Factors affecting the variation in floral diversity on two reclaimed coal mine sites

Michael Ridealgh

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University of York.

Environment Department.

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ABSTRACT

An investigation was carried out into the plant community status of two ex-coal mine sites near Wakefield - Upton and Fitzwilliam. The investigation set out to understand the ways in which the underlying geology, the historical and industrial development and the reclamation processes had influenced the plant composition. An assessment of the condition of each site was also undertaken using local volunteers. Species cover was assessed with 1 m^2 quadrats, using the Domin Scale; soil samples from these quadrats were analysed for pH, % moisture, % carbon, % nitrogen, ammonium-N and nitrate-N, phosphorus, lead, zinc, calcium and magnesium. The reclamation processes were discovered to have been different at each site, and where brick rubble had been spread, it was found to be having a significant effect. The Upton site illustrated well the Intermediate Disturbance Hypothesis, with the old railway cutting acting as a refuge and the construction of drainage scrapes in 2009 had led to new colonisation. As a result, Upton was more species rich (91), whereas at Fitzwilliam, there was less disturbance and lower species richness (33). At Upton, the Spout Lane Fault divided the site between the Permian Limestone and the Coal Measures and this resulted in a distinct change in the plant communities across the fault, as identified by ordination and TWINSPAN. There was a strong relationship between the C: N ratios and the limestone. Nitrogen was found to be an important driver of species composition and in turn correlated with pH and moisture, which were influenced by the underlying geology. At Fitzwilliam, where there is no underlying limestone, the relationship with calcium and magnesium concentrations was still quite strong, due in part to the underlying sandstone aquifer having groundwater of the calcium bicarbonate type, and to the reclamation process.

Words: 293

Keywords: species richness, geology; fault; pH, C: N ratio; aquifer; reclamation; Intermediate Disturbance Hypothesis.

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DECLARATION

“I Michael Ridealgh do hereby declare that the material submitted in this thesis is all my own work, and where there are parts that are not my own work, these are clearly described”

Chapter One

General Introduction

1.1. Background.

This study is part of the OPAL (Open Air Laboratories) Yorkshire and Humberside Project, which aims to involve local communities in understanding, documenting and conserving biodiversity. This study is an investigation into the plant community status of two ex-coalmine sites in the Wakefield area, Fitzwilliam and Upton. These two sites were selected because of their varied and interesting ecology and because it seemed possible to develop links with the local communities. It sets out to try to understand the ways in which the underlying geology, the historical and industrial development and the reclamation processes have influenced the plant composition found on the two sites.

It is important to understand that restoration and reclamation are very different. Definitions, particularly in the United States, seem to have changed over time (Stahl, et al., 2006). Restoration tends to refer to an attempt to return a site to a condition as close as possible as it was originally, whereas reclamation is a remediation process, aiming to establish a set of topographic, soil and plant conditions meeting a set of regulatory standards.

1.1.1. The Regional Background.

In the 1988 Survey of Derelict Land in England (HMSO, Data included in Mabey, 1991), the amount of derelict land in the Yorkshire and Humberside Region was given as 6,100 ha, the only region to have shown an increase since 1982 (+13%). In the same period the amount of derelict land justifying reclamation had shown a +22% change, again the only region to do so (Mabey, 1991). This was mainly due to the increase in derelict spoil heaps across the region as many coal mines closed. The region had managed to reclaim over 2,000 ha of derelict land in that same time period. Being in the heart of the Yorkshire Coalfield (Figure 1.1), the Wakefield area had many derelict mine sites as the shallower workings in the exposed western section of the coalfield became exhausted, and the deeper mines in the eastern concealed part beneath the Permian strata were modernised and developed as part of the National Coal Board's Plan for Coal (North & Spooner, 1982). The Upton and Fitzwilliam collieries had closed by 1967, the Upton site being abandoned until 1990, and the Fitzwilliam site left derelict but still having mine spoil dumped on it. In 1979 the Kinsley Drift Mine was opened on part of the Fitzwilliam site, with a life expectancy of about 25 years (North & Spooner, 1982), only to close in 1986.

1.1.2. The Ecological Significance of Post-Industrial Sites.

During the 1990's it began to be realised that many post-mining sites had potential for nature conservation (Rotherham, et al., 2003), as the often extreme environmental conditions, particularly relating to pH, drought and low levels of soil nutrients, created potentially stable communities and habitat types. These sites contributed to Biodiversity Action Plan (BAP) targets in the South Yorkshire Area, following the UK Steering Group Report (1995). Local BAPs were set up by Sheffield (2002), Barnsley (2002), Doncaster (2007) and Wakefield (2001). The Wakefield LBAP particularly singled out the Upton Railway Cutting for its limestone grassland and scrub as well as the fact that small areas of limestone had "been seeded or allowed to recolonise". As part of this, funding from the Aggregates Levy Sustainability Fund (ALSF), under the Coalfield Heathland Project, allowed for 5 ha of lowland heathland creation work at the Upton Colliery site during the period 2005 -2007.

1.2. Location.

The two ex-coalmine sites, Fitzwilliam and Upton are both situated on the Yorkshire Coalfield to the south-east of Wakefield (Figure 1). Fitzwilliam is approximately 8 km and Upton approximately 14 km from Wakefield.

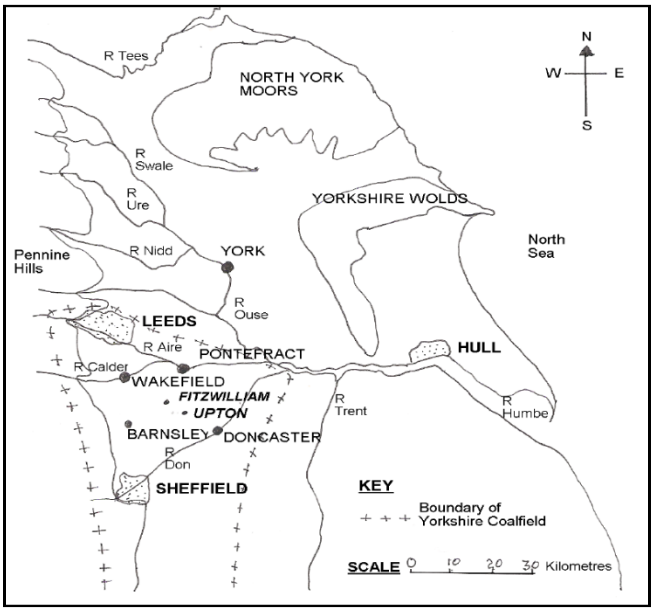


Figure 1.1 Map showing the Location of Fitzwilliam and Upton

Both Fitzwilliam and Upton were closely linked by the development of the rail network in the area, which was primarily constructed for moving coal from the mines to local industries in the Sheffield and Leeds areas, and also to the waterways, focusing on Hull and the Humber Estuary for export (Figure 1.2).

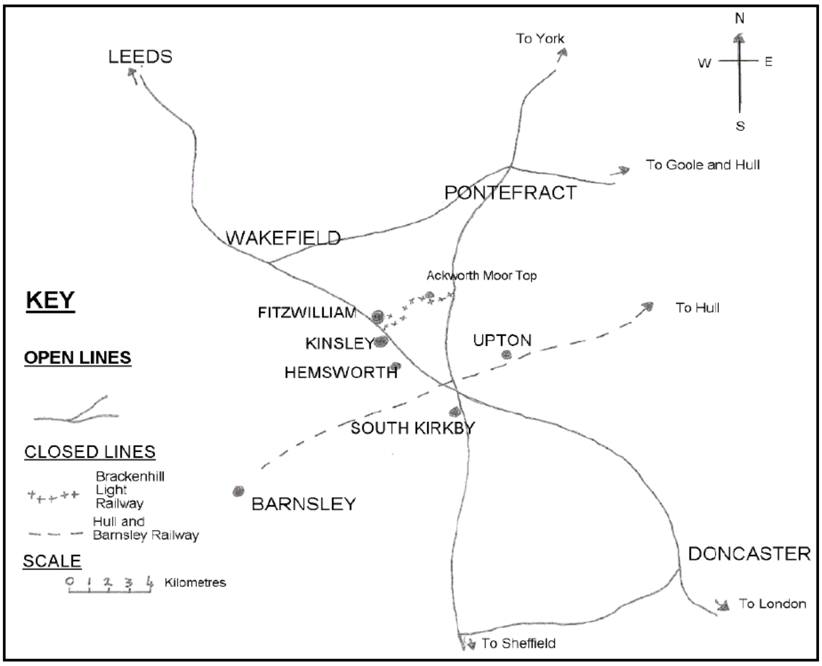


Figure 1. 2 Upton and Fitzwilliam in relation to the Rail Network.

The development of this rail network has been significant in the industrial history of both sites, and has in turn played a part in the reclamation and re-vegetation processes, so possibly influencing the resulting plant diversity.

The two sites, Fitzwilliam and Upton, even though only a short distance apart (6.5 km) have a different geology, a different industrial evolution and a very different history of reclamation. As a result, the difference in plant composition was expected to be quite marked. This study aimed to examine the various factors that may have affected this difference in species composition, both between the two sites and within the two sites.

The next section provides an overview of the key factors at each site.

1.3. Surface Geology.

Although both sites mined coal mainly from the Middle Coal Measures of the Carboniferous Period, the surface geology is in the Upper Coal Measures, and at Fitzwilliam the main area of the site is on sandstones (The Newstead Rock) of the Ackworth Member (Lake, 1999). The waste siltstones, mudstones and sandstones formed the bulk of the spoil heaps which completely covered the site.

The Upton site, on the other hand, is mainly on siltstones, mudstones and thin sandstones of the Hemsworth Member (Lake, 1999), but also has an area of Permian Lower Magnesium Limestone of the Cadeby Formation, brought down to the level of the Upper Coal Measures by the Spout Lane Fault, which downthrows 80 metres to the south-east. As a result, limestone forms the surface rock of the south-east part of the site (Goossens & Smith, 1973; BGS, 1998; Lake, 1999). This is shown in Figure 1.3. Most of the spoil from the pit was transported along a tramway and deposited to the north of the site, with only the north-east and eastern parts of the actual colliery site actually having some spoil placed there, before being used in the colliery brickworks.

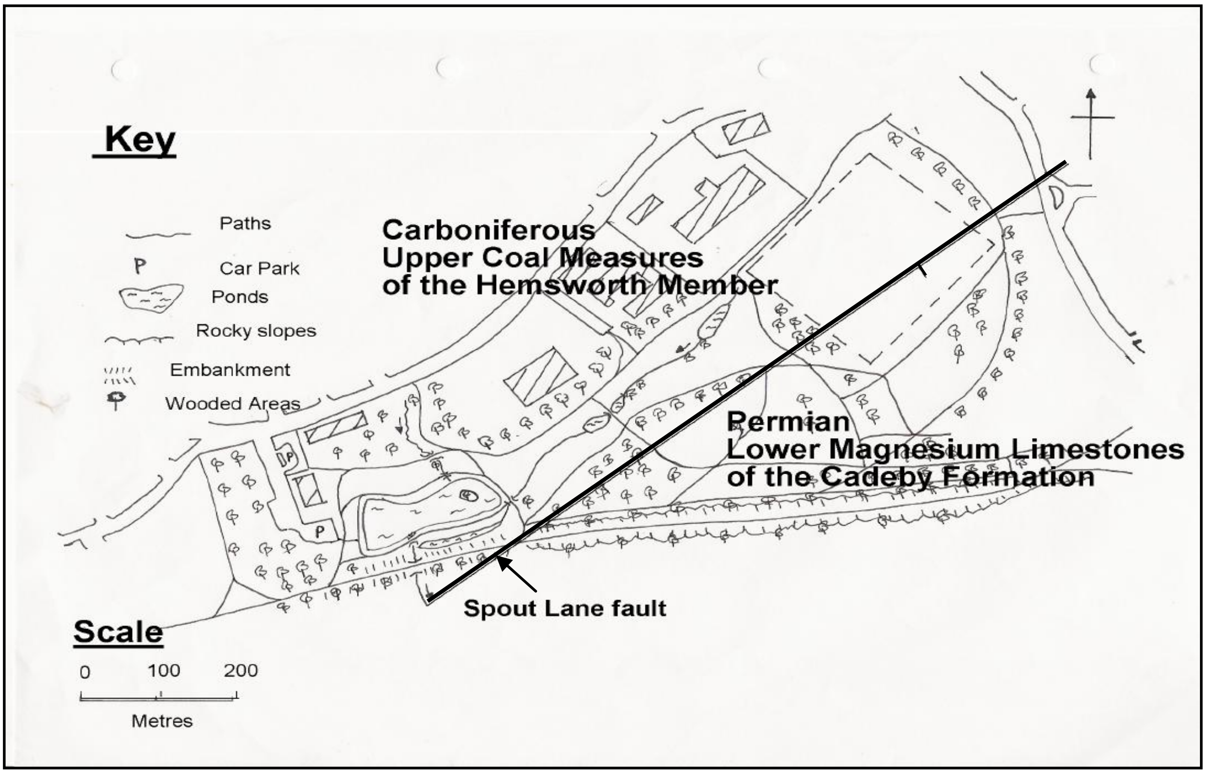


Figure 1.3 Upton Geology – showing how the Spout Lane Fault has formed an abrupt boundary between the Coal Measures on the NW side and the Permian Limestone on the SE side.

The railway cutting at the Upton site was cut through this limestone in 1885 (Hoole, 1972), and reveals the unconformity between the Upper Coal Measures and the Lower Magnesium Limestone at the west end. The top of the cutting may have acted like a hedgerow throughout the whole time period of the colliery, and so been like a potential refuge for many plant species, particularly calcicole plants.

1.4. Industrial Development and Reclamation.

1.4.1. Fitzwilliam (GR: SE 422155).

The first coal mine, Fitzwilliam Main Colliery, was sunk in 1876 to the north-east of the village of Kinsley on agricultural land , part of the Fitzwilliam estate. It produced its first coal in 1877, suffered a major pit disaster in 1879, went through a series of financial difficulties and ownership changes, eventually being renamed Hemsworth Colliery in 1907 (Hall, 2005).

The mine was connected to the Leeds, Wakefield and Doncaster railway line, but traffic congestion eventually led to the colliery being served by the Brackenhill Light Railway, opened in 1914 (Cookson & Chapman, 2003), which went through

Ackworth Moor Top and connected to the Swinton and Knottingley Railway (Franks, 1979), as shown on Figure 1.2. The Brackenhill Light Railway ran along the southern boundary of the mine site.

The original station at Fitzwilliam (on the Leeds to Doncaster main line) was situated further north than the present one and was opened in 1937 and closed in 1967(Goode, 1975). The Brackenhill Light railway closed in 1962 (Cookson & Chapman, 2003). The current Fitzwilliam station was opened in 1982.

Following a merger with South Kirkby Colliery, the pithead was closed in 1967. The mine buildings and railway tracks were cleared by 1972 (although colliery waste continued to be dumped on the site), and then in 1979 Kinsley Drift Mine was opened on part of the site (North & Spooner, 1982)**.** Coal was taken from the drift mine by overhead conveyor and fed into a hopper for loading into railway wagons in sidings just to the south of Fitzwilliam Station. The concrete base of the overhead hopper can still be seen in the undergrowth at the western edge of the site. Demolition of some of the structures began in 1984, with final closure by 1986. During the miners' strike in 1984, coal was collected from the stacks and some trees were cut down for fuel (See Timeline Figure 4.1b). Meanwhile, the former Hemsworth Colliery tip was reclaimed in the 1980's, with the present meadow areas covered with imported topsoil and the wooded areas being treated with turkey manure from the nearby poultry farms (Pipkin, pers.com. 2011). A Phase 1 Habitat Survey was undertaken in 1990 (West Yorkshire Ecology) which showed most of the site as a disused tip, with the Kinsley Drift Mine site as "derelict" or" bare". However, the survey did show the eastern part of the site, the Hemsworth Colliery tip, as Improved Grassland, as indicated on Figure 4. The Kinsley Drift part of the site had an import of topsoil in 1991 as there was a proposal to reclaim to a golf course. Five fairways received 100m topsoil from a housing development on the last liquorice fields in Pontefract, and the greens received about 300 mm topsoil over a drainage blanket (Pipkin, pers. com., 2011). The rest of the site consisted of treated colliery spoil, which was limed at 20 t/ha and fertilised with N: P: K at 10: 15: 10 (%) at 500 kg/ha and seeded with a grass/wildflower seed mix (Pipkin, pers. com., 2011).

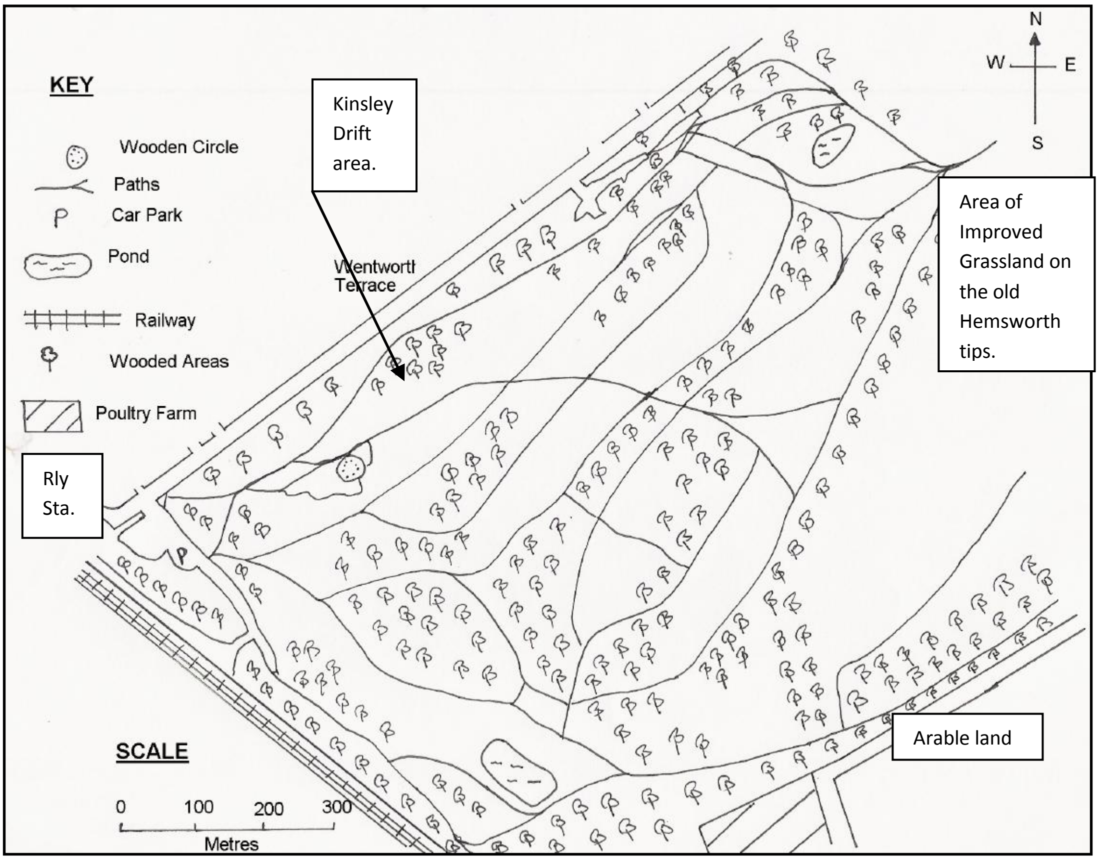


Figure 1.4 Site Map for Fitzwilliam – the northern half is generally level, with slopes to the south and east. The general trend of the grassland areas matches with the prevailing SW winds. Drainage is directed to the south. The path along the southern boundary of the site is along the line of the old Brackenhill Light Railway. The open areas show the extent of the Neutral Grassland. There are several small areas of scattered scrub/neutral grassland mosaic on the edges of the main Broad-leaved tree plantation areas, but the main area is the stretch running alongside Wentworth Terrace, which forms the NW boundary of the site.

In 1998 the Fitzwilliam Country Park Group started up and in 1999 the first paths were laid and fences built. In 2000, the group was formally established and began clearing the site of rubbish and burnt out cars (See Timeline Figure 4.1b). A Phase 1 Habitat Survey was carried out in 2007 (Moore & Frith, 2007), but due to a Traveller's camp on the site, it was an incomplete survey. However, three grassland habitat types were identified: Improved grassland (29 plant species), Neutral Grassland (74 plant species) and Neutral Grassland/Scattered Trees and Scrub Mosaic (75 plant species).

In 2008 the park was given the status of a Local Nature Reserve.

1.4.2. Upton (GR: SE 483135).

This was originally an area of agricultural land, a mixture of arable and pasture, which was cut through in 1885 by the building of the Hull and Barnsley Railway (Hoole, 1972; Hinchcliffe, 1980). The railway was excavated in a cutting in the Permian Lower Magnesium Limestone, and the station (Upton and North Elmsall) was to the west of this, at the southern tip of Upton village. The Upton Colliery Company was formed in 1923 and coal started being produced in 1926, with the Barnsley seam being reached in 1927. At this point unfavourable trading conditions in the coal trade resulted in a 2 year temporary shutdown from September 1927 (Jackson, pers. comm., 2010). The mine suffered badly from gas and there were a number of explosions and fires, resulting in 61 deaths, which, coupled with a number of geological problems, led to the mine closing in 1964, although the Washery continued until 1966, with the railway closing a year later (Chapman, 1999). Clay extraction continued in the eastern part of the site for the on-site brickworks, which had been established by the Upton Colliery Company to supply its own bricks, originally using the mine waste and the local calcareous clay brought down a tramway from the north of the site. The mine buildings were demolished and the salvaging of materials would have disturbed the site. The railway lines were completely removed by 1971 and the whole site was basically left alone to revegetate itself, until in 1980 disturbance to the far eastern part of the site was caused by the creation of a BMX park. Proposals to opencast coal (1976) and quarry limestone (1978) were approved but not acted on (Jackson, pers. com., 2010). According to local people, the Bee Orchid (*Ophrys apifera*) was noticed for the first time in 1980 (See Timeline Figure 4.1a). In 1984 the National Miners' Strike resulted in coppicing for fuelwood and coal digging on the outcrop of the Upton Seam which led to the development of the first pond. In 1985 it was proposed to construct a golf course on the main spoil tip which was on the north side of Waggon Lane, but lack of funding prevented that going ahead. It was also included in the 1990 Planning Application submitted to landscape the western part of the site for ecological purposes, open-cast coal from the Upton Seam in the main area and also quarry limestone from the south east part of the site (Planning Application 90/99/48032). This document indicates that "Very little soil exists on the surface of the site," and that "Colliery spoil would provide an opportunity to create areas of heathland." A Phase 1 Habitat survey was carried out (West Yorkshire Ecology, 1990), recording the area as mostly neutral grassland with scattered scrub. However, it does indicate that much of the spoil covering the site was acidic, resulting in sparse acid grasslands. The area proposed for open-casting of the Upton Seam is shown on the photograph (Figure 1.5) taken by a member of the public involved in opposition to the scheme, and also gives an indication of the extent of the natural re-vegetation. However, although approved in principle, the extraction of coal and limestone was put on hold, and a Phase 1 Planting Plan was drawn up (R/21/27/12A). Following a Planning Enquiry in 1992 (WMDC/40/SE/1) and a revised Afteruse Plan 2 (Drawing R/21/27A), a Phase 2 Planting Plan was incorporated into a major landscaping of the site to create a country park, with the main reclamation begun in 1993 and completed by 1995. This included the excavation of an angling pond. This Phase 2 Planting Plan indicated that the area on the limestone "...be either cleared to original ground level or shall receive 100 mm of crushed limestone and a suitable binding layer of alkaline subsoil from the site." It also indicated that it was "...to be sparsely sown with seeds harvested from the railway cutting."

Photo taken by Margaret Coulson and lent by Tony Kitchen.

Figure 1.5 View of Proposed Open-cast Site facing south west. June 1990.

A fresh Phase 1 Habitat Survey was carried out in 2007 (Moore & Frith, 2007), with the grassland areas divided into three types, Calcareous Grassland (63 plant species), Flower-rich Neutral Grassland (83 plant species) and Neutral Grassland/Tall Ruderal/Scattered Scrub (69 plant species). The main area of Neutral Grassland was mapped in the eastern end of the site, which was reclaimed from the old brickworks, as shown on Figure 1.6. Following major flooding in 2005 some improvements were made to the drainage, including removal of willow trees from Spout Hole, but according to Mark Cropley, the Drainage Engineer for Wakefield Metropolitan District Council, it was not until 2009 that the settling ponds and scrapes and hollows were constructed to slow down the movement of flood water. He informed us (during a site visit, 25/05/2011) that the scrapes were deliberately left to revegetate on their own, and that no treatment was carried out on the soil.

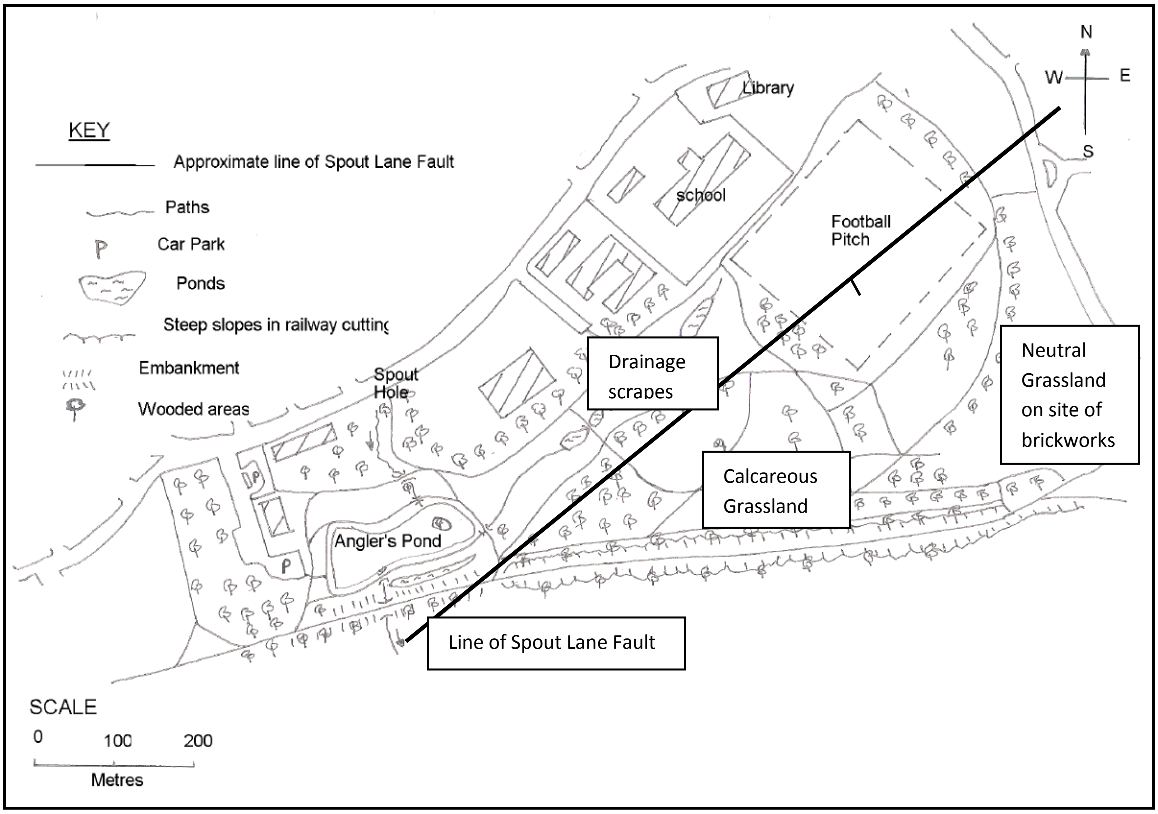


Figure 1.6 Site Map for Upton – the site slopes down from the area of the football pitch towards the SW, the main drainage channel is a valley feature running parallel on the NW side of the fault. Most of the grassland areas are classified as Flower-rich neutral Grassland, with the railway cutting being a mosaic of Calcareous grassland/Neutral grassland/Tall Ruderal/Broad-leaved Woodland and Scattered Scrub.

1.5. Aims and objectives.

Although these various habitat surveys have been carried out, no previous studies have analysed the different factors influencing the vegetation composition on the two sites or related this to the soil characteristics.

1.5.1. Similarities and Differences between the two sites.

1.5.1.1. Geological Factors.

Although both sites were covered with mudstone and sandstone spoil dug from the Coal Measures, and usually expected to be acidic due to the presence of Iron Pyrites (FeS_2) formed under the anaerobic conditions found in the coal measure swamps (Bradshaw & Chadwick, 1980), the Upton site also has an area of limestone covering the south-east part of the site. So although the nature of the mine waste seems similar, the Upton site could be different due to this limestone and so one aim of this study is to see if this is reflected in the plant composition on both sites. The nature of the type of rock should be reflected in the soil, in terms of pH, soil moisture properties, and the levels of certain plant nutrients.

Hypothesis: ***The solid geology is a key factor in the difference in floral diversity between the two sites.***

At the Upton site, the junction between the Permian Limestone and the Upper Coal Measures is marked by the Spout Lane Fault, so there should be a sharp change in the soil properties as this is crossed. This should be reflected in the plant composition as the fault is crossed, and one could reasonable expect to go from a Flower-rich Neutral Grassland to Calcareous Grassland.

Hypothesis: ***At Upton, the abrupt change in the solid geology across the Spout Lane Fault results in a marked floral transition.***

1.5.1.2. Industrial Development and Reclamation.

The Fitzwilliam site has had a much longer period of mining activity, and so a shorter period between abandonment and reclamation, whereas the Upton site was able to revegetate naturally for 20 years before being reclaimed. The whole of the Fitzwilliam site was covered in spoil, whereas at Upton it was mainly the eastern part of the site, and even then much of the spoil went off site. Also, much of the spoil was used for brick making, with clay been dug for this process as well. Much of the waste from the brick making was also spread on parts of the site, which would be expected to modify the properties of the soil (Schadek, et al., 2009). Although both sites had the main episode of reclamation at about the same time, there were subtle differences in the way they were reclaimed. At Upton, the limestone area near the railway cutting was carefully cleared and acted as a seed bank for many calciocolous species. At Fitzwilliam, the whole site had to be landscaped and seeded. So a second aim is to see if the industrial development and the reclamation processes could also have affected the plant composition. This should be reflected in the species composition and richness.

Hypothesis: ***The differences in the process of reclamation of the two sites have contributed to the variation in floral diversity between the sites.***

Also, particularly in the case of Upton, a major disturbance occurred when the drainage scrapes were created. The Intermediate Disturbance Hypothesis could well apply here. This is based on the idea that a certain degree of, or frequency of, disturbance creates fresh niches leading to greater species richness. Too much disturbance and few species can survive; little or no disturbance and competitively superior species exclude all others. Areas of refugia can also lessen the effects of disturbance (Townsend et al., 1997). The railway cutting had acted like a hedge row throughout the history of the Upton site and would have been a seed bank, able to propagate plants into the disturbed areas of the scrapes, the year of excavation of the scrapes being known. A comparison with plant composition data from other areas where the dates for creation are known could help indicate this.

Hypothesis: ***The variation in floral diversity between the two sites is to some extent accounted for by the intermediate disturbance hypothesis, particularly in relation to refugia.***

1.5.1.3. Soil Properties.

These are particularly linked to the solid geology and the industrial development and reclamation processes. These combine to determine the soil properties, which in turn will influence the plant composition. So the third aim arises because certain soil properties appear to be more significant than others in this respect, and a key property has to be pH, as pH affects the behaviour of so many plant nutrients. It also can affect the behaviour of certain toxic elements.

Hypothesis: ***pH and soil moisture are key factors influencing the availability of plant nutrients.***

Hypothesis: ***The level of organic material, as indicated by the Carbon: Nitrogen Ratio is a reflection of the effect of the limestone.***

Hypothesis: ***The levels of Lead and Zinc are related to the amount of organic material as well as the industrial history of the sites and their likely source from the limestone.***

1.5.1.4. Community Involvement

The Fitzwilliam site had an organised group, the Fitzwilliam Country Park Group, taking an active interest in the initial care of the site, whereas at Upton it seemed to be more groups opposing the open-casting and reclamation through the planning process, and then interested individuals and the Anglers Association. This gives the fourth aim; that of trying to assess the effect the local community could have had on the site development and plant composition. This is difficult to formulate as a hypothesis as it depends more on individual observation (See Timelines Figures 4.1a and b). It is clear that at various times sections of the local community have played a part, both positive and negative, in the way they perceive and treat the sites (See RAPGIS Maps Figures 4.2 and 4.3). Examples include the planting of various species, riding motorbikes across the sites, setting fire to areas, as well as clearing litter and emptying rubbish bins.

Hypothesis: ***The level of involvement by the local community has contributed to the floral diversity of both sites.***

CHAPTER 2: Methods

2.1. Sampling.

On both sites, distinct areas of grassland were identified following the maps in the Phase 1 Habitat Surveys (Moore & Frith, 2007), and by visual inspection, and were seen to divide up on the basis of the path network, although at the Upton site the disused railway cutting formed a linear feature all of its own.

For each distinct area of grassland, a point along a path was randomly selected and a transect of 1 m^2 quadrats was then instituted, with up to four quadrats at 3m intervals, generally at 90° from the path if the surface was level. In the case of Area 1 at Fitzwilliam, because it was suspected that there could be windblown deposition from the poultry farm, the quadrats were spaced out further in order to reflect the different slope segments in order to see if and how the deposition varied with distance up the slope.

The same principle was applied along the railway cutting at Upton. A series of random points was selected, with the transect line as near as possible at right angles from the track bed on either side. The first quadrat was then centered 1 m from the edge of the cinder track, and the next at 3m. The number of quadrats was to some extent dictated by the nature of the cutting sides; if a tall, vertical rock face, only two quadrats were possible.

Within each quadrat the different plant species were identified, both flowering plants (Blamey, et al., 1987; Rose & O'Reilly, 2006) and grasses (Hubbard, 1954; Cope & Gray, 2009). Their percentage abundance was estimated, and then the Domin Scale was used to quantify the cover (Kershaw, 1973; Chalmers & Parker, 1989). As Kershaw observes, percentage cover is a good measure of plant abundance and is ideal in grasslands. The 10 point Domin Scale is shown in Table 2.1.

Table 2.1 The Domin Scale.

% Cover/Abundance	Domin Scale Value
91 - 100	10
76 - 90	9
51-75	8
34 – 50	7
26 – 33	6
11 – 25	5
4 - 10	4
<4% (Many Individuals)	3
<4% (Several Individuals)	2
<4% (One or Few Individuals)	1

Areas of bare earth and bare rock were also quantified on the Domin Scale, and a 5 point scale was devised for rabbit droppings (Table 2.2). Rabbit droppings act as a measure of nutrient recycling and soil disturbance, as well as an indication of grazing activity in areas without any form of pastoral farming.

Table 2.2 Five Point Scale for Rabbit Droppings.

Number of Droppings	Scale Value
81 - 100	5
61 - 80	4
41 - 60	3
21 -40	2
1 - 20	1

At Fitzwilliam, 19 quadrats were established and at Upton, 32 (17 of which were in the disused railway cutting). Originally the same number of quadrats was established at Upton as at Fitzwilliam, but it was then decided to include the cutting so that a comparative study within the site could also be carried out. The quadrat survey took place between 12/08/2010 and 19/08/2010 at Upton and between 20/08/2010 and 07/09/2010 at Fitzwilliam.

Each quadrat centre was indicated by a numbered marker and also referenced using a handheld GPS (Geographical Positioning System), the Garmin e-Trex H. The GPS data was also input into a Google Earth view of the particular site so that the position of each quadrat could be clearly seen and located (Figures 2.1 & 2.3). Then base maps were drawn and the sampling areas marked on, as in Figures 2.2 and 2.4.

Figure2.1. Upton Quadrat Locations.

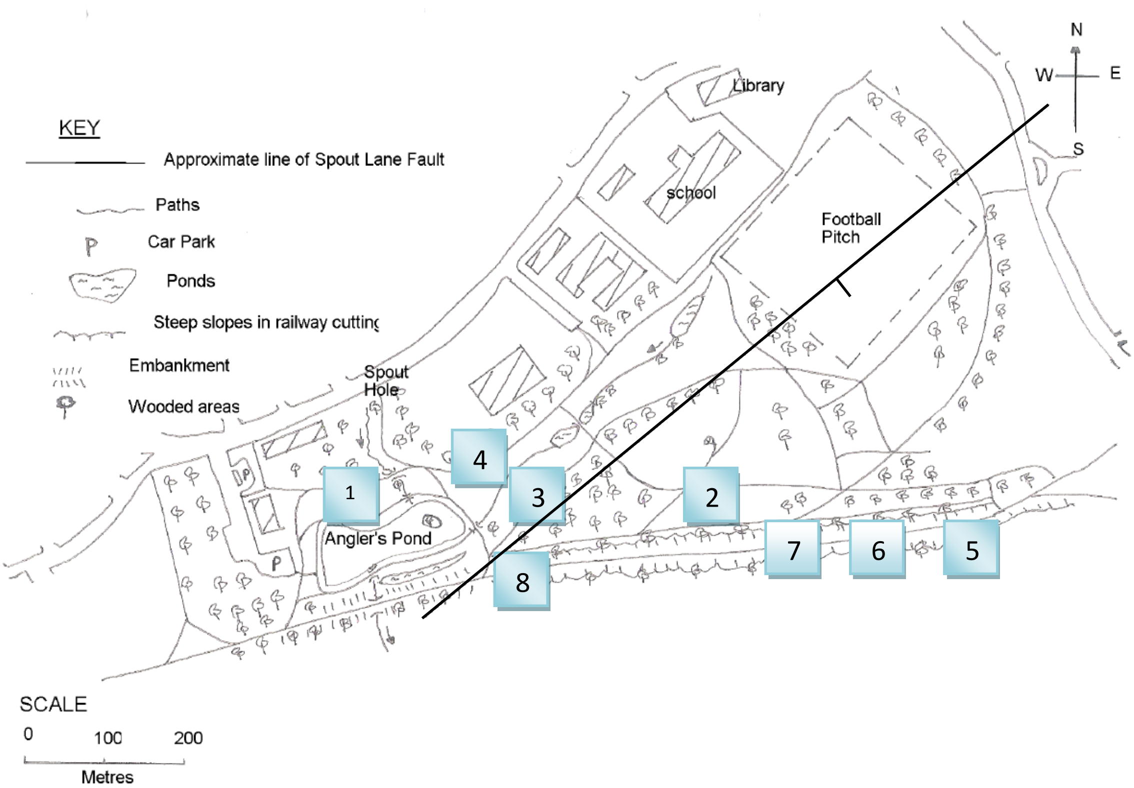


Figure 2.2 Site Map for Upton showing sampling locations: 1

Figure 2.3. Fitzwilliam Quadrat Locations.

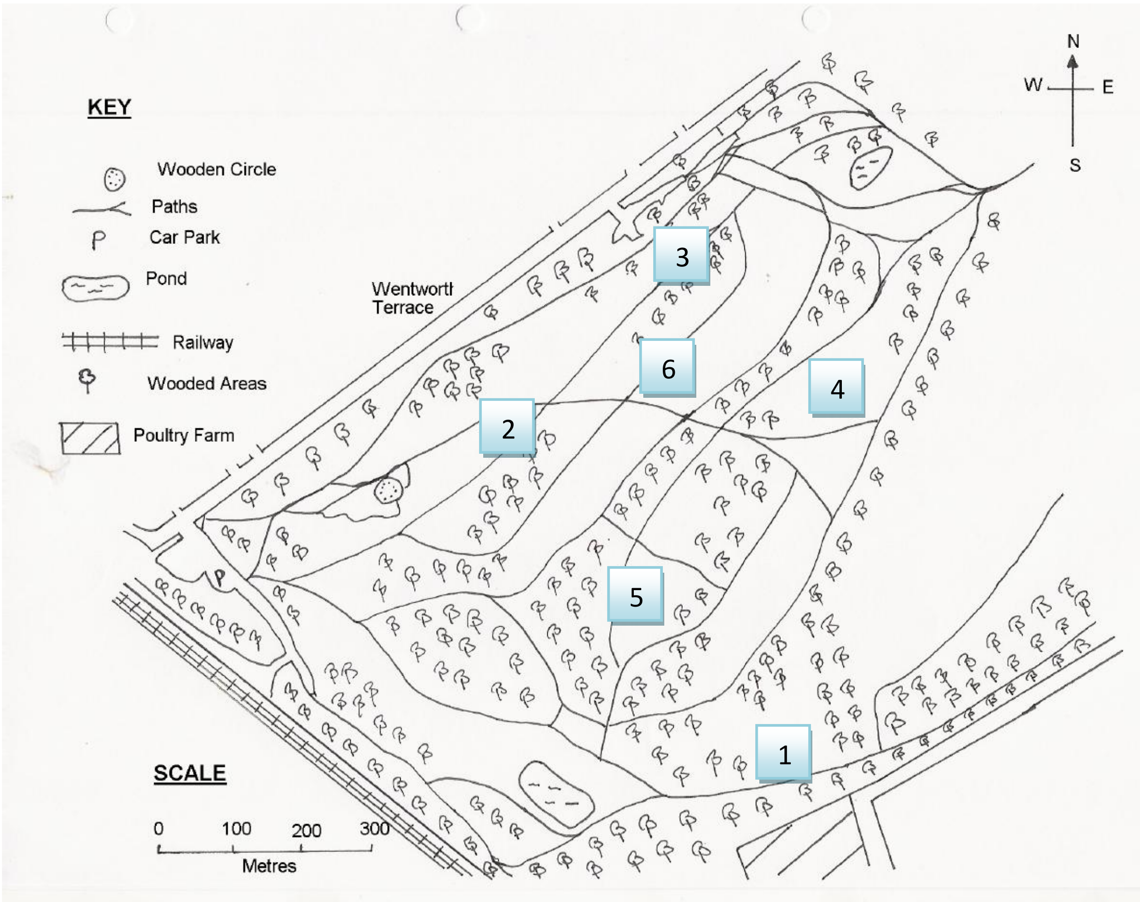


Figure 2.4 Site Map for Fitzwilliam showing sampling locations: 1

Soil samples were taken by means of a graduated bulb planter at 5-10 cm depth. Three samples were taken from each quadrat and mixed to give a representative sample. By using the bulb planter, the top 5 cm could be replaced, so minimising disturbance to the site, both to the vegetation but also visually. The samples were placed into sealable polythene bags and labelled appropriately. In order to maintain environmental conditions as close as possible to when the soil samples were collected, they were placed in a cool box for transporting. Soil sampling took place on the 15th and 18th November 2010 at Fitzwilliam and on the 23rd and 25th November 2010 at Upton.

In order to develop links with the local communities at both Upton and Fitzwilliam, Participatory Geographical Information Systems (PGIS) workshops were set up on site and also inside in the library at Upton and the Working Men's Club at Fitzwilliam, where members of the local community could indicate on maps the areas of the site they used the most and why. They also could indicate which areas they didn't use and why. They also were able to help produce a timeline (Figures 4.1a and b) for each site by historic mapping (Figures 4.2 and 4.3), which was very helpful in establishing sequences of events that had happened to each site.

2.2 Sample Analysis

2.2.1 pH

Immediately on return to the laboratory, the samples from each quadrat were de-stoned, de-rooted and homogenised. Sub-samples were then taken immediately for pH measurement on the basis of 10 ml of moist soil to which 20 ml of deionised water was added in a glass jar. A ThermoOrion Model 420 pH meter was used. The bulk soil samples were immediately placed back in the cool box and stored overnight outside in a secure area to maintain similar environmental conditions to their original locations.

2.2.2 Ammonium-N and Nitrate-N

On the next morning, the bulk samples were spread out on glazed paper and then about 10 g homogenised sub-samples were taken and placed in 250 ml flasks to which 50 ml of 0.5 M KCl was added, and then hand-shaken intermittently for 1 hour. The extract was filtered (Whatman No 42 filter paper) and then transferred to sealed glass vials and placed in a fridge at 4^{o}C for storage. Triplicate blanks of 50 ml KCl were also filtered and stored.

Ammonium nitrate standards in KCl at 2.0 ppm, 1.5 ppm, 1.0 ppm, 0.5 ppm and 0.0 ppm were made up in 100 ml volumetric flasks.

The extracts were then run through the Auto-Analyser – a Bran+Lubbe AA3 Digital Colorimeter on 30/11/2010. For nitrate-N, nitrate in the sample is reduced to nitrite by hydrazine reduction using a copper catalyst, reacted with sulphanilamide and NEDD (N-1-Naphthylethylene diamine dihydrochloride) to form a pink compound measured at 520 nm. For ammonium-N, salicylate and dichloro-isocyanuric acid are the reactants used to produce a blue compound measured at 660 nm, with nitroprusside as a catalyst.

2.2.3 Soil Moisture

The bulk samples on the glazed paper were then air dried for four days and then 10 g sub-samples of the thoroughly mixed air dried soil were weighed to ± 0.001 g into foil dishes before placing in an oven and drying overnight at 105°C. (The remainder of the bulk soil samples were then stored in clean labelled polythene bags). The oven-dried samples were reweighed to allow the moisture percentage of the air dried soil to be calculated.

The oven- dried samples were then transferred to sealed glass vials before grinding with a Retsch MM200 vibratory ball mill for 2.5 minutes at 25 Hz. The ground samples were then put back into the vials for storage.

2.2.4 Carbon: Nitrogen Ratio

To obtain the C:N Ratio, 100 mg of the finely ground dry soil was weighed to ± 0.0001 g on a pre-cut sheet of tin foil for placing in the Elementar Vario Macro C:N

Analyser. Glutamic Acid was weighed out in the same way to provide standards for calibration and drift compensation on the analyser (Courtney & Trudgill, 1976; Briggs, 1977). The samples from Fitzwilliam were run on 07/12/2010 and for Upton on 08/12/2010.

2.2.5 Heavy Metals: Lead and Zinc

As both sites had colliery waste tips derived from the Coal Measure shales and sandstones (Goossens & Smith, 1973; Lake, 1999), and the clay dressing was derived (at least in part) from the Permian limestones known to contain pockets of galena (PbS) and sphalerite (ZnS) (Lake, 1999), it was suspected that there could be higher than normal levels of these metals. Also, as the composition of the railway ballast in the cutting at Upton was an unknown, this could also be a potential source.

To find the concentrations of lead and zinc, the ground samples were digested with 70% concentrated nitric acid (Harrison & Laxen, 1976) in a fume cupboard, before analysis by atomic absorption spectrometry (AAS) using an air-acetylene flame. Approximately 3 g of the finely ground oven dry soil was weighed to ± 0.001 g and placed in a Pyrex tube, to which 10 ml of trace element Standard, 70% concentrated nitric acid was slowly added in two 5 ml amounts using a calibrated Gilson pipette in order to avoid a too violent reaction and so potential loss of digest. The cold digests then had marbles placed on top of the tubes to act as a valve, and, when seen to be stable, were placed in a heater block, along with duplicate acid blanks and left in the fume cupboard overnight, with the extractor fan running. The next morning, the heater blocks were switched on, the tubes given a careful shake, and the heating raised in stages up to 130°C over about 2 hours and then kept at that temperature for over an hour until the reaction had ceased. This was determined by the liquid turning a deep orange colour indicating that all traces of organic material had disappeared. Also, the condensate in the upper part of the tubes had become clear, and no more fumes were observed. The tubes were then transferred to a metal rack and allowed to cool down for about 10 minutes before adding 20 ml of deionised water. The digests were then filtered

(Whatman No 42 filter paper) into 100 ml volumetric flasks and deionised washings used to make up to 100 ml. Each stoppered flask was then shaken and its contents transferred to 125 ml polythene bottles for storage.

Sub-samples of the digest were then transferred to the auto sampler (ASC-6100) of a Shimadzu AA-6300 Atomic Absorption Spectrometer (AAS) after appropriate dilution (Alloway & Ayres, 1997). The prepared samples, at 1:400 dilutions, were then analysed by AAS using matrix-matched standards. The standards were prepared after carefully calibrating the Gilson pipettes and trial runs where made in order to assess the dilution levels necessary. For lead, standards were prepared at 0.00, 0.25, 0.50, 1.00 1.50, 2.50, 5.00 and 10.00 µg ml^{-1}, and for zinc at 0.00, 0.25, 0.50, 1.00, 1.50, 2.50 and 3.00 µg ml^{-1}. The samples were run as follows: zinc for the Fitzwilliam batch on 13/01/2011, with lead on the 14/01/2011. The Upton samples for lead were run on 17/01/2011. However, due to gas bottle supply problems, the zinc run for Upton was unable to be run until 07/03/2011. An excellent set of calibration graphs with an r^2 of 0.9999 or better, were produced. To check for drift, compensating standards were run every 10th sample, but the amount of drift observed was so small that corrections were not needed. Results from the AAS were given in ppm and so the following calculation, based on the dilution factor, was applied in order to convert to mg per kg^{-1}: ((400*ppm)/g weight of dry soil). This was applicable to both the lead and the zinc results, with the exception of sample 6c from Upton, which had to have a further 5-fold dilution and run again for zinc. The calculation for this sample was: ((2000*ppm)/g weight of dry soil).

2.2.6 Calcium and Magnesium

Calcium and magnesium are both important plant nutrients and, as the clay used in the restoration of both sites is derived from on, or near, the Permian limestone, and as the limestone is found in the south-eastern part of the Upton site (Lake,1999), it was suspected that Ca/Mg levels would be high. This meant that a trial run was necessary in order to ascertain suitable dilution levels. This was done on 15/03/2011 and showed that the levels were even higher than first thought. The resulting method followed: 0.5 ml of the 70% HNO_3 digest was made up to 100

ml, giving a 200 times dilution. 5 ml of lanthanum chloride (10,000 ppm solution) was added to 5 ml of the 200-fold diluted digest for analysis. The lanthanum chloride acts as a releasing agent from any aluminium in the soil.
Standards were made up in deionised water for calcium and magnesium separately, and then combined by taking 10 ml of each, and making up to 100 ml in volumetric flasks before adding lanthanum chloride on a 1:1 basis. As these were matrix matched standards, drift compensation was set at flask 5 (Ca 6.00 ppm; Mg 1.00 ppm), and run every 10th sample. The standards were as set out in Figure 2.6. The dilution factor was therefore 20,000

Table 2.3 Calibration Standards for Calcium and Magnesium.

Flask	Calcium (ppm)	Magnesium (ppm)	
1	0.00	0.00	
2	1.00	0.25	
3	2.00	0.5	
4	4.00	0.75	
5	6.00	1.00	Drift
6	8.00	1.25	
7	10.00	1.50	

The samples were run on 22/03/2011, with good calibration curves of $r^2 = 0.9997$ for Ca and $r^2 = 0.9996$ for Mg. However, although the calcium levels were within scale, 11 samples from Fitzwilliam and 9 from Upton were too high for magnesium and so were given a further 5-fold dilution, giving a dilution factor of 100,000, and rerun. The calibration curve was $r^2 = 0.9991$.

2.2.7 Phosphorus

Phosphorus is an important plant nutrient, although available phosphorus as phosphate is relatively immobile in most soils (Marr & Cresser, 1983). Phosphorus deficiency is often a key factor on calcareous soils, and also, the level of phosphorus can affect zinc availability. As the soil samples from both Fitzwilliam and Upton are primarily calcareous, with a pH range from 6.68 to 8.57, the most appropriate method to use was one based on the Olsen sodium bicarbonate method, which was developed specifically for alkaline soils (Frank et al., 1998; Bitcon, 2011).However, because some soils can have high levels of organic matter and therefore dark coloured extracts, which can interfere with the subsequent colorimetric analysis, Polyacrylamide was used instead of Darco G60 carbon for decolourising the soil extracts (Banderis, et al., 1976).

Two sets of process are involved; a), a calibration phase; and b), an extraction from the soil. These involve making up four stock reagent solutions, as follows:

1) Olsen Extracting Fluid (0.5 M $NaHCO_3$, pH 8.5).

210.0 g of analytical grade $NaHCO_3$ was weighed using a plastic boat and then transferred slowly to a 1 L volumetric flask containing 850 ml of deionised water, and then placed on a magnetic stirrer until completely dissolved. The solution was then transferred to a 5 L flask. In the fume cupboard, 25 ml 0.05% aqueous polyacrylamide was added and then the pH was adjusted to 8.5 by the addition of 50% (w/w) NaOH solution, and deionised water added to make up to 5 L.

2) Acid Molybdate Stock Solution.

In the fume cupboard, a 5M sulphuric acid solution was prepared and then transferred to a 1 L volumetric flask, to which antimony potassium tartrate solution and ammonium molybdate solution

were added and made up to 1 L and stored in the fridge.

3) Olsen Colour Development Reagent.

This will not keep longer than 24 hours, so needed to be made up the same day as the analysis. 10.556 g of ascorbic acid (to the nearest 0.1 g) was weighed out and dissolved in 2 L of the Acid Molybdate solution.

4) Phosphorus Standard stock solution.

This will keep stable for up to 6 months if kept in a fridge. It was prepared by drying approximately 0.5 g of monobasic potassium phosphate (KH_2PO_4) in an oven at 100°C for 15 minutes, cooling in a dessicator and then weighing 0.2197 g (to the nearest 0.1 g) and dissolving in 50 ml of deionised water, before making it up to 1 L.

The Phosphorus Standard stock Solution was then diluted with the Olsen Extracting Fluid to prepare the working standard solutions for the calibration curve, as shown in Table 2.3 below. 20 ml of each working standard was pipetted into a 100 ml volumetric flask. Then, 5 ml of Olsen Colour Development reagent was added slowly (being aware that the reaction vigorously generates a large amount of CO_2 gas!), followed by a further 15 ml (20 ml in all).The solution was made up to 100 ml with deionised water and allowed to stand for about 20 minutes for colour development. The samples were run on 23/02/2011.

Table 2.4 Phosphorus Standards dilution Table.

Volume of 50 ppm P Stock Solution (ml)	Final volume (ml)	Final concentration after further 5-fold dilution (ppm P)
0	100	0.0
1	250	0.05
1	100	0.1
2	100	0.2
5	100	0.5
10	100	1.0
20	100	2.0
30	100	3.0

Within two hours the standards were placed in cuvettes and run through a Perkin Elmer Lambda 25 UV/VIS Spectrometer and the absorbance read at 880 nm. A calibration curve was then produced by plotting known concentration v absorbance. This gave an $r^2 = 0.996$. The analysis procedure involved weighing between 1.5 – 2.0 g of finely ground soil, and transferring to a 250 ml Erlenmeyer flask, to which was added 40 ml of the Olsen Extracting Fluid, and swirled to mix. The flasks were then capped and secured on a mechanical shaker for 30 minutes. They were then removed and the contents filtered through Whatman No 42 filter paper. A 20 ml aliquot was then transferred to a fresh 100 ml volumetric flask and diluted to 100 ml with deionised water. Then, as for the standards, 20 ml of Olsen Colour Development Reagent was added in two stages, starting with 5 ml being added slowly because of the violent reaction, and then 15 ml after. Again, the solutions were allowed to stand for about 20 minutes to allow for colour development and within 2 hours the absorbance was measured at 880 nm, and the phosphorus concentration determined from the calibration curve. The soil phosphorus concentration was then determined according to the following calculation:

Phosphorus Concentration in the Soil (µg P/ g of soil)

= (200 x concentration from calibration graph divided by the Weight of soil)

= 200 x concentration/1.5 µg of soil.

2.3 Data Processing and Statistical Analysis

The raw plant data was first entered into EXCEL and then a working spreadsheet based on the Domin Scale was produced in a form that could then be input for analysis using DECORANA (Detrended Correspondence Analysis), within the PICES software package CAP (Community Analysis Package). DECORANA (DCA) facilitates the determination of environmental gradients influencing plant distribution and ordinates the samples (or quadrats in this instance) and species so that similar entities are located close together and dissimilar ones far apart (Jenson, 1990). The underlying environmental gradients are represented as axes in the ordination plot and the amount of variability in the data accounted for by that axis is given as an eigenvalue.

The related technique of TWINSPAN (Two-Way Indicator Species Analysis) was used to show the dominant indicator species in the samples and the significant groupings by level. These results are presented in the form of dendograms.

The axes data produced in DCA were then added to the soil data and input into the statistical package SPSS. Bi-variate correlations between the environmental variables (including bare earth and rabbit droppings) and the axes were explored using Pearson's r and results at $P<0.01$ and $P<0.05$ significance levels were tabulated and the significant correlations examined further by means of scatterplots. The R^2 value produced gives the amount of total variance explained in terms of the size of the correlation coefficient and the amount of shared variance.

For the soil moisture content, both dry weight and wet weight calculations were made, but because the relationship between percentage moisture content and the volume of the soil is not constant with the wet weight calculation, the dry weight percentage has been used because it avoids this problem (Briggs, 1977).

For site comparison purposes, and to reduce the effect of outliers (which could be due to errors), the plant and environmental data were re-tabulated as means, median and range for each sampling area.

The number of species per quadrat was input into excel, the data sorted by order smallest to largest, and a scattergraph produced to show species richness. The mean number of species for each area was calculated and then graphed.

To see how the two sites fitted in to both the National Vegetation Classification (NVC) and the Countryside Vegetation System classification (CVS), the plant data was fed into the MAVIS (Modular Analysis of Vegetation and Interpretation System) software produced for the Centre for Ecology and Hydrology (Bunce et al., 1997). For clarification, the NVC Users' handbook (Rodwell, 2006) was used alongside Plant Communities Volume 3 (Rodwell, 1992) and Volume 5 (Rodwell, 2000).
MAVIS also allows a characterisation of each area to be made in terms of the degree of competition (C), stress (S) and disturbance (R) (Grime, 1977). The indices that were produced were then percentaged and entered into Trigraph (Software for Ecologists produced by the School of GeoSciences at the University of Edinburgh) for mapping into the relevant fields of the CSR triangular graph.

CHAPTER 3 RESULTS

3.1 Soil variables – Upton

For Upton soil data refer to Appendix Table 6, and for Fitzwilliam, Appendix Table 7. For mean, median and ranges refer to Appendix Table 8.

3.1.1 pH Upton

Two quadrats for Area 1 (1d: 6.68 & 1b: 6.7) show the lowest pH readings for the site, yet quadrat 1c gave a reading of 7.66 (Figure 3.1). This area is on the northern slope down to the angling pond, which had been excavated down to the sandstone bedrock found in that area. The area around the pond was given a clay covering. pH readings for the water entering the angling pond from the Spout Hole Inlet produced an average of pH 8.0 (Appendix Table 5a), whereas the pond itself gave an average reading of between ph 8.3 and 8.5. Quadrats in Areas 3 and 4 also show some variation, with Area 3 ranging from 6.73 to 7.01 and Area 4 ranging from 6.93 to 7.42. The drainage ponds between Areas 3 and 4 gave readings that increased downstream (Appendix Table 5a), going from pH 6.9 to pH 9.2. These areas are in the drainage scrapes and reveal a mixture of clay and colliery waste. Quadrat 2a stands out as having the highest pH – 8.57. Area 2 is on the limestone, and the quadrats in Areas 5 to 8, which are all between pH 7 and 8.5, are in the old railway cutting, which is cut through the limestone.

The pattern becomes clearer in Figure 3.2, which shows the mean pH for each area. The division between the limestone underlying Area 2 and Areas 5 – 8 in the cutting stand out from Areas 1, 3 and 4 which are on the sandstones and shales of the coal measures.

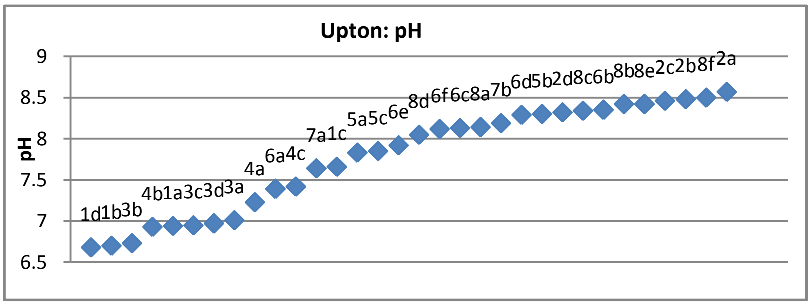


Figure 3.1. pH for each quadrat at Upton.

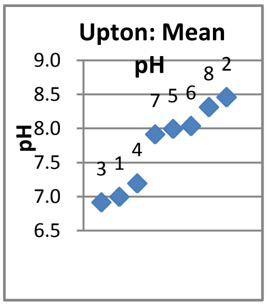
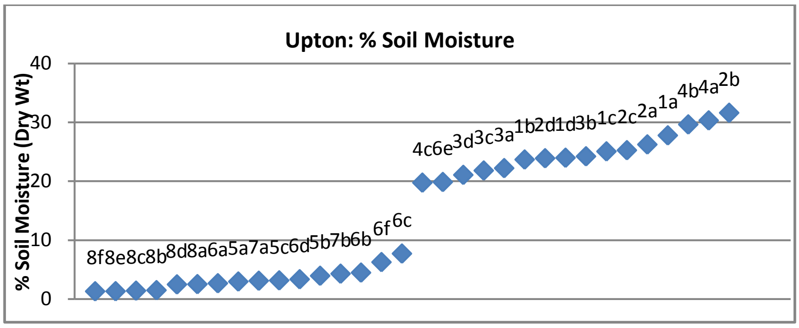


Figure 3.2. Area mean pH for Upton.

3.1.2 Soil Moisture Upton

A clear division between the cutting and the rest of the site stands out in Figure 3.3. The cutting shows low levels of moisture (between 1.32 and 7.72 %) due in the main to the steep or nearly vertical limestone sides, as well as the remaining railway ballast. The rest of the site is in the range 19.75 to 31.61 %. The pattern is again clearer when looking at the mean soil moisture content for each area, as shown in Figure 3.4.

What also is apparent is that whereas Areas 2 and 4 are very similar, although Area 2 is on the thin limestone soil and Area 4 is on the northerly facing slope down off the limestone into the drainage scrape, Area 3 appears different; this is on the south slope of the drainage scrape, with coal measures beneath. This difference could also be partly due to the effect of the Spout Lane Fault, shown on Figure 2.4.



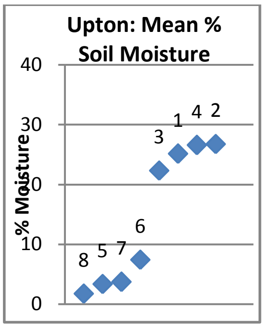


Figure 3.3 % Soil Moisture by quadrat at Upton. Figure 3.4 Upton: Area mean % Soil Moisture.

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3.1.3 Carbon and Nitrogen Upton

From Figure 3.5 two main groups of quadrats present themselves, one in the 0 – 10 % range and the second in the 12 – 20 % range, with 6d (25 %) and 5a (37 %) being the two highest, and above 20 %. Significantly these two quadrats are in the cutting and at the side of the ballast, where there is plant debris/leaf litter accumulation. Figure 3.6 highlights these two groups, with areas 5, 6, and 7 being in the cutting. Area 8 falls within the lower group, although 8a and 8d appear in the upper group for the same reason as 5a and 6d. Together with Area 2, this may be a result of the limestone, with carbon originating from the carbonate ions (CO_3^{--}).

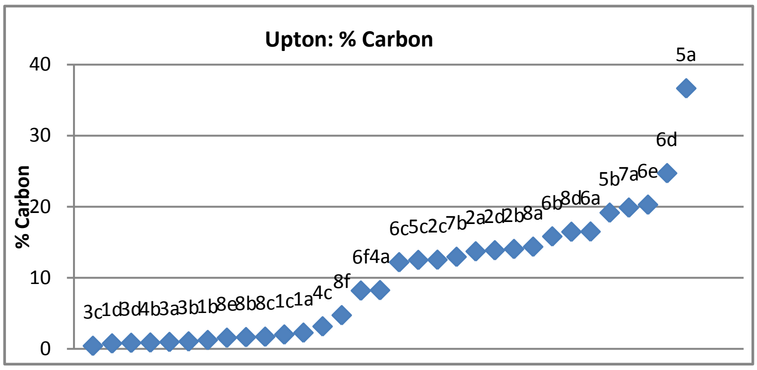


Figure 3.5 % soil carbon by quadrat at Upton.

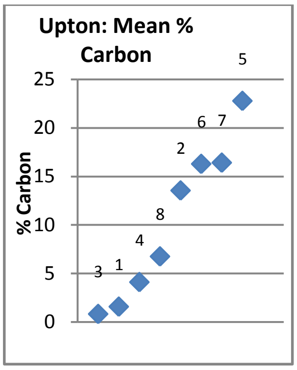


Figure 3.6 Upton: Area Mean soil % carbon.

The pattern with the percentage nitrogen, as shown in Figure 3.7, is similar in appearance to that for carbon seen in Figure 3.5. The higher group (above 0.4 %) are all from the cutting, although, as is clearly seen from Figure 3.8, Area 8 is the exception, apart from quadrat 8a. Area 8 is close to the Spout Lane Fault, which brings the limestone and the coal measures up against each other in the cutting.

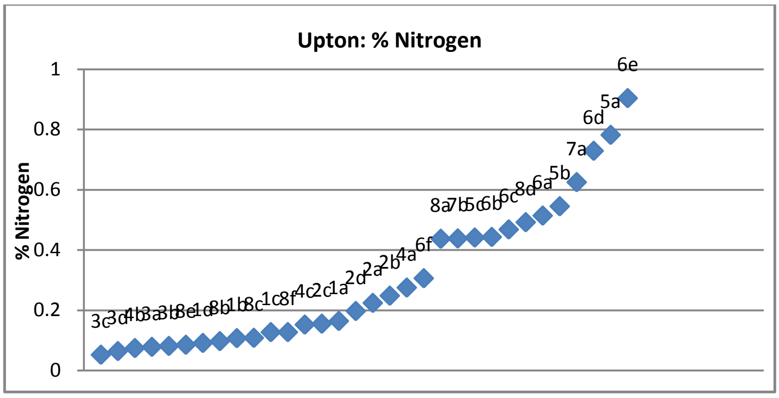


Figure 3.7 % Soil nitrogen by quadrat at Upton.

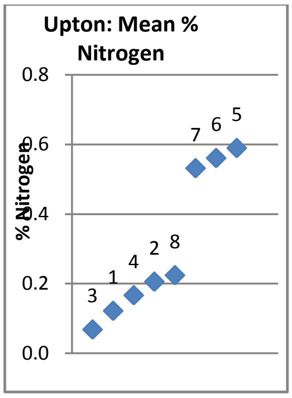


Figure 3.8 Upton: Area Mean soil % nitrogen.

The C: N ratios from Figure 3.9 show a steady progression up to a C: N ratio of 1: 40, then rise sharply up to a C: N of 1: 80 at 2c. The plot of the mean ratios in Figure 3.10 clearly shows that Area 2 is very different from the rest of the site, perhaps reflecting a relatively low level of organic material in the thin limestone soil.

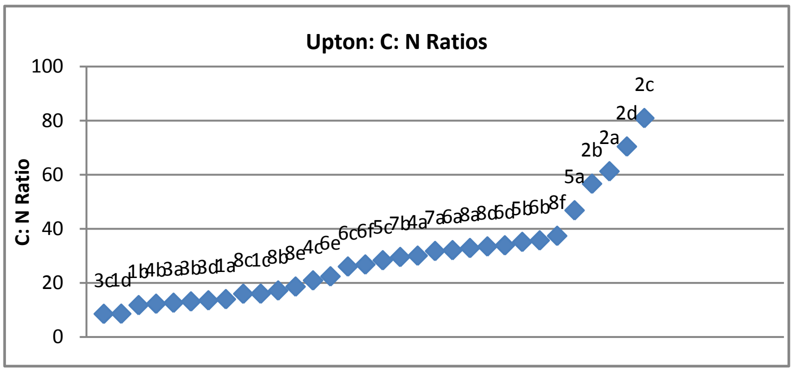


Figure 3.9 C: N ratios of individual quadrats at Upton.

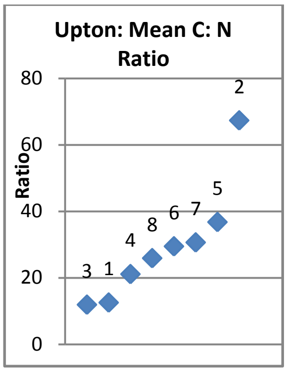


Figure 3.10 Upton: Area Mean C: N ratios.

3.1.4 Ammonium – N and Nitrate – N Upton

Figure 3.11 shows that quadrat 5a has the highest ammonium-N concentration (4.51 µg N kg^{-1} of soil), followed by 2a (3.98 µg N kg^{-1} of soil). Most of the quadrats are in the range 0.6 to 2.8 µg N kg^{-1}. Figure 3.12 shows that the Areas 3 and 4 have the lowest ammonium-N. These are in the scrapes where there is little plant debris and (especially in Area 4) much bare earth still. Areas 5 and 2 are the nearest, and most exposed to, arable land, so windblown deposition could be a factor. For Quadrat 5a, the high level could also be influenced by contamination from the old railway ballast.

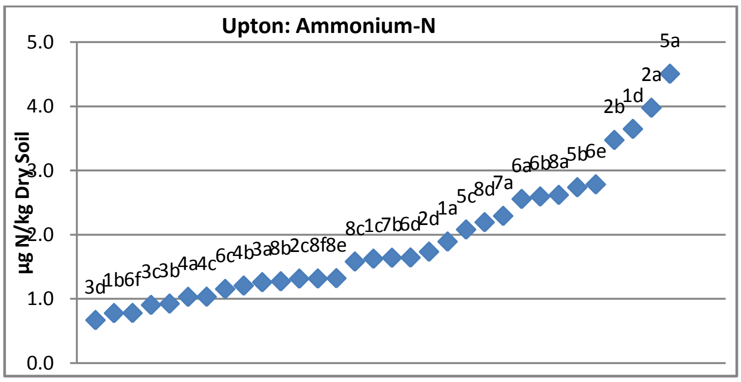


Figure 3.11 Ammonium-N Levels by quadrat at Upton.

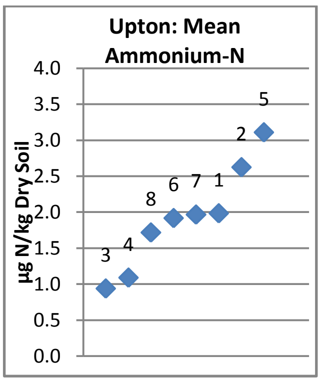
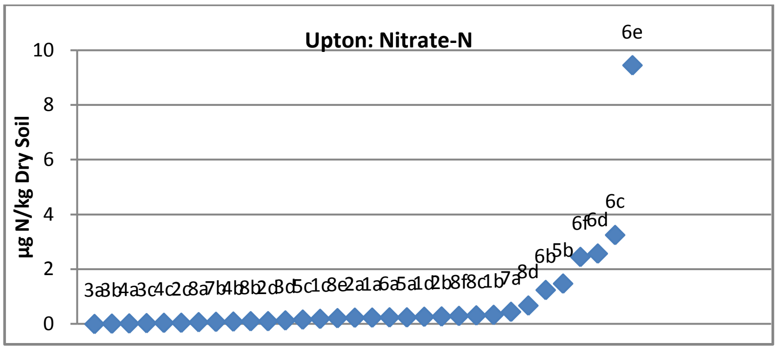


Figure 3.12 Upton: Area Mean NH_4^+-N levels.

As Figure 3.13 indicates nitrate-N levels are generally low (below 0.5 µg N kg^{-1} of soil). Quadrat 3a recorded a value of 0.000 µg/mL, which probably indicates that it was below the detection level of the instrument, giving a figure of 0 µg N kg^{-1} of soil, presumably due to being at the top of the slope into the drainage scrape and leaching had taken place. The mean nitrate-N levels (Figure 3.14) show that Area 6 has a higher concentration of nitrate-N, possibly because it is rich in organic matter in some of the Area 6 quadrats, and significantly quadrats 6d and 6e both had nettles (*Urtica dioica*) growing under the overhanging branches and there was a thick layer of dry leaves. As nitrates are easily leached from soil by rainwater, it is not surprising that Area 6 has the highest nitrate-N level with its overhanging trees/bushes and the general lack of drainage in that part of the cutting.



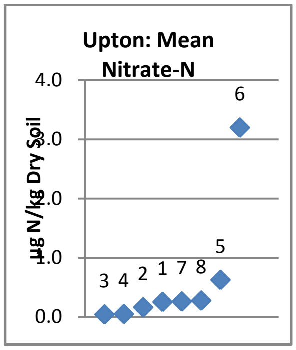
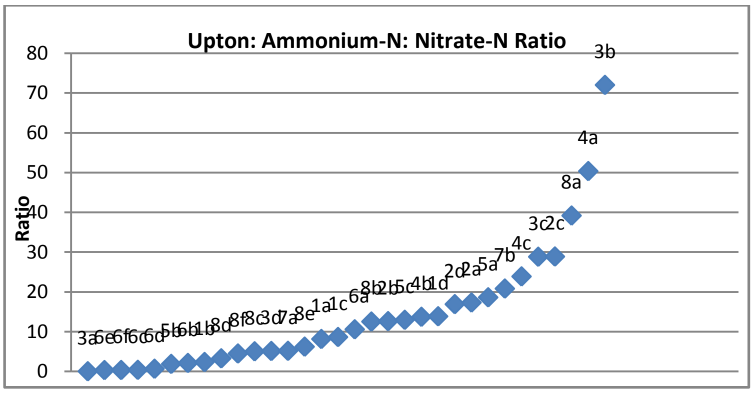


Figure 3.13 Soil nitrate-N Levels by quadrat at Upton. Figure 3.14 Upton: Area Mean NO_3^--N Levels.

The ammonium-N: nitrate-N ratios (Figure 3.15) indicate that quadrats 3b (1: 72) and 4a (1: 50), which are in the drainage scrapes, have the highest ratios followed by 8a (1: 39), which is in the cutting. Apart from quadrat 3a, which is distorted by being below the detection limit for nitrate-N, quadrats 6c, d, e, and f give the lowest ratios (all below 1). The mean ratios (Figure 3.16) reflect this with Area 6 having the lowest ratio, and Areas 3 and 4 the highest.



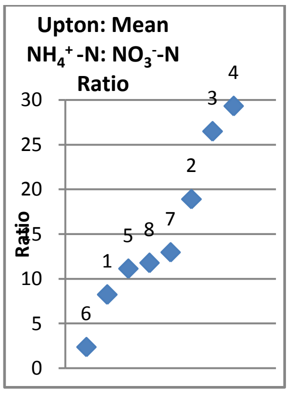
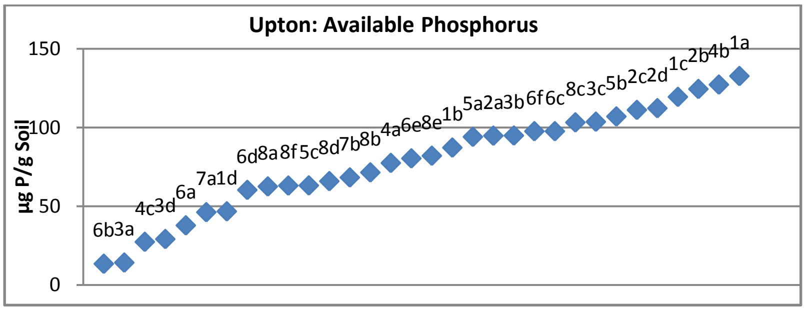


Figure 3.15 NH_4^+-N: NO_3^--N by quadrat at Upton. Figure 3.16 Upton: Area Mean NH_4^+-N: NO_3^--N.

3.1.5 Phosphorus Levels Upton

Phosphorus levels by quadrat (Figure 3.17) range from 13 to 133 µg g^{-1} of soil. The means, however give a much clearer picture (Figure 3.18), with Areas 6, 7, and 3 having the lowest values (under 60 µg g^{-1} of soil) and Area 2 the highest with a mean value of 111 µg g^{-1} of soil. Area 2 also had the highest mean pH at 8.46 (Figure 3.2), and phosphorus, as phosphate, combines readily with calcium in alkaline soils (Bradshaw, 1980), producing insoluble compounds.



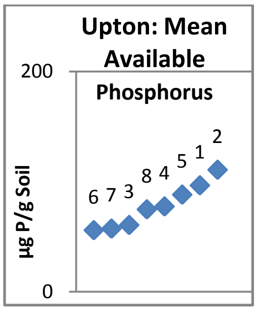
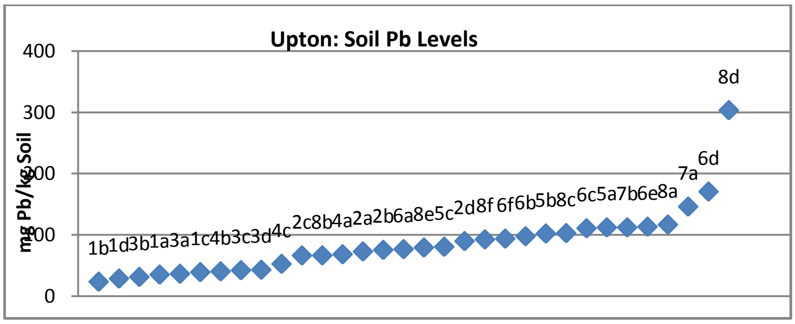


Figure 3.17 Plant available P by quadrat at Upton.

Figure 3.18 Upton: Area Mean plant available P.

3.1.6 Lead levels Upton

Lead levels generally range up to about 120 mg kg^{-1} of soil (Figure 3.19), the highest concentration being in quadrat 8d (303.76 mg kg^{-1} of soil) .It is likely that highest lead levels would be found in the cutting, resulting from contamination from the railway ballast, and Figure 3.20 seems to confirm that. However, other sources could be the coal mine waste and the limestone itself (Harwood & Smith, 1986).



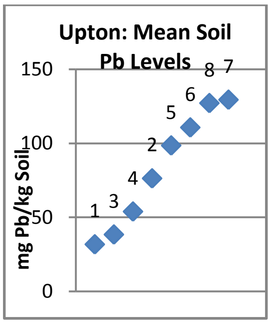
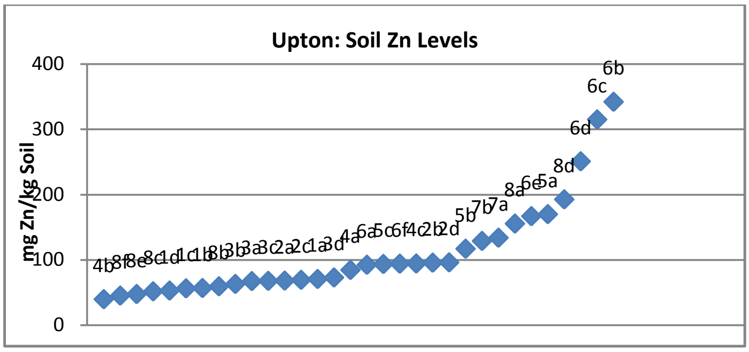


Figure 3.19 Soil Pb levels by quadrat at Upton.

Figure 3.20 Upton: Area Mean soil Pb levels.

3.1.7 Zinc levels Upton

The pattern for zinc in Figure 3.21 is similar to that of lead, with most quadrats recording concentrations lower than 200 mg kg^{-1} of soil. The highest concentration is in quadrat 6b (341.92 mg kg^{-1} of soil). As with lead, the mean zinc levels (Figure 3.22) show Area 6 as the highest, and the railway cutting again has high levels, presumably for the same reasons. Away from the limestone, the levels are generally lower.



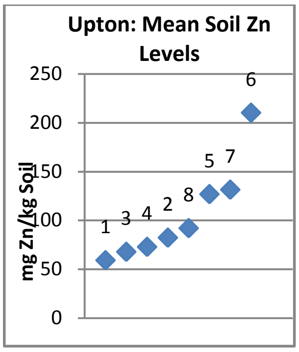
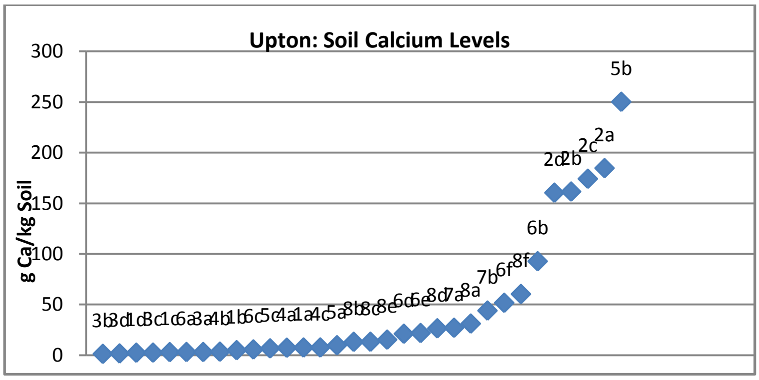


Figure 3.21 Soil Zn Levels by quadrat at Upton.

Figure 3.22 Upton: Area Mean soil Zn levels.

3.1.8 Calcium and Magnesium Levels Upton

Figure 3.23 shows that, with the exception of quadrat 5b (with 30 % bare rock in the quadrat), quadrats from Area 2 have the highest level of calcium in the soil. As these are on the limestone, this is not surprising. Likewise, the soils in the cutting also reflect this, although the ballast would be expected to produce lower concentrations. Figure 3.24 shows a clear distinction between these areas (Areas 6, 7 and 8) and those not on the limestone (Areas 1, 3 and 4).



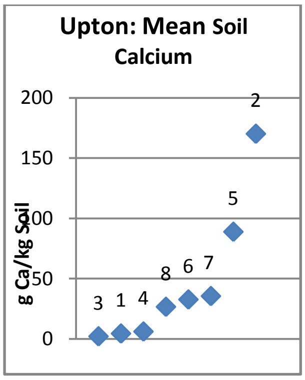
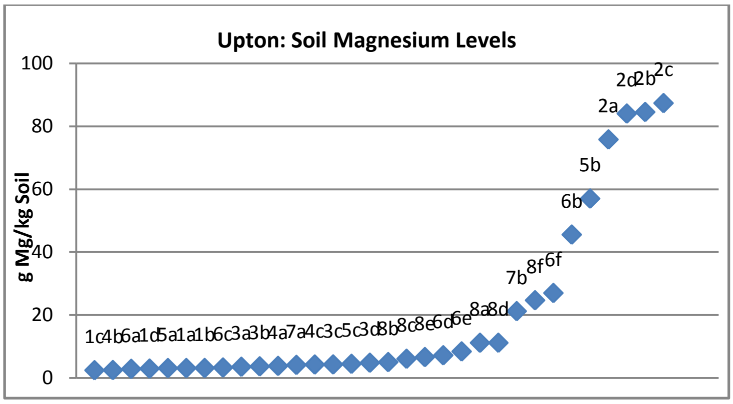


Figure 3.23 Soil Ca levels by quadrat at Upton.

Figure 3.24 Upton: Area Mean soil Ca levels.

Figure 3.25 shows a similar pattern to calcium, with the quadrats in Area 2 having the highest levels of magnesium, between 75 and 87 g kg^{-1} of soil. This is also obvious in Figure 3.26, where the areas in the cutting form a distinct group. The high levels for magnesium are simply explained by the fact that the limestones are dolomitic, that is, they are magnesium rich.

The quadrats from Areas 1, 3 and 4 have low levels of magnesium, generally below 5 g kg^{-1} of soil. These areas are on the coal measures.



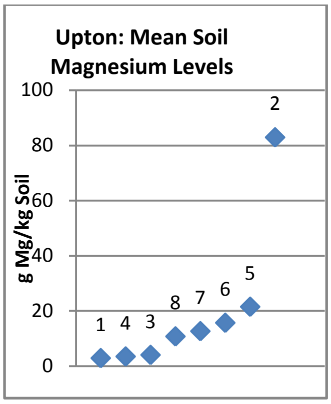
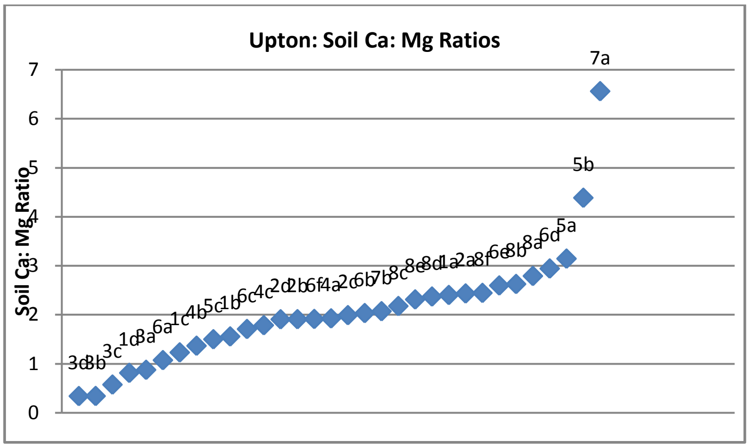


Figure 3.25 Soil Mg levels by quadrat at Upton.

Figure 3.26 Upton: Area Mean soil Mg levels.

The calcium: magnesium ratios shown in Figure 3.27 show quadrat 7a to have the highest ratio at almost 7 :1, and quadrats 3b and 3d having the lowest (0.34), with the means (Figure 3.28) highlighting variability between the areas in the cutting.



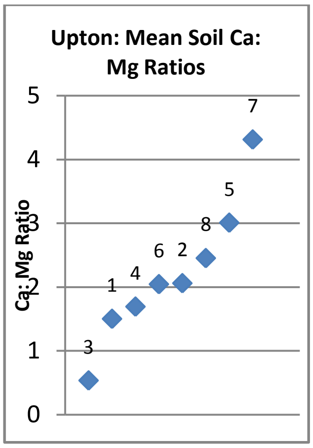


Figure 3.27 Soil Ca: Mg ratios by quadrat at Upton.

Figure 3.28 Upton: Area Mean soil Ca: Mg.

3.2 Soil variables Fitzwilliam

Whereas the Upton site has an underlying geology of both coal measures and limestone, Fitzwilliam is entirely on coal measures. Also, Upton was never completely covered in colliery mine waste, whereas the whole Fitzwilliam site was covered. These factors, if significant, should show up in the soil data.

3.2.1 pH Fitzwilliam

Figure 3.29 shows most quadrats recording a pH between 7.6 and 8.0. For the site of an old colliery waste heap this may seem unusual, as colliery waste usually has a large amount of decomposing iron pyrites from the shales, resulting in acidic conditions, yet all measurements are neutral to alkaline. Figure 3.30 shows Areas 1 and 3 as the lowest at pH 7.57. Area 1 is on a slope and appears to be on colliery waste, and may be affected by rainwater draining down the slope. Most of the site is fairly level with no obvious differences to explain the variation in pH. pH levels at Fitzwilliam not only occur over a narrower range (7.2 – 8.28) than at Upton (6.68 – 8.57), but fall within in that range.

The marshy pond to the north-east of Area 3 (See Figure 2.6) gave an average pH value of 6.9 (Appendix Table 5b). The Anglers pond gave a pH of between 7.3 and 7.6 Appendix Table 5b), also well within the Upton range of 6.9 – 9.2.

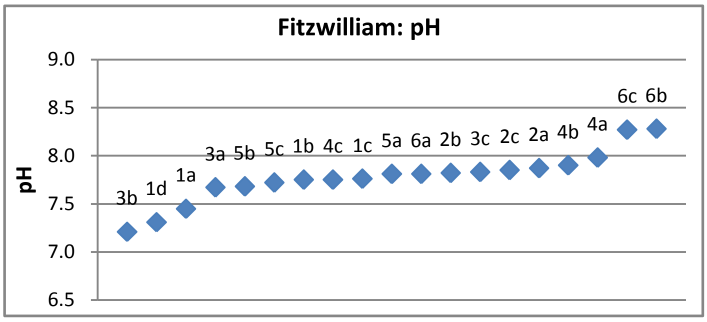


Figure 3.29 Soil pH by quadrat at Fitzwilliam.

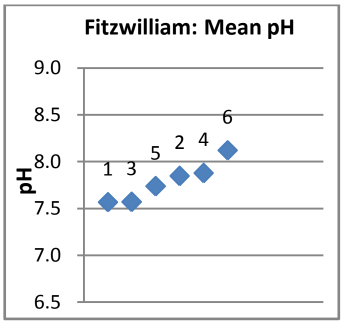
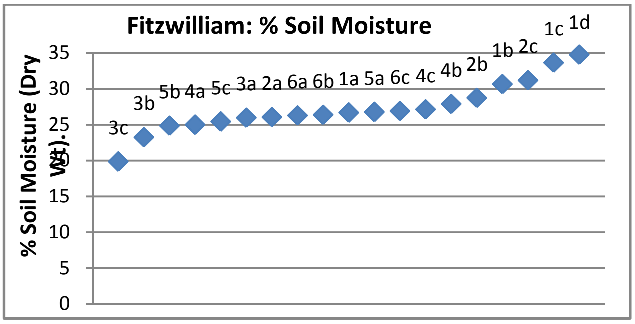


Figure 3.30 Fitzwilliam: Area Mean soil pH.

3.2.2 Soil Moisture Properties Fitzwilliam

As Figure 3.31 illustrates, the majority of the quadrats have soil moisture content between 25 and 30 %. Quadrat 3c is the lowest at 19.8% and 1d highest at 34.8%. The area mean data in Figure 3.32 clearly indicate that Area 1 has the overall higher soil moisture percentage (31.4%). This could be due to the fact that Area 1 is on unconsolidated colliery waste and on a slope, whereas Area 3, which has the lowest mean value (23.02%), is a level area. The soil appears more compacted in Area 3, and was observed to dry out on the surface very quickly. The range of soil moisture values is very similar to those in Areas 1 – 4 on the Upton site (excluding the cutting).



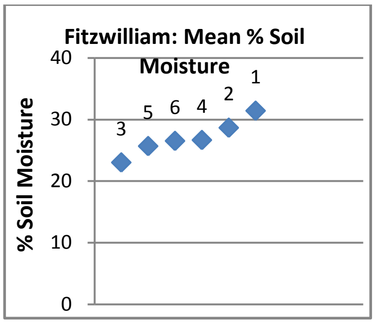
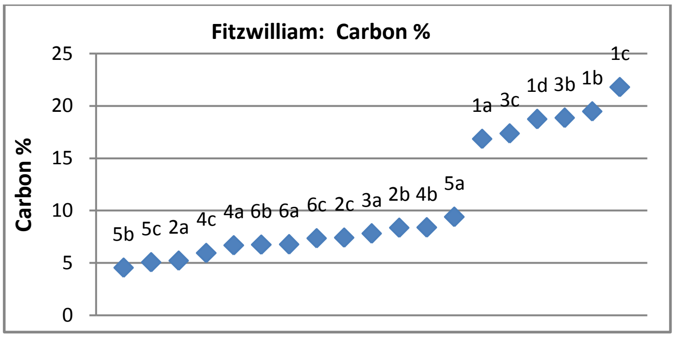


Figure 3.31 % Soil Moisture by quadrat at Fitzwilliam. Figure 3.32 Fitzwilliam: Area Mean % Soil Moisture.

3.2.3 Carbon and Nitrogen : Fitzwilliam

As is often typical of colliery sites, there is a general lack of organic material (Bradshaw,1980), and this is clearly reflected in the carbon content of quadrats from areas 2, 4, 5, and 6, which range from 4.6% in quadrat 5b, to 9.4% in quadrat 5a (figure 3.33). Quadrats in areas 3 and 1 form a separate group, having a much higher carbon content, with 1c having the highest at 21.8 %. The range for % carbon is well within that for Upton, with the higher mean values of Areas 1 and 3 being comparable to those in the cutting at Upton. The area means (Figure 3.34) show that Area 1 stands out, with a mean value of 19.2 %. Area 1 noticeably had more plant debris, possibly reflecting the rather tussocky grasses that dominated the area, particularly *Festuca ovina, Arrhenatherum elatius and Holcus lanatus.*



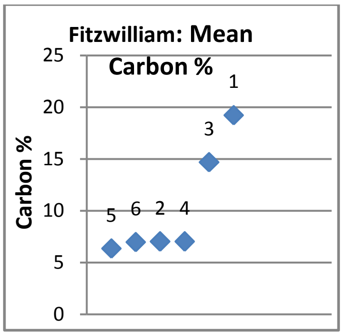
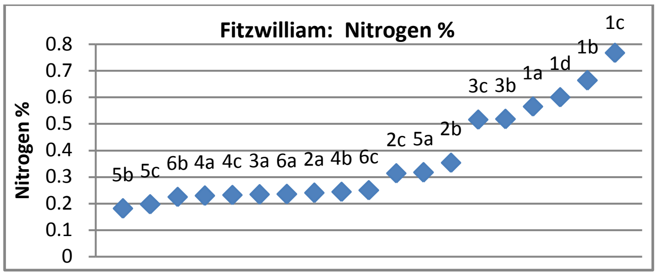


Figure 3.33 % soil C by quadrat at Fitzwilliam. Figure 3.34 Fitzwilliam: Area Mean Soil % C.

The pattern shown in both Figure 3.35 and 3.36 is very similar to that for the percentage carbon, but the percentage nitrogen values are very low, ranging from 0.18 % in quadrat 5c to 0.77 % in quadrat 1c.This is within the range observed at Upton (0.05 – 0.90). Area 1 again has the highest mean value (0.65 %). A lack of organic matter would seem to be the reason for the low values.



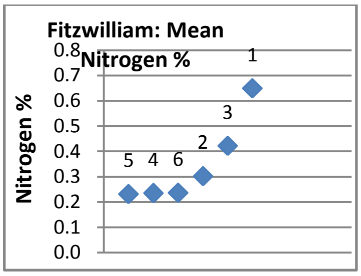
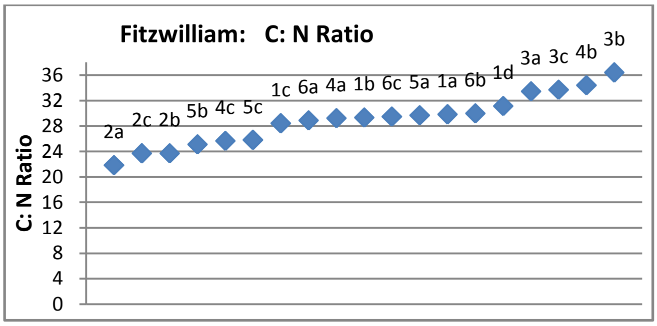


Figure 3.35 % soil N by quadrat at Fitzwilliam. Figure 3.36 Fitzwilliam: Area Mean soil % N.

When the C: N ratios are examined, (Figure 3.37), it is immediately apparent that the range is quite narrow, ranging from 21.8 at quadrat 2a, to 36.4 at quadrat 3b. This is well within the range of values at Upton, although the Upton values range much further at the upper end, but the means are much closer to those for Upton. Figure 3.38 highlights Area 2 as having the lowest mean ratio at 23.1 and Area 3 having the highest at 34.5. This further emphasises the generally low levels of organic matter on this site.



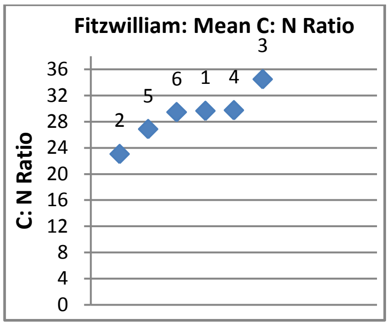
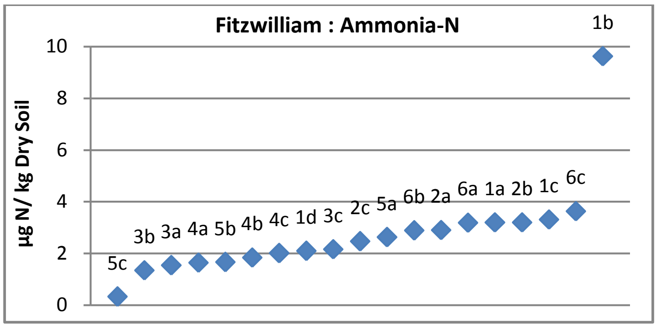


Figure 3.37 C: N by quadrat for Fitzwilliam. Figure 3.38 Fitzwilliam: Area Mean C: N.

3.2.4 Ammonium-N and Nitrate-N Fitzwilliam

Levels of ammonium-N are fairly consistent across the site (Figure 3.39), generally ranging between 1 and 4 µg N kg^{-1} of soil, with the major exception of quadrat 1b which had 9.64 µg N kg^{-1} of soil. The significance of this is that quadrat 1b is possibly exposed to deposition from the intensive poultry unit just below the area, as shown on Figure 2.6. When the wind is from the SW, the smell is very pronounced. The trees to the south of Area 1 probably intercept most of this deposition as they are between 5 and 10 m above the poultry unit, so quadrat 1a (3.2 µg N kg^{-1} of soil) could be in a shadow zone, with the main deposition concentrated at quadrat 1b. Quadrat 1c gives a similar, but slightly higher value (3.32^{-1} µg N kg^{-1} of soil) as 1a. Quadrat 1d, being at the top of the slope and also further away from the source, has a lower level of 2.1 µg N kg^{-1} of soil. The plot of the mean values (Figure 3.40) shows Areas 6 and 2 as having around the 3 µg N kg^{-1} of soil. These two areas are both quite open, whereas Areas 5, 3 and 4 are perhaps more sheltered by trees. Compared to Upton, and leaving out the outlier of 1b, the range of values at Fitzwilliam is comparable although a bit higher.



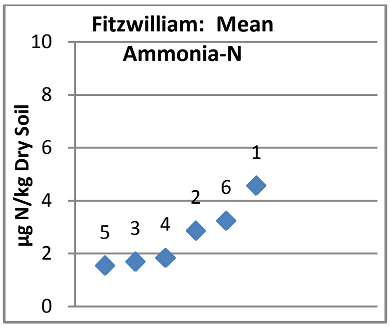
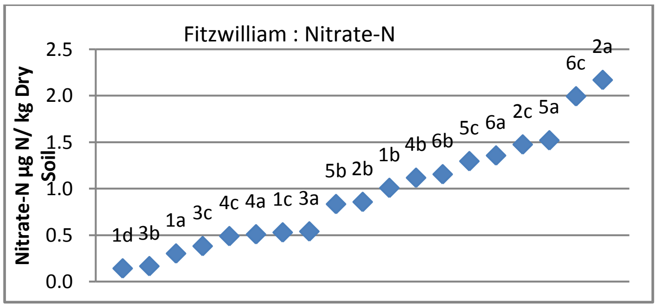


Figure 3.39 NH_4^--N levels by quadrat at Fitzwilliam. Figure 3.40 Fitzwilliam: Area Mean soil NH_4^+-N.

Figure 3.41 shows a range in nitrate-N values from 0.14 µg N kg^{-1} of soil at quadrat 1d, to 2.17 µg N kg^{-1} of soil at quadrat 2a. The generally low values for quadrats 1a, 1c, and 1d suggest that, perhaps as a result of being on a free draining slope, leaching may be taking place. Quadrats in Areas 2 and 6 stand out in Figure 3.41 and Figure 3.42, with the highest mean values at 1.5 µg N kg^{-1} of soil, and with Area 5 close at 1.22 µg N kg^{-1} of soil. Although similar in range to Upton, Nitrate-N levels at Fitzwilliam are slightly higher, with the exception of Area 6 at Upton, where there is quite an accumulation of leaf litter.



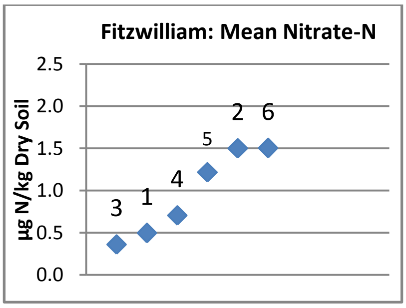


Figure 3.41 Soil NO_3^--N levels by quadrat at Fitzwilliam. Figure 3.42 Fitzwilliam: Area Mean NO_3^--N.

From Figure 3.43, the highest ratios are those in quadrats from Area 1, and the pattern becomes clearer in Figure 3.44, showing the mean ratios. Areas 5, 6, 2 and 4 are all reasonably close as a group, giving mean values below a ratio of 5: 1. These are all open areas of grassland, which may be significant in terms of conversion of ammonium-N to nitrate-N and in relation to soil moisture and pH.

There is a much greater range at Upton, reflecting a similar pattern as for the nitrate-N, with Area 6 at Upton being closest to the Fitzwilliam Areas.

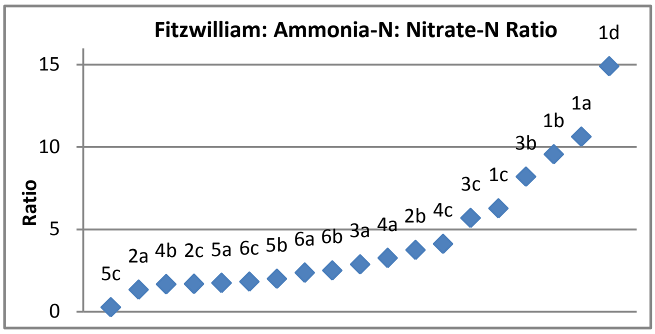


Figure 3.43 NH_4^+-N: NO_3^--N by quadrat at Fitzwilliam.

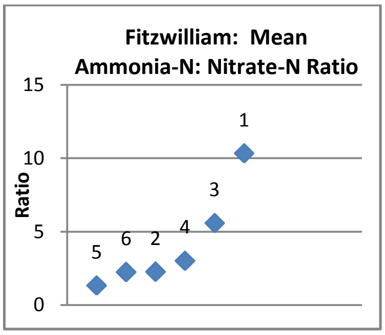


Figure3.44 Fitzwilliam: Area Mean NH_4^+-N: NO_3^--N.

3.2.5 Phosphorus Levels Fitzwilliam

Apart from quadrats 1d (76 µg P g^{-1} of soil) and 5c (95 µg P g^{-1} of soil), the quadrats in Figure 3.45 are fairly close together, ranging between 133 and 168 µg P g soil. Area 5 has the lowest mean value (Figure 3.46), but Areas 6 and 2 have a similar position as they did for nitrate-N. Compared with Upton, all quadrats at Fitzwilliam gave higher mean values for phosphorus. Most phosphorus comes from the recycling of organic matter, so areas with plenty of plant debris should have higher levels, but the availability of phosphorus to the plant roots is very much determined by pH and the presence of mycorrhizal fungi (Bradshaw, 1980).

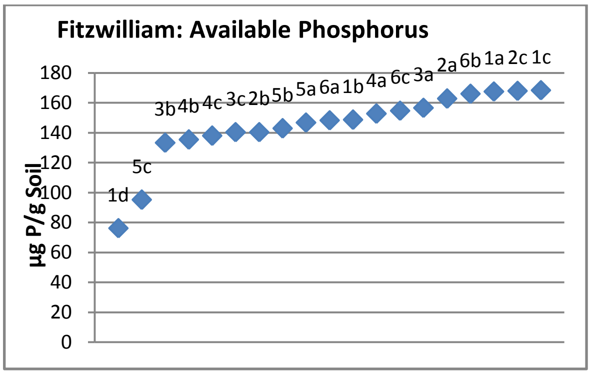


Figure 3.45 Plant available P by quadrat at Fitzwilliam.

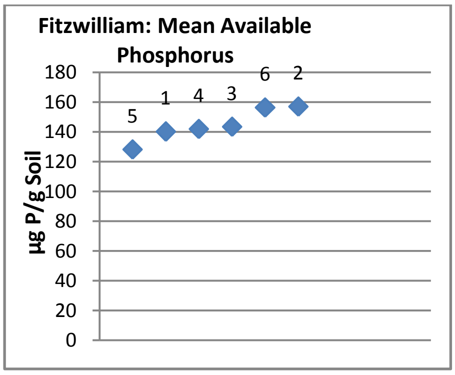


Figure3.46 Fitzwilliam: Area Mean plant available P.

3.2.6 Lead Levels Fitzwilliam

The lead levels as shown in Figure 3.47 are generally high, ranging from 60.8 mg Pb kg^{-1} of soil in quadrat 1a, to 206 mg Pb kg^{-1} of soil in quadrat 5c. Quadrats in area 1 have the lower concentrations, between 60 and 74 mg Pb kg^{-1} of soil. The lead could originate from the colliery spoil itself as well as the reclamation process.

However, due to the pH being neutral to alkaline, the lead should remain stable in the soil. The mean values in Figure 3.48 show Areas 5 and 6 having the highest levels at 154 and 157 mg Pb kg^{-1} of soil respectively. Levels of Pb are broadly comparable with Upton, if not a little higher.

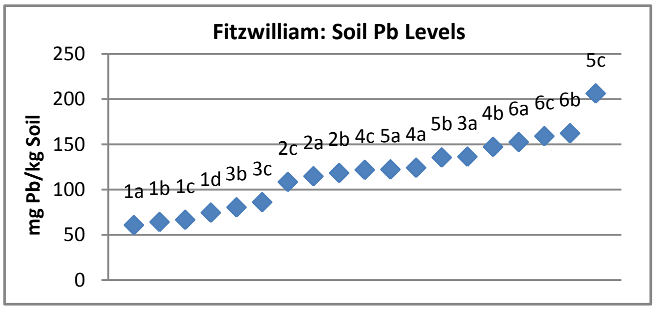


Figure 3.47 Soil Pb levels by quadrat at Fitzwilliam.

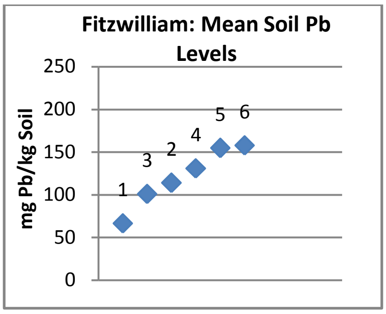


Figure 3.48 Fitzwilliam: Area Mean soil Pb levels.

3.2.7 Zinc Levels Fitzwilliam

The values for zinc follow a similar pattern as for lead, ranging from 81.2 mg Zn kg^{-1} of soil in quadrat 1d to 152.9 mg Zn kg^{-1} of soil in quadrat 5b. As Figure 3.49 shows, most of the quadrats are in the 100 to 150 mg Zn kg^{-1} of soil range. There seems to be much less variation than at Upton. Figure 3.50 shows that the mean values are similar across the site except for Area 1, where they are lowest. There seems to be no clay layer above the colliery spoil here, suggesting that the higher levels elsewhere are linked in some way to the way the site was treated on reclamation.

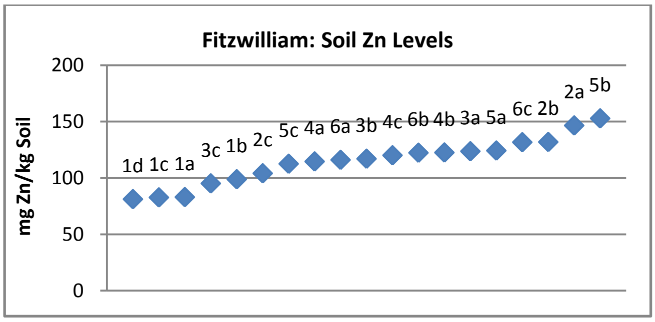


Figure 3.49 Soil Zn levels by quadrat at Fitzwilliam.

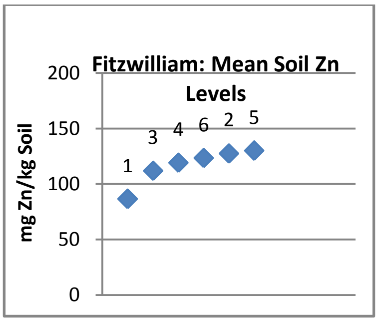


Figure 3.50 Fitzwilliam: Area Mean soil Zn levels.

3.2.8 Calcium and Magnesium levels

Soil calcium levels, as shown in Figure 3.51, range from 2.8 g Ca kg^{-1} of soil in quadrat 1a to 114.7 g Ca kg^{-1} of soil in quadrat 4b. This is a smaller range than at Upton, which has some higher values (up to 250 g Ca kg^{-1} of soil). Areas 1, 3 and 2 have the lowest mean calcium values (Figure 3.52), possibly reflecting the reclamation process. These areas may have had little in the way of a surface clay layer, which would originate from clay deposits derived from the limestone. On the other hand, Areas 4 and 6 could have had a top dressing of clay over the colliery waste. Certainly, during the reclamation process, lime, as well as imported topsoil, was added to these areas (Pipkin, pers. com., 2011).

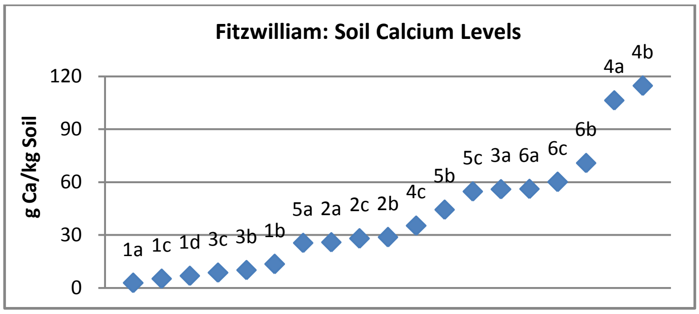


Figure 3.51 Soil Ca levels by quadrat at Fitzwilliam.

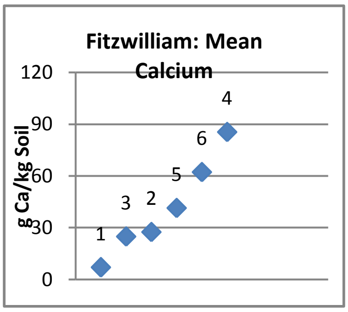


Figure 3.52 Fitzwilliam: Area Mean soil Ca levels.

Magnesium levels show a similar pattern to calcium (Figure 3.53). The range is from 3.8 g Mg kg^{-1} of soil in quadrat 1c to 39.9 g Mg kg^{-1} of soil in quadrat 4b. The range here is also similar to that at Upton, with the exception of Area 2 at Upton. The pattern of the mean levels in Figure 3.54 shows a similar pattern, although Area 6 is the highest, compared to Area 4. This does tie in with the pH, as these two have the highest values, and Area 1 the lowest.

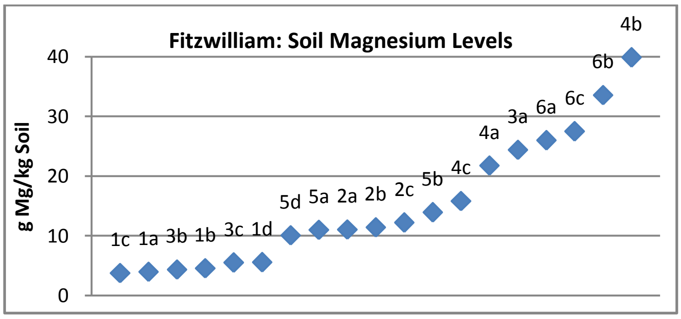


Figure 3.53 Soil Mg levels by quadrat at Fitzwilliam.

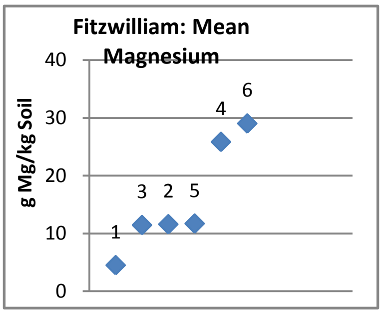
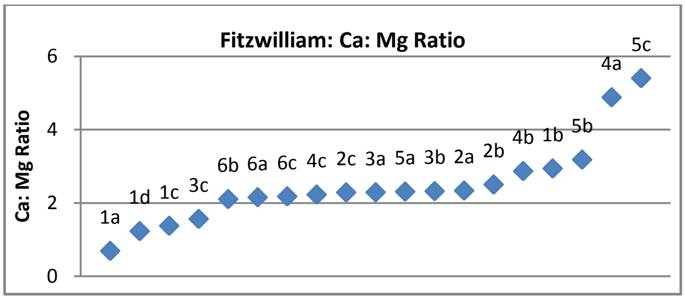


Figure 3.54 Fitzwilliam: Area Mean soil Mg levels.

The calcium: magnesium ratios shown in Figure 3.55 reflect the patterns seen for calcium and magnesium, with only 4a and 5c standing out at the top end. With the mean values (Figure 3.56), all areas other than Area 1, fall between 2 and 4. Again, this is a similar pattern to Upton.



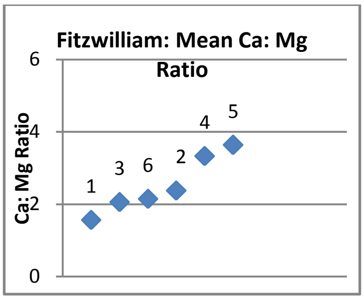


Figure 3.55 Soil Ca: Mg ratios by quadrat for Fitzwilliam.

Figure 3.56 Fitzwilliam: Area Mean Ca: Mg.

Table 3.1 compares the site mean soil data and range for Fitzwilliam and Upton.

In terms of the means, the variables that show the greatest difference between the two sites are:

- % Moisture content, where Fitzwilliam has the higher value (≈27%), compared to Upton (≈14%), but the range at Upton is far greater, being nearly double (≈30% compared to ≈15%), although Upton has more low values (<15 %).

- Ammonium-N; Fitzwilliam has the higher value (2.7 µg kg^{-1}compared to 1.9 µg kg^{-1}) and more than double the range (≈9.0 µg kg^{-1}) than Upton (≈4.0 µg kg^{-1}).

- Phosphorus; Fitzwilliam has a mean value of 144 µg g^{-1} but Upton has a lower value at 79 µg g^{-1}, although the range values show 120 µg g^{-1} for Upton compared to only 92 µg g^{-1} for Fitzwilliam. There are also many more low values (below 75 µg g^{-1}) at Upton.

- Pb; Fitzwilliam has the higher mean value of ≈118 mg kg^{-1} compared to ≈85 mg kg^{-1} for Upton, but Upton has virtually double the range value of 280 mg kg^{-1} to Fitzwilliam's 145 mg kg^{-1}, showing a clear division between the cutting (>75 mg kg^{-1}) Area 2 quadrats (67 – 90 mg kg^{-1}) and Areas 1, 3, and 4 (<70 mg kg^{-1}).

The key feature of the other variables, which have similar mean values, is that in all cases, the range of values for Upton is at least double those for Fitzwilliam, the extreme example being nitrate-N, with a difference in mean values of only 0.15 µg N kg^{-1}, but a range over 4 times greater.

Table 3.1 Summary Table of Soil Data for Fitzwilliam and Upton.

	FITZWILLIAM		UPTON	
Soil Variables	**Mean**	**Range**	**Mean**	**Range**
pH	7.8	7.2 – 8.3	7.8	6.7 – 8.6
% Moisture (Dry Wt)	27	20 – 35	14	1 – 32
% Carbon	11	5 – 22	10	0.5 – 37
% Nitrogen	0.4	0.2 – 0.8	0.3	0.1 – 0.9
C: N ratio	29	22 – 36	29	9 – 81
Ammonium-N µg kg^{-1}	2.7	0.3 – 9.6	1.9	0.7 – 4.5
Nitrate-N µg kg^{-1}	0.9	0.1 – 2.2	0.8	0.0 – 9.5
Phosphorus µg g^{-1}	144	76 – 168	79	13 – 133
Pb mg kg^{-1}	118	61 – 206	85	24 – 304
Zn mg kg^{-1}	115	81 – 153	110	40 – 342
Ca g kg^{-1}	40	3 – 115	44	1 – 250
Mg g kg^{-1}	15	4 – 40	19	2 – 87

Range based on quadrat values. Figures rounded up to whole numbers (To 1 dp for pH, C, NH_4^+- N andNO_3^-N).

3.3 Plant Data

The plant data is found in Appendix Table 1, for Upton and Appendix Table 3 for Fitzwilliam. The Domin Scale data is found in Appendix Table 2 for Upton and Appendix Table 4 for Fitzwilliam. From Appendix Tables 1 and 3, the frequency of species occurrence by quadrat for both Upton and Fitzwilliam is shown in Table 3.2. 91 species were recorded in the 32 quadrats at Upton and 33 species in the 19 quadrats at Fitzwilliam.

Plantago lanceolata occurred the most frequently at Upton (25 quadrats), followed by *Sphagnum cymbifolium* (16), *Medicago lupulina* and *Trifolium pratense* (15), *Achillea millefolium* (14), *Lotus corniculatus, Campanula glomerata, Hypochoeris radicata* and *Trifolium repens* (12), *Centaurea nigra* and *Festuca ovina* (11), *Cynosurus cristatus* (10).

The quadrats were dominated by Plantains (*Plantaginaceae)* with legumes (*Fabaceae*) and members of the daisy family (*Asteraceae)*, followed by grasses (*Poaceae*).

At Fitzwilliam, the species occurring most frequently were *Festuca ovina* (18 quadrats) and *Holcus lanatus* (17), followed by *Plantago lanceolata* and *Sphagnum cymbifolium* (13), *Cirsium arvense* (11) and *Medicago lupulina* (10). However, the quadrat dominance by the grasses (*Poaceae)*, plantains (*Plantaginaceae)* thistles (*Asteraceae*) and legumes (*Fabaceae*) was clear.

At Upton 16 grass species were recorded in the quadrats, but only 8 at Fitzwilliam. However, as a percentage, 18 % of species were grasses at Upton, compared to 24 % at Fitzwilliam.

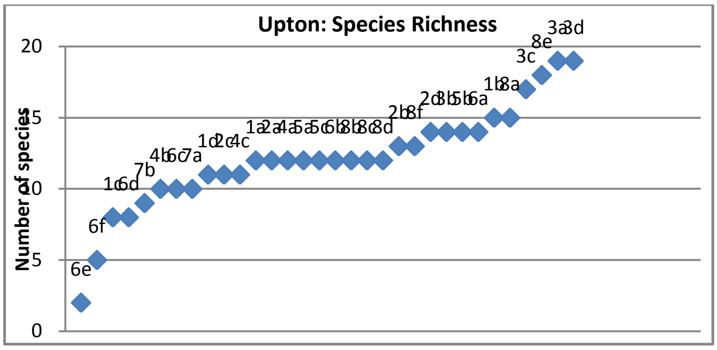
The two sites had 27 species in common, with Upton having 64/91 species different from Fitzwilliam, which had only 6/33 species different from Upton. On both sites, the frequency of occurrences was very similar, with 2/3 of species occurring in 4 or less quadrats and < 20 % in 5 – 9 quadrats. 30 % of the species (27/91) at Upton were single occurrences, with a similar frequency (27 %) at Fitzwilliam (9/33).

Table 3.2 The Frequency of Occurrence by Quadrat for both Upton and Fitzwilliam.

Frequency Range	**Occurrences – Upton.** n = 91	**Occurrences – Fitzwilliam**. n =33
15+	4	2
10 – 14	8	4
5 – 9	15	6
1 - 4	64	21

3.3.1 Species Richness and Diversity at Upton.

In total, 91 species were recorded and used to produce the Species Richness diagrams, Figures 3.57 and 3.58. Figure 3.57 shows that generally there are more than 8 species per quadrat, with only quadrats 6e (2 species) and 6f (5 species) having less. Area 3 stands out, with a mean of 17.25 species (figure 3.58) and a maximum of 19 (in quadrats 3a and 3d.).Area 3 is on the slope of the drainage scrape next to the limestone and also at the boundary created by the Spout Lane Fault (Figure 2.2). Area 8 (mean of 13.67 species), and Area 5 (mean of 12.67), lie in the cutting. Although 6e and 6f are low in species, the other quadrats in Area 6 range from 8 to 12 species. These two quadrats are overshadowed by dense tree and bush cover from the top of the cutting. There is a lack of ground cover, much bare earth and rock and the area is also covered in a thick accumulation of dry dead leaves.



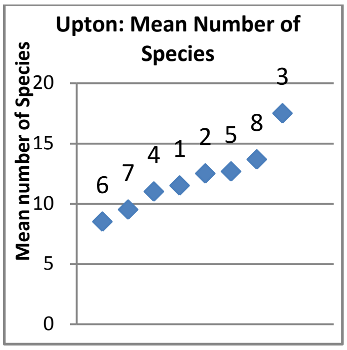
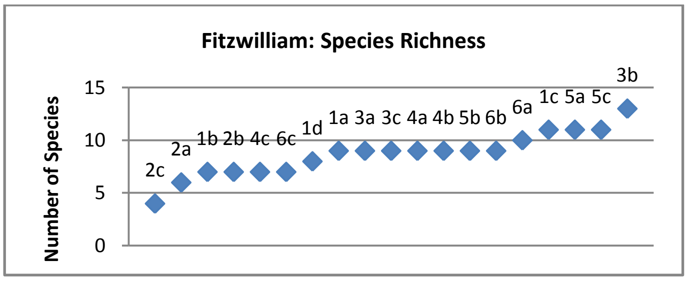


Figure 3.57 Plot of Species Richness by quadrats at Upton. Figure 3.58 Upton: Mean Area Species Richness.

.3.3.2 Species Richness at Fitzwilliam.

In total, 32 species were recorded and used to produce the Species Richness diagrams, Figures 3.59 and 3.60. With the exception of quadrat 2c, Figure 3.59 indicates that for Fitzwilliam, there are generally more than 6 species per quadrat. Quadrat 2c only produced 4 species in an area that was low in species generally, with 2a producing 6 species and 2b 7 species, and all three quadrats in Area 2 only had 4 species in common. Quadrat 3b produced 13 species, and when Figure 3.60, showing the mean values for each area is examined, Areas 3 and 5 give mean values of ≈10 species. Areas 1, 4 and 6 are fairly close, with between 8 – 9 species. Area 2 appears species poor with a mean of 5.67 species. A factor influencing the greater species richness in Areas 3 and 5 may be the more sheltered aspect (as can be seen on Figure 2.4)



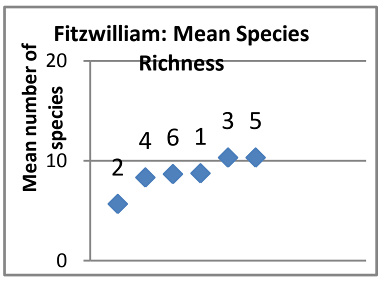


Figure 3.59 Plot of Species Richness for Fitzwilliam. Figure 3.60 Fitzwilliam: Mean Area Species Richness.

3.3.3 Plant Community Classification

The species data for each Area was put into MAVIS, and the Class according to the Countryside Vegetation System (CVS) was produced and is shown in Tables 3.3a and 3.3b. The National Vegetation Classification Groupings were also derived on the basis of the top 10 coefficients.

CVS Classes for Fitzwilliam and Upton.

As Table 3.3a shows, the CVS Class gives some form of Mesotrophic Grassland for five Areas at Fitzwilliam, with Area 3 being different with the Ryegrass/Yorkshire Fog Grassland and the whole site class, not unexpectedly, emerging as enriched Mesotrophic Grassland.

The Phase 1 Habitat Surveys refer to Neutral Grassland, which equates to Mesotrophic Grassland in the NVC types (Jackson, 2000).
The Upton site (Table 3.3b) is far more varied and Areas 2 and 5 appear as Calcareous Grassland, which considering that they are on limestone is to be expected. The classification for Areas 1, 3, and 4 as Ryegrass/Yorkshire Fog Grassland, was surprising and to some extent Areas 6 and 7 as Enriched Mesotrophic Grassland, due to both sites being in the cutting.

Table 3.3a FITZWILLIAM – CVS Classes by Area. Table 3.3b UPTON – CVS Classes by Area.

Area	Class	Description
1	38	Enriched Mesotrophic Grassland
2	47	Diverse Mesotrophic Pasture
3	40	Ryegrass/ Yorkshire Fog Grassland
4	38	Enriched Mesotrophic Grassland
5	47	Diverse Mesotrophic Grassland
6	38	Enriched Mesotrophic Grassland

Whole Site: 38 Enriched Mesotrophic grassland.

Area	Class	Description
1	40	Ryegrass/Yorkshire Fog Grassland
2	44	Calcareous Grassland
3	40	Ryegrass/Yorkshire Fog Grassland
4	40	Ryegrass/Yorkshire Fog grassland
5	44	Calcareous Grassland
6	34	Mixed Grassland Scrub
7	38	Enriched Mesotrophic Grassland
8	38	Enriched Mesotrophic Grassland

Areas 1 – 4: 40 Ryegrass/Yorkshire Fog grassland
Areas 5 – 8: 44 calcareous Grassland

Whole Site: 37 Diverse Mesotrophic Grassland/Scrub

NVC Groupings for Fitzwilliam and Upton.

As Table 3.4a shows, most of the coefficients indicate Mesotrophic Grassland (26/60), with Vegetation of Open Habitats (8/60), Calcareous Grassland (5) and Calcifugous Grassland (2). However, Sand Dune Community (11) and Maritime Cliff

(8) may seem odd, but coal mine wastes heaps are shaly and sandy in places, and this could produce similar habitats. Significantly, the whole site Grouping gives only Mesotrophic Grassland (7/10) and Vegetation of Open Habitats (3/10), which probably summarises the Fitzwilliam site accurately.

Table 3.4a FITZWILLIAM – NVC Groupings by Area and Whole Site

Area 1		Area 2		Area 3		Area 4		Area 5		Area 6	
Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff
SD9a	33.97	MC9a	41.87	OV23c	44.05	MC9c	33.07	OV23d	49.54	MG6c	37.76
OV23d	33.25	MC9c	37.51	OV23d	42.17	MG1e	32.93	MG1e	42.65	MG6	36.70
SD7a	32.43	CG4	35.47	OV23	39.94	MG1d	32.87	OV23c	42.49	MG6b	36.52
MG1a	32.37	MC9	34.09	MG7E	39.89	MG1b	32.50	MC9c	41.67	MG6a	32.66
MG1	31.02	CG4	33.39	MG6	39.79	CG4c	31.59	OV23	41.32	U4b	32.02
MG1e	30.47	SD8d	32.26	MG5	39.67	SD8a	31.13	MG5b	41.27	SD12b	30.37
MG1c	29.27	CG4b	32.07	MG5b	39.59	MC9b	31.07	MG7E	41.27	MC9a	30.15
MG1b	29.12	SD8a	31.87	MG5a	39.12	CG4	30.97	MG5	40.28	SD12	30.11
SD7	28.49	MC8d	31.71	MG6a	39.03	OV23d	30.77	MG1d	40.25	SD8a	29.57
SD7e	28.34	MG1e	31.70	SD8a	38.36	U1d	30.42	MG5a	39.74	MG7E	29.46

Whole Site	
Group	Coeff
MG5a	45.30
MG1e	45.28
MG5	45.06
OV23d	44.65
MG5b	44.22
MG1d	41.31
MG5c	40.30
MG1	40.03
OV23	38.27
OV23c	38.22

As Table 3.4b for Upton shows, most of the coefficients are for Mesotrophic Grasslands (31/80) or Calcareous grassland (26/80). Part of the site being on limestone, this is to be expected. Vegetation of Open Habitats (12/80) is also not surprising, but Sand Dunes (6/80) and Maritime Cliffs (5/80) may be unusual, but as mentioned for Fitzwilliam, coal mine spoil heaps are often shaly and sandy, so producing similar conditions. The whole site NVC Grouping simplifies down to just Mesotrophic Grassland (6/10) and Calcareous Grassland (4/10). When Areas 1 – 4 and 5 – 8 are looked at separately, the pattern is a little different, although Mesotrophic grassland dominates (6/10 in both) and Calcareous Grassland is present in both areas. Areas 1- 4 have Sand Dune classifications and Areas 5 – 8 Vegetation of Open Grassland. Mine sites are often a mosaic of open grassland communities, and the fit with the NVC communities is not always clear (ADAS, 2010).

Table 3.4b) UPTON – NVC Groupings by Area and Whole Site

Area 1		Area 2		Area 3		Area 4		Area 5		Area 6		Area 7		Area 8	
Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff	Group	Coeff
MG5b	49.00	CG2c	39.98	MG5b	33.30	OV23c	44.28	MG5b	31.67	CG3b	29,22	MG1d	32.20	MG5b	30.90
MG5a	45.40	OV37b	36.89	MG6b	33.03	MG6a	38.07	OV23d	31.33	CG2c	27.03	MC9c	31.97	MG5a	30.89
MG5	45,11	CG2b	35.84	MG5a	32.88	OV23	38.00	CG2c	31.14	CG3	26.20	MG7E	31.34	MG5	30.50
MC9c	43.57	CG3c	35.61	MG4	32.63	MG7E	36.38	CG4c	30.88	CG8b	25.78	OV23c	31.25	OV23c	30.28
SD8d	41.96	CG3b	35.60	MG5	32.50	MG5b	35.64	CG2b	30.82	CG3c	24.42	OV23d	30.67	MG5c	30.00
MG5c	41.95	CG4b	34.03	MG3b	31.99	OV23d	35.39	MG1d	30.64	CG3a	24.17	MC11c	30.61	CG3c	28.96
SD8a	41.94	MG5b	33.98	MG3	31.71	MG6	35.05	CG4b	30.44	CG2	23.69	OV23	29.48	OV23d	28.43
CG3c	41.84	SD8d	33.96	MG3a	31.00	MG6b	35.02	MG5a	30.37	CG8	23.33	MG5b	28.52	SD8a	28.22
SD8	41.37	CG2	33.67	MG5c	30.88	OV21c	34.92	CG3c	30.30	CG2b	21.23	MC9b	28.47	CG8b	27.79
CG2c	40.75	CG4	33.52	MC9c	30.47	OV21	34.62	MG1e	29.93	CG4	23.19	MG1	27.85	SD8d	27.68

Whole Site		Areas 1 -4		Areas 5 - 8	
Group	Coeff	Group	Coeff	Group	Coeff
CG3c	34.78	MG4	39.38	MG5b	33.02
MG5b	32.20	MG5b	38.05	CG3c	32.92
MG4	31.38	CG3c	36.90	MG5a	32.61
CG2c	31.19	MG5a	36.86	MG5c	32.56
MG5a	30.86	MG5	35.69	MG1e	32.40
MG5	29.97	CG2c	34.22	MG1d	32.14
CG8b	29.70	MG5c	33.07	CG2c	31.87
MG5c	29.04	SD8e	31.85	MG5	31.81
MG1d	28.50	SD8d	31.35	CG3b	30.33
CG2b	28.26	MG3b	31.15	OV23d	30.12

The NVC system and the CVS system are reasonably similar for Fitzwilliam, but do show differences for Upton, particularly for Area 6, which was classified as Mixed Grassland Scrub under the CVS system, yet is classified as Calcareous Grassland under the NVC system.

Two new communities have since been found to occur in the coalfield (Lunn, 2005; Lunn, 2005; Lunn et al., 2005), *Vulpia bromoides – Arenaria serpyllifolia* and *Agrostis stolonifera – Holcus lanatus.* The *A. stolonifera- - H. lanatus* community appears to be the pioneering vegetation of Yorkshire colliery sites (Lunn, 2005), grading to MG9, MG1 and MG12 as conditions change.

3.3.4 Plant Ordination

The plant data from Appendix Tables 2 (Upton) and 4 (Fitzwilliam) were put into DECORANA, and the axis scores for the quadrats produced are shown in Appendix Tables 6 (Upton) and 7 (Fitzwilliam).
DECORANA also summarises the underlying covariance and co-occurrences (Bastin et al., 2007). The eigenvalues are used to assess the amount of variability in the data, as shown in Table 3.5.The results in Table 3.5 show that for Upton, the first three axes explain 88 % of the total variability in the data set, with the suggestion that 68 % of the variability in plant composition can be expressed in only two dimensions (axes 1 and 2), and that axis four probably represents noise (Gauch, 1982).

For Fitzwilliam, Table 3.5 shows the first three axes explaining over 90 % of the total variability, with the clear suggestion that nearly 75 % of the variability in plant composition can be expressed by axes 1 and 2 alone. Again, axis 4 probably represents noise.

For both Upton and Fitzwilliam, axis 3, with nearly 20 % (Upton) and nearly 17 % (Fitzwilliam), suggests that a third dimension could be considered.

Table 3.5 Eigenvalues and the Cumulative Percentage of the Total Variance for the four Axes.

	Upton			Fitzwilliam		
Axes	**Eigenvalue**	**% Variance**	**Cumulative % of Total Variance**	**Eigenvalue**	**% Variance**	**Cumulative % of Total Variance**
1	0.691342	39.65	39.65	0.35931	47.91	47.91
2	0.499648	28.65	68.30	0.202782	27.04	74.95
3	0.347058	19.90	88.20	0.126462	16.86	91.81
4	0.205699	11.80	100	0.0614969	8.20	100.01

Both the quadrat data and the species data are presented as ordination plots, in which each quadrat is at the centre of gravity of the species that occur there (Ter Braak and Prentice, 1988). Nearby species points give an idea of species composition, with the abundance of a species tending to decrease with distance from its position on the plot.

Axis 1 represents an environmental gradient underlying the distribution and abundance of the plants, with quadrats 1a, b, c, d, 2a, b, d and 8d having relatively low axis 1 scores (Figure 3.61) and quadrats 6d and 6e having high axis 1 scores (Figure3.61). Quadrat 4a has an exceptionally low score (0) and is characterised by a group of ruderal plants typical of a disturbed environment with areas of bare earth (Maidment, 2007), namely *Agropyron repens* (2)*, Chenopodium bonus-henricus* (16)*, Polygonum aviculare* (61)*, Senecio vulgaris* (77) and *Tripleurospermum inodorum* (86) (Figure 3.62 - Numbers in brackets represent plant number identification on Appendix Table 1). Quadrats 6d and 6e, with their high axis 1 scores are characterised by the plants *Bromus erectus* (9)*, Galium aparine* (32)*, Stellaria media* (79)*, Torilis japonica* (82) and *Urtica diocia* (88)*.* The low axis 1 scores, other than quadrat 4a which is significantly different, are characterised by the plants *Alopecurus pratensis* (5)*, Cirsium dissectum* (17)*, Holcus lanatus* (37)*, Lathyrus pratensis* (44)*, Odontites verna* (52)*, Origanum vulgare* (53)*, Phleum pratensis* (55)*, Rosa arvensis* (69) and *Vicia cracca* (89)*.*

Axis 2, representing the secondary environmental variable, has quadrats 3a, b, c, d (Appendix Table 7 and Figure 3.61) with the lowest scores, characterised by *Dactylorhiza fuschii* (22)*, Equisetum arvense* (25)*, Lathyrus hirsutus* (42)*, Lathyrus montanus* (43)*, Rhinanthus minor* (68)*, Rumex acetosa* (72) and *Sanguisorba officinalis* (75)*,* which all have negative species scores. Area 3 quadrats are on the slope down from the limestone into the drainage scrape. Quadrats 6c and 6b have the highest axis 2 scores, and are characterised by *Potentilla reptans* (62) and *Pilosella officinarium* (56).

Site

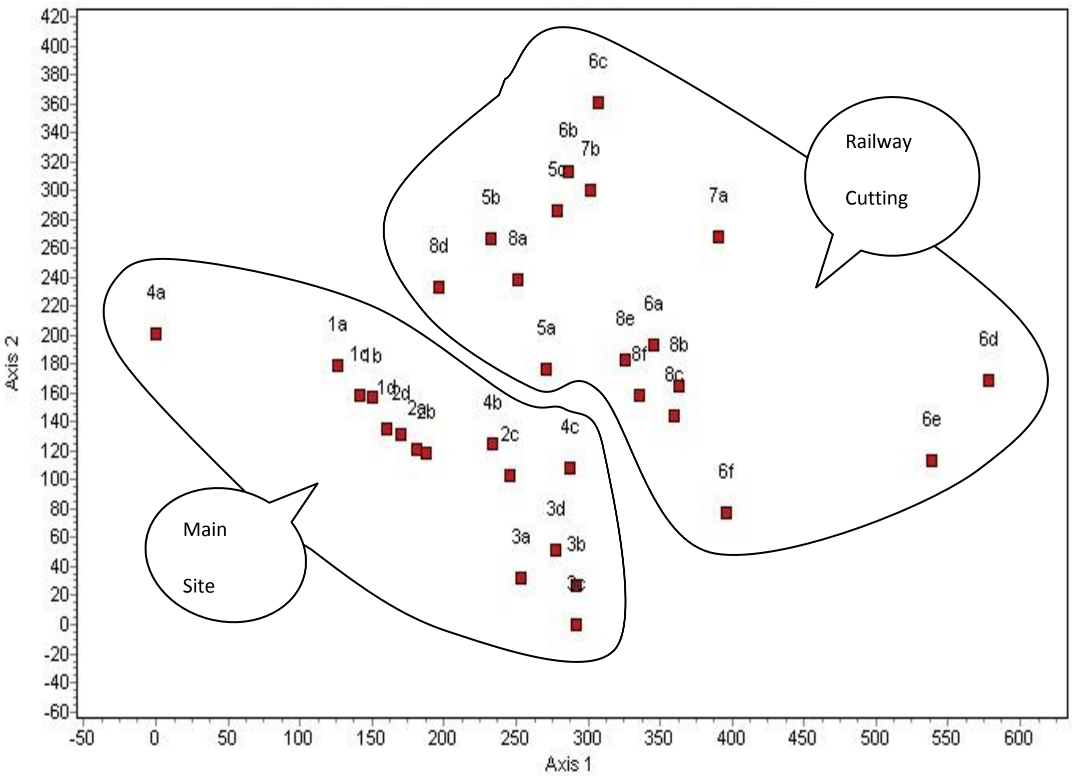


Figure 3.61 Quadrat Ordination Plot for Upton.

The ordination plot for the quadrats (Figure 3.61) divides up into two distinct groups, one group consisting of the quadrats in the railway cutting and the other group covering the rest of the site. There does seem to be a reflection of this two-fold grouping with the ordination plot for the species (Figure 3.62).

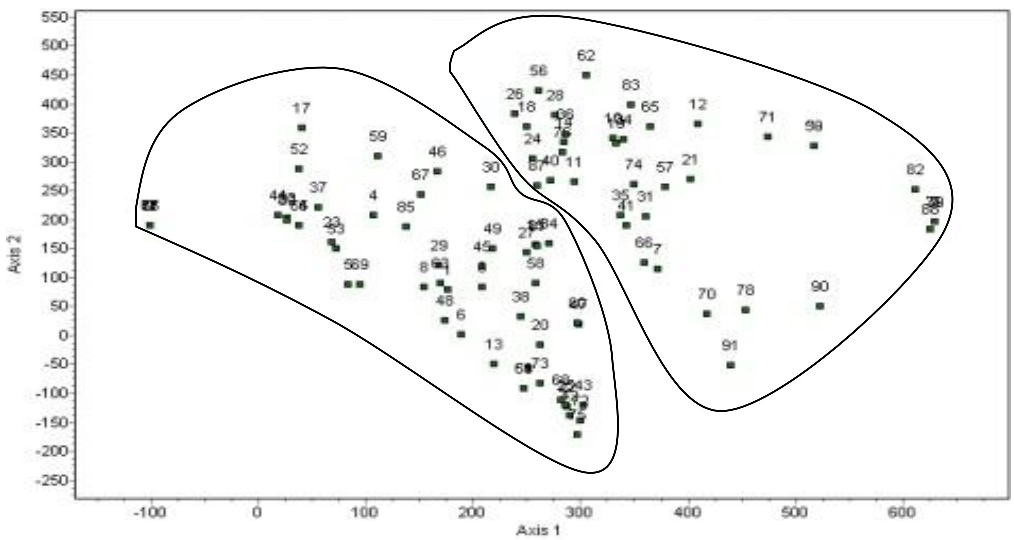


Figure 3.62 Species Ordination Plot for Upton (See Appendix Tables 1 and 2 for names).

Figure 3.63 for Fitzwilliam shows quadrats 1a and 1b as having the highest scores for axis 1, and being characterised by *Arrhenatherum elatius* (4)*, Lathyrus pratensis* (15)*, Rumex conglomerates* (25) *and Tragopogon pratensis* (29) (Figure 3.64).These two quadrats are on the slope closest to the poultry farm. The quadrats scoring lowest for axis 1 are 5b, 6c, 6a, 1c and 5c, and are characterised by *Knautia arvensis* (14)*, Hypochaeris radicata* (13)*, Melilotus officinalis* (19)*, Dactylis glomerata* (9)*, Poa pratensis* (24) and *Agrostis capillaris* (2).

For axis 2, the quadrats scoring highest 4b, 4a and 1d, are characterised by *Anthyllis vulneria* (3)*, Knautia arvensis* (14) *and Achillea millefolium* (1)*.* The quadrats scoring lowest are 6c, 6b, 2a, 2b and 1b, and are characterised by *Vicia cracca* (32)*, Lathyrus pratensis* (15)*, Poa pratensis* (24)*, Rumex conglomerates* (25) and *Trifolium repens* (31)*.*

It would seem that, overall, the ranges of axis scores from the ordinations for Fitzwilliam are much lower than at Upton, suggesting a more homogeneous setting.

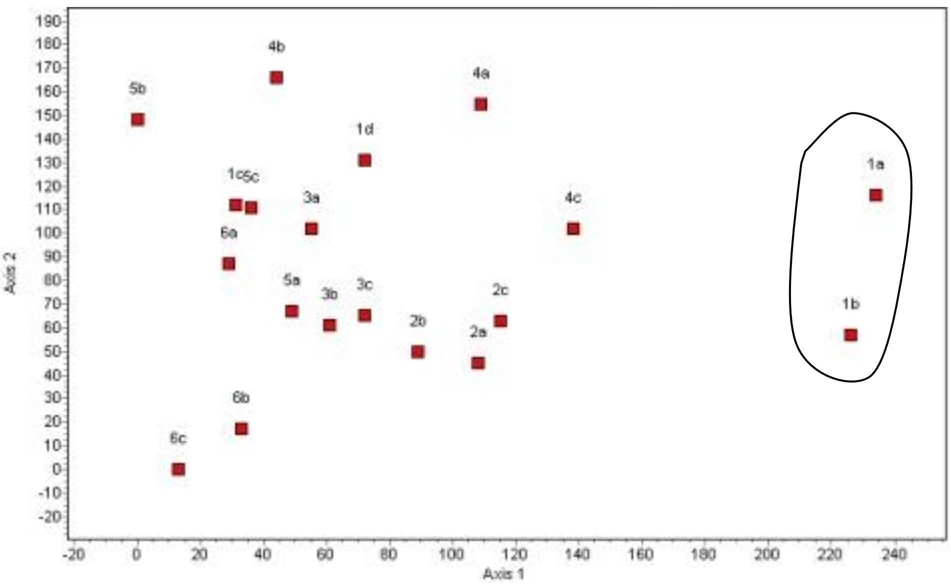


Figure 3.63. Quadrat Ordination Plot for Fitzwilliam.

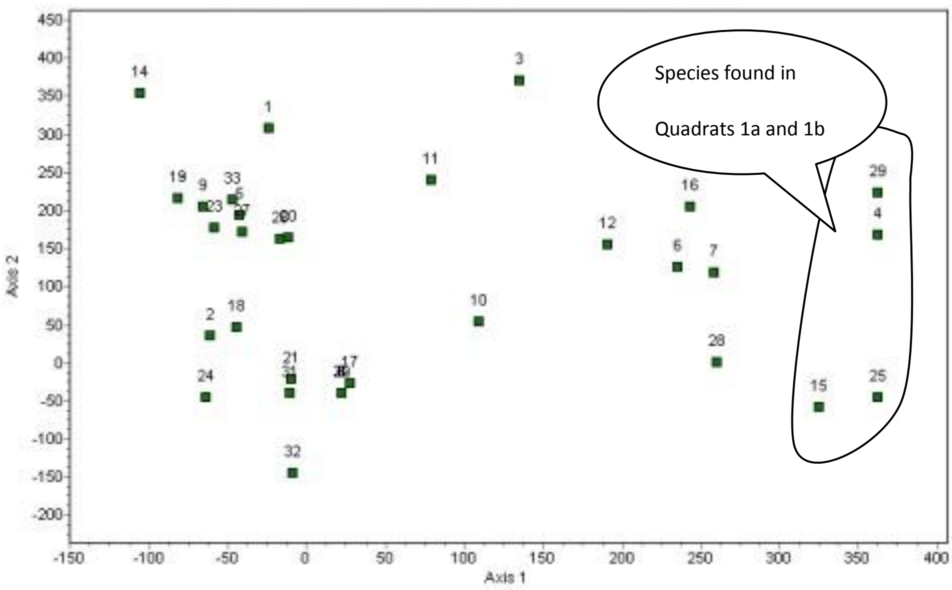


Figure 3.64. Species Ordination Plot for Fitzwilliam (See Appendix Tables 3 and 4 for Names).

3.3.5 TWINSPAN Analysis.

The dendograms produced help to show the grouping of the quadrats at different levels, and these are shown in Figure 3.65 for Upton and Figure 3.67 for Fitzwilliam.

The dominant indicator species are also shown by dendogram, Figure 3.66 for Upton and Figure 3.68 for Fitzwilliam.

For Upton, Figure 3.65 shows that at the Level 1 division the quadrats divide up into a group in the cutting, with the exception of quadrats 5a and 5b, and a group covering the rest of the site. The Level 2 division indicates that quadrat 4a is different from the any in the rest of that group, and also that 6d, 6e and 6f, form a small group that is different on the south side of the cutting. This is not surprising, considering that 6d, 6e, and 6f are overhung by trees and bushes and had a significant amount of bare earth and rock. Quadrat 4a is in a drainage gulley in the scrapes, with bare earth patches. The Level 3 division is interesting because it begins to separate the quadrats on or close to the limestone, from those on the coal measures. The Level 5 division makes an interesting distinction with quadrats 8a and 8d; that is the fact that they are on opposite sides of the trackway through the cutting and so in what had been a drainage gulley for the railway on the edge of the track ballast.

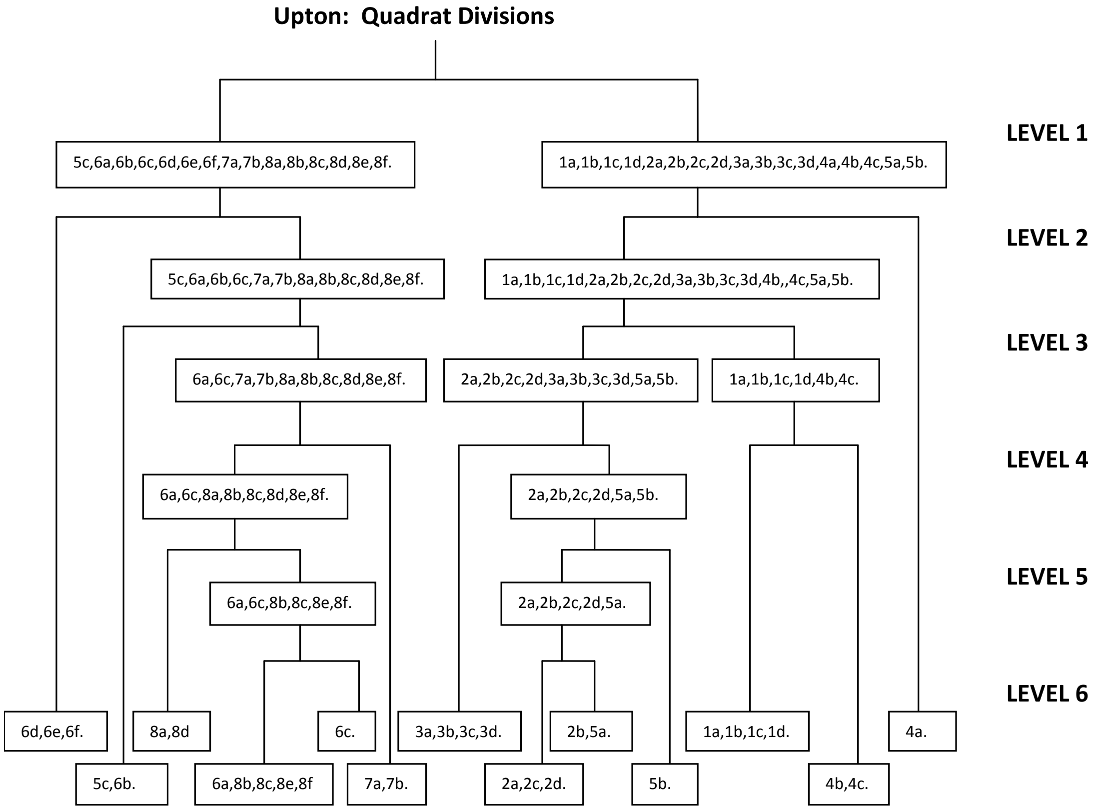


Figure 3.65. TWINSPAN Quadrat Divisions for Upton.

Figure 3.66 shows the indicator species for Upton, and, with the exceptions of quadrats 5a and 5b, they again highlight the division between the cutting and the rest of the site. The indicator plants for the cutting at Level 1 are *Campanula glomerata* and *Rubus fructicosus,* with *Festuca ovina* and *Lotus corniculatus* for the rest of the site. At Level 2, *Agropyron repens* characterises quadrat 4a, and *Urtica dioica quadrats* 6d, 6e and 6f. The rest of the cutting is characterised by *Campanula glomerata, Centaurea nigra* and *Plantago lanceolata.* The fact that *Achillea millefolium* and *Agrostis stolonifera* occur on both sides of the dendogram, suggests that they may not be reliable indicators.

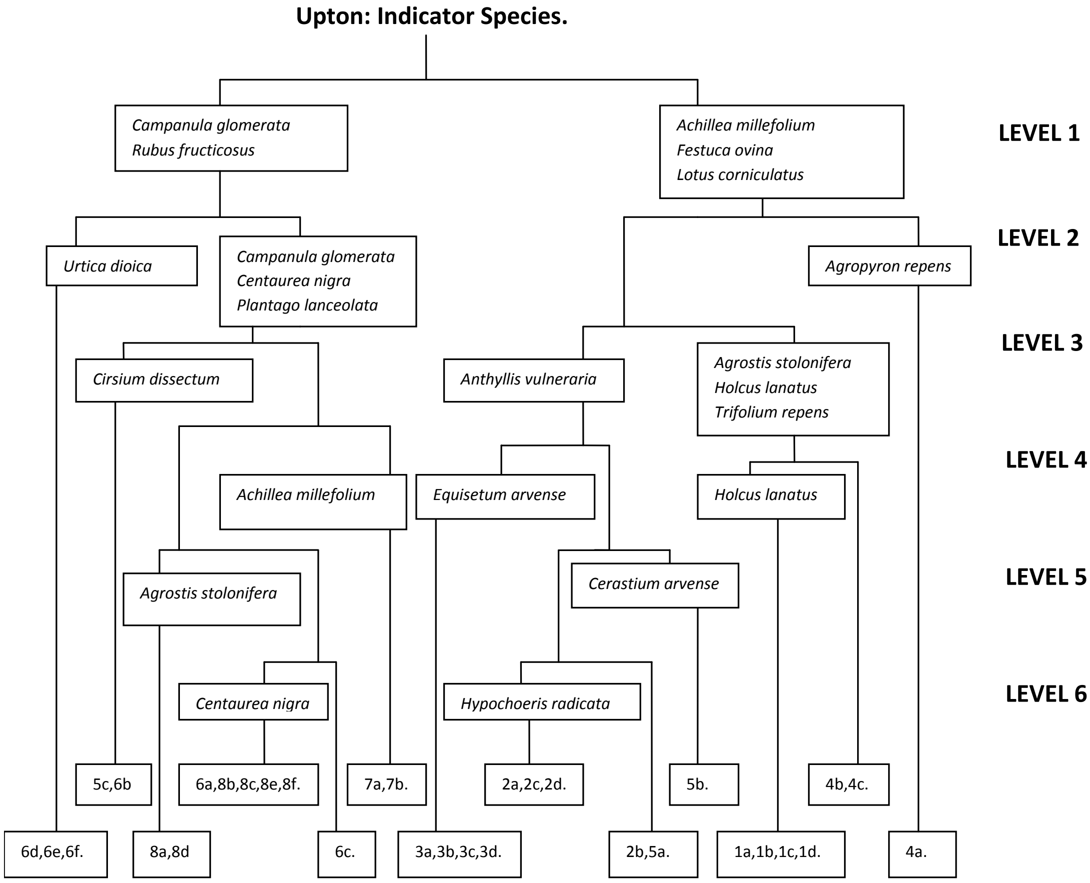


Figure 3.66 TWINSPAN showing main indicator species for Upton.

For Fitzwilliam, Figure 3.67 shows that at the first division (Level 1), quadrats 1a and 1b immediately form a distinct group on their own. These two quadrats are on the lower part of the slope above the poultry farm. At the Level 2 division, quadrats 2b, 6a, 6b and 6c, also now form a separate group. These quadrats are all in a broad grass sward. The Level 3 division separates out the three quadrats from Area 3 plus 5a. Area 3 is more sheltered, as is Area 5, so this may help account for the particular grouping.

It is noticeable that Fitzwilliam only has 5 levels of division compared to Upton's 6.

Fitzwilliam: Quadrat Divisions

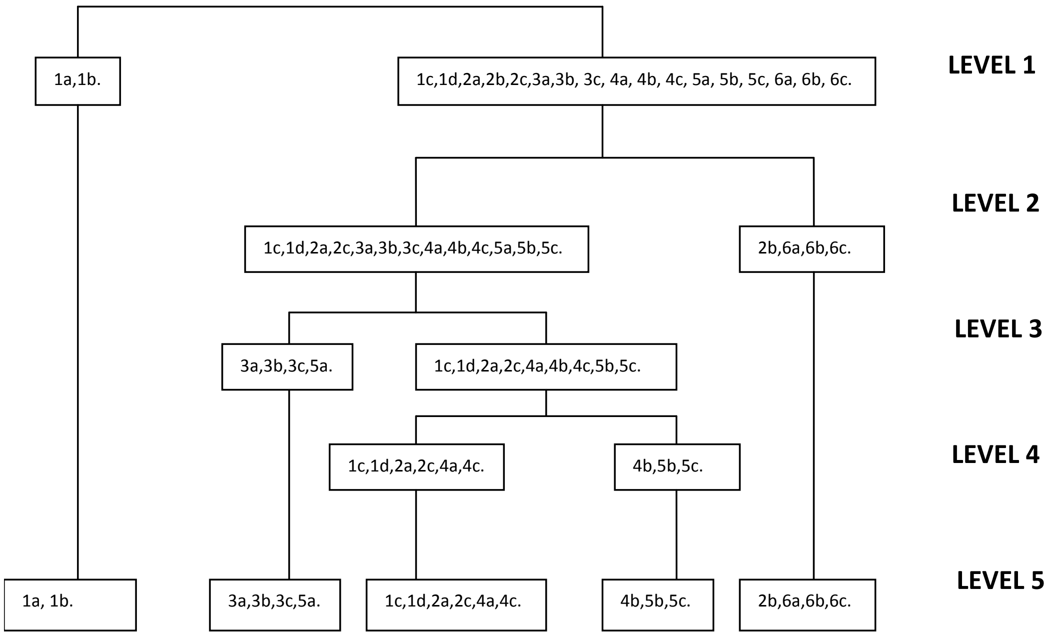


Figure 3.67 TWINSPAN Quadrat Divisions for Fitzwilliam.

From Figure 3.68, the first level division separates out the quadrats 1a and 1b, characterised by the grass *Arrhenatherum elatius*. At the second division, no particular species appears to characterise the group consisting of quadrats 2b, 6a, 6b and 6c. Level 3 separates out the quadrats in Area 3, together with 5a, characterised by *Plantago lanceolata, Taraxacum officinale* and *Trifolium repens,* but the Level 5 division produces a more varied group of quadrats, with 4b, 5b and 5c characterised by *Achillea millefolium, Knautia arvensis* and the *grass Agrostis capillaris.*

Fitzwilliam seems to have a more restricted group of indicator species, having 10 indicator species compared to 16 at Upton, but it also has many fewer plant species to start with and a much less complex set of communities.

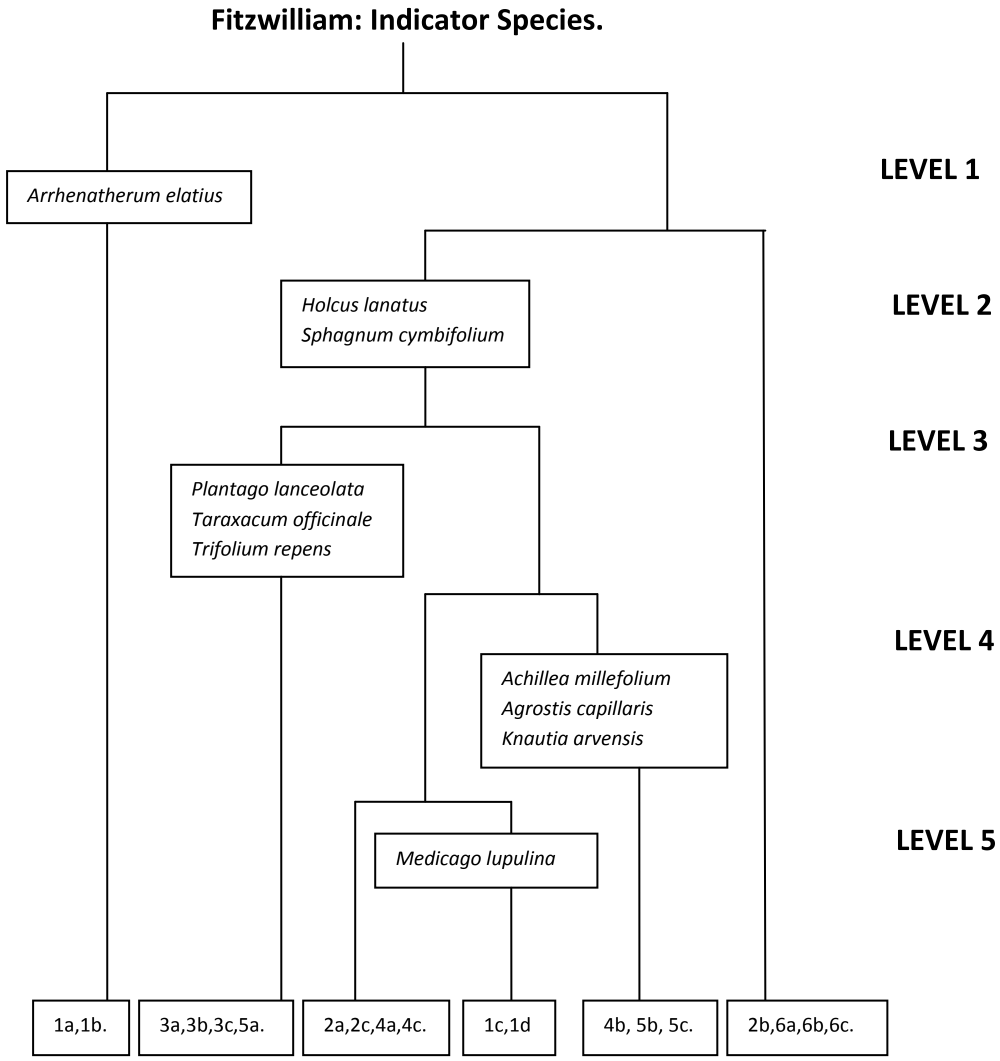


Figure 3.68 TWINSPAN showing main Indicator Species for Fitzwilliam.

At Upton, the 91 species that occurred in the 33 quadrats could easily be increased by the various other species observed across the site, such as *Chichorium intybus*, *Ophrys apifera*, *Orchis mascula*, *Parentucellia viscosa* and *Pulicaria dysenterica*. In fact species observed for the first time, but not recorded in the Phase 1 Habitat Survey, included *Hypericum montanum, Parentucellia viscosa* and *Bryonia dioica*.

As at Upton, the number of species (33) recorded in the 19 quadrats at Fitzwilliam could easily be added to by other observed species across the site, such as *Festuca rubra, Dactylorhiza fuchsia, Ophrys apifera, Echium vulgare* and *Dipsacus fullonum.*

3.3.6 C-S-R Characterisations (%) for Upton and Fitzwilliam

Plant data was fed into the MAVIS software to see where the sites fitted into the NVC and CSV classifications. MAVIS also allows a characterisation to be made for each area in terms of competition (C), disturbance(R) and stress (S) (Grime, 1977). Ruderals are used to indicate disturbance, hence C-S-R.

Figure 3.69 shows that 5 of the 8 Upton Quadrat Areas are fairly close together in the 30 – 40 % zone for all three criteria; competition, disturbance and stress, with a slight emphasis towards disturbance and stress. Area 2 and Area 7 behave differently. Area 2 is lower in terms of competition and disturbance, but much higher in terms of stress. Area 2 is on the thin limestone soils, and moisture could be the stress factor operating here. Area 7 is in the cutting and is between the track and the vertical limestone cutting side, consists of several different species resulting in competition, particularly as this location has a large stand of bracken (*Pteridium aquilinum*).

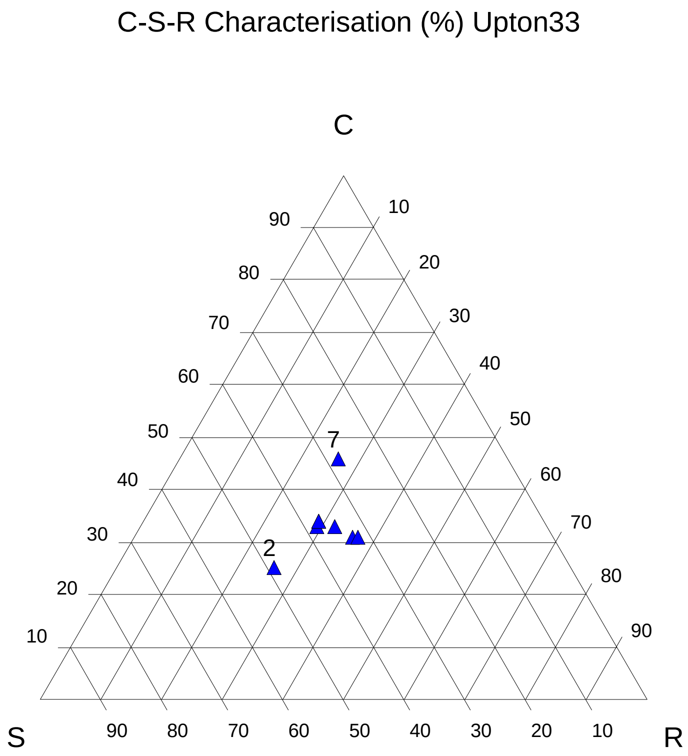


Figure 3.69 Triangular graph giving the C-S-R Characterisation for Upton.

Figure 3.70 shows that all six of the Fitzwilliam Quadrat Areas are grouped between 20 – 30 % for competition and disturbance, but score more highly with stress, being between 40 and 60 %. Area 2 is shown to have the highest stress level. Area 2 is particularly dominated by grasses and seems likely to suffer rapid drying out.

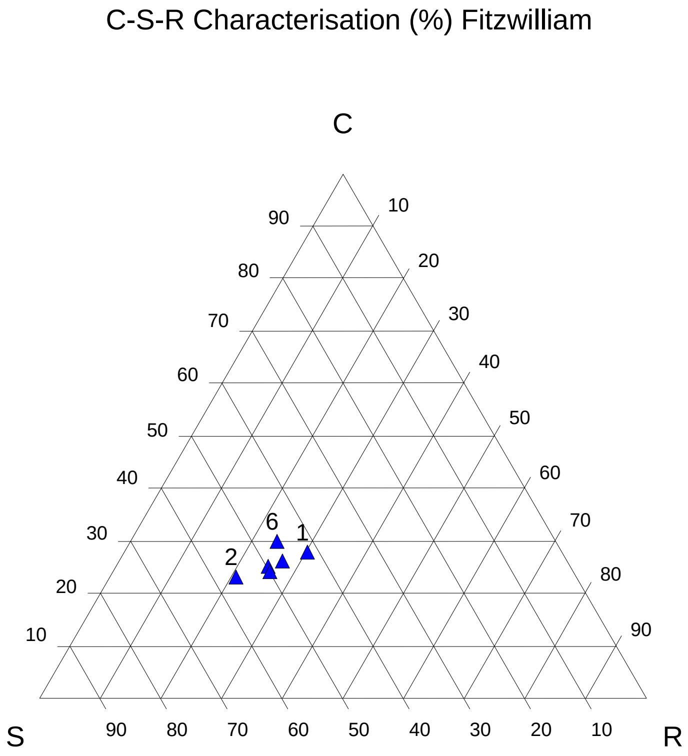


Figure 3.70 Triangular graph giving the C-S-R Characterisation for Fitzwilliam.

In Figure 3.71 the pattern is quite clear in that Upton quadrat areas are generally characterised more by competition and disturbance, whilst Fitzwilliam quadrat areas are characterised by stress. The appearance of Area 2 from Upton in the middle of the Fitzwilliam quadrat areas adds weight to the idea that the key stress factor is probably soil moisture.

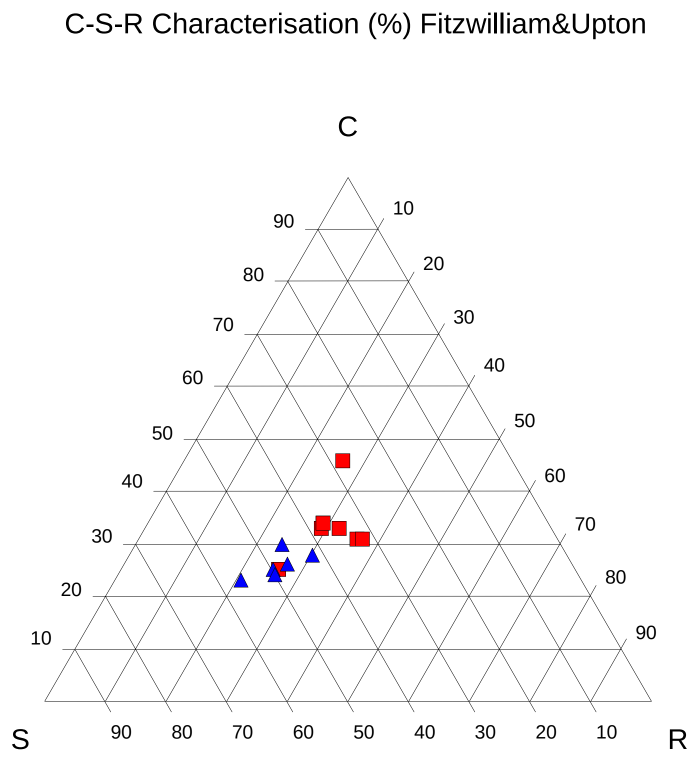


Figure 3.71 Triangular graph combining both sites. Triangles for Fitzwilliam, and squares for Upton.

3.4 Correlation Analysis

The plant axis data from the ordination was combined with the soil data (including the scaled data for rabbit droppings and bare earth) in Excel to produce a database (Appendix Tables 6 and 7). This data was then input into SPSS in order to investigate the relationships between the different variables. As axes 1 and 2 accounted for about 70 % of the total variance (Table 3.5), these were focussed on and bivariate correlation analysis was used to look at the strength and direction of the linear relationships using the Pearson r product-moment correlation coefficient. The correlations at the $P<0.01$ and $P<0.05$ significance levels are shown in Appendix Tables 8 and 9. From this database the correlations for each axis were tabulated separately for each site as shown in Table 3.6 (Upton) and 3.7 (Fitzwilliam).

For Upton, Table 3.6 shows that for Axis 1, three correlations (Nitrate-N, % Moisture & % Nitrogen) appear at the $P<0.01$ significance level. For Axis 2, four correlations are at the $P<0.01$ level and two at the $P<0.05$ level. Axis 3 produced no significant correlations and would appear to be noise, and Axis 4 has three correlations at the $P<0.01$ level.

For Fitzwilliam, Table 3.7 shows that for Axis 1, there is one correlation (Pb) at the $P<0.01$ level and one (Ammonium-N) at the $P<0.05$ level. Axis 2 has one significant correlation (Nitrate-N) at the $P<0.05$ level. Axis 3 has one significant correlation (% Moisture) at the $P<0.01$ level, and Axis 4 has three correlations at the $P<0.01$ level and two at the $P<0.05$ level.

Table 3.6 Upton: Pearson Correlations for each Axis.Table 3.7 Fitzwilliam: Pearson Correlations for each Axis.

Soil Variable	Axis 1	Axis 2	Axis 3	Axis 4	Soil Variable	Axis 1	Axis 2	Axis 3	Axis 4
pH	.313	**.393***	-.099	**.529****	pH	-.264	-.406	.031	.399
% Moisture (Dry Wt)	**-.555****	**-.553****	.155	-.098	% Moisture (Dry Wt)	.155	.113	**.698****	-.144
% Carbon	.298	**.439***	.126	-.021	% Carbon	.333	.020	.296	**-.600****
% Nitrogen	**.473****	**.514****	.022	-.100	% Nitrogen	.394	-.005	.357	**-.590****
Ammonium-N μg/kg^{-1}	-.066	.245	.126	-.242	Ammonium-N μg/kg^{-1}	**.543***	-.363	.378	.163
Nitrate-N μg/kg^{-1}	**.565****	.072	-.255	.082	Nitrate-N μg/kg^{-1}	-.222	**-.492***	-.106	.446
Phosphorus μg/g^{-1}	-.261	-.123	.072	.280	Phosphorus μg/g^{-1}	.197	-.330	-.142	-.170
Pb mg/kg^{-1}	.313	**.459****	.087	.088	Pb mg/kg^{-1}	**-.583****	-.054	-.202	**.631****
Zn mg/kg^{-1}	.322	**.601****	-.057	-.021	Zn mg/kg^{-1}	-.411	-.191	-.334	**.485***
Ca g/kg^{-1}	-.165	.080	-.064	**.455****	Ca g/kg^{-1}	-.353	.289	.021	**.479***
Mg g/kg^{-1}	-.195	-.034	.012	**.537****	Mg g/kg^{-1}	-.421	.027	-.034	.375

***. Correlation is significant at the 0.05 level (2-tailed).** ****. Correlation is significant at the 0.01 level (2-tailed).**

The soil variables are presented in separate correlation tables, Table 3.8 for Upton and Table 3.9 for Fitzwilliam.

Table 3.8 indicates that pH plays a significant role at Upton; producing correlations with five other soil variables at the $P<0.01$ level, notably calcium, magnesium and lead, as well as soil moisture and % carbon. % Carbon itself has a strong correlation with % nitrogen, and good correlations with ammonium-N, zinc and lead. % nitrogen also correlates with zinc and lead, as well as nitrate-N and ammonium-N. Soil moisture also correlates with lead and % nitrogen and at the $P<0.05$ level with zinc and phosphorus.

Table 3.8. Upton: Soil Variable Pearson Correlations.

pH	pH										
M %	-.505**	M %									
C %	.459**	-.396*	C %								
N %	.330	-.470**	.900**	N %							
NH_4^+-N µg kg^{-1}	.265	-.093	.635**	.495**	NH_4^+-N µg kg^{-1}						
NO_3^--N µg kg^{-1}	.176	-.077	.338	.603**	.113	NO_3^--N µg kg^{-1}					
P µg g^{-1}	.120	.351*	-.040	-.145	.015	.022	P µg g^{-1}				
Pb Mg kg^{-1}	.499**	-.580**	.602**	.626**	.228	.253	-.130	Pb mg/kg^{-1}			
Zn Mg kg^{-1}	.332	-.398*	.608**	.671**	.220	.429*	-.273	.557**	Zn Mg kg^{-1}		
Ca g kg^{-1}	.575**	.098	.324	.079	.353*	-.012	.300	.095	.040	Ca g kg^{-1}	
Mg g kg^{-1}	.572**	.227	.259	-.032	.300	-.059	.306	.041	.024	.932**	Mg g kg^{-1}

***. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). n= 32**

For Fitzwilliam, Table 3.9 indicates that at the $P<0.01$ level, % carbon correlates with five other soil variables, % nitrogen, lead, zinc, calcium and magnesium, as well as nitrate-N at the $P<0.05$ level. % nitrogen is similar, except for a correlation at the $P<0.05$ level with both nitrate-N and ammonium-N. pH is only significant at the $P<0.01$ level with magnesium and ammonium-N, but at the $P<0.05$ level there are correlations with calcium, lead, % nitrogen and phosphorus.

Table 3.9. Fitzwilliam: Soil Variable Pearson Correlations.

pH	pH										
M %	-.120	M %									
C %	-.533	.303	C %								
N %	-.482*	.425	.975**	N %							
NH_4^+-N µg kg^{-1}	.148	.351	.386	.462*	NH_4^+-N µg kg^{-1}						
NO_3^--N µg kg^{-1}	.637**	-.006	-.575*	-.500*	.168	NO_3^--N µg kg^{-1}					
P µg g^{-1}	.458*	-.128	-.104	-.044	.293	.279	P µg g^{-1}				
Pb Mg kg^{-1}	.540*	-.312	-.830**	-.852**	-.423	.527*	-.145	Pb Mg kg^{-1}			
Zn Mg kg^{-1}	.382	-.415	-.771**	-.782**	-.204	.542*	.170	.589**	Zn Mg kg^{-1}		
Ca g kg^{-1}	.563*	-.216	-.646**	-.705**	-.281	.264	.050	.699**	.437	Ca g kg^{-1}	
Mg g kg^{-1}	.641**	-.147	-.615**	-.679**	-.186	.357	.184	.672**	.454	.880**	Mg g kg^{-1}

***.Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). n= 19.**

The highlighted areas in Tables 3.8 and 3.9 indicate the significant correlations

3.4.1 Upton: Axis 1 Correlations at the P<0.01 Level.

The three interesting correlations with Axis 1 (Table 3.6) seem to relate Nitrate-N, Soil Moisture and % Nitrogen. Soil moisture (Figure 3.73) shows a negative correlation. As it increases, the Axis 1 gradient decreases, and two groups can be discerned, one in the cutting (Lower soil moisture), the other across the site. With % nitrogen, higher values in the cutting match with higher values on the axis. The correlation separates the two groups on the basis of soil moisture and nitrogen.

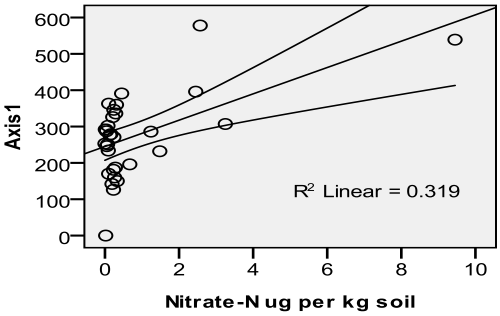


Figure 3.72 Upton: Axis 1 Correlations with NO_3^- - N.

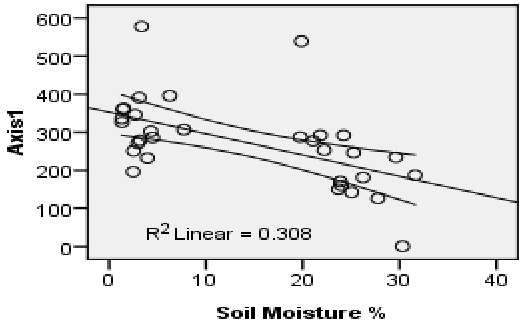


Figure 3.73 Upton: Axis 1 Correlations with % Soil Moisture.

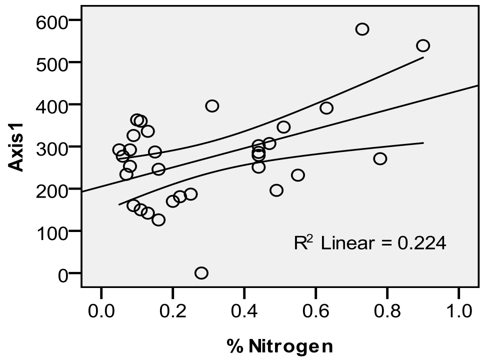


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Figure 3.74 Upton: Axis 1 Correlations with % Nitrogen.

3.4.2 Upton: Axis 2 Correlations at $P<0.01$ Significance Level.

With the Axis 2 correlations Soil Moisture shows a negative correlation and as with Axis 1, differentiates the cutting from the main site. % nitrogen reflects this same division, with higher concentrations in the cutting, and the other correlations possibly suggest a driving influence from Pb and Zn.

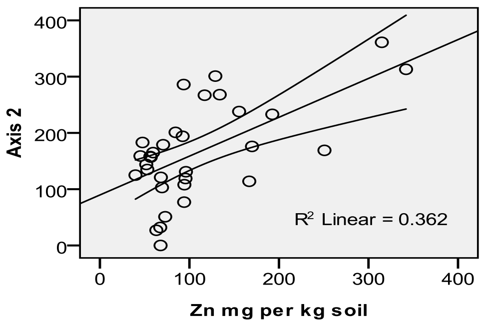


Figure 3.75 Upton: Axis 2 Correlations with Zinc.

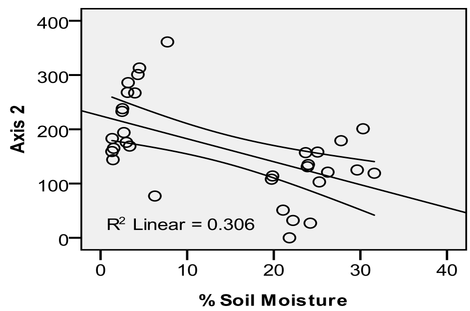
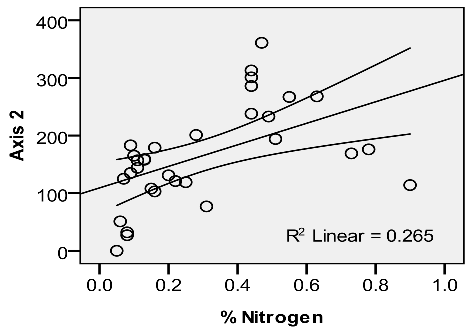


Figure 3.76 Upton: Axis 2 Correlations with % Soil moisture.



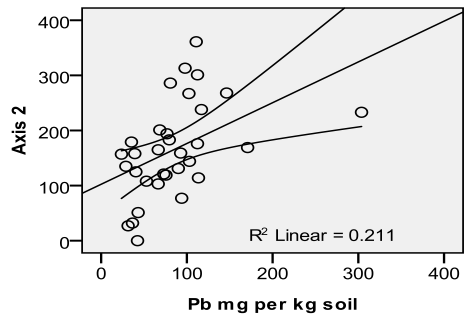


Figure 3.77 Upton: Axis 2 Correlations with % Nitrogen. Figure 3.78 Upton: Axis 2 Correlations with Pb levels.

Axis 2 produced one correlation at P<0.05 level, that for pH (Figure 3.79). This showed a division between the limestone areas (Area 2 and the cutting) and the rest of the site (Areas 1, 3, 4). The lower pH values reflect the quadrats not on the limestone.

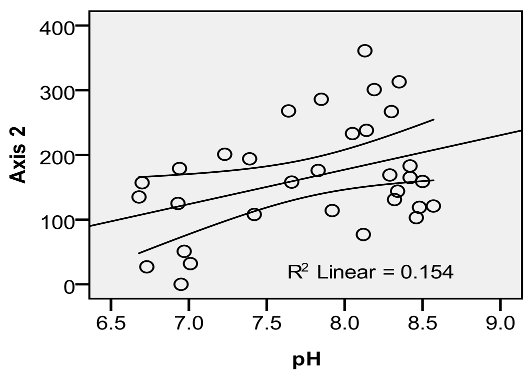


Figure 3.79 Upton: Axis 2 Correlations with pH at P<0.05.

3.4.3 Upton: Axis 4 correlations at the P<0.01 level.

Axis 4 seems to be linked to pH, calcium and magnesium at the P<0.01 significance level. pH (Figure 3.81) only showed a division between the cutting and the main site (apart from Area 2 quadrats on the limestone). Calcium and magnesium levels would be expected to show some correlation because many of the plant species on these sites like calcareous soils. Magnesium (Figure 3.80) had 28 % shared variance, as did pH, whereas Calcium (Figure 3.82) only shared 20 % of the variance.

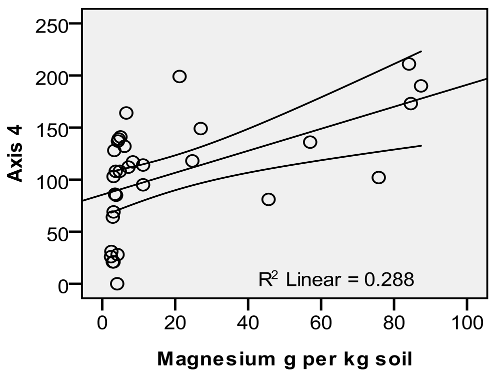


Figure 3.80 Upton: Axis 4 Correlations with Mg levels.

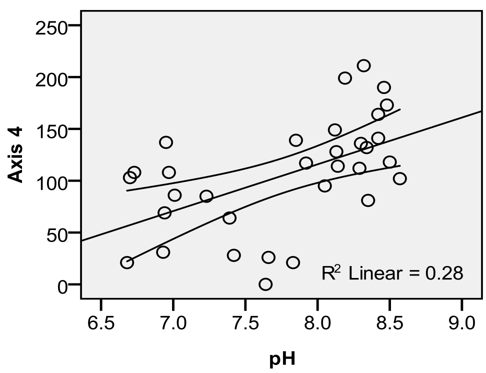


Figure 3.81 Upton: Axis 4 Correlations with pH.

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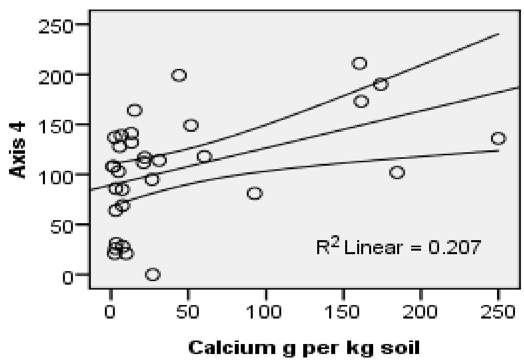

Figure 3.82 Upton: Axis 4 Correlations with calcium Levels

3.4.4 Fitzwilliam: Axis 1 Correlations at the P<0.05 Level or better.

Examining Axis 1(Table 3.7), two correlations appear significant at the 0.05 level or better. These are for Pb and ammonium-N. Figure 3.83 show that there is a negative correlation (-.583) between Axis 1 and the level of Pb in the soil, with 33.9 % shared variance. This indicates (based on the quadrats) the relationship between the Pb concentration and the Axis 1 value. The outliers are quadrats 1a and 1b.

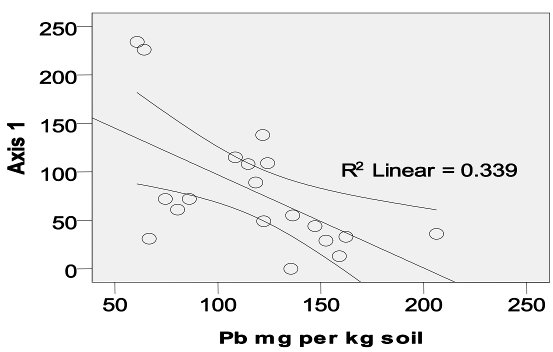

Figure 3.83 Fitzwilliam: Axis 1 Correlations with Pb (P<0.01)

The correlation between Axis 1 and the level of ammonium-N, shown by Table 3.7 and Figure 3.84 is a positive one (.543), but with only 29.5 % shared variance. The outliers (quadrats 1a and 1b) could be having an effect as quadrat 1b has the highest value of 9.64 µg kg^{-1} of soil. These two quadrats are highly influenced by the poultry farm, and there is probably no significant relationship without these two plots.

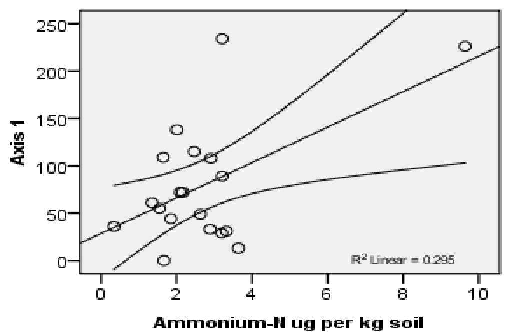

Figure 3.84 Fitzwilliam: Axis 1 Correlations with Ammonium-N (P<0.05).

3.4.5 Fitzwilliam: Axis 2 Correlations at P<0.05.

Axis 2 produced only one significant correlation, which was -.492 (Table 3.9) for Nitrate-N levels.

With a negative correlation of -.492 (Table 3.7), scattergraph (Figure 3.85) shows that as the level of NO_3^- -N increases, the length of the Axis 2 gradient gets shorter. 24.2 % of the variance is explained.

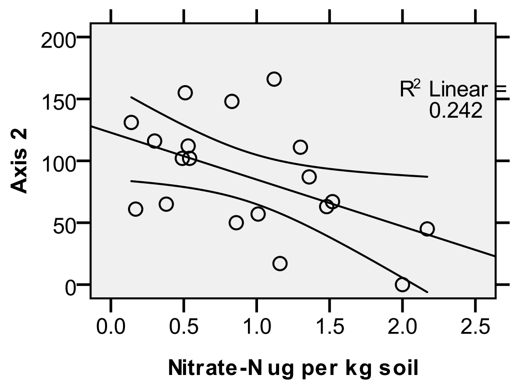

Figure 3.85 Fitzwilliam: Axis 2 Correlations with Nitrate-N (P<0.05).

3.4.6 Fitzwilliam: Axis 3 Correlation at P<0.01.

Axis 3 only produced one significant correlation, a positive for the percentage soil moisture (.698). The positive correlation between Axis 3 and % Soil moisture (Table 3.7 and Figure 3.86) shows up clearly, with 48.7 % shared variance.

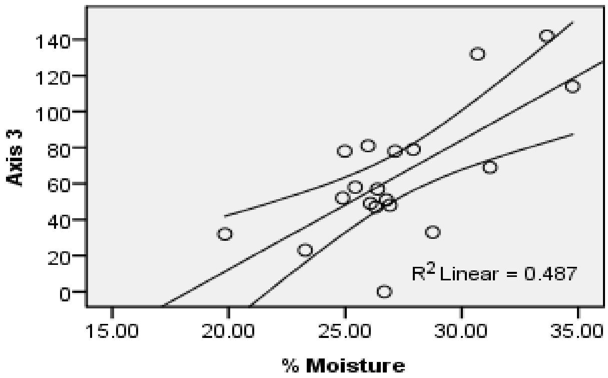

Figure 3.86 Fitzwilliam: Axis 3 Correlations with % Soil Moisture (P<0.01).

3.4.7 Fitzwilliam: Axis 4 Correlations at the P<0.05 Significance Level or better.

Axis 4 for Fitzwilliam produced five correlations of which three were significant at P<0.01 and two at P<0.05 (Table 3.7).

Figure 3.87 shows a positive correlation between Axis 4 and the level of Pb in the soil, with 39.8 % shared variance. The outlier is quadrat 1b.

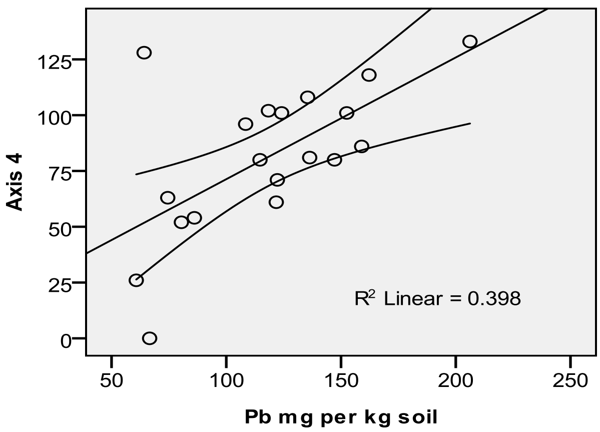

Figure 3.87 Fitzwilliam: Axis 4 Correlations with Pb (P<0.01).

Figure 3.88 shows a negative correlation between Axis 4 and the % Carbon (-.600) with 36.1 % shared variance. The outlier is quadrat 1b.

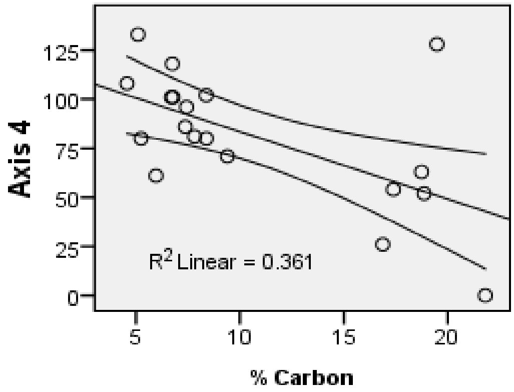

Figure 3.88 Fitzwilliam: Axis 4 Correlations with % Carbon (P<0.01).

Figure 3.89 shows a negative correlation between Axis 4 and the percentage Nitrogen (-.590), with 34.8 % variance. The outlier is quadrat 1b.

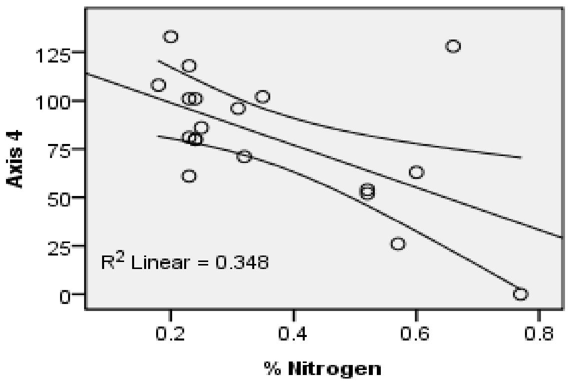

Figure 3.89 Fitzwilliam: Axis 4 Correlations with % Nitrogen (P<0.01).

Figure 3.90 shows a positive correlation between Axis 4 and the level of Zinc in the soil (.485), with 23.5 % variance.

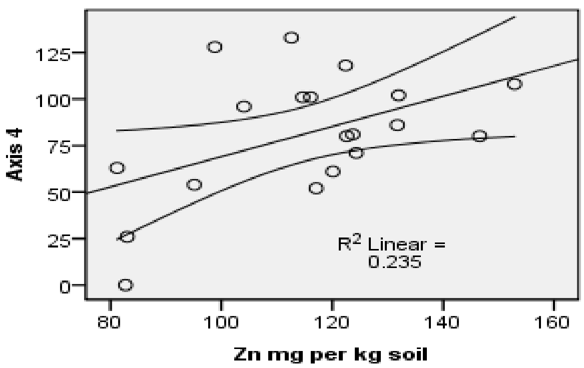

Figure 3.90 Fitzwilliam: Axis 4 Correlations with Zn (P<0.05).

Figure 3.91 shows a positive correlation between Axis 4 and the level of calcium in the soil (.479), with 22.9 % variance.

Axis 4 at Fitzwilliam would appear to represent a gradient for metal content of the soil.

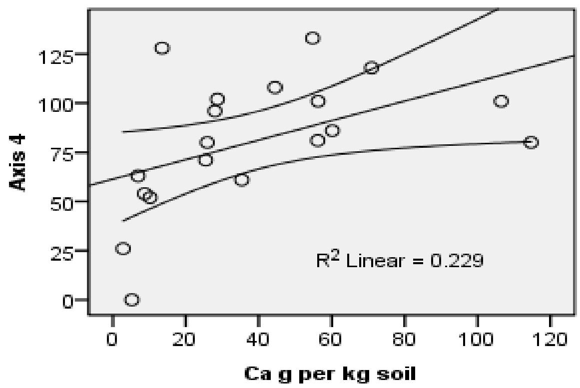

Figure 3.91 Fitzwilliam: Axis 4 Correlations with Calcium (P<0.05).

3.5 Mean Soil Variable Correlations.

3.5.1 Correlations common to both sites.

When the correlation coefficients for the mean soil variables for both sites are examined (Tables 3.10 and 3.9), two correlations at the P<0.01 level, and one correlation at the P<0.05 level can be identified as common to both Upton and Fitzwilliam. These are:

P<0.01:

- **% C to % N,**
- **%N to Zn.**

P<0.05:

- **%N to Pb.**

%C to Zn correlates at P<0.01 at Fitzwilliam and at P<0.05 at Upton.

The link between nutrient levels and Pb and Zn on both sites seems a strong one.

3.5.2 Significant Mean Soil Variables

Table 3.10 for Upton further emphasises the links between pH and moisture with Pb, and also a relationship involving ammonium-N with calcium and % carbon. The correlations between calcium and magnesium, pH and calcium are not unexpected, considering the type of limestone present.

Table 3.10 Upton: Pearson r correlation coefficients at 0.01 and 0.05 significance levels for mean soil variables only.

Variable	Variable	Pearson r	Significance (2-tailed)	Variable	Variable	Pearson r	Significance (2-tailed)
Ca	Mg	.960	.0001	pH	Pb	.798	.018
%C	%N	.920	.001	%C	NH_4^+-N	.791	.019
Moisture%	Pb	-.882	.004	Moisture%	%N	-.752	.031
%N	Zn	.856	.007	NH_4^+-N	Ca	.744	.034
				%N	Pb	.732	.039
				pH	Ca	.709	.049
				%C	Zn	.708	.049

Correlation significant at P<0.01 level (2-tailed) Correlation significant at P<0.05 level (2-tailed)

Correlations highlighted are those common to both sites.

For Fitzwilliam, Table 3.11 highlights a relationship between Pb and Zn that is not unexpected, although the Pb to calcium is interesting, as to where the source of the calcium might be. Moisture % with ammonium-N could be emphasising the deposition from the poultry farms.

Table 3.11 Fitzwilliam: Pearson r correlation coefficients at 0.01 and 0.05 significance levels for mean soil variables only.

Variable	Variable	Pearson r	Significance (2-tailed)	Variable	Variable	Pearson r	Significance (2-tailed)
%C	%N	.972	.001	%N	Pb	-.894	.016
%N	Zn	-.951	.004	Pb	Ca	.875	.022
%C	Zn	-.942	.005	pH	Mg	.864	.026
				Moisture%	NH_4^+-N	.848	.033
				Pb	Zn	.827	.042

Correlation significant at P<0.01 level (2-tailed) Correlation significant at P<0.05 level (2-tailed)

Correlations highlighted are those common to both sites.

Chapter 4

Community Involvement

As part of this study to try to determine the factors influencing the plant diversity on these two sites, it was important to get a historical perspective of the events that had affected them. Although officers of Wakefield Metropolitan District Council went out of their way to track down documents relating to the restoration of the sites, it was discovered that in all probability, many of the relevant files either no longer existed, or their whereabouts were unknown. This meant that input from the local community was vital. Contacts were made with Local Interest Groups, in particular, The Fitzwilliam Country Park Group/Friends of Fitzwilliam, The Upton Anglers' Association, and The Upton Local History Group.

As a result of these contacts a number of local people came forward with often very detailed information about the sites, including photographs and even documents. There had been a planning enquiry at Upton to do with opencast mining as well as the restoration and several local people produced documents from this, including a tree planting diagram which recorded also that the seeds for the wildflower restoration would be collected from the railway cutting.

Online, the Fitzwilliam Archive (www.fitzwilliamarchive.co.uk/history.aspx) proved very useful, and not just for the history of the site. Wakefield MDC also had a useful website for historical information on the sites (www.wakefield.gov.uk:).

It was decided to carry out a Rapid Action Participatory GIS mapping exercise on each site to get as much information about the sites as people could recall.

Figures 4.1a and b show the timelines produced as part of the RAP GIS work carried out at Upton and Fitzwilliam respectively. Figures 4.2 and 4.3 show the resulting maps produced for each site. One key difference between the sites lies in the period of time between mine closure and restoration. Upton closed in 1964, the site cleared by 1971, but restoration didn't happen until 1990-1996, whereas although the Hemsworth Colliery at Fitzwilliam had closed by 1967, the site was still used to deposit mine waste, and it wasn't until after 1987 that restoration began. So Upton had a 20 year natural regeneration period, with the railway cutting acting as a natural seed bank, whereas Fitzwilliam basically went from mine spoil tip to restoration. A second key factor brought out by the local community at Upton, was that the spoil from the mine was not dumped on the mine site, but went to an area to the north of the site, and it was this area that was proposed to be turned into a golf course. Fitzwilliam, however was laid out as a golf course in 1990, hence the large areas of grass as can be seen on Figure 4. 3.

Year	Activity	Vegetation impacts	Mapped
1964	Pit Shutdown		
1965			
1966			
1967			
1968	Railway lines into site shut, Clay extraction (for the brick works)	Salvaging materials would have disturbed the site	
1969			
1970			
1971	Railway lines completely removed		Yes
1972			
1973			
1974			
1975			
1976	Proposed open cast coal mine for the site		
1977			
1978	Proposed limestone quarry		
1979			
1980	BMX park built; Bee orchids noticed for first time	Disturbance of soil to build BMX track and jumps	Yes
1981			
1982			
1983			
1984	National Miners Strike	Tree coppicing for fuelwood, coal digging led to development of first pond (since infilled during development of the big pond)	
1985	Proposed golf course		
1986			
1987			
1988	Wildlife Trust recognises the wildlife value of the site		
1989			
1990	Doctor's surgery built encroaching onto the site, planning application approved for open casting of coal and relocation of the clothing factory	Disturbance around surgery during building	
1991	January - Phase 1 planting plan (tree planting on site) (not clear if undertaken)		
1992	May - Planning enquiry about the site. After use plan version 2 produced February		
1993			
1994	Major landscaping - Phase II planting	Sluices built on marshy land, brick rubble and flues crushed with rubble spread around site, air raid shelter demolished, new topsoil brought in from Green Lane area for the sport field, rest of site covered in rubble	Yes
1995			
1996	School built	Disturbance of site around school building; Seskew environment group undertake tree planting onsite	
1997			
1998			
1999			
2000			
2001			
2002			
2003			
2004			
2005	Major floods; Factory Built; Walkways to the Spout Hole installed	Floods around the 'coffin' ponds; trees planted to screen the factory site from park	Yes
2006			
2007	Play area installed. Phase I Habitat Survey undertaken	Top soil skimmed off, protective covering added	
2008	Spout Hole tree clearance	Willow trees removed from Spot Hole - leaving trunks;	Yes
2009	Settling ponds built; Scrapes and hollows built	Extra ponds built to improve (slow) movement of flood water	
2010			

a) Upton.

1967	Pit Closed		
1968			
1969			
1970			
1971			
1972	***Site Cleared - Buildings removed and cleared, railway lines removed***		
1973	***Pit waste continues to be dumped onsite***		
1974			
1975			
1976			
1977	Drift Mine Opens		
1978	***Pit waste continues to be dumped onsite***		
1979			
1980			
1981			
1982			
1983			
1984	Miners Strike - Coal collected from coal stacks; Pit waste continues to be dumped onsite		
1985			
1986			
1987	Drift Mine Closes		
1988			
1989			
1990	***Topsoil added to site - probably sourced from close by; Coucil begin feeding trees on-site; Park landscaped to become a golf course***	Tree planting	
1991			
1992			
1993	Mixed use of site		
1994			
1995	Site cleared of abandoned cars and rubbish		
1996	BMX path built in park		
1997			
1998	Country park group started up		
1999	First paths through site built; Fences built to deter cars entering park; Seats added around the pond	Little disturbance to vegetation	
2000			
2001			
2002			
2003			
2004	***Improvements in wildlife and plantlife; Range of different species seen; Decline in butterflies***		
2005	Stolen digger damages park - demolishing seats and felling trees	Trees knocked down	
2006	Wildlife survey undertaken; Water voles found onsite		
2007			
2008	Given status of nature reserve		
2009			
2010	Some trees removed	Trees cut down	

b) Fitzwilliam.

Figure 4.1 Timelines: a) Upton, b) Fitzwilliam.

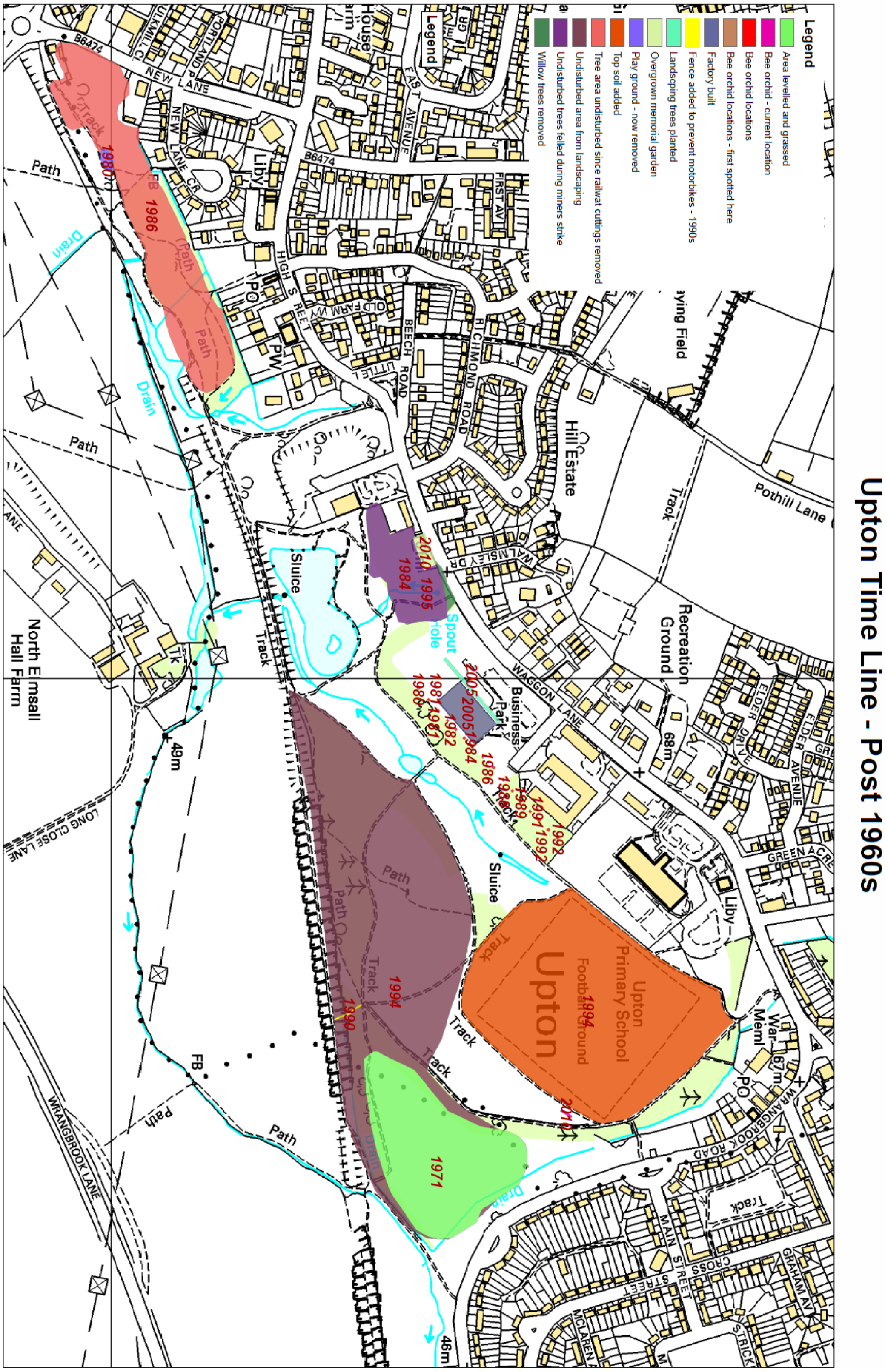

Figure 4.2 RAPGIS Map for Upton. S. Cinderby.

Figure 4.3 RAPGIS Map for Fitzwilliam. S. Cinderby.

A number of people wanted to get involved with recording what was on the sites. One particular exercise which it was hoped would produce useful data was to look for key indicator plants in order to assess whether the grassland areas were in good or poor condition. This was based on the indicator plants used in the Environmental Stewardship Farm Environment Plan Guidance (RDS, 2005) and particularly the Lincolnshire Wildlife Trust's "Life on the Verge Survey" (Schofield, 2009) which was concerned with the state of the road verges in the limestone areas of Lincolnshire and Rutland, As this survey was specifically for limestone grassland, and considering the pH levels, it was felt to be more appropriate for adaptation to be used for Upton and Fitzwilliam. The volunteers were given a map with different areas of grassland coloured in and each area numbered. The boundaries of the areas were defined by the paths, and the idea was that they would walk round the areas and identify which of the indicator plants was present. They could also try to judge abundance on a simple Few, Several, Many scale, but it was the present/not present that was the most important. They were also given a plant identification guide. The areas on their maps matched the quadrat areas, so the results from their survey would provide broad confirmation of the Area data derived from the quadrats. Sessions were arranged to take the volunteers round and help them in identifying the plants.

Three volunteers carried out the survey at Fitzwilliam, but for a number of reasons only one person did the survey at Upton, and that was for the cutting only (Table 4.2). The data from each volunteer was merged to produce a simple record. The results for Fitzwilliam are shown in Table 4.1, which suggests that the Fitzwilliam grassland areas are generally not in the best condition.

Table 4.1 Summary of Survey Data assessing condition at Fitzwilliam.

Indicator of Good Condition	Areas present	Indicators of Poor Condition	Areas present
Orchids	3, 5	Ivy	
Cowslip		Bracken	1
Perforate St John's Wort	3, 4	Bramble	1,2,4,5,6
Yellow Rattle	1,2,3,5,6	Nettle	2,5,6
Wild Carrot		Cow Parsley	1,2,4,5,6
Clustered Bellflower		Hogweed	1,2,3,4,5,6
Fairy Flax		Broad-leaved Dock	2,4,5,6
Marjoram		Common Ragwort	1,2,3,4,5,6
Wild Basil		Creeping Thistle	1,2,3,4,5,6
Viper's Bugloss	2,5	Spear Thistle	1,2,3,4,5,6

Table 4.2 shows the single survey of the cutting, and reflects the variety of habitats along there, from open, grassier areas, to shaded tree/bush understory. The nature of the ballast may well be having an effect here, as well as the weathered limestone rock faces.

Table 4.2 Summary of Survey Data assessing condition of cutting at Upton.

Indicator of Good Condition	Indicator of Poor Condition
Perforate St John's Wort	Ivy
Clustered Bellflower	Bracken
Wild Basil	Bramble
Bladder Campion	Nettle
Common Knapweed	Hogweed
	Spear Thistle

Compared to the plant list originally produced by the Fitzwilliam Country Park Group, and from the Phase 1 Habitat Survey the list of just 33 species in the quadrats suggests a possible reduction in plant richness. Other plant species that were once more common like the Viper's Bugloss, were seen in only two areas, and there were only a few specimens, yet following the restoration in 1991 (Pipkin. Pers.com. 2011), it was more numerous and more widespread. A number of other plant species were observed whilst walking round the site, but the conclusion is still that for many species abundance has declined at Fitzwilliam. At Upton, this was not the case, and here both abundance and number of species seemed to be on the increase, even since the Phase 1 Habitat Survey in 2007. This was brought out by the discovery of *Hypericum montanum and Parentucellia viscosa*. *P. viscosa* is a new record for the area, and has only been recorded in West Yorkshire on three occasions in recent times (Lavin and Wilmore, 1994).

The Upton site was also notable for the involvement of members of the local community in planting trees, flowers and shrubs in various places across the site, but particularly near the Angler's pond. Near the car park are two *Leylandii spp.* trees and by two of the fishing platforms can be found two different coloured *Cyclamen spp.* that someone planted. Near the information board by the pit shaft monument, are examples of the Spindle tree (*Euonymous europaeus)*, *Potentilla spp.* and apple (*Malus spp)*.

The implication being that the local community has contributed to the floral diversity.

Chapter 5: Discussion

5.1 Soil Variables

For reclaimed coal mine sites only 6.5 km apart (Figure 1), one would expect to see a certain degree of similarity in plant species composition and plant diversity. Whereas that is true up to a point, there are also a number of differences which stand out, not only between the two sites, but also within them, and especially within the Upton site. Plants can obtain from the soil all the elements they need, apart from carbon and oxygen (Bradshaw & Chadwick, 1980), so the soil is the likely key to explaining the differences at such climatically similar sites. Certain inorganic macronutrients such as nitrogen, phosphorus, calcium and magnesium are needed in relatively large amounts, whereas other micro-nutrients, such as zinc, are needed in small or trace amounts. However, a lack or deficiency of some of these elements can contribute to poor establishment of certain plant species (Stahl et al., 2006). Also, different species require different amounts of nutrients and fast growing species require more than those which grow slowly. For example, *Lolium perenne* (perennial ryegrass) requires fertile soils (Bradshaw, 1980) and only appeared in one quadrat at Upton and none at Fitzwilliam, yet the north east area of the Fitzwilliam site (outside the study area because of its limited botanical interest) was sown with *L. perenne* to be harvested as a hay crop following the reclamation in the 1980s, when the former Hemsworth Colliery tip was treated with imported topsoil and manure from the nearby poultry farms (Pipkin, pers. com., 2011). Other grasses, such as *Festuca ovina*, can tolerate much poorer soils and occurred in 11 quadrats at Upton and 18 at Fitzwilliam, which suggests that perhaps the soil in the areas studied at Fitzwilliam and Upton may be more suited to a grass that can tolerate lower levels of key nutrients.

pH appears to be critical to what is happening on both sites. On reclaimed coal mines, the expectation would be for the mine spoil to be acidic, due to the levels of iron pyrites present in the shales becoming oxidised, but the pH levels for Upton show a range from 6.6 to 8.5, and for Fitzwilliam from 7.2 to 8.2. An explanation for this apparent anomaly can be found at Upton, where not only is there an outcrop of the Permian Lower Magnesium Limestone of the Cadeby Formation (Lake, 1999), but the site was partly covered with local calcareous clay and waste material from the onsite brickworks. Water draining on to the site has a high pH (pH 8 at Spout Hole) as a result of being derived from the limestone. However, this situation does not apply at Fitzwilliam, where the whole site consists of mine waste on top of the Newstead Rock sandstone of the Ackworth Member of the Upper Coal Measures (Lake, 1999). The fact that the spoil heaps had suffered internal combustion could have helped reduce the acidic effect of the iron pyrites, but it is debateable whether that on its own could produce these relatively high pH levels. The sandstone is an aquifer, and it has been recognised that in the Yorkshire Coalfield, groundwater at outcrop tends to be of the calcium bicarbonate type (Lake, 1999), and this would seem to be the most likely explanation for the Fitzwilliam pH levels, which fall within the range of examples given by Lake (1999).The Upton site has a much greater range of pH (Figures 3.1 and 3.2), but the pattern shows a distinct split between Areas 5, 6, 7 and 8 in the railway cutting, together with Area 2, and Areas 1, 3 and 4.The dividing line seems to be the Spout Lane Fault, which has brought the limestone down to the level of the coal measures, and the change is quite abrupt (Figure 1.3). For both Upton and Fitzwilliam it is more than likely that the faults have acted as water conduits and so allowed water from the Cadeby Formation Limestones to penetrate the Upper Coal Measure formations (Lake, 1999). It is also significant that the Upper Coal Measures in particular in this area seem to have high carbonate content, with iron deposits occurring in the carbonate form and pyritization being an uncommon occurrence (Goossens and Smith, 1973).

The implication is therefore that the underlying solid geology is having an influence on the soil conditions and manifesting itself through the pH, influenced by water movements.

Water availability is another key property of any soil (Briggs, 1977). Water infiltration is dependent on the state of the soil pores and fissures in the surface layers. Water is held in the pore space by cohesive and adhesive forces (Pierzynski, et al., 2005). Cohesive forces are the result of water molecule polarity and hydrogen bonding, whereas adhesive forces are those responsible for attracting water molecules to the soil mineral and organic matter surfaces. If the soil is compacted during the reclamation process then pore spaces are reduced and infiltration will be slow and surface run-off will dominate. The variable nature of mine spoil and the way a site is treated can result in variations in moisture holding properties over very short distances. This can lead to soil particles being moved down slopes and gulley erosion developing. Slight hollows in otherwise level areas will collect water until they dry out, either through infiltration or evaporation. At Upton, there is a very clear division between the railway cutting and the rest of the site with regards to the soil moisture content (Figures 3.3 and 3.4). The railway cutting has a low moisture level relative to the rest of the site, probably due mainly to the very loose structure of the soil on the cutting sides and top (partly due to rabbit activity) and the loose nature of the old railway ballast. The moisture here would be that held by adhesive forces. The rest of the site reflects better water retention and movement. This is due to a better soil structure linked to the reclamation processes and the later alteration in 2007 for the drainage scrapes, particularly around Areas 3 and 4. Being on slopes facilitates drainage. Fitzwilliam (Figures 3.31 and 3.32) matches well with the main site at Upton, and Area 1 at Fitzwilliam, which has the highest value at Fitzwilliam, is also on a slope and both sites have had some clay covering during reclamation. This indicates certain similarities between the two sites if one discounts the railway cutting at Upton.

Soil organic matter serves as a source of many essential nutrients (Cresser & Killham, 1993), especially nitrogen and phosphorus, and trace elements such as zinc. It also is a source of carbon, as organic matter is a highly complex mixture of plant compounds which are being recycled by the soil biota into forms which the plant roots can absorb for the plant to use. Decomposition yields CO_2, NH_4^+, NO_3^-, PO_3^-, and SO_4^{2-}. Organic matter can also hold up to twenty times its weight in water (Pierzynski, et al., 2005) and can absorb trace element pollutants such as Pb. The correlation matrices for Upton support the idea that nitrogen, in the nitrate-N form, together with rabbit droppings, are key drivers for Axis 1, reflecting the importance of nutrient levels, as well as moisture availability, in determining plant species composition.

The implication is that the availability of these nutrients is closely tied to pH, together with soil moisture.

Taking carbon and nitrogen content first, the pattern at Upton (Figures 3.5 – 3.8) shows a distinction between Areas 1, 3 and 4 and the cutting, although Area 8 in the cutting has values similar to the main site, possibly due to being near to the Spout Lane Fault which brings the limestone up against the coal measures. Area 2 at Upton also behaves differently for carbon, having more in common with the cutting, as it is on the limestone. Nitrogen has a lower value, most likely reflecting a relatively low level of organic matter in the thin limestone soil. The pattern at Fitzwilliam is similar (Figures 3.33 to 3.36), with most areas having C and N contents within the range observed at Upton, and only Area 1 standing out. Significantly Area 1 at Fitzwilliam is on the slope nearest to the poultry farm, and with the prevailing south-westerly winds, the farm is a potential source for nitrogen deposition. The C: N ratios show that Area 3 at Fitzwilliam (Figures 3.37 and 3.38) has the biggest ratio there (35) at that site, although Area 2 at Upton (Figures 3.9 and 3.10) has the greater value, of 67. A C: N ratio less than 32-35 is necessary for significant N mineralisation to occur (Charman & Murphy, 2007), and most quadrats at both Upton and Fitzwilliam fall below that value. The dividing line between immobilisation and release of N is about 20: 1. Mineralisation is the process by which organic nitrogen is converted by nitrogen-fixing microorganisms, such as *Rhizobium spp.* to ammonium, a process that is pH and temperature dependent (Cresser & Killham, 1993). Although these figures reflect a relatively low level of organic material on both sites, the findings of Ingram et al. (2005) suggest that the requirements by plant communities for N mineralisation are potentially more than satisfied on reclaimed mine soils in general. It would seem that the rate of N-mineralisation in reclaimed mine soils is equal to, or even greater than on nearby undisturbed soils (Stahl et al., 2006). It also needs to be considered that nitrogen can also originate from certain marine pelagic sediments (Morford, et al., 2011), many of which have high levels of organic matter, as do coal measure shales and mudstones, a source of nitrogen often over-looked and in the past, ignored (Morford, et al., 2011). The ammonium can be oxidised to nitrate, but any nitrate not immediately used by the plants can be leached, so sites on slopes are likely to have lower nitrate levels, particularly if they have low concentrations of organic material (and therefore low ammonium levels) as well. At Upton (Figures 3.11 and 3.12) the drainage scrapes followed this pattern, as did most of the cutting, apart from Areas 2 and 5, which, being the nearest and most exposed to, arable land could be subject to windblown deposition, as well as organic matter. At Fitzwilliam (Figures 3.39 and 3.40) the effect of deposition from the poultry farm stands out in Area 1, which produced the highest concentration of ammonium in quadrat 1b. Nitrogen deposition can have the effect of increasing soil nutrient levels and causing "more sensitive and often uncommon species to be replaced by more aggressive, generally commoner, opportunistic species" (Rotherham, et al., 2003). Acidic conditions reduce the rate of bacterial conversion of ammonium to nitrate, and although the pH levels at both sites are in the neutral to alkaline range, both sites have areas with pH>8, a point beyond which the mineralisation rate also declines (Cresser & Killham, 1993). At Upton the very high pH is related to the limestone, but at Fitzwilliam it is harder to explain, unless it is caused by an area of clay or limestone rubble. For nitrate-N, both sites had relatively low concentrations, although Fitzwilliam (Figures 3.41 and 3.42) showed less range but slightly higher concentrations than at Upton (Figures 3.13 and 3.14). At Fitzwilliam, the quadrats with the higher levels of nitrate-N (Areas 2, 5 and 6) are all in grasslands and have lower C: N ratios, suggesting that there are reasonable levels of organic material and that leaching is not an issue in these areas. The area at Upton which most closely matches the higher nitrate-N levels at Fitzwilliam is Area 6, which does have a significant accumulation of leaf litter. The ammonium-N: nitrate-N ratios are greater in the scrapes at Upton (Figures 3.15 and 3.16) and Area 1 at Fitzwilliam (Figures 3.43 and 3.44), reflecting both the leaching effect of being on slopes, and higher ammonium-N inputs.

The implication is that N, NO_3^- and NH_4^+ are the variables more directly related to plant response.

At Upton there seems to be a strong relationship between the C: N ratios and the limestone, with the highest levels of calcium found on the limestone, and coinciding with higher C: N ratios, whereas the lower ratios match with the areas not on the limestone. However, at Fitzwilliam, where there is no limestone bedrock, the pattern shows only a little variation (21 – 36), probably caused by the way the site was reclaimed.

Like nitrogen, most phosphorus is derived from the recycling of organic material, being released when the organic matter decays, As soil pH declines to approach neutrality (pH 7), phosphorus availability increases (Cresser & Killham, 1993), but at the same time microbial activity increases, resulting in mineralisation of some of the organic phosphorus. Above pH 7, due to the high calcium concentrations, calcium phosphate begins to be precipitated, which is only sparingly soluble. However, the presence of iron minerals and zinc can result in increased adsorption of phosphate (Bolland, et al., 1977). Organic phosphorus can make up to 65 % of the total soil phosphorus and only a small amount needs to be hydrolysed to meet the demands of the plants (Turner, 2008). Most plants only take up the phosphorus available within no more than 2 mm of the plant roots (Bradshaw & Chadwick, 1980), so a poor root system means a poor uptake of phosphorus. The phosphorus levels did not relate clearly to the axes of variation at either site, and the small variation and values may not reflect real phosphorus availability. At Upton, Area 2 not only has the highest mean pH (8.46), but also the highest mean phosphorus level at 111 $\mu g\ g^{-1}$ of soil (Figures 3.17 and 3.18). Being on the limestone, the pH level is to be expected and means that phosphate will be present as calcium phosphate, and so of limited availability, although mycorrhizal fungi may ameliorate this to some extent, especially through resource partitioning, whereby different species can make use of the various organic compounds (Turner, 2008). At Fitzwilliam (Figures 3.45 and 3.46), most areas had similar phosphorus levels, apart from Areas 6 and 2, which followed the same pattern of higher nutrient levels as for nitrate-N. It could be that enough organic material is available, and being level areas, the nitrate-N and the phosphates are not being leached away so quickly.

Lead and zinc concentrations were examined because it is known that the Lower Magnesium Limestone of the Cadeby Formation contains Pb-Zn sulphides. These occur in vugs and breccias of sedimentary origin (Harwood & Smith, 1986). They are the result of the movement of low-temperature hypersaline brines from the underlying Carboniferous strata (Scruton, 1994) during the period of the Pennine mineralisation following the Variscan earth-movements in latest Carboniferous and early Permian times (Lake, 1999). These mineralising fluids would have utilised the faults as conduits and permeated the Coal Measure sediments, so providing another possible source of Pb and Zn on the two sites. Another possible source to consider was railway ballast, particularly in the cutting at Upton. The lead levels at Upton (Figure 3.19) were all below 200 mg kg^{-1}, except for quadrat 8d at 303 mg kg^{-1}. The range of Pb in normal soils is between 2-200 mg kg^{-1} of soil (Morrey et al.,1988), suggesting that on the whole, Pb would not be an issue regarding toxicity at Upton, especially as the pH levels (all above 6.6) would result in lead precipitating as insoluble lead phosphates (Clark & Clark, 1981) and becoming immobile. The higher concentrations in the railway cutting could be from the ballast, but quadrat 8d is close to the Spout Lane Fault and weathered Coal Measure rocks are exposed in the cutting at the unconformity with the Cadeby Formation Limestone. Therefore a more detailed investigation of the ballast is needed to see if it is contributing lead and zinc, rather than just acting as a depositional substrate for downwash from the cutting sides. At Fitzwilliam (Figures 3.47 and 3.48), the levels of Pb are generally higher than at Upton (Figures 3.19 and 3.20), but with one exception (Quadrat 5c), they are within the range in normal soils (Morrey, et al., 1988). Quadrat 5c, at 206 mg kg^{-1} of soil, is only just over this normal range. The Pb at Fitzwilliam can only come from the colliery spoil, or the deposit of topsoil brought in during the reclamation process in 1991 (Pipkin, pers.com. 2011). However, as at Upton, with the pH levels all above 7, the Pb is in effect immobile.

Soils formed from the weathering of limestones tend not to be zinc deficient and shales tend to have the highest concentrations (Shuman, 1980), although iron minerals can also play a part in zinc adsorption, Goethite (α-FeOOH) in particular, especially in the presence of phosphate (Bolland, et al., 1977).The pattern for zinc is very similar to that for lead, with concentrations within the range in normal soils (10-300 mg kg^{-1}) (Morrey, et al., 1988) apart from quadrats 6b (342mg kg^{-1}) and 6c (315 mg kg^{-1}) at Upton (Figures 3.21 and 3.22). Again, these higher concentrations are in the cutting, significantly in quadrats with large areas of bare earth derived from the burrowing effects of rabbits in the limestone soil. These high levels are not directly linked to ballast. The rabbits could be increasing the nutrient levels in the soil with their droppings, which could help reduce the harmful effects of the metals (Clark & Clark, 1981). However, the buffering effect of the limestone and high pH may be immobilising the zinc, causing zinc deficiencies. Tiller et al. (1972) however, argued that, as well as soluble organic matter content, the particle size of the carbonate was important, rather than the calcium carbonate content itself. Sandy-textured, low-organic matter soils have lower zinc adsorption than finer textured or high organic content ones (Stahl & James, 1991). Yet, it appears that plants can abstract from organic complexes the required levels of zinc they need if the pH is high (Shuman, 1980). Interestingly, Areas 1, 3 and 4 at Upton have the lowest mean concentrations of zinc, as they did for lead, again implying that the metals are most likely originating from the limestone, although the ballast in the cutting cannot be ruled out as a possible contributor. At Fitzwilliam (Figures 3.49 and 3.50), the zinc levels, whist following a similar pattern as for lead, showed even less variation, with Area 1 again having the lowest concentration. Area 1 appears not to have any layer of clay on top of the spoil and to have had less treatment during reclamation. This suggests that the zinc level has been augmented elsewhere on the site from the topsoil and clay used in the reclamation process. The presence of both organic matter and clay increases the cation exchange capacity (CEC) of the soil, which also increases as pH increases (Brooks, 1972). Zinc toxicity has been found to affect various species of soil microorganisms, in particular the nitrogen-fixing symbiotic bacterium *Rhizobium* found in the root nodules of legumes such as *Trifolium repens* (white clover), even within the EU maximum permissible value of 300 mg kg^{-1} (Alloway & Ayres, 1997). This could account for the very low presence of *T. repens* in the Area 6 quadrats at Upton and the cutting in general. The correlation matrices for both Upton (Axis 2) and

Fitzwilliam (Axis 4) seem to suggest the possible contamination role of lead and zinc. However this could be spurious as the correlations with % carbon and % nitrogen reflect the influence of organic material, together with pH and moisture, which would reduce their activity suggesting that pH or organic matter could be the true key drivers.

The significance here is that it appears that the levels of lead and zinc are related to the amount of organic material and their source from the Coal Measure shales and the limestone. The way the sites were treated on reclamation would seem to be another factor.

Upton has the higher calcium concentrations (Figures 3.23 and 3.24), with Area 2 quadrats clearly reflecting their position on the limestone. The quadrats in the cutting, apart from 5b and 6b, are lower in calcium than one might expect, although they do form a distinct group compared to the rest of the site. It could be that the ballast has in some way diluted the concentration in the quadrats at the edge, as could water draining through, although pH is generally over 7.5 throughout the cutting. The organic material in the cutting could, through the activity of the soil biota, also be involved. At Fitzwilliam, the calcium levels (Figures 3.51 and 3.52) cover a much smaller range than at Upton and quadrats in Area 1 clearly reflect the untreated nature of that part of the site, as well as the leaching effect of being on a slope. The variations elsewhere reflect the reclamation process, particularly Areas 4 and 6, which could well have had some topsoil and added clay treatment , as well as added lime in 1991 (Pipkin, pers. com., 2011). The situation with magnesium shows a similar pattern, and at Upton (Figures 3.25 and 3.26) the quadrats on the main site, other than Area 2 which is on the limestone, have very low concentrations. Although concentrations are higher in the cutting, considering the cutting is in a dolomitic limestone, the levels are still lower than one would expect. However, this may be due to the fact that the limestone in the cutting has been exposed since 1885 and that weathering has removed much of the magnesium exacerbated by the action of acid rain. The railway was operated by steam locomotives up to 1967, the smoke from which would have increased the rate of attack. The railway through the cutting would have good drainage at the

side of the tracks, so removing the dissolved magnesium salts, as well as the calcium. This could be a key factor in the lower than expected calcium and magnesium levels. Regarding Fitzwilliam (Figures 3.53 and 3.54), the pattern for magnesium is similar to that for calcium, again reflecting the reclamation process, with similar concentrations to Upton. The low concentrations of Area 1 quadrats again may reflect the untreated nature of the area as well as the leaching effect down the slope. Areas 4 and 6 again have the highest concentrations, suggesting a source of magnesium from the topsoil and clay used to treat part of the site.
The Ca: Mg ratios, with one major exception (Area 3) at Upton (Figures 3.27 and 3.28), nearly all fall within the 1:1 and 5:1 range desirable for good plant production (Charman & Murphy, 2007). For Fitzwilliam (Figures 3.55 and 3.56) the ratios also fall within the range, with one quadrat (1a) below and one above (5c).

5.2 Plant distribution

5.2.1 Upton

The species richness for Upton (Figures 3.57 and 3.58), ranges from 2 – 19 per quadrat, but with much variation between quadrats in the same area. When the means are examined, however, then the pattern becomes clearer, with two divisions in the cutting (Areas 5 and 8; Areas 6 and7) and two on the main site (Areas1, 2 and 4; Area3). Areas 6 and 7 in the cutting have noticeably lower numbers of species and Area 3 on the main site stands out with the greater number. Area 3 is on the slope crossing the fault into the drainage channel and so is a well drained area. It also has the lowest mean pH (6.9) on the site, the lowest mean % carbon (0.8%), the lowest mean % nitrogen (0.07%), the lowest mean C: N ratio (12), the lowest mean ammonium-N concentration (0.9 µg kg^{-1}), the lowest mean nitrate-N concentration (0.04 µg kg^{-1}) and the lowest mean calcium concentration (2.1 g kg^{-1}). Phosphorus mean concentrations are also low, but at this pH and calcium levels, the phosphorus should be readily available, as should zinc and magnesium. The limiting factor in Area 3 is most likely the very low levels of nitrogen, which could be reflected in the presence of *Rhinanthus minor* and *Orobranche minor*, both hemi-parasitic species. A factor in the low level of nitrate-

N here could be related to leaching, as a result of being on a slope. However, leguminous species, such as *Lathyrus hirsutus, L.montanus, Lotus corniculatus, Medicago lupulina, Trifolium pratense* and *T. repens* are thriving in this area.

Areas 1 and 4 generally follow a similar pattern in terms of soil characteristics, but, as the photograph taken during the reclamation shows (Figure 5.1), Area 1 was covered in clay/brick waste and compacted by vehicles.

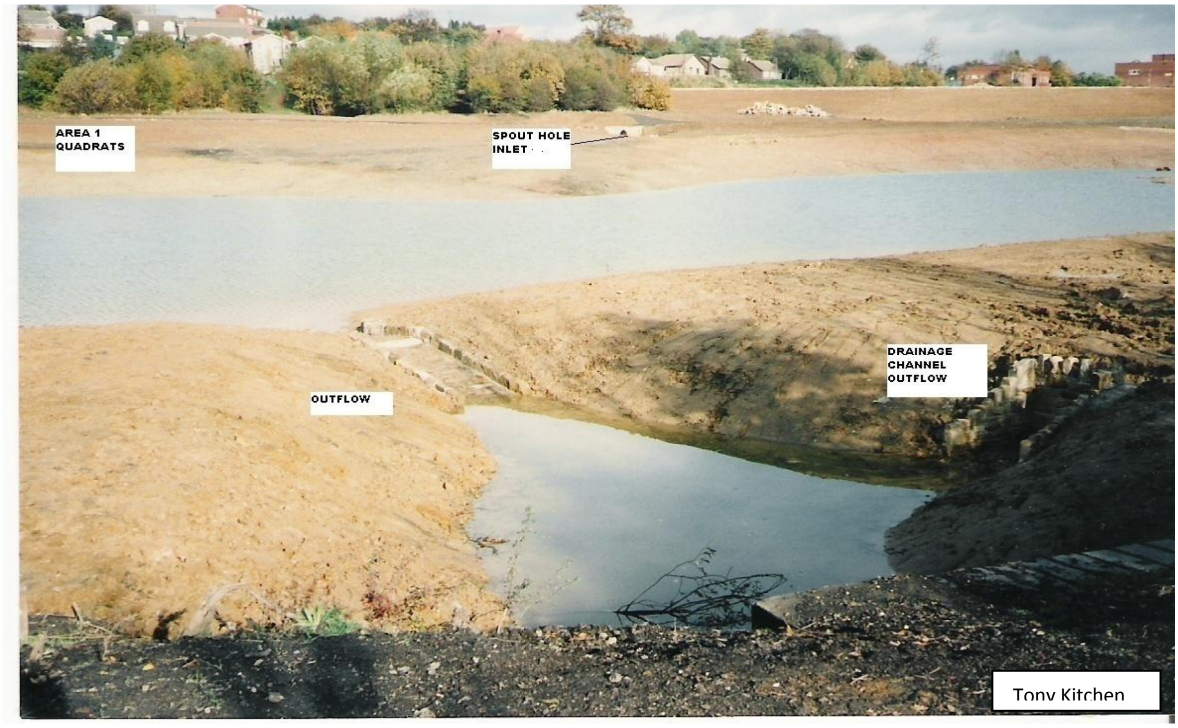

Figure 5.1. The Angling Pond just after excavation and landscaping 1994.

A key difference in Area 1 is the higher ammonium-N and nitrate-N concentrations, indicating that despite being on a slope, leaching is not a major issue. Quadrat 1a also produced the highest phosphorus value at Upton. This fits in with the findings of Schadek et al. (2009) on urban brownfield sites in Germany regarding the effect of brick rubble on nutrient levels and species richness. They found that “the absolute values of most biotic and abiotic parameters were significantly higher for sites that contained brick rubble”. The drainage scrapes where Area 4 quadrats are found were excavated in 2009 in order to alleviate flooding. They were simply excavated, the material turned over and formed into banks, with no treatment whatsoever and left to revegetate naturally (Cropley, pers. com. 2011). The key differences here are that the % carbon value in Area 4 is higher than for Areas 1 and 3, % nitrogen and nitrate-N levels are low in Area 4, and lead and zinc concentrations raised. The turning over of the untreated shale helps account for the higher levels of lead and zinc. The fact that the scrapes are for drainage purposes helps account for the low nitrate-N values as a result of leaching, and the good moisture properties have enabled a better accumulation of organic material in a remarkably short time. It is also significant that so many species have recolonised these drainage scrapes, agreeing with the findings of Schadek et al. (2009) that plant species richness can be maintained by the "resetting of successional cycles as a result of strong disturbance".

Area 2 at Upton is on the limestone and has a relatively thin soil. The high pH and the expectedly high calcium and magnesium concentrations should be restricting the availability of phosphorus and zinc, although the sandy texture of the soil here must be taken into account (Stahl & James, 1991). It is also significant that parts of Area 2 have had the least disturbance of anywhere on the site and are next to the railway cutting, the top of which will have acted as a linear refuge in an area dominated by intensive agriculture. Many plant species typical of a limestone habitat occur here (Martin, 2009), such as *Anthyllis vulneraria, Briza media, Campanula glomerata, Centaurea nigra, Euphrasia spp*., *Gallium verum, Hypericum montanum, Linum catharticum, Lotus corniculatus, Origanum vulgare and Primula veris.* This area of Magnesian Limestone generates its own special flora and fauna (RDS, 2005), and being generally in areas of intensive agriculture, there are relatively few reserves protecting these species. Therefore Upton is valuable as a refuge for characteristic magnesian limestone species and needs careful management.

The cutting at Upton highlights the variability of conditions that can develop over time, and this is reflected both in the species and the soil properties. Areas 5 and 8 are similar in species richness to Area 2, as are quadrats 6a, 6b, 6c and 7a. Quadrats on the south side of the cutting (6d,6e,6f, 8d,8e,8f) often show differences to those on the north side, depending on the height of the cutting and the degree of shade. Moisture content is low generally, due to the nature of the

ballast and the sandy textured soil, except in Area 6 which had a thick accumulation of dead leaves from the overhanging trees on the south side. This accumulation of leaf litter has been steadily replenishing the soil organic content, which is why the nutrient levels are generally high, particularly for those quadrats at the edge of the ballast and at the base of the vertical limestone faces. Area 8 has a number of quadrats with lower values of % carbon and % nitrogen than elsewhere in the cutting, which probably reflects the more open nature of that transect. However, the low levels of calcium and magnesium reflect the nearness to the line of the Spout Lane Fault, which has exposed the coal measures in the cutting at this point, the resulting soil being more clay like in texture.
The TWINSPAN analysis (Figures 3.65 and 3.66) shows these divisions well, with the quadrats in the cutting, other than 5a and 5b, being separated from the rest of the site at the first level division, with *Campanula glomerata* and *Rubus fructicosus*. At the second division, *Urtica dioica* separates off quadrats 6d, 6e and 6f, which are located on the south side of the cutting under a dense overhanging canopy with much leaf litter and also has elevated levels of phosphorus and nitrate-N. At the level 3 division Areas 1 and 4 have branched off with *Holcus lanatus* and *Trifolium repens,* and at the level 4 divisions, Area 2 (with *Hypochoeris radicata*) is separated from Area 3 (with *Equisetum arvense).*

The significance here is that the fault line corresponds to the first divisions between areas of different plant species composition.

5.2.2 Fitzwilliam

The situation at Fitzwilliam reflects a more homogenous distribution, with Area 2 being rather species poor, and Areas 3 and 5 being the most species rich, but the mean difference in total ranging from 6 – 10 species per area is not great. As vegetation density and height increase, less-competitive plants will be restricted through the reduction in light at the soil surface (Schadek, et al., 2009). The planting of aggressive species could not only reduce species richness, but also slow down long term recovery (Holl, 2002). Grazing or repeated mowing has been shown to produce a higher level of plant species diversity, because they increase nutrient availability through recycling and by creating gaps, allow less-competitive species to reach the canopy and so disperse seed (Fédoroff, et al., 2005). Whereas parts of the grassland at Fitzwilliam were observed to have been mown, it was made clear talking to local people that this did not always happen and that not all areas were mowed each year, or at a set time. This would also appear to be a significant factor in reducing the species richness.

The TWINSPAN analysis for indicator species at the first division (Figure 3.68) separates out quadrats 1a and 1b due to the presence of *Arrhenatherum elatius,* a species which thrives best on moderately fertile, well-drained soils with a pH <8 (Cope and Gray, 2009). These quadrats are affected by the deposition from the poultry farm and as a result have higher levels of ammonium-N and nitrate-N. The correlation matrices for Fitzwilliam clearly suggest that for Axis 1 ammonium-N is a key driver, with nitrate-N for Axis 2. At Fitzwilliam grasses dominate particularly *Festuca ovina* and *Holcus lanatus*, with *H. lanatus* separating the rest of the quadrats from Area 6 at the second level of division. Area 6 is dominated by the grasses *Festuca ovina* and *Agrostis tenuis*, together with the legume*, Vicia cracca.* Area 6 at Fitzwilliam has high ammonium-N and nitrate-N concentrations as well as high phosphorus levels, but it also has high lead, zinc, calcium and magnesium, and both *F. ovina* and *A. tenuis* are known to tolerate high lead levels (Cope and Gray, 2009). Area 6, from observation, appears to have had a covering of clay, rubble (brick and concrete), and possibly some crushed limestone as a layer on top of the colliery spoil, which would help to explain the high levels of calcium and magnesium and the pH. As a result the lead and zinc will be immobilised to some extent. As with *A. elatius*, *H. lanatus* does best on moderately fertile soils, particularly those with some impedance to the drainage, although it is more tolerant of a variety of soil conditions and because it is a good seed producer, can soon dominate (Hubbard, 1954; Cope and Gray, 2009).

The C-S-R characterisation indicates quite clearly that there is a difference between Upton and Fitzwilliam, reflecting a greater influence of competition and disturbance factors at Upton and a greater influence of stress at Fitzwilliam. The Intermediate Disturbance Hypothesis (IDH) basically describes a mechanism by which occasional disturbance creates opportunities for species to colonise (Connell, 1978). If disturbance levels are low, the more competitive species will come to dominate and species richness will decline. If disturbance is too frequent, then species will be eliminated and richness will again decline. However, scale must be taken into account in order to distinguish within-patch or between-patch mechanisms (Wilson, 1994). The within-patch mechanism has limitations, as over time species with a higher population growth rate will oust the others through competitive interactions (Ikeda, 2003). Between-patch mechanisms allow for patches to be at various stages, from early colonisation, through mid-succession even to a climax state, and depend on there being refugia providing local seed sources (Townsend, et al., 1997; Collins, et al., 1995).

Coupled to the IDH is the relationship of resistance and resilience. Resistance is about how well plant communities withstand disturbance, and resilience reflects how well they can recover to the pre-disturbed state (Bernhardt-Römermann, et al., 2011). Resistance is not only to do with the functional composition, but also with land-use history, which can lead to species adaptations enabling them to withstand disturbances. Resilience is a direct response to factors affecting growth rates, such as nutrient availability, moisture and climate.

The variations in soil variables and species over short distances on the two reclaimed mine sites fit in well with the idea of between-patch interpretation (Kunin, 1998), and the ideas of resistance and resilience. The Upton site in particular illustrates this. Having had a twenty year natural re-vegetation period and there being natural refugia along the top of the cutting, the major disturbance that followed the reclamation meant that many species could spread onto the site in addition to those that were sown, especially as some of that seed was collected from the cutting. This was then followed by a period of relative stability which would allow the site to settle down, and, because of the geological and physical environmental variations of the site, a number of habitats developed with a wide range of species. The next major disturbance came in 2009 when the drainage scrapes were created, but because they were left bare, species were able to colonise from the rest of the site, enabling a wide range of species to establish and accounting for Area 3 having the highest level of species richness. It is to be expected that over time, the better adapted and more competitive species will begin to dominate and species richness may drop to the levels found today in Areas 1, 2 and 4. As far as the Fitzwilliam site is concerned, there has been little disturbance since reclamation, and as a result the species richness may have fallen as the more dominant species have out-competed the rest, particularly with the higher fertility that is found in some places.

The implication therefore, is that the variation in floral diversity between the two sites is partially explained by the intermediate disturbance hypothesis and particularly linked to patch dynamics and the role of refugia.

It is also implied that the differences in the reclamation processes between the two sites have contributed to this variation in floral diversity.

Chapter 6 Conclusions, Further Research and Management Implications

6.1 Conclusions

The aim of this study was to investigate the different factors influencing the vegetation composition on the two sites.

The difference in floral diversity between and within the two sites is a result of a number of factors of which the most important are:

- The underlying geology
- The processes of reclamation
- The intermediate disturbance hypothesis

The presence of the Permian Magnesium Lower Limestone at Upton has been a key factor influencing pH, along with the water movement from the limestone on to the site. There is a distinct difference in the species richness across the Upton site and the differences are shown by the ordination. The fact that the Upper Coal Measures are also high in carbonate may have also influenced the pH levels on both sites. The soil concentrations of lead and zinc, and of calcium and magnesium, are also clearly related to the distinctive geology. At Fitzwilliam, the underlying aquifer, the Newstead Rock sandstone, has also brought water into the spoil, so helping create pH levels that are in the neutral to alkaline range, hence reducing any acidic effects normally associated with coal mine spoil. However, the species richness is less than at Upton and variation across the site less marked. The original hypothesis that "***The solid geology is a key factor in the difference in floral diversity between the two sites"*** is therefore supported by the evidence.

Linked to this is the role of the Spout Lane Fault at Upton. The abrupt change in rock type from limestone to sandstone and mudstones is reflected very clearly in the pH, % carbon, C: N ratio, calcium and magnesium values, and to a lesser extent in the Ammonium-N, lead and zinc values. This is seen in the plant composition and the ordination plot reflects this with distinct divisions down to Level 4. As a result, the original hypothesis that ***"At Upton, the abrupt change in the solid geology***

across the Spout Lane Fault results in a marked floral transition" is also supported by the evidence.

The reclamation processes have been different at the two sites. Upton had a longer time period before reclamation began, and even then, had areas that were deliberately disturbed as little as possible, and together with the cutting, acted as refugia from which species could migrate. The disturbance in 2009 to produce the drainage scrapes provided fresh niches for plants to colonise. The spreading of the clay and waste from the brickworks seems also to have played a critical role in the recovery after reclamation, and this is reflected in the species richness and floral diversity compared with Fitzwilliam, where the initial reclamation treated the site more as preparation for a golf course, using imported soil. Some brick rubble was used, but only in a few areas, helping to account for the change in soil conditions over relatively short distances. With very little in the way of disturbance, the emphasis on established grass is now reflected at Fitzwilliam by the dominance of the more grass aggressive species, resulting in a gradual exclusion of less competitive species. The original hypotheses that ***"The differences in the process of reclamation of the two sites have contributed to the variation in floral diversity between the sites"*** and ***"The variation in floral diversity between the two sites is to some extent accounted for by the intermediate disturbance hypothesis, particularly in relation to refugia"*** are hence both supported by the evidence.

Within each site, certain other specific factors apply:

- The influence of pH and soil moisture on the availability of plant nutrients
- The relationship between the amount of organic material and the levels of lead and zinc
- The relationship of the levels of lead and zinc, the industrial history of the sites, and their potential source.
- The way in which the local community have contributed to the floral diversity

At Upton, pH shows positive correlations with axes 2 and 3, % carbon, and a negative correlation with % moisture. It also correlates with calcium and magnesium. % moisture, on the other hand correlates with axes 1 and 2 and %

carbon, % nitrogen, phosphorus and zinc. Nitrogen is an important driver of plant species composition, and is in turn correlated with pH and moisture. At Fitzwilliam soil moisture correlates with axis 3 only, but pH correlates with % nitrogen, nitrate-N, phosphorus, calcium and magnesium, indicating that pH is a key driver here. However, when combined, the implication is clear and the original hypothesis ***"pH and soil moisture are key factors influencing the availability of plant nutrients"*** holds up.

Using the C: N ratios as an indicator of the levels of organic material, and matching this with the calcium and magnesium values as representative of the limestone, it was found that at Upton the correlations were very strong, whereas at Fitzwilliam no significant correlations were found, hence the original hypothesis ***"The level of organic material, as indicated by the carbon: nitrogen ratio, is a reflection of the effect of the limestone"*** is supported by the evidence.

Lead and zinc show strong correlations with % carbon, % nitrogen and nitrate-N on both sites, but only lead shows a significant correlation with pH. The pH levels mean the lead and the zinc are probably immobile and have relatively low bioavailability, but possibly also are being held in some of the organic material, emphasising the importance of the relationship. The source of the lead and zinc is most likely from the Permian Limestone and the Coal Measures, but it is possible that at Upton, some may have come from the railway ballast. However, that is unlikely at Fitzwilliam, where the most likely source is the mine spoil. So the original hypothesis; ***"The levels of lead and zinc are related to the amount of organic material as well as the industrial history of the sites and their likely source from the limestone"*** needs changing. The relation to organic material holds and a new hypothesis would be ***"The levels of lead and zinc are related to the amount of organic material".*** The rest of the original hypothesis could be changed to; ***"The levels of lead and zinc are related to their likely source from the limestone and the Coal Measures, as well as the industrial history of the sites".***

The local community have affected the floral diversity in a number of small ways. For example individuals had planted unusual species e.g. *Leylandii spp.*, and

Cyclamen spp. Although it is harder to assess, the disturbance caused by youths riding motorbikes on these sites may actually assist in opening up new niches, but obtaining good data on this is difficult. The original hypothesis ***"The level of involvement by the local community has contributed to the floral diversity"*** holds to a limited extent, but the evidence is patchy and proved difficult to obtain.

6.2 Further Research and Management Implications

Due to the variation in soil characteristics over short distances, a more systematic sampling over each site needs to be undertaken in order to construct a more accurate picture, especially considering the large grassland areas at Fitzwilliam.

It would be interesting to look at other mine sites in both similar and different situations to see how they are developing, and match the plant composition with the soil variables and the process of reclamation, and also to compare that data with the results from Upton and Fitzwilliam. It is unclear whether the effect of the limestone and the relatively high pH levels, and the role of the brick rubble, are unique features of these sites, or are more widely characteristic of reclaimed mine sites. A comparative study between sites known to have had brick rubble spread on them, and similar sites which had not, might indicate a more effective process of reclamation.

It would have been instructive to have carried out repeat recording and sampling at different times in the year in order to obtain a fuller record of the species present as well as their abundance. It would also be useful to repeat this exercise over a time period of several years in order to get a clear picture of what is happening regarding species richness and succession on the sites.

Soil chemical analysis in this study did not cover all the relevant chemical species. It would be useful, for example, to know the level of potassium (as a plant nutrient) and sulphur (as an indicator of the level of pyrite). Soil sampling at greater depths would also give an indication of the health of the sites and how well the reclamation processes were proceeding.

Regarding future management of the sites, the most important issue at Upton is one of succession. *Crataegus monogyna* (hawthorn) in particular is spreading and there is a change going on in some areas from grassland to scrub. In time, this will be followed by other broad-leaved species and the floral richness will begin to decline, so careful and selective removal is necessary. At Fitzwilliam the situation is very different and is related to the pattern of mowing. If this is done properly at the right time to allow less competitive smaller species to establish, then it is possible to restore some of the species richness. An element of disturbance near to more species rich patches might also improve the situation.

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APPENDIX

TABLES:

	Appendix Table 1 : TABLE OF PLANT DATA FOR UPTON																																	
	Scientific Name	Common Name	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	4a	4b	4c	5a	5b	5c	6a	6b	6c	6d	6e	6f	7a	7b	8a	8b	8c	8d	8e	8f
1	Achillea millefolium	Yarrow	50%	20%	25%		<4%F	5%		5%	<4%S	5%	<4%S	20%		<4%F		<4%S									<4%F							
2	Agropyron repens	Couch Grass													25%																			
3	Agrostis capillaris	Common Bent	<4%F	<4%F									<4%F	<4%F		<4%F	<4%S															<4%S		
4	Agrostis stolonifera	Creeping bent	30%	20%	5%	5-10%				5%				<4%F		5-10%													15%			5%		
5	Alopecurus pratensis	Meadow Foxtail					5%																											
6	Anthyllis vulneraria	Kidney Vetch					20%	<4%M	<4%F	10-15%	<4%S	<4%S	10%	<4%F																				
7	Brachypodium sylvaticum	False Brome															10%													50%	90%			
8	Briza media	Quaking Grass						10%	20%	10%																								
9	Bromus erectus	Upright Brome																						20%										
10	Campanula glomerata	Clustered Bellflower								<4%F											<4%F	<4%F	<4%F				<4%F	10%	<4%F	<4%F	<4%F	<4%F	<4%F	<4%F
11	Centaurea nigra	Black or Common Knapweed						<4%S		<4%F								<4%S	<4%F	<4%F	<4%S								5%	<4%S	<4%F		<4%M	<4%F
12	Centaurea scabiosa	Greater Knapweed																			<4%F	<4%F	<4%F				<4%S		<4%F	<4%F				
13	Centaurium erythraea	Common Centaury				<4%F					<4%F		<4%F																					
14	Cerastium arvense	Field Mousear																	<4%F															<4%F
15	Cerastium fontanum	Common Mousear											<4%F	<4%F					<4%F															
16	Chenopodium bonus-henricus	Good King Henry													<4%F																			
17	Cirsium dissectum	Meadow Thistle													<4%F					<4%F		<4%F												
18	Clinopodium vulgare	Wild Basil																<4%S		<4%S														
19	Crataegus monogyna	Hawthorn																	<4%F	<4%F	<4%F	<4%S				<4%F				<4%F			<4%F	
20	Cynosurus cristatus	Crested Dog's tail		<4%F		<4%F					5-10%	10%	<4%F	5%		<4%F	<4%F		<4%F												<4%F			
21	Dactylis glomerata	Cock's Foot Grass																40%									5-10%							
22	Dactylorhiza fuchsii	Common Spotted Orchid											<4%F	<4%F																				
23	Daucus carota	Wild Carrot								<4%F																								
24	Epilobium angustifolium	Rosebay Willowherb																											<4%F					
25	Equisetum arvense	Horsetail									<4%F	<4%S	5%	10%																				
26	Erigeron acer	Blue Fleabane																	<4%F	<4%F														
27	Euphrasia officinalis	Eyebright						<4%F																									<4%F	
28	Festuca gigantea	Great fescue																	<4%F	70%		5%												
29	Festuca ovina	Sheep's Fescue			50%	50%	75%	90%	50%	15%	5%						10%	50%	<4%S							<4%F								
30	Festuca rubra	Red Fescue	10%	15%																									15%	10%		60%	10%	
31	Fraxinus excelsior	Ash																			<4%F								<4%F	<4%S	<4%F		<4%F	<4%F
32	Galium aparine	Cleaver's																						<4%F										
33	Gallium verum	Lady's Bedstraw	20%		5%																													
34	Hedera helix	Ivy																			20%	10%												
35	Heracleum sphondylium	Hogweed																											<4%F		<4%F		<4%F	<4%F
36	Hieracium murorum	Common Hawkweed												<4%F						<4%S								<4%F						
37	Holcus lanatus	Yorkshire Fog	10%	<4%F	<4%M	5%																												
38	Hypericum montanum	Pale St John's Wort							<4%F																									
39	Hypericum perforatum	Perforate St John's Wort																									<4%F							
40	Hypochoeris radicata	Common Cat'sear					<4%F		5-10%	5-10%		<4%F	<4%F								<4%F	<4%F	<4%F					<4%M			<4%S		<4%F	<4%F
41	Knautia arvensis	Field Scabious																															<4%F	
42	Lathyrus hirsutus	Hairy Vetchling											<4%S	<4%F																				
43	Lathyrus montanus	Bitter Vetchling										<4%F																						
44	Lathyrus pratensis	Meadow Vetchling	5-10%	<4%F																														
45	Leucanthemum vulgare	Ox-eye Daisy		<4%S			5-10%	<4%S	<4%F				<4%F	35%				<4%F	<4%S	<4%F														
46	Linum catharticum	Fairy Flax					5%	<4%F	<4%S	<4%S									<4%S	<4%F		<4%F												
47	Lolium perenne	Perennial RyeGrass															<4%F																	
48	Lotus corniculatus	Bird's-foot Trefoil	5%			30%	<4%F		25%	10%	20%	10%	<4%S	<4%F	<4%F	<4%F		<4%F																
49	Medicago lupulina	Black Medick	5%		<4%S	<4%F	<4%F	<4%F			<4%S	<4%F		20%			<4%F	<4%F	<4%F	<4%F	<4%F	<4%F									<4%F			
50	Melilotus officinalis	Ribbed Melilot																									<4%F							
51	Mercurialis perennis	Dog's mercury									<4%F																							
52	Odontites verna	Red Bartsia													<4%F														<4%S			<4%F		
53	Origanum vulgare	Wild Margoram						<4%F		25%																								
54	Orobanche minor	Common Broomrape									<4%F																							
55	Phleum pratensis	Timothy		<4%F																														
56	Pilosella officinarium	Mouse-ear Hawkweed																	<4%M				5%											
57	Pimpinella saxifraga	Burnet Saxifrage																			<4%F													
58	Plantago lanceolata	Ribwort Plantain	<4%F	<4%F		<4%M	5-10%	<4%S	<4%F	<4%F	5%	30%	20%	30%	<4%F	5-10%	<4%M	5-10%			<4%S	<4%F	<4%F				<4%F		15%	<4%F	<4%F	<4%F	<4%S	<4%S
59	Plantago major	Greater Plantain									<4%F				<4%F				<4%F	<4%F									<4%F			<4%S		
60	Poa annua	Annual Meadow-grass									<4%F																							
61	Polygonum aviculare	Knotgrass													<4%F																			
62	Potentilla reptans	Creeping Cinquefoil																					5%											
63	Primula veris	Cowslip							<4%S	<4%S																								
64	Prunella vulgaris	Selfheal		<4%M																														
65	Pteridium aquilinum	Bracken																									<4%F	20%						
66	Quercus	Oak																																<4%F
67	Ranunculus repens	Creeping Buttercup				<4%F									<4%F	<4%F													<4%F			5%		<4%S
68	Rhinanthus minor	Yellow Rattle									10%	20%	5-10%	20%																				
69	Rosa arvensis	Field Rose						<4%F																										
70	Rosa canina	Dog Rose																								<4%F				<4%F				
71	Rubus fructicosus	Bramble																				<4%F	<4%F	<4%F				<4%F	20%	<4%F		<4%F	<4%F	
72	Rumex acetosa	Common Sorrel										<4%F	<4%F																					
73	Salix caprea	Pussy Willow									<4%F			<4%F																				
74	Sanguisorba minor	Salad Burnet																										<4%F			<4%F		<4%F	<4%F
75	Sanguisorba officinalis	Great Burnet											<4%F																					
76	Senecio jacobaea	Ragwort				<4%F		<4%F										<4%F					<4%F							<4%F			<4%F	<4%F
77	Senecio vulgaris	Groundsel													<4%F																			
78	Sphagnum cymbifolium	Sphagnum Moss							75%		25%	90%	90%	90%		<4%S	70%			5-10%	40%			20%	<4%F	5-10%				70%	30%		50%	60%
79	Stellaria media	Common Chickweed																						<4%M										
80	Tanacetum parthenium	Feverfew									<4%F																						<4%F	
81	Taraxacum officinale	Dandelion														<4%F	<4%F																<4%F	
82	Torilis japonica	Hedge Parsley																						<4%M			<4%F							
83	Trifolium campestra	Hop Trefoil																					<4%F								<4%F			
84	Trifolium pratense	Red Clover	<4%S	5%			<4%F					<4%M		5-10%		5%	20%	15%			<4%F		<4%F				<4%F		<4%S			<4%F	<4%S	5%
85	Trifolium repens	White Clover	20%	10%	50%	25%	<4%S				<4%S				<4%F		20%				<4%S	<4%F						<4%F	<4%S					
86	Tripleurospermum inodorum	Scentless Mayweed													<4%F																			
87	Tussilago farfara	Coltsfoot																														<4%F	<4%F	
88	Urtica dioica	Stinging Nettle																						20%	<4%F									
89	Vicia cracca	Tufted Vetch	<4%M	5%																														
90	Vicia tetrasperma	Smooth Tare			<4%F						<4%F	<4%F		<4%F				<4%F			<4%F			<4%F										
91	Viola riviniana	Common Dog-violet																								<4%F								
	Bare Earth														50%	25%	5-10%		15%	25%		50%	60%		100%	80%		80%			5%		5%	10-15%
	Bare Rock																		30%			25%				15%								
	Rabbit Droppings				23	4		3	1		1	12			21	43		4	90	2			13		2									1

Appendix Table 2 : Upton Plant Data Domin Scale		1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	4a	4b	4c	5a	5b	5c	6a	6b	6c	6d	6e	6f	7a	7b	8a	8b	8c	8d	8e	8f
Achillea millefolium	1	7	5	5	0	1	5	0	4	2	4	2	5	0	1	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Agropyron repens	2	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agrostis capillaris	3	1	1	0	0	0	0	0	0	0	0	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Agrostis stolonifera	4	6	5	4	4	0	0	0	4	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	4	0	0
Alopecurus pratensis	5	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthyllis vulneraria	6	0	0	0	0	5	3	1	5	2	2	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachypodium sylvaticum	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	7	9	0	0	0
Briza media	8	0	0	0	0	0	4	5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bromus erectus	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Campanula glomerata	10	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	4	1	1	1	1	1	1
Centaurea nigra	11	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	2	1	1	2	0	0	0	0	0	0	0	4	2	1	0	3	1
Centaurea scabiosa	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	2	0	1	1	0	0	0	0
Centaurium erythraea	13	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastium arvense	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cerastium fontanum	15	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chenopodium bonus-henricus	16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium dissectum	17	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Clinopodium vulgare	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crataegus monogyna	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	0	0	0	1	0	0	0	1	0	0	1	0
Cynosurus cristatus	20	0	1	0	1	0	0	0	0	4	4	1	4	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dactylis glomerata	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Dactylorhiza fuchsii	22	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daucus carota	23	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epilobium angustifolium	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Equisetum arvense	25	0	0	0	0	0	0	0	0	1	2	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron acer	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia officinalis	27	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Festuca gigantea	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Festuca ovina	29	0	0	7	7	8	9	7	5	4	0	0	0	0	0	4	7	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Festuca rubra	30	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	0	8	4	0
Fraxinus excelsior	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	1	0	1	1
Galium aparine	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Gallium verum	33	5	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedera helix	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	0	0	0	0	0	0	0	0	0	0	0	0
Heracleum sphondylium	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1
Hieracium murorum	36	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Holcus lanatus	37	4	1	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hypericum montanum	38	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypericum perforatum	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Hypochoeris radicata	40	0	0	0	0	1	0	4	4	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	3	0	0	2	0	1	1
Knautia arvensis	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lathyrus hirsutus	42	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lathyrus montanus	43	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lathyrus pratensis	44	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leucanthemum vulgare	45	0	2	0	0	4	2	1	0	0	0	1	7	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Linum catharticum	46	0	0	0	0	4	1	2	2	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lolium perenne	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lotus corniculatus	48	0	4	0	6	1	0	5	4	5	4	2	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medicago lupulina	49	4	0	2	1	1	1	0	0	2	1	0	5	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0
Melilotus officinalis	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Mercurialis perennis	51	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odontites verna	52	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0
Origanum vulgare	53	0	0	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orobanche minor	54	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phleum pratensis	55	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pilosella officinarium	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Pimpinella saxifraga	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Plantago lanceolata	58	1	1	0	3	4	2	1	1	4	6	5	6	1	4	3	4	0	0	2	1	1	0	0	0	1	0	5	1	1	1	2	2
Plantago major	59	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	2	0	0
Poa annua	60	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polygonum aviculare	61	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla reptans	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Primula veris	63	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prunella vulgaris	64	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridium aquilinum	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0
Quercus	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Ranunculus repens	67	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	2
Rhinanthus minor	68	0	0	0	0	0	0	0	0	4	5	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosa arvensis	69	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosa canina	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Rubus fructicosus	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	5	1	0	1	1	0
Rumex acetosa	72	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salix caprea	73	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanguisorba minor	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1
Sanguisorba officinalis	75	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Senecio jacobaea	76	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1
Senecio vulgaris	77	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphagnum cymbifolium	78	0	0	0	0	0	0	8	0	5	9	9	9	0	2	8	0	0	4	7	0	0	5	1	4	0	0	0	8	6	0	7	8
Stellaria media	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Tanacetum parthenium	80	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Taraxacum officinale	81	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Torilis japonica	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0
Trifolium campestra	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Trifolium pratense	84	2	4	0	0	1	0	0	0	0	3	0	4	0	4	5	5	0	0	1	0	1	0	0	0	1	0	2	0	0	1	2	4
Trifolium repens	85	5	4	7	5	2	0	0	0	2	0	0	0	1	0	5	0	0	0	2	1	0	0	0	0	0	1	2	0	0	0	0	0
Tripleurospermum inodorum	86	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tussilago farfara	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Urtica dioica	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0
Vicia cracca	89	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vicia tetrasperma	90	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Viola riviniana	91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Bare Earth		0	0	0	0	0	0	0	0	0	0	0	0	7	5	4	0	5	5	0	7	8	0	10	9	0	9	0	0	4	0	4	5
Bare Rock		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	5	0	0	0	5	0	0	0	0	0	0	0	0
Rabbit Droppings		0	0	2	1	2	1	1	0	1	1	0	0	2	3	0	1	5	2	0	0	1	0	1	0	0	0	0	0	0	0	0	1

Appendix Table 3: TABLE OF PLANT DATA FOR FITZWILLIAM																					
	Scientific Name	**Common Name**	1a	1b	1c	1d	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	5b	5c	6a	6b	6c
1	Achillea millefolium	Yarrow											<4%M	5-10%		<4%F	<4%S	<4%S			
2	Agrostis capillaris	Common Bent															10%	5-10%	10%	20%	
3	Anthyllis vulneraria	Kidney Vetch											<4%F								
4	Arrhenatherum elatius	False Oat Grass	20%	<4%S																	
5	Centaurea nigra	Black or Common Knapweed						<4%F									<4%F				
6	Cirsium arvense	Creeping Thistle	<4%M		<4%F	<4%F	<4%F	<4%F				5%	<4%F	<4%F	<4%F				<4%F	<4%F	
7	Crepis capillaris	Smooth Hawksbeard	<4%F								<4%F							<4%F			
8	Cynosurus cristatus	Crested Dog's Tail									<4%F										
9	Dactylis glomerata	Cocksfoot										<4%F					<4%F				
10	Festuca ovina	Sheep's Fescue	30%	50%	30%	70%	90%	90%	90%	90%	70%	70%	75%	80%	50%	30%	80%	50%	90%	50%	
11	Heracleum sphondylium	Hogweed			<4%F								<4%F		<4%F						
12	Holcus lanatus	Yorkshire Fog	10%	5%	20%	30%	10-15%	<4%F	5-10%	5%	20%	<4%M	25%	20%	30%	10%	<4%F	5-10%	<4%F		
13	Hypochaeris radicata	Common Catsear			<4%F																
14	Knautia arvensis	Field scabious												5%			5%				
15	Lathyrus pratensis	Meadow Vetchling	<4%F	20%																<4%S	
16	Leucanthemum vulgare	Ox-eye Daisy	<4%F	<4%F	<4%F	<4%F					<4%F		<4%F	<4%F	<4%F			<4%F			
17	Lotus corniculatus	Bird'sfoot Trefoil					<4%F			<4%F	20%	<4%S			<4%F	5%					
18	Medicago lupulina	Black Medick			10-15%	<4%F				<4%F		<4%M		<4%F		<4%F		<4%F	<4%S	<4%F	<4%S
19	Melilotus officinalis	Ribbed Melilot			<4%F																
20	Odontites verna	Red Bartsia								<4%S	<4%S		<4%F						<4%M		
21	Plantago lanceolata	Ribwort Plantain					<4%F	<4%F	<4%F	<4%S	5%	20%		<4%F	<4%F	5-10%	<4%F	5-10%	<4%F	<4%F	
22	Plantago major	Greater Plantain									<4%F										
23	Poa annua	Annual Meadow Grass																<4%F			
24	Poa pratensis	Smooth Meadow Grass			10%															<4%S	<4%S
25	Rumex conglomeratus	Clustered Dock		<4%F																	
26	Senecio jacobaea	Ragwort				<4%F				<4%F						<4%F		<4%F			
27	Sphagnum cymbifolium	Sphagnum Moss			90%	90%				60%	70%	<4%S	<4%F	70%		20%	70%	70%	5-10%	10%	10%
28	Taraxacum officinale	Dandelion	<4%F	<4%F						<4%F	<4%S					<4%F					
29	Tragopogon pratensis	Goatsbeard	<4%F																		
30	Trifolium pratense	Red Clover									5%										
31	Trifolium repens	White Clover						<4%F			<4%S	<4%F				<4%F		<4%F			<4%F
32	Vicia cracca	Tufted Vetch					<4%M	<4%F	<4%F							<4%F				20%	40%
33	Vicia tetrasperma	Smooth Tare			<4%F	<4%F													<4%F		
34	Rabbit Droppings										17										1

Appendix Table 4 : TABLE OF DOMIN PLANT DATA FOR FITZWILLIAM																			
Scientific Name	1a	1b	1c	1d	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	5b	5c	6a	6b	6c
Achillea millefolium	0	0	0	0	0	0	0	0	0	0	3	4	0	1	2	2	0	0	0
Agrostis capillaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	5	0
Anthyllis vulneraria	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Arrhenatherum elatius	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centaurea nigra	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Cirsium arvense	3	0	1	1	1	1	0	0	0	4	1	1	1	0	0	0	1	1	0
Crepis capillaris	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Cynosurus cristatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Dactylis glomerata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Festuca ovina	6	7	6	8	9	9	9	9	8	8	8	9	7	6	9	7	9	7	8
Heracleum sphondylium	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Holcus lanatus	4	4	5	6	5	1	4	4	5	3	5	5	6	4	1	4	1	0	0
Hypochaeris radicata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Knautia arvensis	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0	0	0	0
Lathyrus pratensis	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Leucanthemum vulgare	1	1	1	1	0	0	0	0	1	0	1	1	1	0	0	1	0	0	0
Lotus corniculatus	0	0	0	0	1	0	0	1	5	2	0	0	1	4	0	0	0	0	0
Medicago lupulina	0	0	5	1	0	0	0	1	0	3	0	1	0	1	0	1	2	1	2
Melilotus officinalis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odontites verna	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	0	3	0	0
Plantago lanceolata	0	0	0	0	1	1	1	2	4	5	0	1	1	4	1	4	1	1	4
Plantago major	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Poa annua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Poa pratensis	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Rumex conglomeratus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Senecio jacobaea	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
Sphagnum cymbifolium	0	0	9	9	0	0	0	8	8	2	1	8	0	5	8	8	4	4	4
Taraxacum officinale	1	1	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0
Tragopogon pratensis	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trifolium pratense	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Trifolium repens	0	0	0	0	0	1	0	0	2	1	0	0	0	1	0	0	1	0	1
Vicia cracca	0	0	0	0	3	1	1	0	0	0	0	0	0	1	0	0	0	5	7
Vicia tetrasperma	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Rabbit Droppings	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1

Appendix Table 5a : pH OF WATER AT UPTON.

Tested 06/09/2010. Tested 13/09/2010

LOCATION	Sample	Sample	Average	Sample	Sample	Average
Fish Pond	8.54	8.53	8.5	8.29	8.31	8.3
Spout Hole Inlet	8.07	8.00	8.0	8.09	7.95	8.0
Exit from Fish Pond	8.40	8.45	8.4	8.14	8.23	8.2
Upper Pond	6.92	6.86	6.9	6.98	6.93	6.96
Middle Pond (Opposite play equipment)	7.97	7.89	7.9	7.69	7.60	7.65
Third Pond down	8.96	8.99	8.98	8.66	8.82	8.7
Lower Pond	9.26	9.18	9.2	9.01	8.89	8.95

Appendix Table 5b: pH of WATER AT UPTON.

Tested 07/09/2010 Tested 13/09/2010

LOCATION	Sample 1	Sample 2	Average	Sample1	Sample2	Average
Fish Pond	7.62	7.61	7.6	7.34	7.25	7.3
Upper Pond	6.84	6.94	6.9	6.83	6.94	6.9

Appendix Table 6 : Upton Soil Data

Quadrat	Axis 1	Axis 2	Axis 3	Axis 4	RabDropping	BareEarth	pH	M. Dry %	M. Wet %	C %	N %	C:N Ratio	Amm-N: µg N per kg Dry Soil	Nit-N: µg N per kg Dry Soil	Ratio Am-N:Nit-N	µg P per g soil	mg Pb per kg Soil	mg Zn per kg Soil	g Ca per kg soil	g Mg per kg Soil	Ca : Mg Ratio
1a	126	179	196	69	0	0	6.94	27.77	21.74	2.30	0.16	13.99	1.89	0.23	8.1	133	35.33	70.63	7.5	3.1	2.40
1b	150	157	194	103	0	0	6.7	23.68	19.14	1.26	0.11	11.77	0.78	0.33	2.3	87	23.66	56.81	4.9	3.1	1.56
1c	142	158	219	26	2	0	7.66	25.06	20.04	2.04	0.13	15.97	1.62	0.19	8.6	119	39.26	56.30	3.0	2.4	1.23
1d	160	135	219	21	1	0	6.68	23.98	19.34	0.79	0.09	8.642	3.65	0.26	13.8	47	28.83	52.94	2.4	2.9	0.82
2a	181	121	171	102	2	0	8.57	26.24	20.78	13.73	0.22	61.41	3.98	0.23	17.3	95	73.03	68.13	184.6	75.8	2.43
2b	187	119	217	173	1	0	8.48	31.61	24.02	14.06	0.25	56.72	3.47	0.28	12.6	124	75.60	95.62	161.4	84.6	1.91
2c	246	103	205	190	1	0	8.46	25.26	20.16	12.55	0.16	80.87	1.31	0.05	28.9	111	66.55	69.36	174.0	87.4	1.99
2d	170	131	241	211	0	0	8.32	23.89	19.29	13.88	0.20	70.47	1.73	0.10	16.9	112	90.00	96.09	160.3	84.1	1.91
3a	253	32	177	86	1	0	7.01	22.22	18.18	0.99	0.08	12.62	1.26	0.00	0.0	14	36.58	67.41	3.1	3.5	0.88
3b	292	27	173	108	1	0	6.73	24.22	19.50	1.07	0.08	13.09	0.92	0.01	72.0	95	31.45	63.04	1.3	3.7	0.34
3c	292	0	144	137	0	0	6.95	21.81	17.91	0.45	0.05	8.535	0.90	0.03	28.8	104	42.43	67.77	2.5	4.3	0.58
3d	277	51	153	108	0	0	6.97	21.07	17.40	0.87	0.06	13.57	0.67	0.13	5.1	29	43.14	72.96	1.6	4.8	0.34
4a	0	201	156	85	2	7	7.23	30.31	23.26	8.27	0.28	30.13	1.03	0.02	50.3	77	68.41	84.50	7.3	3.8	1.93
4b	234	125	215	31	2	5	6.93	29.63	22.86	0.91	0.07	12.38	1.20	0.09	13.7	127	40.52	39.73	3.4	2.5	1.37
4c	287	108	167	28	0	4	7.42	19.75	16.50	3.18	0.15	20.94	1.03	0.04	23.9	27	52.82	94.36	7.6	4.2	1.79
5a	271	176	257	21	1	0	7.83	2.98	2.89	36.65	0.78	46.88	4.51	0.24	18.6	94	112.36	169.94	9.8	3.1	3.14
5b	232	267	58	136	3	5	8.3	3.96	3.81	19.17	0.55	35.16	2.74	1.48	1.9	107	102.38	116.99	250.0	57.0	4.38
5c	279	286	0	139	2	5	7.85	3.18	3.08	12.52	0.44	28.37	2.08	0.16	12.9	63	80.73	93.57	6.7	4.5	1.50
6a	346	194	121	64	0	0	7.39	2.69	2.62	16.51	0.51	32.1	2.56	0.24	10.6	38	76.82	92.43	3.1	2.9	1.08
6b	286	313	78	81	0	7	8.35	4.49	4.30	15.83	0.44	35.71	2.59	1.24	2.1	13	97.90	341.97	92.7	45.6	2.03
6c	307	361	171	128	1	8	8.13	7.72	7.17	12.20	0.47	26.05	1.15	3.25	0.4	98	110.89	314.92	5.6	3.3	1.71
6d	578	169	179	112	0	0	8.29	3.36	3.26	24.72	0.73	33.9	1.64	2.57	0.6	60	170.87	250.85	21.1	7.2	2.94
6e	539	114	110	117	1	10	7.92	19.86	16.57	20.29	0.90	22.44	2.78	9.45	0.3	80	113.51	166.85	21.8	8.4	2.60
6f	396	77	45	149	0	9	8.12	6.27	5.90	8.21	0.31	26.82	0.78	2.45	0.3	98	93.97	94.09	51.7	27.0	1.91
7a	391	268	387	0	0	0	7.64	3.11	3.02	19.88	0.63	31.81	2.29	0.45	5.1	46	146.35	133.86	27.0	4.1	6.56
7b	302	301	364	199	0	9	8.19	4.31	4.13	12.96	0.44	29.55	1.64	0.08	20.8	68	112.40	128.95	44.0	21.2	2.07
8a	251	238	195	114	0	0	8.14	2.53	2.47	14.38	0.44	32.95	2.62	0.07	39.2	63	116.95	155.48	31.1	11.2	2.79
8b	363	165	110	141	0	0	8.42	1.51	1.49	1.67	0.10	17.21	1.27	0.10	12.5	71	66.61	59.41	13.1	5.0	2.63
8c	360	144	131	132	0	4	8.34	1.43	1.41	1.73	0.11	16.07	1.58	0.31	5.0	103	103.02	51.76	13.2	6.1	2.18
8d	196	233	178	95	0	0	8.05	2.49	2.43	16.48	0.49	33.48	2.19	0.67	3.3	66	303.76	192.56	26.5	11.2	2.37
8e	326	183	167	164	0	4	8.42	1.34	1.32	1.59	0.09	18.61	1.32	0.21	6.2	82	79.49	47.62	15.3	6.6	2.31
8f	336	159	184	118	1	5	8.5	1.32	1.31	4.75	0.13	37.33	1.32	0.29	4.5	63	92.73	45.26	60.3	24.7	2.45

Appendix Table 7 : Fitzwilliam Soil Data

Quadrat	Axis 1	Axis 2	Axis 3	Axis 4	RabDropping	Bare Earth	pH	M. Dry %	M. Wet %	C %	N %	C:N Ratio	Amm-N: µg N per kg Dry Soil	Nit-N: µg N per kg Dry Soil	Ratio Am-N:Nit-N	µg P per g Soil	mg Pb per kg Soil	mg Zn per kg Soil	g Ca per kg Soil	g Mg per kg Soil	Ca: Mg Ratio
1a	234	116	0	26	0	0	7.45	26.67	21.06	16.87	0.57	29.81	3.21	0.30	10.6	168	60.77	83.01	2.8	4.0	0.70
1b	226	57	132	128	0	0	7.75	30.68	23.48	19.48	0.66	29.34	9.64	1.01	9.6	149	64.19	98.84	13.5	4.6	2.95
1c	31	112	142	0	0	0	7.76	33.65	25.18	21.81	0.77	28.40	3.32	0.53	6.3	168	66.60	82.71	5.2	3.8	1.38
1d	72	131	114	63	0	0	7.31	34.76	25.80	18.74	0.60	31.15	2.10	0.14	14.9	76	74.49	81.19	6.9	5.6	1.24
2a	108	45	49	80	0	0	7.87	26.07	20.68	5.24	0.24	21.83	2.91	2.17	1.3	163	114.69	146.59	25.9	11.1	2.34
2b	89	50	33	102	0	0	7.82	28.75	22.33	8.38	0.35	23.69	3.21	0.86	3.7	140	118.35	131.94	28.7	11.4	2.51
2c	115	63	69	96	0	0	7.85	31.21	23.79	7.43	0.31	23.68	2.47	1.48	1.7	168	108.43	104.10	28.0	12.2	2.29
3a	55	102	81	81	0	0	7.67	25.97	20.61	7.82	0.23	33.46	1.55	0.54	2.9	157	136.34	123.67	56.1	24.4	2.30
3b	61	61	23	52	0	0	7.21	23.27	18.87	18.86	0.52	36.38	1.35	0.17	8.2	133	80.43	117.06	10.2	4.4	2.33
3c	72	65	32	54	0	0	7.83	19.84	16.55	17.38	0.52	33.70	2.17	0.38	5.7	140	86.10	95.14	8.7	5.5	1.57
4a	109	155	78	101	0	0	7.98	24.97	19.98	6.70	0.23	29.23	1.65	0.51	3.3	153	124.12	114.63	106.5	21.8	4.89
4b	44	166	79	80	0	0	7.9	27.91	21.82	8.39	0.24	34.40	1.85	1.12	1.7	135	147.16	122.58	114.7	39.9	2.87
4c	138	102	78	61	0	0	7.75	27.13	21.34	5.96	0.23	25.67	2.01	0.49	4.1	138	121.78	120.09	35.4	15.9	2.23
5a	49	67	51	71	0	0	7.81	26.76	21.11	9.40	0.32	29.69	2.63	1.52	1.7	147	122.25	124.29	25.5	11.0	2.31
5b	0	148	52	108	0	0	7.68	24.88	19.92	4.56	0.18	25.12	1.67	0.83	2.0	143	135.46	152.88	44.5	13.9	3.19
5c	36	111	58	133	0	0	7.72	25.42	20.27	5.09	0.20	25.78	0.34	1.30	0.3	95	206.20	112.58	54.7	10.1	5.41
6a	29	87	47	101	0	0	7.81	26.30	20.82	6.78	0.24	28.89	3.20	1.36	2.4	148	152.49	116.06	56.2	26.0	2.16
6b	33	17	57	118	0	0	8.28	26.38	20.87	6.75	0.23	29.99	2.89	1.16	2.5	166	162.19	122.38	70.9	33.6	2.11
6c	13	0	48	86	1	0	8.27	26.91	21.20	7.37	0.25	29.48	3.64	2.00	1.8	155	159.00	131.72	60.1	27.5	2.18

Appendix Table 8 Upton: Pearson r correlation coefficients at P< 0.01 and P< 0.05 Levels

Variable	Variable	Pearson r	Sig (2-tailed)	Variable	Variable	Pearson r	Sig (2-tailed)
Ca	Mg	.932	.0001	pH	Ca:Mg	.447	.010
%C	%N	.900	.0001	Axis2	%C	.439	.012
C:N	Mg	.847	.0001	NO_3^--N	Zn	.429	.014
C:N	Ca	.756	.0001	Axis4	C:N	.399	.024
%N	Zn	.671	.0001	Moisture%	Zn	-.398	.024
pH	C:N	.646	.0001	C:N	NH_4^+-N	.397	.025
%C	NH_4^+-N	.635	.0001	Moisture%	%C	-.396	.025
%N	Pb	.626	.0001	Axis2	pH	.393	.026
%C	Zn	.608	.0001	Axis2	BareEarth	.371	.037
%N	NO_3^--N	.603	.0001	Moisture%	NH_4^+-N:NO_3^--N	.358	.048
%C	Pb	.602	.0001	RabDrop	Ca	.353	.047
Axis2	Zn	.601	.0001	NH_4^+-N:NO_3^--N	Ca	.353	.047
Moisture%	Pb	-.580	.001	Moisture%	P	.351	.049
%C	C:N	.580	.001	Axis1	RabDrop	-.350	.050
pH	Ca	.575	.001				
pH	Mg	.572	.001				
%C	Ca:Mg	.569	.001				
%N	Ca:Mg	.566	.001				
Axis1	NO_3^--N	.565	.001				
Pb	Zn	.557	.001				
Axis1	Moisture%	-.555	.001				
Axis2	Moisture%	-.553	.001				
Axis4	Mg	.537	.002				
Bare Earth	NO_3^--N	.530	.002				
Axis4	pH	.529	.002				
Axis2	%N	.514	.003				
pH	Moisture%	-.505	.003				
pH	Pb	.499	.004				
%N	NH_4^+-N	.495	.004				
Pb	Ca:Mg	.493	.004				
Axis2	Ca:Mg	.485	.005				
Axis1	%N	.473	.006				
Moisture%	%N	-.470	.007				
Axis2	Pb	.459	.008				
pH	%C	.459	.008				
Axis4	Ca	.455	.009				
Moisture%	Ca:Mg	-.451	.010				

Correlation significant at P<0.01 level (2-tailed)

Correlation significant at P<0.05 level (2-tailed)

Appendix Table 9: Fitzwilliam Pearson r correlation coefficients at 0.01 and 0.05 significance levels.

Variable	Variable	Pearson r	Sig (2-tailed)	Variable	Variable	Pearson r	Sig (2-tailed)
%C	%N	.975	.0001	%C	NO_3^--N	-.575	.010
Ca	Mg	.880	.0001	pH	Ca	.563	.012
%N	Pb	-.852	.0001	NH_4^+:NO_3^-	Mg	-.557	.013
%C	Pb	-.830	.0001	Axis1	NH_4^+-N	.543	.016
%C	NH_4^+-N:NO_3^-	.826	.0001	NO_3^--N	Zn	.542	.016
%N	NH_4^+-N:NO_3^--N	.804	.0001	pH	Pb	.540	.017
NH_4^+-n:NO_3^--N	Pb	-.785	.0001	pH	%C	-.533	.019
%N	Zn	-.782	.0001	NO_3^--N	Pb	.527	.020
%C	Zn	-.771	.0001	%N	Ca:Mg	-.518	.023
NH_4^+-N:NO_3^--N	Zn	-.713	.001	%C	Ca:Mg	-.512	.025
%N	Ca	-.705	.001	NH_4^+:NO_3^-	Ca:Mg	-.502	.029
Pb	Ca	.699	.001	%N	NO_3^--N	-.500	.029
Axis3	Moisture%	.698	.001	Axis2	NO_3^--N	-.492	.032
Axis4	Ca:Mg	.681	.001	%C	C:N	.491	.033
%N	Mg	-.679	.001	C:N	NO_3^--N	.491	.033
Nit-N	NH_4^+-N:NO_3^--N	-.672	.002	Axis1	NH_4^+-N:NO_3^--N	.486	.035
Pb	Mg	.672	.002	Axis4	Zn	.485	.035
pH	NH_4^+-N:NO_3^--N	-.658	.002	pH	%N	-.482	.037
%C	Ca	-.646	.003	Axis4	Ca	.479	.038
pH	Mg	.641	.003	%N	NH_4^+-N	.462	.046
pH	NO_3^--N	.637	.003	pH	P	.458	.049
Axis4	Pb	.631	.004				
%C	Mg	-.615	.005				
Pb	Ca:Mg	.606	.006				
Axis4	%C	-.600	.007				
Axis4	%N	-.590	.008				
Pb	Zn	.589	.008				
NH_4^+-N:NO_3^--N	Ca	-.586	.008				
Ca	Ca:Mg	.585	.009				
Axis1	Pb	-.583	.009				

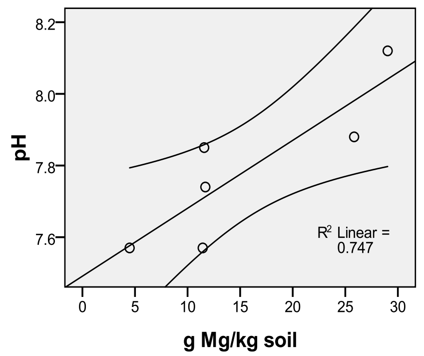
Correlation significant at P<0.01 level (2-tailed)　　Correlation significant at P<0.05 level (2-tailed)

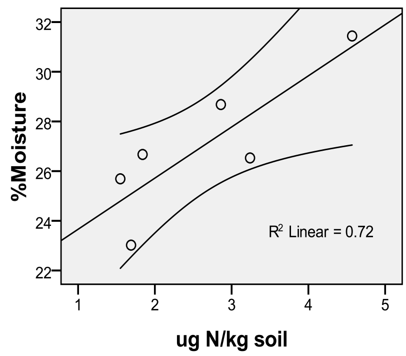
Appendix Table 10 Means, Median and Ranges for Fitzwilliam and Upton

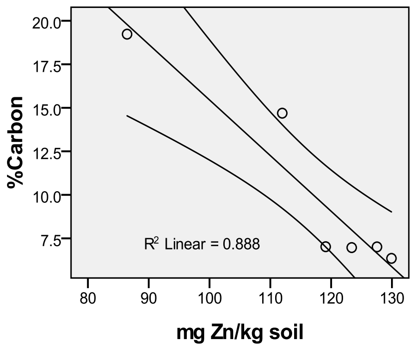
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Fitzwilliam	pH			% Moisture			% Carbon			% Nitrogen			C: N Ratio			Ammonia-N ug N/kg soil		
2	Area	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
3	1	7.57	7.6	7.31 - 7.76	31.44	32.17	26.67 - 34.76	19.23	19.11	16.87 - 21.81	0.65	0.63	0.57 - 0.77	29.67	29.58	28.40 - 31.15	4.57	3.27	2.10 - 9.64
4	2	7.85	7.85	7.82 - 7.87	28.68	28.75	26.07 - 31.21	7.01	7.43	5.24 - 8.38	0.30	0.31	0.24 - 0.35	23.07	23.68	21.83 - 23.69	2.86	2.91	2.47 - 3.21
5	3	7.57	7.67	7.21 - 7.83	23.02	23.27	19.84 - 25.97	14.69	17.38	7.82 - 18.86	0.42	0.52	0.23 - 0.52	34.51	33.7	33.46 - 36.38	1.69	1.55	1.35 - 2.17
6	4	7.88	7.9	7.75 - 7.98	26.67	27.13	24.97 - 27.91	7.02	6.7	5.96 - 8.39	0.24	0.23	0.23 - 0.24	29.77	29.23	25.67 - 34.40	1.84	1.85	1.65 - 2.01
7	5	7.74	7.72	7.68 - 7.81	25.69	25.42	24.88 - 26.76	6.35	5.09	4.56 - 9.40	0.23	0.2	0.18 - 0.32	26.86	25.78	25.12 - 29.69	1.55	1.67	0.34 - 2.63
8	6	8.12	8.27	7.81 - 8.28	26.53	26.38	26.30 - 26.91	6.97	6.78	6.75 - 7.37	0.24	0.24	0.23 - 0.25	29.45	29.48	28.89 - 29.99	3.24	3.2	2.89 - 3.64
9																			
10																			
11	Upton	pH			% Moisture			% Carbon			% Nitrogen			C: N Ratio			Ammonia-N ug N/kg soil		
12	Area	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
13	1	7.00	6.82	6.68 - 7.66	25.12	24.52	23.68 - 27.77	1.60	1.65	0.79 - 2.30	0.12	0.12	0.09 - 0.16	12.59	12.88	8.64 - 15.97	1.98	1.76	0.78 - 3.65
14	2	8.46	8.47	8.32 - 8.57	26.75	25.75	23.89 - 31.61	13.56	13.81	12.55 - 14.06	0.21	0.23	0.16 - 0.25	67.37	65.94	56.72 - 80.87	2.62	2.6	1.31 - 3.98
15	3	6.92	6.96	6.73 - 7.01	22.33	22.02	21.07 - 24.22	0.84	0.93	0.45 - 1.07	0.07	0.07	0.05 - 0.08	11.95	12.86	8.54 - 13.57	0.94	0.91	0.67 - 1.26
16	4	7.19	7.23	6.93 - 7.42	26.57	29.63	19.75 - 30.31	4.12	3.18	0.91 - 8.27	0.17	0.15	0.07 - 0.28	21.15	20.94	12.38 - 30.13	1.09	1.03	1.03 - 1.20
17	5	7.99	7.85	7.83 - 8.3	3.37	3.18	2.98 - 3.96	22.78	19.17	12.52 - 36.65	0.59	0.55	0.44 - 0.78	36.80	35.16	28.37 - 46.88	3.11	2.74	2.08 - 4.51
18	6	8.03	8.13	7.39 - 8.35	7.40	5.38	2.69 - 19.86	16.29	16.17	8.21 - 24.72	0.56	0.49	0.31 - 0.90	29.50	29.46	22.44 - 35.71	1.92	2.1	0.78 - 2.78
19	7	7.92	7.92	7.64 - 8.19	3.71	3.71	3.11 - 4.31	16.42	16.42	12.96 - 19.88	0.53	0.53	0.44 - 0.63	30.68	30.68	29.55 - 31.81	1.97	1.97	1.64 - 2.29
20	8	8.31	8.38	8.05 - 8.50	1.77	1.47	1.32 - 2.49	6.77	3.24	1.59 - 16.48	0.22	0.12	0.09 - 0.49	25.94	25.78	16.07 - 37.33	1.72	1.45	1.27 - 2.62
21																			
22	Fitzwilliam	Species Number					Upton	Species Number											
23	Area	Mean	Median	Range			Area	Mean	Median	Range									
24	1	8.75	8.5	7 - 11.			1	11.5	11.5	8 - 15.									
25	2	5.67	6	4 - 7.			2	12.5	12.5	11 - 14.									
26	3	10.33	9	9 - 13.			3	17.25	18	14 - 19.									
27	4	8.33	9	7 - 9.			4	11	11	10 - 12.									
28	5	10.33	11	9 - 11.			5	12.67	12	12 - 14.									
29	6	8.67	9	7 - 10.			6	8.5	9	2 - 14.									
30							7	9.5	0.5	9 - 10.									
31							8	13.67	12.5	12 - 18.									
32																			

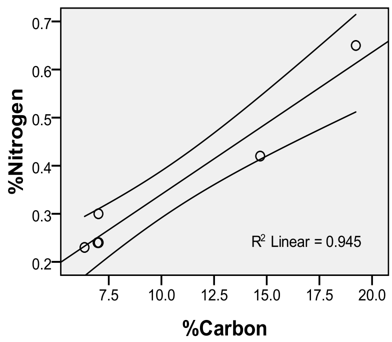
	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1	Nitrate-N ug N/kg soil			Phosphorus ug P/g soil			Lead mg Pb/kg soil			Zinc mg Zn/kg soil			Calcium g Ca/kg soil			Magnesium g Mg/kg soil		
2	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
3	0.50	0.42	0.14 - 1.01	140	159	76 - 168	66.51	65.4	60.77 - 74.49	86.44	82.86	81.19 - 98.84	7.10	6.05	2.8 - 13.5	4.49	4.3	3.8 - 5.6
4	1.50	1.48	0.86 - 2.17	157	163	140 - 168	121.04	114.69	108.43 - 118.35	127.54	131.94	104.10 - 146.59	27.55	28	25.9 - 28.7	11.58	11.4	11.1 - 12.2
5	0.36	0.38	0.17 - 0.54	143	140	133 - 157	108.40	86.1	80.43 - 136.34	111.96	117.06	95.14 - 123.67	24.97	10.2	8.7 - 56.1	11.44	5.5	4.4 - 24.4
6	0.71	0.51	0.49 - 1.12	142	138	135 - 153	131.02	124.12	121.78 - 147.16	119.10	120.09	114.63 - 122.58	85.52	106.5	35.4 - 114.7	25.84	21.8	15.9 - 39.9
7	1.22	1.3	0.83 - 1.52	128	143	95 - 147	154.64	135.46	122.25 - 206.20	129.92	124.29	112.58 - 152.88	41.56	44.5	25.5 - 54.7	11.69	11	10.1 - 13.9
8	1.50	1.36	1.16 - 2.00	156	155	148 - 166	157.89	152.49	152.49 - 162.19	123.38	122.38	116.06 - 131.72	62.37	60.1	56.2 - 70.9	29.03	27.5	26.0 - 33.6
9																		
10																		
11	Nitrate-N ug N/kg soil			Phosphorus ug P/g soil			Lead mg Pb/kg soil			Zinc mg Zn/kg soil			Calcium g Ca/kg soil			Magnesium g Mg/kg soil		
12	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
13	0.25	0.25	0.19 - 0.33	97	103	47 - 133	31.77	32.08	23.66 - 39.26	59.17	56.56	52.94 - 70.63	4.44	3.95	2.4 - 7.5	2.90	3	2.4 - 3.1
14	0.16	0.17	0.05 - 0.28	111	112	95 - 124	76.30	74.32	66.55 - 90.00	82.30	82.49	68.13 - 96.09	170.09	167.7	160.3 - 184.6	82.95	84.35	75.8 - 87.4
15	0.04	0.02	0.00 - 0.13	60	62	14 - 104	38.40	39.51	31.45 - 43.14	67.80	67.59	63.04 - 72.96	2.11	2.05	1.3 - 3.1	4.06	4	3.5 - 4.8
16	0.05	0.04	0.02 - 0.09	77	77	27 - 127	53.92	52.82	40.52 - 68.41	72.86	84.5	39.73 - 94.36	6.09	7.3	3.4 - 7.6	3.50	3.8	2.5 - 4.2
17	0.63	0.24	0.16 - 1.48	88	94	63 - 107	98.49	102.38	80.73 - 112.36	126.84	116.99	93.57 - 169.94	88.82	9.8	6.7 - 250.0	21.53	4.5	3.1 - 57.0
18	3.20	2.51	0.24 - 9.45	56	70	13 - 98	110.66	104.4	76.82 - 170.87	210.19	208.85	92.43 - 341.97	32.66	21.5	3.1 - 92.7	15.71	7.8	2.9 - 45.6
19	0.26	0.27	0.08 - 0.45	57	57	46 - 68	129.38	129.38	112.40 - 146.35	131.40	131.41	128.95 - 133.86	35.49	35.5	27.0 - 44.0	12.67	12.65	4.1 - 21.2
20	0.28	0.25	0.07 - 0.67	75	69	63 - 103	127.09	97.88	66.61 - 303.76	92.02	55.59	45.26 - 192.56	26.60	20.9	13.1 - 60.3	10.78	8.9	5.0 - 24.7
21																		

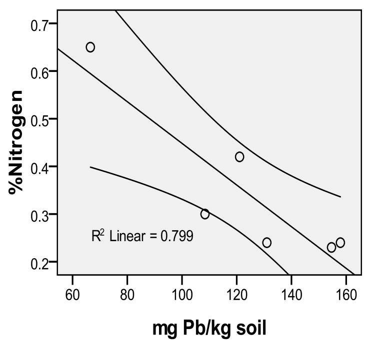
Appendix Table 11 Fitzwilliam – Mean Correlations.

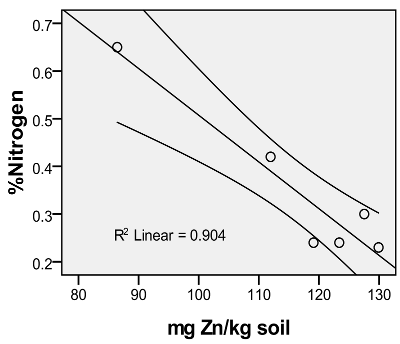


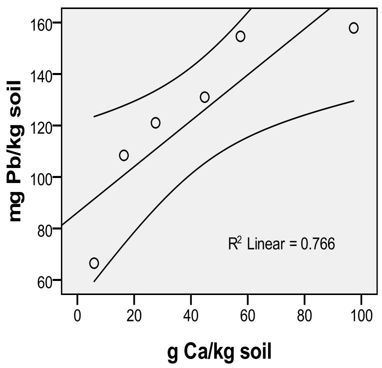


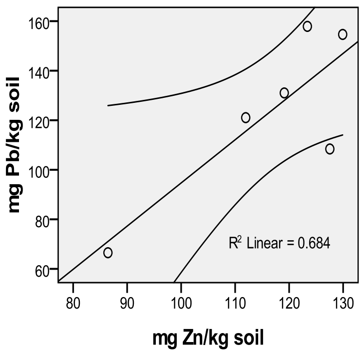




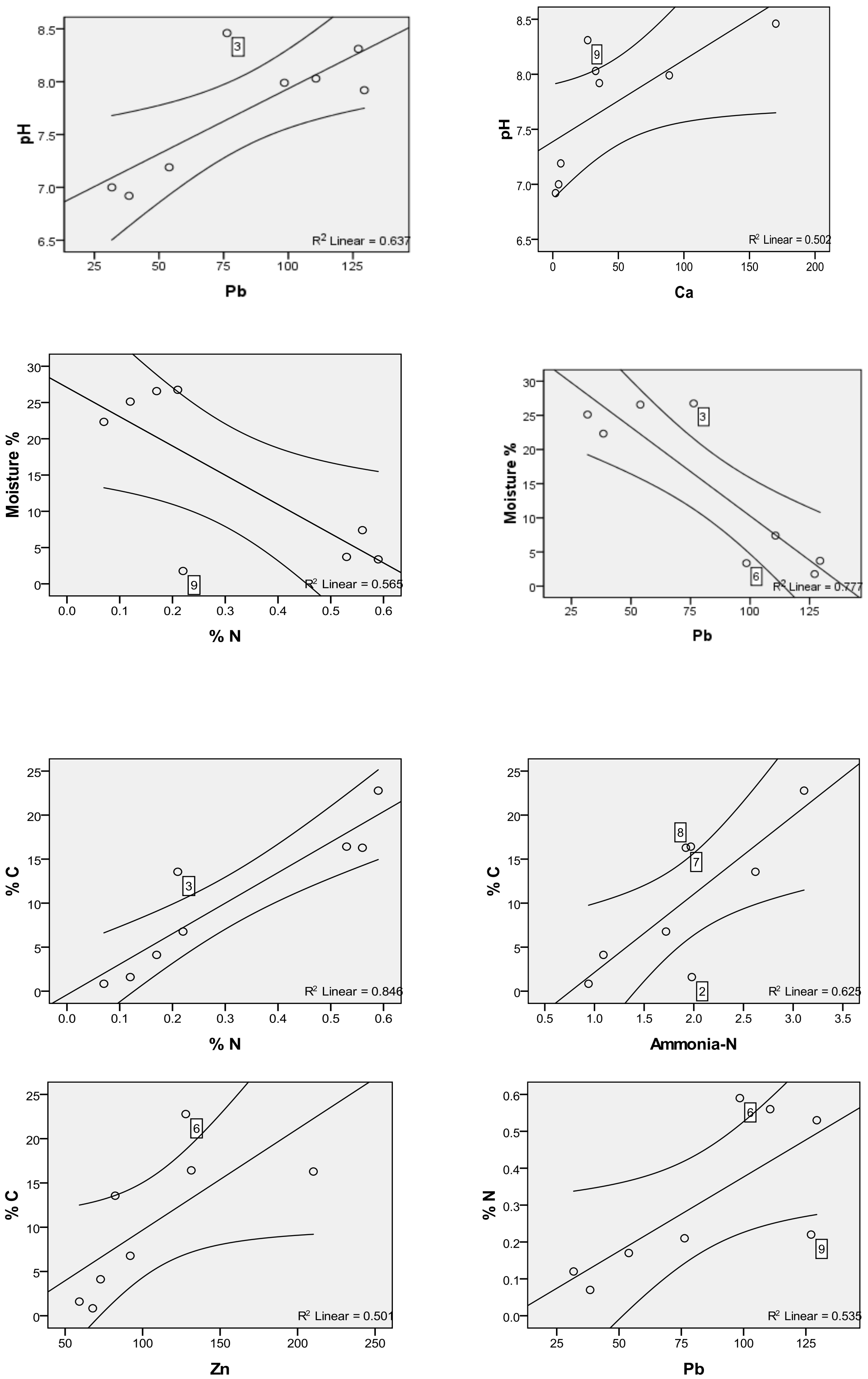


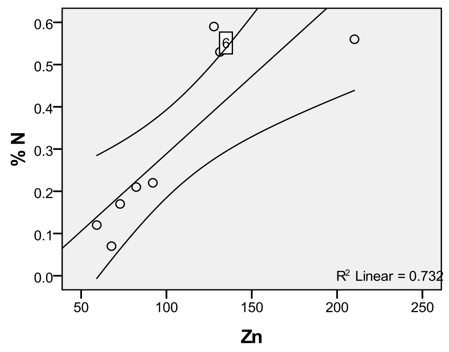


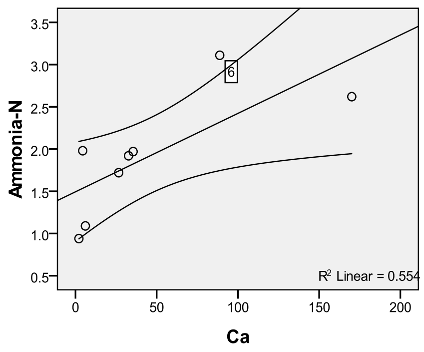


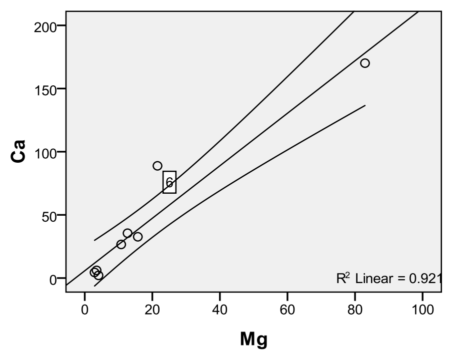


<u>Appendix Table 12. Upton: Significant Correlations</u>









Appendix Table13 Species Data by Quadrat

Upton	
Total No. Of Species	91

Quadrats	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	4a	4b	4c	5a	5b	5c	6a	6b	6c	6d	6e	6f	7a	7b	8a	8b	8c	8d	8e	8f
No. Of Species	12	15	8	11	12	13	11	14	19	14	17	19	12	10	11	12	14	12	14	12	10	8	2	5	10	9	15	12	12	12	18	13
Mean No. of Species	11.5				12.5				17.25				11			12.67				12			5.3		9.5			13			14.3	
	11.5				12.5				17.25				11			12.67			8.5						9.5		13.67					
Quadrat areas	1				2				3				4			5			6						7		8					

Fitzwilliam	
Total No. of Species	33

Quadrats	1a	1b	1c	1d	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	5b	5c	6a	6b	6c
No.of Species	9	7	11	8	6	7	4	9	13	9	9	9	7	11	9	11	10	9	7
Mean No. of Species	8.75				5.67			10.33			8.33			10.33			8.67		
Quadrat Areas	1				2			3			4			5			6		

Fitzwilliam & Upton	
Species in Common	27
Species not in Common	6