the profile. Clearly labelled boards with the Site ID (National Grid Reference) should be used in photographs and each photograph of the profile should have a black and white colour correction card in shot.

#### **Sampling the Main Profile Pit:**

Once excavated, the profile should be examined, the main horizons identified and a full pedological description of the profile recorded using the NSIS 2 protocols. The boundaries of the horizons to be sampled should be marked on the pit face and where possible, with the exception of iron pans (Bf horizon), each horizon in the profile should be sampled. All surface organic and organic-rich horizons (L, F, H, O and A horizons) must be sampled. In circumstances where surface organic horizons are not thick enough, or the delineation so indistinct to allow sampling horizons individually, composite samples may have to be taken to allow a satisfactory volume of sample to be obtained. Suggested composite samples are LF and FH. The surface organic and organic-rich horizons (L, F, H, O and A horizons), including any composited, should be sampled over their full depth. Approximately 1.5 kg of relatively stone free soil should be collected from each of these horizons with as many stones removed from the sample as possible.

At the centre of each profile pit, a 15cm long (5 cm diameter) sample ring should be inserted from the soil surface and an intact soil core extracted. The rings will be inserted by applying an even pressure into the soil from the surface (after removal of vegetation and living plant material) so that the top edge is flush with the soil surface, incorporating any L horizon. A knife or other sharp instrument can be used to ease insertion. Ensure there is no compression or compaction sustained in the process. The sample ring is then extracted with the core intact using a trowel to dig the core out as necessary and the soil is trimmed flush

with the base of the core. While still contained within the sample ring, the core is placed intact into a bag labelled with profile name, NGR of the main pit, type of sample, date of sampling and surveyor initials.

Bulk samples of the mineral subsoil horizons should be taken from a 10 cm depth band, approximately in the middle of the horizon or at depths thought to be appropriate to characterise the horizon. In some situations where the thickness of the horizon is less than 10 cm, the top and bottom sample depths should be set to allow a representative and pure sample to be collected from the horizon. Thin transition zones up to 6 cm thick can be excluded where boundaries are gradual or diffuse. Approximately 1.5 kg of relatively stone free soil should be collected from each of these horizons with as many stones removed from the sample as possible.

The soil material should be loosened and extracted by a clean trowel or knife, collected in a sampling tray held level with the lower boundary of the sample depth, and placed in a bag. Excess air should be removed from the sample bag and sealed as soon as possible to avoid contamination. It should be made air tight by folding over the top few centimetres twice. If not to be double bagged, a sample label should be slotted under the fold and another attached to the outside before stapling shut. This bag can be placed inside another if required, in which case, a label can be placed between both bags. This second bag is then stapled with the second label attached to it.

In addition to the profile horizon bulk samples described above, bulk density samples should also be collected from the main horizons within the profile. Food-grade stainless steel rings of 7.6 cm diameter (7.2 cm internal diameter) x 5 cm height should be inserted either vertically or horizontally into the appropriate horizon by applying an even pressure and at a depth which best characterises the horizon. Bulk density samples should be taken in triplicate from each horizon wherever possible.

All the material from the bulk density sample rings should be extruded into individual mini-grip bags which are labelled using a marker pen with sample number 1-3. These bags can then be placed into a large soil sample bag for ease of transport and sorting later. This bag should then be labelled with profile name, NGR, horizon symbol, depth and type of sample, date of sampling and surveyor initials and then stapled. Where horizons are thinner than 5cm, it is legitimate to partially fill the ring, excavate, move to a fresh area and insert the partially filled ring until full. Take care not to compress the material. All the material should then be extruded into individual mini-grip bags, which should be labelled using a marker pen with sample number 1-3. These bags can then be placed into a large soil sample bag for ease of sorting later. This bag should be labelled with profile name, NGR, horizon symbol, depth and type of sample, date of sampling and surveyor initials and then stapled.

For litter layers (L) thinner than 5cm an alternative method to determine bulk density which matches the BioSoil protocols is to sample a volume comprising an area and the full horizon thickness and record the dimensions. This volume may exceed that of the mini-grip bags so the material should be placed in a normal soil sample bag, labelled with profile name, NGR, horizon symbol, depth and area of sample, type of sample date of sampling and surveyor initials and then stapled.

A guide to achieving equivalent sample volumes by this method is given below compared with 3 ring samples each 210cm<sup>3</sup>:

Thickness L layer (cm)	Sample area	Volume cm <sup>3</sup>
1	25 x 25	625
2	18 x 18	578
3	15 x 15	675
4	13 x 13	676

### Sampling the Four Satellite Pits:

Four additional satellite pits, aligned to each of the 4 intercardinal direction (NW,NE,SE,SW) from the main pit and located in the centre of the vegetation subplots, will be dug sufficiently deep to allow the determination of the thickness of all organic and organic-rich horizons and, wherever possible, to determine the depth and nature of the subsoil and parent material horizons. At each site, record the soil type (according to the Soil Survey of Scotland 1984 & 2013 classification systems and the Scottish Forestry soil classification system), the horizon sequence and depths. A 15cm long (5 cm diameter) sample ring should be inserted from the soil surface on one of the pit faces and an intact soil core extracted as described above. Although each of these cores will be bulked along with the 0-15cm core from the profile pit, they should be bagged separately and labelled with NGR of the main pit, intercardinal direction depth of sample, type of sample, date of sampling and surveyor initials. Excess air should be removed from the sample bag and sealed as soon as possible to avoid contamination. It should be made air tight by folding over the top few centimetres twice. If not to be double bagged, a sample label should be slotted under the fold and another attached to the outside before stapling shut. This bag can be placed inside another if required, in which case, a label can be place between both bags. This second bag is then stapled with the second label attached to it.

### PLFA sampling:

Composite samples for PLFA analyses should be taken from immediately around the sides of the main soil pit in each exclosed/un-exclosed area using a thin rockery trowel. The sample will be ca. 500 g of fresh soil made up of 12 sub-samples (more if the material is highly organic) from 0-15cm. On each of the left hand side, face and right hand side of the pit, insert the trowel vertically from the soil surface to a depth of 15cm, twist and remove a plug of soil. In some cases it may be necessary to cut roots with a sharp knife. Take at least 4 plugs from each face or a sufficient number of times to obtain 500g of soil. Each soil plug should be added to a large sample bag, labelled with NGR of the main pit, depth of sample, type of sample, date of sampling and surveyor initials. Excess air should be removed from the sample bag and sealed as soon as possible to avoid contamination. It should be made air tight by folding over the top few centimetres twice. If not to be double bagged, a sample label should be slotted under the fold and another attached to the outside before stapling shut. This bag can be placed inside another if required, in which case, a label can be place between both bags. This second bag is then stapled with the second label attached to it.

All soil samples will be transported to the Institute to undergo sample preparation including drying (at 30°C) and sieving to <2mm. These samples can then be added to the National Soil Archive held by the Institute at the Aberdeen site and preserved indefinitely.

## Soil horizon nomenclature and definitions

### Master horizons

A master horizon is represented by one of nine capital letters: L, F, H, O, A, E, B, C or R. An Arabic figure following a letter indicates vertical subdivision (e.g. C1, C2). A transitional horizon with properties of two master horizons is shown by the combination of two capital letters (e.g. AE, BC). In layered parent materials, an Arabic numeral is used as a symbol prefix when it is necessary to distinguish lithological or textural contrasts (e.g. 2C when the C horizon differs from the material in which the solum, i.e. A and B horizons, is presumed to have formed).

L	Fresh annual litter, normally loose, original plant structures obvious.
F	Decomposed litter, only some of the original plant structures obvious.
H	Well-decomposed organic matter formed under aerobic conditions. Plant structures not visible. May be mixed with some mineral matter. (Mor humus).
O	Peaty material formed under wet, anaerobic conditions.
A	Mineral horizon formed at or near the surface that shows an accumulation and incorporation of organic matter, or which has morphology acquired by soil formation but lacks the properties of E or B horizons.
E	Eluvial horizon underlying an H, O or A horizon from which it can normally be differentiated by a lower content of organic matter and lighter colour, particularly when dry. Usually shows a concentration of sand and silt fractions with a large component of resistant minerals resulting from a loss of clay, iron or aluminium.
B	Mineral horizon in which there is little or no obvious rock structure and having one or both of the following: <ol style="list-style-type: none"><li>1. alteration of the original material involving solution and removal of carbonates; formation, liberation or residual accumulation of silicate clays or oxides; formation of granular, crumby, blocky or prismatic peds; or (normally) some combination of these;</li><li>2. illuvial concentration of silicate clay or iron, aluminium or humus.</li></ol>
C	Mineral horizon of unconsolidated material from which the solum is presumed to have formed.
R	Underlying consolidated bedrock sufficiently coherent when moist to make hand digging with a spade impracticable.

### *Sub-horizons*

A lower case letter may be added to the capital to qualify the master horizon designation. More than one letter may be used if necessary, e.g. Bhs1 indicates the first of two B horizons enriched in humus and sesquioxide material. Symbols may be bracketed if the feature development is weak.

These symbols have more precise significance when applied to specific major soil subgroups.

b	Buried (e.g. bA).
f	Sharply defined thin iron pan.
g	Horizon with gley features.
h	Accumulation of organic matter in a mineral horizon (e.g. Ah or Bh).
m	A cemented horizon, other than a thin iron pan. Often used in conjunction with another symbol (e.g. Bmh for a horizon cemented with organic matter).
p	Disturbed by ploughing.
s	Accumulation of sesquioxide material.
t	Accumulation of illuvial clay.
w	Alteration in situ in accordance with section 1 of the description of the B horizon
x	Indurated layer, compacted but not cemented.

## ANNEX 4: SOIL PROFILE DESCRIPTIONS AND ANALYTICAL RESULTS

Profile name: ARDURA 1 (IN)  
Site code (1F)  
Surveyor: A.J.Nolan  
Sample date: 13/05/2014  
NGR: NM7251031471  
Slope: 36 degrees, straight and simple  
Altitude: 24m  
Aspect: 258 degrees West South West  
Rockiness: No rocks; no boulders  
Vegetation: Grassy Atlantic oakwood  
Flushing: Not flushed  
Site drainage: Normal site  
Soil drainage: Free  
Erosion: None  
Association: Darleith  
Series: Darleith  
Parent material: Colluvium  
Major soil subgroup (1984): Brown earth  
Major soil subgroup (2013): Brown earth  
Soil type (FC): Basic brown earth  
Rock types: Basalts  
Climate: O1H1T1; Hyperoceanic extremely humid northern temperate  
Maximum rooting depth: 75cm  
Base of pit: Arrow  
Sample depths (cm): 0-2; 5-15; 30-40; 65-75  
Sample ids: 1170419-422

**L: 0 - 1 cm;** reddish brown, 5YR 5/4 fibrous; no mineral; von Post 1; no structure; moist; no roots; no stones(0%); sharp smooth boundary.

**F: 1 - 2 cm;** dark reddish brown, 5YR 3/2 semi fibrous; no mineral; von Post 5; very weak, fine, platy structure; moist; many very fine fibrous roots; no stones (0%); sharp smooth boundary.

**A: 2 - 18 cm;** dark brown, 10YR 3/3 fine sandy silt loam; no mottles; moderate medium subangular blocky tending to weak fine granular structure; very moist; friable; abundant very fine fibrous, few, coarse rhizomatous and few coarse woody roots; common medium subangular and few large subangular stones (15%); clear wavy boundary.

**B: 18 - 54 cm;** dark yellowish brown, 10YR 4/4 and brown 7.5YR 4/4 fine sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; common very fine fibrous, few medium woody and few coarse woody roots; common medium subangular and common large angular stones (20%); clear wavy boundary.

**BC: 54 – 92+ cm;** brown, 7.5YR 4/2 fine sandy silt loam; no mottles; weak medium subangular blocky structure; very moist; friable; few very fine fibrous and few medium woody roots; many large angular, common medium subangular and common small subangular stones (45%); merges into shattered rock at around 100cm.

**CR: 100+ cm;** shattered rock

ARDURA 1 (IN) (1F)

HORIZON	L	LF	A	B	BC
TOP SAMPLE DEPTH		0	5	30	65
BOTTOM SAMPLE DEPTH		2	15	40	75
SAMPLE POSITION		2	3	4	5
SAMPLE ID	NO SAMPLE	1170419	1170420	1170421	1170422
C		35.71	9.24	4.33	7.68
N		1.91	0.7	0.34	0.48
C:N ratio		18.7	13.2	12.74	16
EXCHANGEABLE CATIONS (meq/100g)					
Al		0.09	0.49	0.92	2.04
Fe		0.03	0.04	0.07	0.04
Mn		2.79	0.08	0.01	<0.00004
Ca		15.45	0.78	0.29	0.21
K		1.18	0.26	0.14	0.14
Mg		15.45	0.58	0.21	0.24
Na		1.37	0.24	0.12	0.19
H		43.37	21.51	13.34	24.05
SUM BASE CATIONS		76.82	23.37	14.1	24.83
BASE SATURATION%		43.54	7.96	5.39	3.14
AVAILABLE NUTRIENTS (mg/kg)					
Ca		2375.78	112.82	40.17	74.84
K		473.58	100.11	47.33	50.09
Mg		1643.36	77.45	21.47	25.82
P		52.68	4.92	1.12	3.4
LOSS ON IGNITION (450 °C)					
pH(H <sub>2</sub> O)		4.87	3.83	3.64	4.35
pH(CaCl <sub>2</sub> )		4.45	3.89	4.13	4.18
BULK DENSITY		0.01	0.6	0.83	0.67
BULK DENSITY (FINE EARTH)		0.01	0.43	0.68	0.46
GRAVIMETRIC MOISTURE CONTENT		65.6	44.97	32.22	44.54
C STOCK (Kg/m <sup>2</sup> )					
PERCENTAGE STONES		0	15	20	45



Profile name: ARDURA 1 (OUT)  
 Site code: (1U)  
 Surveyor: A.J.Nolan  
 Sample date: 14/05/2014  
 NGR: NM7265631538  
 Slope: 33 degrees, straight and simple  
 Altitude: 39m  
 Aspect: 128 degrees South East  
 Rockiness: Slightly rocky; no boulders  
 Vegetation: Grassy Atlantic oakwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Darleith  
 Series: Darleith  
 Parent material: Colluvium  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Basalt (80%) and Andesite (20%)  
 Climate: O1H1T1; Hyperoceanic extremely humid northern temperate  
 Maximum rooting depth: 85cm  
 Base of pit: Arrow  
 Sample depths (cm): 0-2; 5-15; 30-40; 65-75  
 Sample ids: 1170424-427

**L: 0 - 1 cm;** brown, 7.5YR 5/4 fibrous; no mineral; von Post 1; no structure; dry; no roots; no stones (0%); sharp smooth boundary.

**F: 1 - 2 cm;** dark reddish brown, 5YR 3/2 semi fibrous; no mineral; von Post 5; very weak, fine, platy structure; moist; many very fine fibrous roots; no stones (0%); sharp smooth boundary.

**A: 2 - 19 cm;** dark yellowish brown, 10YR 3/4 fine sandy silt loam; no mottles; weak medium subangular blocky tending to weak fine granular structure; moist; friable; many very fine fibrous, few, coarse rhizomatous and few medium woody roots; common medium subangular and common small subangular stones (15%); clear smooth boundary.

**B: 19 - 52 cm;** brown, 10YR 4/3 fine sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; common very fine fibrous, common medium woody and few coarse woody roots; common small subangular, common medium angular and few large subangular stones (25%); clear smooth boundary.

**BC: 52 – 95+ cm;** dark yellowish brown, 10YR 4/4 fine sandy silt loam; no mottles; weak medium subangular blocky structure; very moist; friable; few very fine fibrous and few medium woody roots; many medium angular basalts, common large angular andesite and few small subangular basalt stones (30%).

ARDURA 1 (OUT) (1U)

HORIZON	L	LF	A	B	BC
TOP SAMPLE DEPTH		0	5	30	65
BOTTOM SAMPLE DEPTH		2	15	40	75
SAMPLE POSITION		2	3	4	5
SAMPLE ID	NO SAMPLE	1170424	1170425	1170426	1170427
C		44.93	10.27	8.4	10.4
N		1.87	0.7	0.53	0.55
C:N ratio		24.03	14.67	15.85	18.91
EXCHANGEABLE CATIONS (meq/100g)					
Al		0.12	2.03	1.52	4.29
Fe		0.01	0.06	0.03	0.05
Mn		1.58	0.02	<0.00004	<0.00004
Ca		33.07	1.35	0.2	0.07
K		1.72	0.48	0.24	0.11
Mg		18.78	0.77	0.31	0.17
Na		1.5	0.44	0.27	0.28
H		46.61	26.01	21.54	34.47
SUM BASE CATIONS		101.68	29.05	22.56	35.1
BASE SATURATION%		54.16	10.46	4.52	1.79
AVAILABLE NUTRIENTS (mg/kg)					
Ca		4410	190.82	27.71	36.34
K		602.92	159.35	76.93	33.24
Mg		1867.12	84.27	33.06	19.7
P		99.74	8.14	3.13	1.13
Moist_Loss		9.09	4.99	4.2	6.63
LOSS ON IGNITION (450 °C)		89.06	23.11	17.89	25.2
pH(H2O)		3.72	3.93	3.69	3.58
pH(CaCl2)		4.66	4.34	4.15	4.13
BULK DENSITY		0.02	0.8	0.72	0.64
BULK DENSITY (FINE EARTH)		0.02	0.37	0.4	0.3
GRAVIMETRIC MOISTURE CONTENT		59.79	38.39	37.15	41.61
C STOCK (Kg/m2)		0.103	5.491	8.316	9.391
PERCENTAGE STONES		0	15	25	30



Profile name: ARDURA 2 (IN)  
 Site code (2F)  
 Surveyor: A.J.Nolan  
 Sample date: 15/05/2014  
 NGR: NM7340530197  
 Slope: 25 degrees, straight and simple  
 Altitude: 59m  
 Aspect: 306 degrees West North West  
 Rockiness: Slightly rocky; no boulders  
 Vegetation: Grassy Atlantic oakwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Darleith  
 Series: Darleith  
 Parent material: Colluvium  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Basalts  
 Climate: O1H1T1; Hyperoceanic extremely humid northern temperate  
 Maximum rooting depth: 60cm  
 Base of pit: Rock  
 Sample depths (cm): 0-3; 5-15; 30-40; 60-70  
 Sample ids: 1170429-432

**L: 0 - 2 cm;** yellowish brown, 7.5YR 5/4 fibrous; no mineral; von Post 1; no structure; moist; no roots; no stones (0%); sharp smooth boundary.

**F: 2 - 3 cm;** dark reddish brown, 5YR 3/4 semi fibrous; no mineral; von Post 5; very weak, fine, platy structure; moist; many very fine fibrous and few coarse woody roots; no stones (0%); sharp smooth boundary.

**A: 3 - 21 cm;** dark brown, 10YR 3/3 fine sandy silt loam; no mottles; weak medium subangular blocky tending to weak fine granular structure; moist; friable; many very fine fibrous, common coarse rhizomatous and few coarse woody roots; few medium subangular and few small subangular stones (5%); gradual and smooth boundary.

**B: 21 - 53 cm;** dark yellowish brown, 10YR 3/4 fine sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; common very fine fibrous and few fine woody roots; common medium subangular and few small subangular stones (10%); clear smooth boundary.

**BC: 53 – 76** dark brown, 7.5YR 3/2 fine sandy silt loam; no mottles; very weak medium subangular blocky structure; very moist; friable; few fine woody roots; common medium subangular and common large subangular stones (15%); sharp wavy boundary.

**R: 76+ cm;** rock

ARDURA 2 (IN) (2F)

HORIZON	L	LF	A	B	BC	R
TOP SAMPLE DEPTH		0	5	30	60	
BOTTOM SAMPLE DEPTH		3	15	40	70	
SAMPLE POSITION		2	3	4	5	
SAMPLE ID	NO SAMPLE	1170429	1170430	1170431	1170432	
C		41.17	18.03	10.16	9.41	
N		1.84	1.18	0.59	0.5	
C:N ratio		22.38	15.28	17.22	18.82	
EXCHANGEABLE CATIONS (meq/100g)						
Al		0.24	1.22	3.08	3.81	
Fe		0.04	0.07	0.05	0.06	
Mn		1.43	0.15	<0.00004	0.01	
Ca		17.38	1.38	0.12	0.08	
K		1.48	0.64	0.1	0.05	
Mg		20.37	2.4	0.22	0.17	
Na		1.15	0.72	0.25	0.2	
H		55.31	36.29	28.95	24.8	
SUM BASE CATIONS		95.69	41.43	29.64	25.3	
BASE SATURATION%		42.2	12.41	2.33	1.98	
AVAILABLE NUTRIENTS (mg/kg)						
Ca		2347.37	346.43	38.3	42.93	
K		507.75	228.56	25.75	15.48	
Mg		1750.92	295.53	27.58	23.73	
P		54.27	8.61	1.82	1.04	
LOSS ON IGNITION (450 °C)						
		81.15	36.84	23.55	25.02	
pH(H2O)		4.05	3.83	3.88	3.96	
pH(CaCl2)		4.33	4.03	4.22	4.34	
BULK DENSITY		0.05	0.34	0.58	0.64	
BULK DENSITY (FINE EARTH)		0.05	0.27	0.35	0.31	
GRAVIMETRIC MOISTURE CONTENT		65.33	65.9	51.47	46.84	
C STOCK (Kg/m2)		0.019	8.324	10.241	5.703	
PERCENTAGE STONES		0	5	10	15	



Profile name: ARDURA 2 (OUT)  
 Site code (2U)  
 Surveyor: A.J.Nolan  
 Sample date: 16/05/2014  
 NGR: NM7321630364  
 Slope: 24 degrees, straight and complex  
 Altitude: 89m  
 Aspect: 102 degrees East South East  
 Rockiness: Slightly rocky; no boulders  
 Vegetation: Grassy Atlantic oakwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Darleith  
 Series: Darleith  
 Parent material: Colluvium  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Basalts  
 Climate: O1H1T1; Hyperoceanic extremely humid northern temperate  
 Maximum rooting depth: 65cm  
 Base of pit: Rock  
 Sample depths (cm): 0-3; 5-15; 30-40; 60-70  
 Sample ids: 1170434-437

**L: 0 - 2 cm;** yellowish brown, 7.5YR 5/4 fibrous; no mineral; von Post 1; no structure; dry; no roots; no stones (0%); sharp smooth boundary.

**F: 2 - 3 cm;** dark reddish brown, 5YR 3/4 semi fibrous; no mineral; von Post 5; very weak, fine, platy structure; moist; few very fine fibrous roots; no stones (0%); sharp smooth boundary.

**A: 3 - 21 cm;** dark brown, 10YR 3/3 fine sandy silt loam; no mottles; weak medium subangular blocky tending to weak fine granular structure; moist; friable; many very fine fibrous, few medium woody and few coarse rhizomatous roots; common medium subangular and common small subangular stones (15%); gradual and smooth boundary.

**B: 21 - 54 cm;** dark yellowish brown, 10YR 3/4 fine sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; few very fine fibrous, few medium woody and few coarse rhizomatous roots; common medium subangular; common small subangular and few large angular stones (20%); clear smooth boundary.

**BC: 54 – 75** dark brown, 7.5YR 3/2 fine sandy silt loam; no mottles; very weak medium subangular blocky structure; very moist; friable; few very fine fibrous and few fine woody roots; common medium angular; common small subangular and few large angular stones (25%); sharp smooth boundary.

**R: 75+ cm;** rock

ARDURA 2 (OUT) (2U)

HORIZON	L	LF	A	B	BC
TOP SAMPLE DEPTH		0	5	30	60
BOTTOM SAMPLE DEPTH		3	15	40	70
SAMPLE POSITION		2	3	4	5
SAMPLE ID	NO SAMPLE	1170434	1170435	1170436	1170437
C		41.82	14.47	9.72	3.14
N		1.71	1.04	0.58	0.18
C:N ratio		24.46	13.91	16.76	17.44
EXCHANGEABLE CATIONS (meq/100g)					
Al		0.26	0.55	2.86	1.09
Fe		0.02	0.08	0.04	0.01
Mn		1.23	0.14	<0.00004	<0.00004
Ca		22.02	1.54	0.09	0.03
K		1.22	0.84	0.23	0.05
Mg		21.29	2.07	0.2	0.05
Na		0.79	0.79	0.13	0.02
H		45.29	34.91	28.24	11.87
SUM BASE CATIONS		90.61	40.15	28.89	12.02
BASE SATURATION%		50.02	13.05	2.25	1.25
AVAILABLE NUTRIENTS (mg/kg)					
Ca		3238.69	402.7	60.54	40.54
K		405.09	307.59	74.72	16.12
Mg		1903.31	254.38	19.03	0.46
P		44.6	6.44	1.94	4.37
LOSS ON IGNITION (450 °C)					
		80.91	28.59	20.14	8.02
pH(H2O)		4.27	4.74	4.99	5.23
pH(CaCl2)		4.36	3.99	4.09	4.26
BULK DENSITY		0.01	0.6	0.7	1.2
BULK DENSITY (FINE EARTH)		0.01	0.34	0.43	0.81
GRAVIMETRIC MOISTURE CONTENT		51.19	48.95	43.46	21.62
C STOCK (Kg/m2)		0.06	7.527	11.034	4.006
PERCENTAGE STONES		0	15	20	25



Profile name: MORRONE BIRKWOOD 1  
 Site code: 5F19  
 Surveyor: W. Towers  
 Sample date: 12/05/2014  
 NGR: NO1401990460  
 Slope: 8 degrees, straight and simple  
 Altitude: 437m  
 Aspect: 330 degrees North West  
 Rockiness: No rocks; no boulders  
 Vegetation: Eastern highland birchwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Tarves  
 Series: Tarves  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Limestone (60%) and mica schist (40%)  
 Climate: O3H2B1; Hemiroceanic very humid upper oroboreal  
 Maximum rooting depth: 46cm  
 Base of pit: Indurated  
 Sample depths (cm): 0-25; 30-40; 56-66  
 Sample ids: 1170415-417

**A: 0 - 25 cm;** dark brown, 10YR 3/3 sandy silt loam; no mottles; moderate medium subangular blocky structure; moist; friable; many very fine fibrous, few medium woody and few coarse woody roots; common medium subangular limestone, common large platy mica schist and common small subangular mica schist stones (20%); clear smooth boundary.

**B: 25 - 46 cm;** dark yellowish brown, 10YR 4/4 sandy silt loam; no mottles; moderate medium angular blocky structure; moist; friable; common very fine fibrous and common fine fibrous roots; many medium subangular limestones, common large angular limestones and common large angular mica schist stones (40%); sharp and wavy boundary.

**BCx: 46 - 66 cm;** brown, 10YR 5/3 coarse sandy loam; no mottles; strong coarse platy structure; moist; very firm; strongly indurated; no roots; many small subangular mica schist; many small subangular limestone and common medium subangular limestone stones (40%).

MORRONE BIRKWOOD 1 (5F19)

HORIZON	A	B	BCx
TOP SAMPLE DEPTH	0	30	56
BOTTOM SAMPLE DEPTH	25	40	66
SAMPLE POSITION	1	2	3
SAMPLE ID	1170415	1170416	1170417
C	5.16	1.75	0.31
N	0.38	0.12	0.03
C:N ratio	13.58	14.58	10.33
EXCHANGEABLE CATIONS (meq/100g)			
Al	0.15	0.24	0.15
Fe	0.02	0.01	0.01
Mn	0.17	0.01	<0.00004
Ca	4.84	1.36	0.36
K	0.24	0.08	0.04
Mg	1.22	0.26	0.07
Na	0.1	0.07	0.03
H	11.4	5.69	1.64
SUM BASE CATIONS	17.8	7.46	2.14
BASE SATURATION%	35.96	23.73	23.36
AVAILABLE NUTRIENTS (mg/kg)			
Ca	1138.81	285.77	574.56
K	99.94	25.09	13.73
Mg	153.89	30.46	5.58
P	3.8	1.83	142.09
LOSS ON IGNITION (450 °C)	11.08	4.04	1.35
pH(H <sub>2</sub> O)	5.34	5.43	5.53
pH(CaCl <sub>2</sub> )	4.74	4.72	4.89
BULK DENSITY	0.67	1.08	1.19
BULK DENSITY (FINE EARTH)	0.67	0.61	0.82
GRAVIMETRIC MOISTURE CONTENT	39.2	17.65	8.57
C STOCK (Kg/m <sup>2</sup> )	6.914	1.345	0.305
PERCENTAGE STONES	20	40	40



Profile name: MORRONE BIRKWOOD 2  
 Site code: 5F36  
 Surveyor: W. Towers  
 Sample date: 13/05/2014  
 NGR: NO1395390410  
 Slope: 8 degrees, straight and simple  
 Altitude: 437m  
 Aspect: 357 degrees North  
 Rockiness: No rocks; no boulders  
 Vegetation: Eastern highland birchwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Tarves  
 Series: Tarves  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Limestone (50%) and mica schist (50%)  
 Climate: O3H2B1; Hemiroceanic very humid upper oroboreal  
 Maximum rooting depth: 50cm  
 Base of pit: Arrow  
 Sample depths (cm): 0-19; 25-35; 70-80  
 Sample ids: 1170412-414

**A: 0 - 19 cm;** dark brown, 7.5YR 3/3 humose sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; many very fine fibrous, many medium woody and few coarse woody roots; common medium subangular limestone, common large subangular mica schist and few small subangular limestone stones (25%); clear wavy boundary.

**B: 19 - 45 cm;** brown, 7.5YR 4/4 fine sandy silt loam; no mottles; weak fine subangular blocky structure; moist; friable; common very fine fibrous, few medium woody and few coarse woody roots; common medium subangular mica schist, few small subangular limestone and few large subangular mica schist stones (20%); sharp and wavy boundary.

**BCx: 45 - 80 cm;** brown, 7.5YR 5/4 medium sandy loam; no mottles; massive structure; moist; very firm; moderately indurated; few very fine fibrous roots; many medium subangular limestone; common medium subangular mica schist and common small subangular limestone stones (40%).

MORRONE BIRKWOOD 2 (5F36)

HORIZON	A	B	BC(x)
TOP SAMPLE DEPTH	0	25	70
BOTTOM SAMPLE DEPTH	19	35	80
SAMPLE POSITION	1	2	3
SAMPLE ID	1170412	1170413	1170414
C	6.22	1.96	0.76
N	0.42	0.12	0.03
C:N ratio	14.81	16.33	25.33
EXCHANGEABLE CATIONS (meq/100g)			
Al	0.54	0.41	0.27
Fe	0.06	0.01	< 0.001
Mn	0.11	<0.00004	<0.00004
Ca	0.93	0.21	0.16
K	0.24	0.09	0.06
Mg	0.5	0.09	0.05
Na	0.15	0.03	0.06
H	16.3	6.99	3.51
SUM BASE CATIONS	18.12	7.41	3.84
BASE SATURATION%	10.04	5.67	8.59
AVAILABLE NUTRIENTS (mg/kg)			
Ca	195.65	95.87	223.27
K	110.29	31.6	18.1
Mg	61.16	7.97	3.17
P	9.08	4.36	42
LOSS ON IGNITION (450 °C)	11.98	4.69	1.91
pH(H <sub>2</sub> O)	4.75	4.93	5.16
pH(CaCl <sub>2</sub> )	4.09	4.43	4.52
BULK DENSITY	0.52	0.78	1.13
BULK DENSITY (FINE EARTH)	0.51	0.6	0.86
GRAVIMETRIC MOISTURE CONTENT	44.64	25.23	12.7
C STOCK (Kg/m <sup>2</sup> )	4.52	2.446	1.373
PERCENTAGE STONES	25	20	40



Profile name: MORRONE BIRKWOOD 3  
 Site code: 4F  
 Surveyor: W. Towers  
 Sample date: 14/05/2014  
 NGR: NO1384590280  
 Slope: 17 degrees, straight and simple  
 Altitude: 468m  
 Aspect: 352 degrees North  
 Rockiness: No rocks; no boulders  
 Vegetation: Eastern highland birchwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Tarves  
 Series: Tarves  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Limestone (75%) and mica schist (25%)  
 Climate: O3H2B1; Hemiroceanic very humid upper oroboreal  
 Maximum rooting depth: 70cm  
 Base of pit: Arrow  
 Sample depths (cm): 0-6; 6-27; 45-55; 74-84  
 Sample ids: 1170404-407

**LF: 0 - 6 cm;** very dark brown, 7.5YR 2/3 fibrous; no mineral; von Post 2; very weak, fine, platy structure; moist; many very fine fibrous, common fine woody and few medium woody roots; no stones (0%); sharp wavy boundary.

**A: 6 - 27 cm;** brown, 7.5YR 4/3 sandy silt loam; no mottles; moderate fine subangular blocky and weak very fine subangular blocky structure; moist; very friable; many fine woody, common medium woody and common very fine fibrous roots; few small subangular limestone and few medium subangular limestone stones (5%); gradual wavy boundary.

**B: 27 - 70 cm;** brown, 7.5YR 4/4 sandy silt loam; no mottles; moderate fine subangular blocky and weak fine subangular blocky structure; moist; very friable; common very fine fibrous, common medium woody and common fine woody roots; few medium subangular limestone and few small subangular limestone stones (5%); sharp and wavy boundary.

**C(x): 70 - 84 cm;** brown, 7.5YR 5/4 and light brown 7.5YR 6/3 ped face colour sandy loam; no mottles; moderate medium platy structure; moist; firm; weakly indurated; no roots; common medium platy mica schist; common small subangular limestone and few medium subangular limestone stones (25%).

MORRONE BIRKWOOD 3 (4F)

HORIZON	LF	A	B	C(x)
TOP SAMPLE DEPTH	0	6	45	74
BOTTOM SAMPLE DEPTH	6	27	55	84
SAMPLE POSITION	1	2	3	4
SAMPLE ID	1170404	1170405	1170406	1170407
C	24.28	5.08	3.2	1.14
N	1.03	0.33	0.23	0.06
C:N ratio	23.57	15.39	13.91	19
EXCHANGEABLE CATIONS (meq/100g)				
Al	0.37	0.93	0.54	0.16
Fe	0.07	0.02	< 0.001	< 0.001
Mn	0.69	0.09	0.03	<0.00004
Ca	6.8	0.73	1.13	2.25
K	1.31	0.13	0.06	0.03
Mg	3.55	0.25	0.11	0.17
Na	0.27	0.07	0.1	0.06
H	37.99	13.16	6.49	4.31
SUM BASE CATIONS	49.92	14.34	7.89	6.82
BASE SATURATION%	23.9	8.23	17.74	36.8
AVAILABLE NUTRIENTS (mg/kg)				
Ca	1266.45	181.42	262.17	598.16
K	438.39	45.6	17.08	6.27
Mg	371.55	23.72	14.16	21.22
P	15.14	6.68	1.73	0.56
LOSS ON IGNITION (450 °C)	46.17	10.45	6.73	3.55
pH(H <sub>2</sub> O)	4.64	5.17	5.63	6.24
pH(CaCl <sub>2</sub> )	3.83	4.29	4.78	5.26
BULK DENSITY	0.1	0.69	0.71	1.16
BULK DENSITY (FINE EARTH)	0.1	0.46	0.53	0.63
GRAVIMETRIC MOISTURE CONTENT	69.75	26.13	27.45	12.06
C STOCK (Kg/m <sup>2</sup> )	1.457	4.662	6.928	0.754
PERCENTAGE STONES	0	5	5	25



Profile name: MORRONE BIRKWOOD 4  
 Site code: 4U  
 Surveyor: W. Towers  
 Sample date: 15/05/2014  
 NGR: NO1377790239  
 Slope: 10 degrees, straight and simple  
 Altitude: 460m  
 Aspect: 352 degrees North  
 Rockiness: No rocks; no boulders  
 Vegetation: Eastern highland oakwood and birchwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Tarves  
 Series: Tarves  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Phyllite (80%) and limestone (20%)  
 Climate: O3H2B1; Hemiroceanic very humid upper oroboreal  
 Maximum rooting depth: 62cm  
 Base of pit: Arrow  
 Sample depths (cm): 0-12; 12-30; 40-50; 72-82  
 Sample ids: 1170408-411

**A: 0 - 12 cm;** dark brown, 7.5YR 3/4 fine sandy silt loam; no mottles; moderate medium subangular blocky structure; moist; friable; common very fine fibrous, few medium woody and few fine fibrous roots; common small angular phyllite, few medium platy phyllite and few small subangular phyllite stones (10%); sharp wavy boundary.

**AB: 12 - 30 cm;** brown, 7.5YR 4/3 sandy silt loam; no mottles; moderate medium subangular blocky structure; moist; friable; many very fine fibrous, few coarse woody and few medium woody roots; many medium angular phyllite, common large platy phyllite and common small subangular phyllite stones (40%); clear and wavy boundary.

**B: 30 - 62 cm;** brown, 7.5YR 4/4 sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; common very fine fibrous, few medium woody and few fine woody roots; many large platy phyllite, common medium platy phyllite and few small subangular limestone stones (20%); sharp and wavy boundary.

**C(x): 62 - 82 cm;** brown, 7.5YR 5/4 sandy loam; no mottles; massive structure; moist; firm; weakly indurated; no roots; many medium platy phyllite; common small subangular phyllite and few large platy phyllite stones (35%).

MORRONE BIRKWOOD 4 (4U)

HORIZON	A	AB	B	C(x)
TOP SAMPLE DEPTH	0	12	40	72
BOTTOM SAMPLE DEPTH	12	30	50	82
SAMPLE POSITION	1	2	3	4
SAMPLE ID	1170408	1170409	1170410	1170411
C	6.9	2.56	0.99	0.48
N	0.47	0.18	0.06	0.03
C:N ratio	14.68	14.22	16.5	16
EXCHANGEABLE CATIONS (meq/100g)				
Al	0.16	0.14	0.14	0.15
Fe	0.03	0.02	<0.001	<0.001
Mn	0.19	0.02	<0.00004	<0.00004
Ca	4.97	3.73	2.3	1.51
K	0.32	0.14	0.09	0.07
Mg	1.32	0.62	0.33	0.21
Na	0.13	0.1	0.1	0.08
H	13.83	7.32	5.04	3.18
SUM BASE CATIONS	20.57	11.91	7.86	5.05
BASE SATURATION%	32.77	38.54	35.88	37.03
AVAILABLE NUTRIENTS (mg/kg)				
Ca	926.59	742.18	513.08	635.62
K	122.08	53.7	32.3	23.48
Mg	149.13	75.69	42.35	26.38
P	2.83	1.26	2.97	56.96
LOSS ON IGNITION (450 °C)	13.75	6.1	3.4	2.2
pH(H <sub>2</sub> O)	5.15	5.67	5.87	5.99
pH(CaCl <sub>2</sub> )	4.47	4.88	5.02	5.15
BULK DENSITY	0.59	0.89	1.03	1.04
BULK DENSITY (FINE EARTH)	0.57	0.53	0.73	0.61
GRAVIMETRIC MOISTURE CONTENT	39.17	20.69	20.7	14.1
C STOCK (Kg/m <sup>2</sup> )	4.248	1.465	1.85	0.381
PERCENTAGE STONES	10	40	20	35



Profile name: COILLE THOGABHAIG 1  
 Site code: 6U  
 Surveyor: A. Lilly  
 Sample date: 13/05/2014  
 NGR: NG6135712136  
 Slope: 12 degrees, concave and complex  
 Altitude: 87m  
 Aspect: 228 degrees South West  
 Rockiness: Slightly rocky; slightly bouldery  
 Vegetation: Birch dominated with Hazel  
 Flushing: Not flushed  
 Site drainage: Slightly receiving site  
 Soil drainage: Free  
 Erosion: Some terracettes  
 Association: Inchnadamph  
 Series: None named  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Cambrian limestone  
 Climate: O1H1B3; Hyperoceanic extremely humid hemiboreal and orohemiboreal  
 Maximum rooting depth: 110cm  
 Base of pit: lowest horizon continues  
 Sample depths (cm): 0-2; 2-10; 10-28; 28-54; 70-78; 88-98  
 Sample ids: 1170398-403

**L: 0 - 2 cm;** light yellowish brown, 10YR 6/4 no identifiable mineral grains; fibrous; moist; von Post H1; weak very coarse platy structure; no roots; no stones; sharp smooth boundary.

**Ah: 2 - 10 cm;** dark yellowish brown, 10YR 3/4 silt loam; no mottles; moderate medium subangular blocky and moderate fine subangular blocky structure; moist; friable; common very fine fibrous, few fine fibrous and many coarse rhizomatous roots; few medium subangular stones (5%); clear smooth boundary.

**A: 10 - 28 cm;** brown, 10YR 4/3 silt loam; no mottles; moderate medium subangular blocky structure tending to weak fine subangular blocky structure; moist; friable; many medium woody, common coarse rhizomatous and common fine fibrous roots; common large subangular, common medium subangular and common small subangular stones (30%); clear wavy boundary.

**AB: 28 - 54 cm;** dark yellowish brown, 10YR 4/4 sandy silt loam; no mottles; moderate coarse subangular blocky and moderate medium subangular blocky structure; moist; friable; few fine fibrous and few medium fibrous roots; common large subangular, common medium subangular and common medium platy stones (35%); clear wavy boundary.

**Bw: 54 - 86 cm;** strong brown, 7.5YR 5/8 and 7.5YR5/6 sandy silt loam; no mottles; weak coarse subangular blocky and weak medium subangular blocky structure; moist; very friable; few fine fibrous and few medium fibrous roots; few small angular and few medium platy stones (15%); clear smooth boundary.

**C: 86 - 120+ cm;** brownish yellow, 10YR 6/6 and brownish yellow 10YR5/8 silt loam; no mottles; very weak coarse platy structure; moist; friable; few medium woody roots; few medium platy stones (10%).



COILLE THOGABHAIG 1 (6U)

HORIZON	L	Ah	A	AB	Bw	C
TOP SAMPLE DEPTH	0	2	10	28	70	88
BOTTOM SAMPLE DEPTH	2	10	28	54	78	98
SAMPLE POSITION	1	2	3	4	5	6
SAMPLE ID	1170398	1170399	1170400	1170401	1170402	1170403
C	44.31	12.79	5.87	1.81	0.88	0.42
N	0.97	0.95	0.48	0.13	0.07	0.04
C:N ratio	45.68	13.46	12.23	13.92	12.57	10.5
EXCHANGEABLE CATIONS (meq/100g)						
Al	0.07	0.11	0.26	0.42	0.19	0.15
Fe	0.02	0.03	0.03	0.01	<0.001	0.01
Mn	1.92	1.05	0.24	0.01	0.01	0.01
Ca	17.14	4.92	0.74	0.41	0.52	0.59
K	1.42	0.82	0.31	0.04	0.09	0.11
Mg	16.64	4.96	0.77	0.21	0.45	0.78
Na	0.79	0.92	0.43	0.16	0.19	0.16
H	33.08	21.2	16.58	7.68	5.51	3.3
SUM BASE CATIONS	69.07	32.82	18.83	8.5	6.76	4.94
BASE SATURATION%	52.11	35.41	11.95	9.65	18.49	33.2
AVAILABLE NUTRIENTS (mg/kg)						
Ca	2377.61	1104.17	150.47	113.12	114.26	117.13
K	482.1	329.93	102.88	9.19	24.84	33.44
Mg	1665.22	645.07	84.7	20.48	65.56	103.46
P	102.41	10.26	3.57	1.78	<0.32	<0.32
LOSS ON IGNITION (450 °C)						
	84.86	26.51	12.56	5.51	4.09	2.64
pH(H <sub>2</sub> O)	5.11	5.05	5.03	5.72	5.79	5.67
pH(CaCl <sub>2</sub> )	4.35	4.46	4.17	4.72	4.8	4.68
BULK DENSITY	0.06	0.32	0.41	0.95	0.78	0.72
BULK DENSITY (FINE EARTH)	0.06	0.32	0.4	0.64	0.76	0.71
GRAVIMETRIC MOISTURE CONTENT	65.49	64.36	50.79	25.67	37.45	38.06
C STOCK (Kg/m <sup>2</sup> )	0.53	3.111	2.958	1.958	1.819	0.912
PERCENTAGE STONES	0	5	30	35	15	10

Profile name: COILLE THOGABHAIG 2  
 Site code: 6F  
 Surveyor: A. Lilly  
 Sample date: 14/05/2014  
 NGR: NG6139612144  
 Slope: 13 degrees, straight and complex  
 Altitude: 102m  
 Aspect: 224 degrees South West  
 Rockiness: Slightly rocky; slightly bouldery  
 Vegetation: Typical western ash-oakwood  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Inchnadamph  
 Series: None named  
 Parent material: Till  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Cambrian limestone and basalt  
 Climate: O1H1B3; Hyperoceanic extremely humid hemiboreal and orohemiboreal  
 Maximum rooting depth: 70cm  
 Base of pit: Weathered rock  
 Sample depths (cm): 0-16; 16-29; 22-32\*; 60-70  
 Sample ids: 1170394-397

**L: Trace;**

**A: 0 - 16 cm;** brown, 7.5YR 4/4 silt loam; no mottles; weak medium subangular blocky tending to weak fine subangular blocky structure; moist; friable; few fine fibrous, common medium woody and many very coarse woody roots; common medium subangular and few small subangular stones (10%); clear wavy boundary.

**AB: 16 – 29<sup>‡</sup> cm;** brown, 7.5YR 4/4 sandy silt loam; no mottles; weak medium subangular blocky structure; moist; friable; few fine fibrous, few medium woody and few coarse woody roots; common medium subangular stones (10%); clear wavy boundary.

**Bw: 29 – 38\* cm;** strong brown, 7.5YR5/6 sandy silt loam; no mottles; moderate coarse subangular blocky and moderate medium subangular blocky structure; moist; very friable; common fine fibrous and few medium fibrous roots; common large angular basalt stones and limestones (15%); sharp broken boundary.

**C: 38 - 80 cm;** yellowish brown, 10YR 5/6 silt loam; no mottles; moderate very coarse subangular blocky breaking to moderate medium subangular blocky structure; moist; friable; few fine fibrous and few medium fibrous roots; many very large subangular, many large angular and many medium subangular stones (60%); sharp wavy boundary.

**R: 80;** weathering Cambrian limestone but with a large basalt erratic.

*\* & ‡ the AB horizon was not evident on the face of the pit when sampling began but as the profile was cut back it became clear that there was a transitional horizon present between the A and Bw. This horizon was then sampled but this means that sample depths overlap.*

COILLE THOGABHAIG 2 (6F)

HORIZON	L	A	AB	Bw	C
TOP SAMPLE DEPTH		0	16	22	60
BOTTOM SAMPLE DEPTH		16	29	32	70
SAMPLE POSITION		1	2	3	4
SAMPLE ID	No sample	1170394	1170395	1170396	1170397
C		5.34	3.14	1.72	1.36
N		0.48	0.25	0.12	0.1
C:N ratio		11.13	12.56	14.33	13.6
EXCHANGEABLE CATIONS (meq/100g)					
Al		0.21	0.75	0.62	0.14
Fe		0.02	0.01	0.05	0.02
Mn		0.23	0.02	0.01	0.02
Ca		1.42	0.27	0.09	4.56
K		0.35	0.08	0.05	0.08
Mg		1.25	0.19	0.07	4.57
Na		0.36	0.16	0.09	0.2
H		14.13	10.6	6.85	4.34
SUM BASE CATIONS		17.51	11.3	7.15	13.75
BASE SATURATION%		19.3	6.19	4.2	68.44
AVAILABLE NUTRIENTS (mg/kg)					
Ca		199.92	75.75	42.98	3963.55
K		98.07	25.1	16.28	37.64
Mg		109.5	22.78	15.37	2252.35
P		3.83	3.21	0.86	<0.32
LOSS ON IGNITION (450 °C)					
		11.11	7.81	5.44	5.16
pH(H <sub>2</sub> O)		5.06	5.36	5.27	6.36
pH(CaCl <sub>2</sub> )		4.33	4.49	4.5	6.14
BULK DENSITY		0.53	0.72	0.8	0.63
BULK DENSITY (FINE EARTH)		0.52	0.6	0.76	0.61
GRAVIMETRIC MOISTURE CONTENT		51.33	32.88	37.49	35.87
C STOCK (Kg/m <sup>2</sup> )		3.999	2.204	1	1.394
PERCENTAGE STONES		10	10	15	60



Profile name: COILLE THOGABHAIG 3  
 Site code: 7F  
 Surveyor: J. Bell  
 Sample date: 20/05/2014  
 NGR: NG6160912705  
 Slope: 14 degrees, straight and simple  
 Altitude: 62m  
 Aspect: 352 degrees North  
 Rockiness: Slightly rocky; no boulders  
 Vegetation: Birch dominated with Hazel  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Inchnadamph  
 Series: None named  
 Parent material: Colluvium  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Cambrian limestone and basalt  
 Climate: O1H1B3; Hyperoceanic extremely humid hemiboreal and orohemiboreal  
 Maximum rooting depth: 80cm  
 Base of pit: Rock  
 Sample depths (cm): 0-18; 30-40; 65-75  
 Sample ids: 1170438-440

**A: 0 - 18 cm;** brown, 7.5YR 5/2 fine sandy silt loam; no mottles; weak medium subangular blocky tending to moderate fine subangular blocky structure; moist; friable; many very fine fibrous, common medium fleshy and common medium woody roots; few medium angular and few medium subangular stones(7%); clear smooth boundary.

**Bw: 18 - 52 cm;** strong brown, 7.5YR5/6 fine sandy silt loam; no mottles; weak medium angular blocky structure; moist; friable; common very fine fibrous, common fine woody and few medium woody roots; common medium angular limestones and few medium subangular basalts (10%); clear smooth boundary.

**BCh: 52 - 80 cm;** dark reddish brown, 5YR 3/2 humose fine sandy loam; no mottles; weak fine subangular blocky structure; moist; very friable; common fine fibrous, common very fine fibrous and few fine woody roots; common medium angular and common large angular stones (15%); sharp irregular boundary.

**R: 80;** weathering Cambrian limestone.

COILLE THOGABHAIG 3 (7F)

HORIZON	A	Bw	BCh
TOP SAMPLE DEPTH	0	30	65
BOTTOM SAMPLE DEPTH	18	40	75
SAMPLE POSITION	1	2	3
SAMPLE ID	1170438	1170439	1170440
C	4.57	2.58	5.32
N	0.41	0.17	0.32
C:N ratio	11.15	15.18	16.63
EXCHANGEABLE CATIONS (meq/100g)			
Al	0.11	0.32	0.58
Fe	0.02	0.02	0.02
Mn	0.15	<0.00004	0.08
Ca	1.01	0.41	3.09
K	0.41	0.2	0.11
Mg	1.44	0.55	4.39
Na	0.26	0.11	0.11
H	10.23	10	13.36
SUM BASE CATIONS	13.35	11.27	21.06
BASE SATURATION%	23.37	11.27	36.56
AVAILABLE NUTRIENTS (mg/kg)			
Ca	287.74	135.77	2986.27
K	178.59	74.26	40.82
Mg	184.32	74.46	1702.51
P	4.49	<0.32	<0.32
LOSS ON IGNITION (450 °C)	9.54	6.03	16.77
pH(H <sub>2</sub> O)	4.89	5.43	5.92
pH(CaCl <sub>2</sub> )	4.24	4.38	5.22
BULK DENSITY	0.62	0.84	0.3
BULK DENSITY (FINE EARTH)	0.61	0.71	0.29
GRAVIMETRIC MOISTURE CONTENT	43.17	31.43	53.5
C STOCK (Kg/m <sup>2</sup> )	4.667	5.605	3.672
PERCENTAGE STONES	7	10	15



Profile name: COILLE THOGABHAIG 4 (7U)  
 Surveyor: J.Bell  
 Sample date: 21/05/2014  
 NGR: NG6156512725  
 Slope: 14 degrees, convex and simple  
 Altitude: 59m  
 Aspect: 310 degrees North West  
 Rockiness: Moderately rocky; slightly bouldery  
 Vegetation: Birch dominated with Hazel  
 Flushing: Not flushed  
 Site drainage: Normal site  
 Soil drainage: Free  
 Erosion: None  
 Association: Inchnadamph  
 Series: None named  
 Parent material: Colluvium  
 Major soil subgroup (1984): Brown earth  
 Major soil subgroup (2013): Brown earth  
 Soil type (FC): Basic brown earth  
 Rock types: Cambrian limestone and chert  
 Climate: O1H1B3; Hyperoceanic extremely humid hemiboreal and orohemiboreal  
 Maximum rooting depth: 65cm  
 Base of pit: Rock  
 Sample depths (cm): 0-18; 30-40; 48-58  
 Sample ids: 1170441-443

**A: 0 - 18 cm;** brown, 7.5YR 3/2 fine sandy silt loam; no mottles; weak medium subangular blocky tending to weak fine granular structure; moist; friable; many very fine fibrous, common medium fleshy and common medium woody roots; common medium angular limestones and few large angular cherts (15%); clear smooth boundary.

**Bw: 18 - 45 cm;** yellowish brown, 10YR5/6 fine sandy silt loam to silt loam; no mottles; weak medium angular blocky and weak fine subangular blocky structure; moist; friable; common very fine fibrous and common fine woody roots; many large angular cherts and common medium angular limestones (30%); sharp irregular boundary.

**BCh: 45 - 58 cm;** very dark grey, 10YR 3/1 humose fine sandy loam; no mottles; weak fine subangular blocky structure; moist; very friable; few fine fibrous and few fine woody roots; very abundant large angular stones (80%); sharp broken boundary.

**R: 58+;** weathering Cambrian limestone.

COILLE THOGABHAIG 4 (7U)

HORIZON	A	Bw	BCh
TOP SAMPLE DEPTH	0	30	48
BOTTOM SAMPLE DEPTH	18	40	58
SAMPLE POSITION	1	2	3
SAMPLE ID	1170441	1170442	1170443
C	9.02	2.26	7.74
N	0.71	0.21	0.12
C:N ratio	12.7	10.76	64.5
EXCHANGEABLE (meq/100g)	CATIONS		
Al	0.53	0.5	0.04
Fe	0.05	0.03	<0.001
Mn	0.26	0.03	0.01
Ca	2.93	0.87	8.79
K	0.65	0.24	0.15
Mg	3.45	1.18	10.14
Na	0.61	0.24	0.07
H	16.31	6.58	0.85
SUM BASE CATIONS	23.95	9.11	20
BASE SATURATION%	31.9	27.77	95.75
AVAILABLE NUTRIENTS (mg/kg)			
Ca	770.65	371.62	34730
K	239.36	74.91	62.7
Mg	432.02	246.87	20500
P	6.96	<0.32	<0.32
LOSS ON IGNITION (450 °C)	19.64	8.76	3.81
pH(H <sub>2</sub> O)	5.23	5.63	7.12
pH(CaCl <sub>2</sub> )	4.68	4.88	6.78
BULK DENSITY	0.6	0.8	0.59
BULK DENSITY (FINE EARTH)	0.55	0.77	0.57
GRAVIMETRIC MOISTURE CONTENT	49.59	37.55	37.6
C STOCK (Kg/m <sup>2</sup> )	7.59	3.289	1.147
PERCENTAGE STONES	15	30	80



## ANNEX 5: HORIZON SEQUENCES OF PROILE PITS

### INSIDE

### OUTSIDE

#### Coille Thogabhaig Site 6

6F

6U

Horz Symb	Depths
L	Trace
A	16
AB	29
Bw	38
C	80
Rock	80+

Horz Symb	Depths
L	2
Ah	10
A	28
AB	54
Bw	86
C	120+

#### Coille Thogabhaig Site 7

7F

7U

Horz Symb	Depths
A	18
Bw	52
BCh	80
Rock	80+

Horz Symb	Depths
A	18
Bw	45
BCh	58
Rock	58+

#### Ardura Site 1

1F

1U

Horz Symb	Depths
L	1
F	2
A	18
B	54
BC	92
CR	100+

Horz Symb	Depths
L	1
F	2
A	19
B	52
BC	95+

#### Ardura Site 2

2F

2U

Horz Symb	Depths
L	2
F	3
A	21
B	53
BC	76
Rock	76+

Horz Symb	Depths
L	2
F	3
A	21
B	54
BC	75
Rock	75+

**INSIDE**

**Morrone Birkwood Site 4**

**OUTSIDE**

**4F**

**4U**

Horz Symb	Depths
LF	6
A	27
B	70
C(x)	84+

Horz Symb	Depths
A	12
AB	30
B	62
C(x)	82+

**Morrone Birkwood Site 5**

**5F19**

**5F36**

Horz Symb	Depths
A	25
B	46
BCx	66

Horz Symb	Depths
A	19
B	45
BCx	80

## ANNEX 6: HORIZON SEQUENCES OF SATELLITE PITS

### Coille Thogabhaig Site 6 (Inside)

Pit 1 NW

Horz Symb	Depths
L	1
A	12
Bw	30
Rock	30+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
L	Trace
Ah	8
AB	60
Rock	60+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 1 SW

Horz Symb	Depths
L	Trace
A	60
B	62+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
L	2
Ah	6
A	28
B	30+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

### Coille Thogabhaig Site 6 (Outside)

Pit 1 NW

Horz Symb	Depths
L	1
A	15
Bw	55
Rock	55+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
L	2
Ah	6
A	15
Bw	28
C	50+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 1 SW

Horz Symb	Depths
L	1
A	23
AB	55
C	60+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
L	3
Ah	10
A	17
Bw	55
C	55+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

**Coille Thogabhaig Site 7 (Inside)**

Pit 1 NW

Horz Symb	Depths
A	19
Bw	43
BCh	68
BC	85+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Typical brown earth

Pit 2 NE

Horz Symb	Depths
A	11
Bw	34
Rock	34+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 1 SW

Horz Symb	Depths
L	1
A	11
Bw	49
Rock	49+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Typical brown earth

Pit 2 SE

Horz Symb	Depths
L	2
A	19
Bw	48
BC	64
Rock	64+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Typical brown earth

**Coille Thogabhaig Site 7 (Outside)**

Pit 1 NW

Horz Symb	Depths
Rock	
Soil Type 1984	Rock
Soil Type 2013	Rock
Soil Type FC	Rock

Pit 2 NE

Horz Symb	Depths
A	11
Bw	36
Rock	36+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Typical brown earth

Pit 1 SW

Horz Symb	Depths
A	11
Bw	48
BC	75+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Typical brown earth

Pit 2 SE

Horz Symb	Depths
A	19
Rock	19+
Soil Type 1984	Brown ranker
Soil Type 2013	Brown ranker
Soil Type FC	Brown ranker

### Ardura Site 1 (Inside)

Pit 1 NW

Horz Symb	Depths
L	1
F	2
A	28
B	53
BC	72
R	72+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
L	1
F	2
A	23
B	51
BC	75
R	90+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 1 SW

Horz Symb	Depths
L	1
F	3
A	31
B	50
BC	67+
R	
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
L	2
F	3
A	29
B	55
BC	90+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

### Ardura Site 1 (Outside)

Pit 1 NW

Horz Symb	Depths
L	3
F	6
Ah	13
A	24
B	50
BC	80+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
L	1
A	22
B	47
BC	80+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Brown earth

Pit 1 SW

Horz Symb	Depths
L	2
A(g)	18
B(g)	50
BC	70
Rock/Boulder	70+
Soil Type 1984	Brown earth with gleying
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth with gleying

Pit 2 SE

Horz Symb	Depths
L	1
F	2
A	19
B	50
BC	75
Rock	75+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

### Ardura Site 2 (Inside)

Pit 1 NW

Horz Symb	Depths
Os1	21
Os2	50
Oa	100+
Soil Type 1984	Basin peat
Soil Type 2013	Basin peat
Soil Type FC	Juncus articulatus or acutiflorus bog

Pit 2 NE

Horz Symb	Depths
L	2
F	3
A(g)	19
B(g)	50
BC(g)	75+
Soil Type 1984	Brown earth with gleying
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth with gleying

Pit 1 SW

Horz Symb	Depths
L	2
F	3
A	17
B	52
R	52+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
L	1
Os	11
Ah	16
R	16+
Soil Type 1984	Peaty ranker
Soil Type 2013	Peaty ranker
Soil Type FC	Peaty ranker

### Ardura Site 2 (Outside)

Pit 1 NW

Horz Symb	Depths
L	2
F	3
Ah	17
B	35
R	35+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
L	2
F	3
A	20
B	49
BC	57
R	57+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 1 SW

Horz Symb	Depths
L	1
F	2
A	18
B	45
BC	79
R	79+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
L	3
F	4
Ah	13
A	22
B	47
BC	73
R	73+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Os and Oa are semi fibrous and amorphous peat respectively.

**Morrone Birkwood Site 4 (Inside)**

Pit 1 NW

Horz Symb	Depths
LF	4
A(h)	9
AB	19
B	44
BC	54+
Soil Type 1984	Brown podzolic soils
Soil Type 2013	Brown podzolic soils
Soil Type FC	Podzolic brown earth

Pit 2 NE

Horz Symb	Depths
LF	3
H	7
AB	22
B	42
BC	52+
Soil Type 1984	Brown podzolic soils
Soil Type 2013	Brown podzolic soils
Soil Type FC	Podzolic brown earth

Pit 1 SW

Horz Symb	Depths
O	25
Ag	40
Bg	45+
Soil Type 1984	Peaty gley
Soil Type 2013	Peaty gley
Soil Type FC	Flushed peaty surface-water gley

Pit 2 SE

Horz Symb	Depths
LF	5
H	12
A	30
B	45+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Podzolic brown earth

**Morrone Birkwood Site 4 (Outside)**

Pit 1 NW

Horz Symb	Depths
L	1
A	21
B	46
BC	51+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
F	1
A	21
B(g)	46+
Soil Type 1984	Brown earth with gleying
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth with gelying

Pit 1 SW

Horz Symb	Depths
A	35
B	60
C	75+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
A	21
B	45
B(g)	60+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

**Morrone Birkwood Site 5 (Inside)**

Pit 1 NW

Horz Symb	Depths
A	21
B	60
BC	70+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
LF	4
A	35
B	55
BC	65+
Soil Type 1984	Brown podzolic soils
Soil Type 2013	Brown podzolic soils
Soil Type FC	Podzolic brown earth

Pit 1 SW

Horz Symb	Depths
L	2
H	4
A	9
AE	15
Bs	35+
Soil Type 1984	Humus-iron podzol
Soil Type 2013	Humus-iron podzol
Soil Type FC	Typical podzol

Pit 2 SE

Horz Symb	Depths
LF	1
A	18
B	40
BC(x)	40+
Soil Type 1984	Brown podzolic soils
Soil Type 2013	Brown podzolic soils
Soil Type FC	Podzolic brown earth

**Morrone Birkwood Site 5 (Outside)**

Pit 1 NW

Horz Symb	Depths
A	26
B	47
BC	47+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 NE

Horz Symb	Depths
LFH	3
AB	30
Bx	40+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Podzolic brown earth

Pit 1 SW

Horz Symb	Depths
A	24
B	46
BC(x)	46+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

Pit 2 SE

Horz Symb	Depths
Root mat	2
A	23
B	45
BC	50+
Soil Type 1984	Brown earth
Soil Type 2013	Brown earth
Soil Type FC	Basic brown earth

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