An investigation into the impact of nitrogen deposition from traffic emissions of NO_2 on the heathland in Cannock Chase, Staffordshire

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An extended report of fieldwork carried out for a final year project for Module SXE390 of a BSc(Hons) in Environmental Science with The Open University, Milton Keynes.

November 2012

1 Abstract

The effect of traffic emissions in areas of conservation interest is of mounting concern. Studies have identified increased nitrogen deposition alongside busy roads and have noted effects on many habitat types including heathlands. This study attempts to establish whether the road traffic crossing Cannock Chase Country Park in Staffordshire is increasing nitrogen deposition in the adjacent heathland, whether it is changing the soil properties and to what extent these changes are impacting on the vegetation community.

Atmospheric NO_2, soil properties of texture, % moisture, % organic matter, bulk density, pH and soluble nitrate, and percentage cover of *Calluna vulgaris, Vaccinium spp., Molinia caerulea, Deschampsia flexuosa, Rubus fruticosus,* and *Pteridium aquilinum* were measured across 8, 200m transects of dry heathland at right angles to 4 roads in Cannock Chase County Park. Each transect consisted of 8 sites at distances of approximately 1m, 3m, 5m, 10m, 20m, 50m, 100m and 200m from the road.

Traffic sources of atmospheric NO_2 were assessed using Palmes type diffusion tubes. The results showed increased concentrations above background NO_2 levels (between 11.7% and 72.7% higher) within 20m of the roads at 6 of the 8 transects. These 6 transects all showed a significant decrease in NO_2 levels with distance from their respective road. Correlations were found between the highest roadside NO_2 concentrations and greatest measured traffic counts taken over the same time period. Estimates of nitrogen deposition were made from the measured atmospheric NO_2 concentrations.

Soil pH decreased with distance from the road at all transects (mean 6.35 by the road to 4.33 200m from the road) while soil soluble nitrate showed high concentrations close to the road decreasing with distance for 6 transects (mean 142.2mg kg^{-1} by the road decreasing to 81.4mg kg^{-1} 200m from the road). However, there was large variation in the nitrate concentrations between transects. There was no significant pattern found in the other soil properties across any of the transects.

The percentage cover of *Calluna, Vaccinium, Molinia and Deschampsia* increased with distance from the road whilst *Rubus* decreased and *Pteridium* showed no overall pattern of change with distance from the road. Regression analysis showed no significant association between the percentage cover of any species and N deposition. *Calluna* abundance showed a significant positive relationship with soil acidity (R^2=0.3057, p=<0.001) for all sites and a significant negative relationship (R^2=0.121, p=0.02) with soil nitrate concentrations at 6 of the 8 transects.

The results indicate that the NO_2 emissions from the traffic are not sufficient to impact on the abundance of heathland vegetation or effect the soil pH and nitrate concentrations. However, the soil pH and nitrate concentrations do appear to be related to *Calluna* and to a lesser degree *Vaccinium* abundance but further investigations are required to assess the drivers that are altering these variables in the Park.

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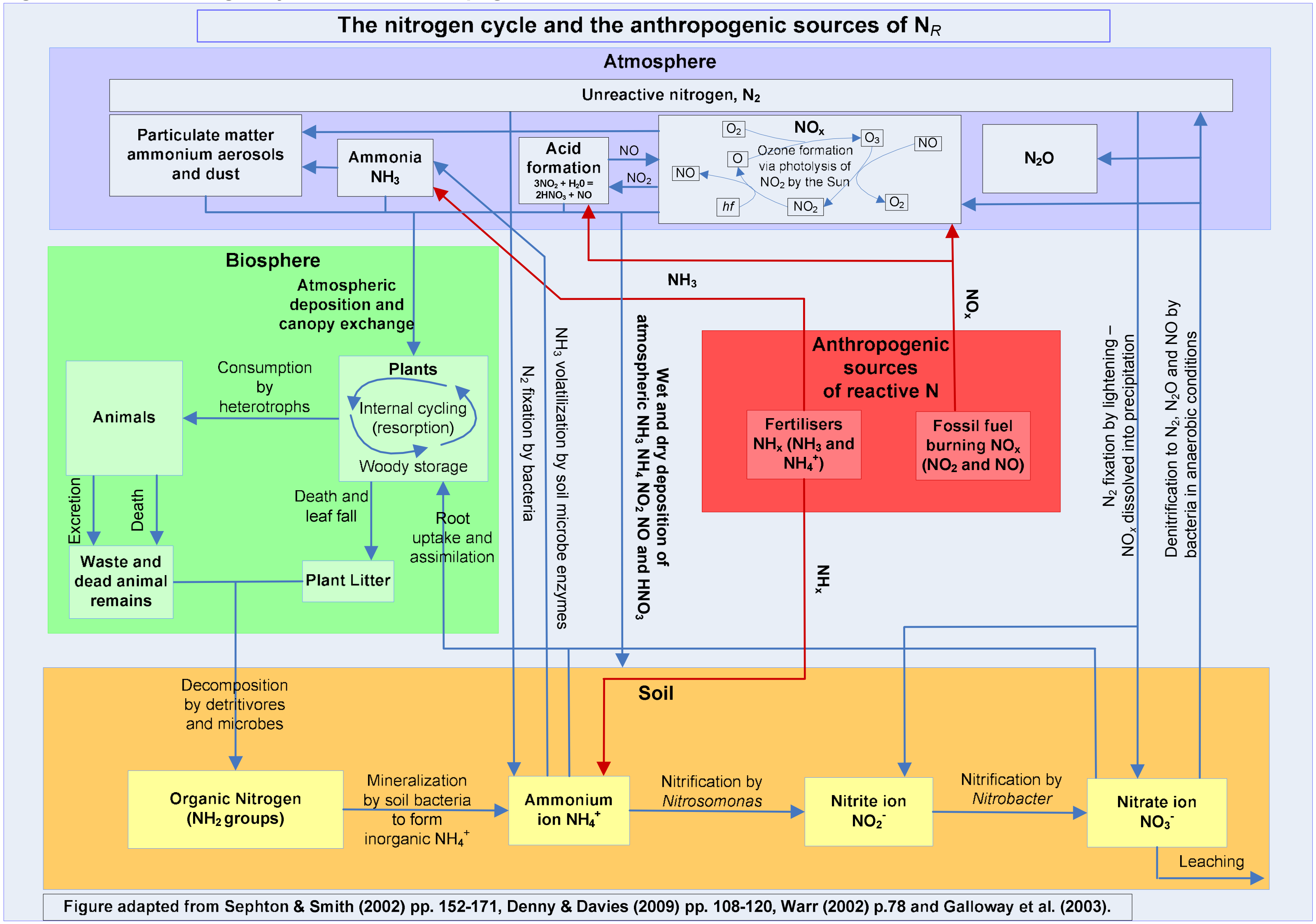
4 Introduction

Heathlands are a threatened ecosystem, which have dramatically declined in Britain in the last 200 years. Through development pressures the sites that remain are small and fragmented but are an important habitat for invertebrates, birds and reptiles. Heathland plants are highly specialised, and have adapted to acidic and low nutrient soil conditions. Input of nutrients, particularly nitrogen can disrupt the balance of the ecosystem, reducing biodiversity and allow domination of competitive plant species. Studies have shown that heathland habitats adjacent to busy roads have declined in species diversity due to deposition of nitrogen from the atmosphere.

4.1 Nitrogen deposition and the nitrogen cycle

In the natural nitrogen cycle atmospheric nitrogen, N_2 is unavailable to plants until it has been transformed into reactive forms (NH_3 or NO_3) either by the action of lightening or by nitrogen-fixing micro-organisms. Anthropogenic sources of reactive nitrogen, N_R, chiefly from the production and use of fertilisers and the burning of fossil fuels has dramatically increased the amount of N_R in the environment and therefore available to plants (UKREATE, 2012). Figure 3.1 shows how nitrogen cycles between the atmosphere, biosphere and soil in the terrestrial ecosystem via the actions of bacteria, plants, animals and natural physical and chemical processes. The figure also shows how anthropogenic sources of N_R (in red) accelerate some of the pathways (in bold) through the cycle, including wet and dry deposition from the atmosphere to the soil and vegetation. Denitrifying bacteria in the soil cannot however keep pace with the increase of N_R from anthropogenic sources and as a result N_R builds up in the environment, leading to a nitrogen cascade (Galloway et al., 2003).

Figure 4.4.1 - The nitrogen cycle and the anthropogenic sources of N_R



Increased N_R in the soil has two main impacts:

4.1.1 Eutrophication - increasing the soil nutrient levels to an extent that nitrogen no longer becomes a limiting factor for plant growth.

4.1.2 Acidification – addition of HNO_3 to the soil lowers its pH, affecting the functioning of plant roots and also releasing toxic metals into soil solution.

Heathlands have declined in species diversity due to large scale increases in N deposition, however it is not clear whether eutrophication or acidification is the significant driver for these changes.

4.2 Objectives and hypotheses

The objective of this study was to investigate the impact of locally produced NO_2 from vehicle traffic and statistically test whether it is having an effect on the adjacent heathland within Cannock Chase Country Park. To enable this, the study aimed to:

4.2.1 Measure the concentration of atmospheric NO_2 at various distances from roads adjacent to areas of heathland.

4.2.2 Estimate the contribution of atmospheric NO_2 to dry N deposition onto the surrounding vegetation and soil.

4.2.3 Assess the abundance of heathland plants *Calluna vulgaris* (hence forth referred to as *Calluna*), *Vaccinium myrtillus, V.vitis-idaea and V.*(collectively referred to as *Vaccinium)*, *Deschampsia flexuosa* (*Deschampsia*) and competing plants *Molinia caerulea* (*Molinia*), *Rubus fruticosus* (*Rubus*) and *Pteridium aquilinum* (*Pteridium*) at the same survey sites as 4.2.1. A description of the general characteristics of the vegetation composition and the management and grazing impact at the sites was also considered.

4.2.4 At the same sites as 4.2.1 and 4.2.3 describe the soil profiles and characteristics in terms of texture, moisture, organic content, bulk density, pH and water soluble nitrate.

4.2.5 Statistically test the hypotheses:

1. The level of N deposition decreases with distance from the road.
2. The abundance of heathland plant species (*Calluna, Vaccinium* and *Deschampsia*) reduces with increased N deposition (lower abundance close to the road).
3. The abundance of heathland plant species (*Calluna, Vaccinium* and *Deschampsia*) decreases with increased soil soluble nitrate (increased nitrate is expected with increased N deposition – 4.1.1).
4. The abundance of heathland plant species (*Calluna, Vaccinium* and *Deschampsia*) decreases with increased soil acidity (lower soil pH is expected with increased N deposition – 4.1.2).

An assessment will also be made on the contribution to variation in heathland plant species cover by other soil properties of moisture content, organic content and bulk density and by direct competition by the three invasive plant species (*Molinia, Rubus* and *Pteridium*).

4.3 The study site – Cannock Chase Country Park

The study was carried out in Cannock Chase Country Park, Staffordshire, an Area of Outstanding Natural Beauty, containing wet and dry heathland that are Sites of Special Scientific Interest and Special Areas of Conservation. The areas of heathland used in this study are European dry heath with an NVC of H9 *Calluna vulgaris – Deschampsia flexuosa, w*here *Calluna* is the dominant heather species (although *Erica cinerea* and *E.tetralix* is found in some areas) and *Deschampsia* is the dominant grass species. *Vaccinium myrtillus* and *V.vitis-idaea* are also dominant and the area is an important habitat for the hybrid bilberry *V.x intermedium* (Cannock Chase Berry). However these characteristic heathland species are under threat from invasive species such as *Pteridium, Rubus* and a variety of grasses, in particular *Molinia*.

Cannock Chase is situated north of Birmingham within a triangle between the towns of Stafford, Rugeley and Cannock attracting many recreational visitors every year. Many of the roads through the park are also used by commuters between the towns. As pressure to develop housing in the neighbouring towns continues, the impact of increasing traffic emissions on the heathland habitat is of concern.

5 Methodology

5.1 Methodology of fieldwork and laboratory analysis

4 roads in Cannock Chase were chosen for the study and from each road 2 transects were plotted across adjacent heathland. Each transect consisted of 8 sample points approximately 1m, 3m, 5m, 10m, 20m, 50m, 100m and 200m from the road (sites will be referred to as 1.1, 1.2, 1.3 etc for transect 1, and 2.1, 2.2, 2.3 etc for transect 2 and so on). Figure 5.1 shows the locations of the transects and adjacent roads.

The selection of the transect sites was made under advice from Staffordshire County Council site managers, with consideration of the habitat type, proximity to the busiest roads within the Chase, avoidance of areas of *Vaccinium myrtillus* known to be affected by the fungus *Phytophthora pseudosyringae* (precautionary biosecurity procedures were followed as directed by site managers) and avoidance of favoured areas of ground nesting birds. However, it is recognised and unavoidable that the sites differed with regards to predominant wind direction, topography (which may affect sunlight and drainage), large vegetation (that may provide shade, shelter and affect soil moisture levels for surrounding plants), historical land use and management programmes. In particular transect 3 had a bank of mixed deciduous trees between 3-20m from the road and transects 5 and 6 had a dense hedge of *Ulex europaeus* between 2-6m from the road. The other transects were more open with either isolated or small stands of trees and shrubs. Areas within transect 4 had been mown at various times in the last 5-10 years. Parts of the Chase were used as a military base in the early 20th Century. The soils of Transects 5 and 6 in particular may be affected as there are concrete bases of military huts in this area.

Figure 5.1 - Transects and background sites within Cannock Chase Country Park.
Transects 1 and 2 - approximately north from Chase Road (grid ref for site 1.1 - SJ 97846,17498 and 2.1 - SJ 97935,17542). Transects 3 and 4 - east from Camp Road (3.1 - SJ 97761, 16976 and 4.1 - SJ 98097,15877). Transects 5 and 6 north from Penkridge Bank Road (5.1 - SK 00358,16872 and 6.1 - SK 00460,16895). Transect 7 and 8 - west from Brindley Heath Road (7.1 - SK 00187,15521 and 8.1 - SK 00297,15107).

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The fieldwork for transects (5 & 6) was carried out by Staffordshire County Council's department of Environment and Countryside using the same methodology as outlined here, and the laboratory analysis conducted alongside the samples from the other 6 transect sites by the author at Staffordshire Scientific Services laboratory.

Traffic counts on the roads within the Park (carried out by Staffordshire County Council Highway Data Team on behalf of SCC Environment and Countryside) during part of the same time period as this study (second half of June and July 2012) will be used as supporting data in this report.

5.1.1 Measurement of atmospheric NO_2

During the months of May, June and July 2012, 3 sets of NO_2 diffusion tubes were deployed for 4 weeks each at 50 survey points (8 points along transects 1-4, 7 and 8, plus roadside sites on transects 5 and 6) and 2 sets (during June and July) at 14 survey points (another 7 points along transects 5 and 6). The tubes were attached to the trunk of each sample tree (or wooden posts if no trees were available, see Figure 5.2) using a plastic clip and flexible plastic tie. Although the tree vegetation may reduce the diffusion of the air around the NO_2 tubes, there was concern that the tubes sited on posts were at a greater risk of vandalism due to higher visibility and easier access. However, some lower branches were removed to allow positioning of the tubes, and to increase the air diffusion. Where possible the tubes were sited at 1m-2m above ground in order to measure the conditions just above the dwarf shrubs and ground level plants. Two transects (1 & 8) had triplicate tubes located at each site to assess the precision of the results. The ambient background NO_2 level was also measured in triplicate at a distance greater than 500m from any road (background site grid reference SJ 98530,17740).

Palmes type diffusion tubes are commonly used to measure the mean concentration of NO_2 normally over a 2-4 week period (Targa et al. 2008). For this study the preparation of the NO_2 diffusion tubes followed the procedure as outlined by Targa et al. (2008). An absorbent solution of 20% triethanolamine (TEA) to 80% deionised water (v/v) was used. The tubes were exposed for 4 weeks before being collected and returned to the laboratory for analysis. A further

2 sets of tubes were exposed at each site for 4 weeks each, giving a total of 3 sets of 4 weeks data.

Figure 5.2 - Transect 2 viewed from Chase Road.
The *C.monogyna* tree in the centre was site 2.3. The poles positioned to the left of centre were sites 2.4 and 2.5. Sites 2.1 and 2.2 were also *C.monogyna* trees just off the left hand side of this picture.

The analysis of the NO_2 diffusion tubes followed the procedure as outlined by Targa et al. (2008), using a colour reagent of sulphanilamide:N-1 (Naphthyl-1) Ethylene Diamine Dihydrochloride (NEDD) (using a ratio of 1:7 x 10^{-3}). After 40 minutes of colour development the solution was read on a calibrated spectrophotometer (Cecil 2000 series), set at a wavelength of 540nm. The reading was compared to a calibration graph prepared using a range of standard solutions (0-5µg NO_2) to calculate the amount of µg of NO_2 absorbed in the tube. Using this result and the total exposure time, the diffusion rate of NO_2 and the dimensions of the tube, the concentration of NO_2 in µg/m^3 in the atmosphere was calculated. Details of the calculation can be found in Appendix A.

Using the standard deposition velocity for NO_2 of 0.001m/s (Highways Agency, 2007) the amount of dry nitrogen deposition was estimated for each site. See Appendix A for details of the calculation.

5.1.2 Measurement of percentage cover of plant species

During June and August 2012, at each site used for the NO_2 measurements (5.1.1), a 1m x 10m belt transect parallel to the road was surveyed every 2 meters using a 1m x 1m frame quadrat (5 quadrats in total for each site). The percentage cover of *Calluna, Vaccinium, Deschampsia, Molinia, Rubus* and *Pteridium* was assessed. A description of the general vegetation community was carried out, identifying any other predominant species, presence of trees and scrub and the management and grazing impact on the site.

5.1.3 Measurement of soil characteristics

During May to July 2012, within the same 1m x 10m belt transect of the vegetation survey (5.1.2), a soil survey was carried out. Using a soil auger the profile of the soil was assessed on site, with regards to texture, colour and depth of horizons. A sample of the soil was taken from a depth of 0cm to 30cm, the rest of the soil was replaced. The soil sample was analysed in the laboratory for texture, moisture, organic matter, bulk density, pH and water soluble nitrate.

5.1.3.1 Texture

The texture of each soil was qualitatively categorized using a finger assessment (details of test in Appendix B).

The fresh soil samples had a range of water content depending on the conditions on site on the day of sampling. In order to compare the samples, the % dry matter was calculated by air drying the samples to remove most of the moisture.

5.1.3.2 Dry matter

The fresh soil samples were weighed into individual, labelled dishes and allowed to dry in the open air for 7 days and then weighed again.

The dried soils were passed through a 2mm gauge sieve, any clumps were broken up in a pestle and mortar, stones and pieces of vegetation were removed from the sample.

5.1.3.3 Moisture

To determine the full moisture content of the soils a sample of the air dried soil was further dried in an oven set at 105°C.

3g of air dried, sieved soil was accurately weighed (to the nearest 0.1mg) into a previously dried and weighed ceramic dish. The soil and dish were dried in an oven set at 105°C for 3 hours. The dish and sample was removed from the oven, allowed to cool in a desiccator and weighed. The sample was returned to the oven for a further hour, cooled and weighed again. This was repeated until successive weighings did not differ by more than 1mg.

5.1.3.4 Organic matter

The organic matter content of the soil was estimated by loss on ignition, which burns off the carbon content in the sample.

The soil sample and dish used to calculate the moisture content were dried in a muffle furnace set at 500°C for 4 hours. The sample was removed, allowed to cool in a desiccator and weighed. The sample was returned to the muffle furnace for a further hour, cooled and weighed again. This was repeated until successive weighings did not differ by more than 1mg.

5.1.3.5 Bulk density

50g of air dried and sieved soil was dried in an oven at 105°C to constant weight. Using a measuring spoon of known volume (15cm^3) a sample of the soil was accurately measured and weighed. To increase the precision of the test 3 measurements were taken for each sample and a mean weight calculated.

5.1.3.6 Soluble nitrate

10g of air dried and sieved soil was placed into a water tight plastic bottle. 100ml of deionised water was added to the bottle which was then capped and fitted to a mechanical rotating shaker for 1 hour. After removal from the shaker the sample was left to settle before the solution was decanted off, filtered through a Whatman 42 filter paper and the filtrate kept for analysis. The filtrate was analysed for NO_3^- by ion chromatography (Dionex Dx-120).

5.1.3.7 pH

10g of the air dried, sieved soil was weighed into a glass beaker. Deionised water was added to the beaker in a 1:10 soil:water ratio and allowed to stand for 1 hour. The pH of the solution was read using a calibrated pH meter and probe (Jenway 3150) whilst the solution was gently stirred using a magnetic stirrer.

Note: All soil laboratory methods adapted from Radojević & Bashkin (2006). Details of the calculation used for the soil parameters can be found in Appendix B.

5.2 Methodology of statistical analysis

The hypotheses (4.2.5) was assessed using regression analysis using Microsoft Excel Data Analysis tool.

Hypothesis 1 – Linear regression to compare the estimated N deposition values with the log of distance from the road.

Hypothesis 2 – Linear regression to compare the mean percentage cover of *Calluna, Vaccinium*, and *Deschampsia* with the estimated N deposition at each site.

Hypothesis 3 – Linear regression to compare the mean percentage cover of *Calluna, Vaccinium*, and *Deschampsia,* with the soil soluble nitrate at each site.

Hypothsis 4 – Linear regression to compare the mean percentage cover of *Calluna, Vaccinium*, and *Deschampsia,* with the soil pH at each site.

The contribution to variation in percentage cover of *Calluna, Vaccinium*, and *Deschampsia,* from soil parameters of moisture content, organic content and bulk density and the contribution of competing species was assessed using linear regression analysis.

6 Results

6.1 Atmospheric NO_2

Atmospheric NO_2 concentrations were calculated for 3 sets of 4 weeks exposure for 47 sites and 2 months for 17 sites. For the final month of exposure the tube at site 4.2 was found on the ground and at sites 8.1 and 8.2 the posts and triplicate tubes had been removed. The complete atmospheric NO_2 results can be found in Appendix C.

6.1.1 Method precision and accuracy

Figures 6.1 and 6.2 show the mean results for the triplicate tubes from transects 1 and 8.

Figure 6.1 - Atmospheric NO_2 concentration - Transect 1.
The error bars show standard error. Note: the y axis does not start at 0

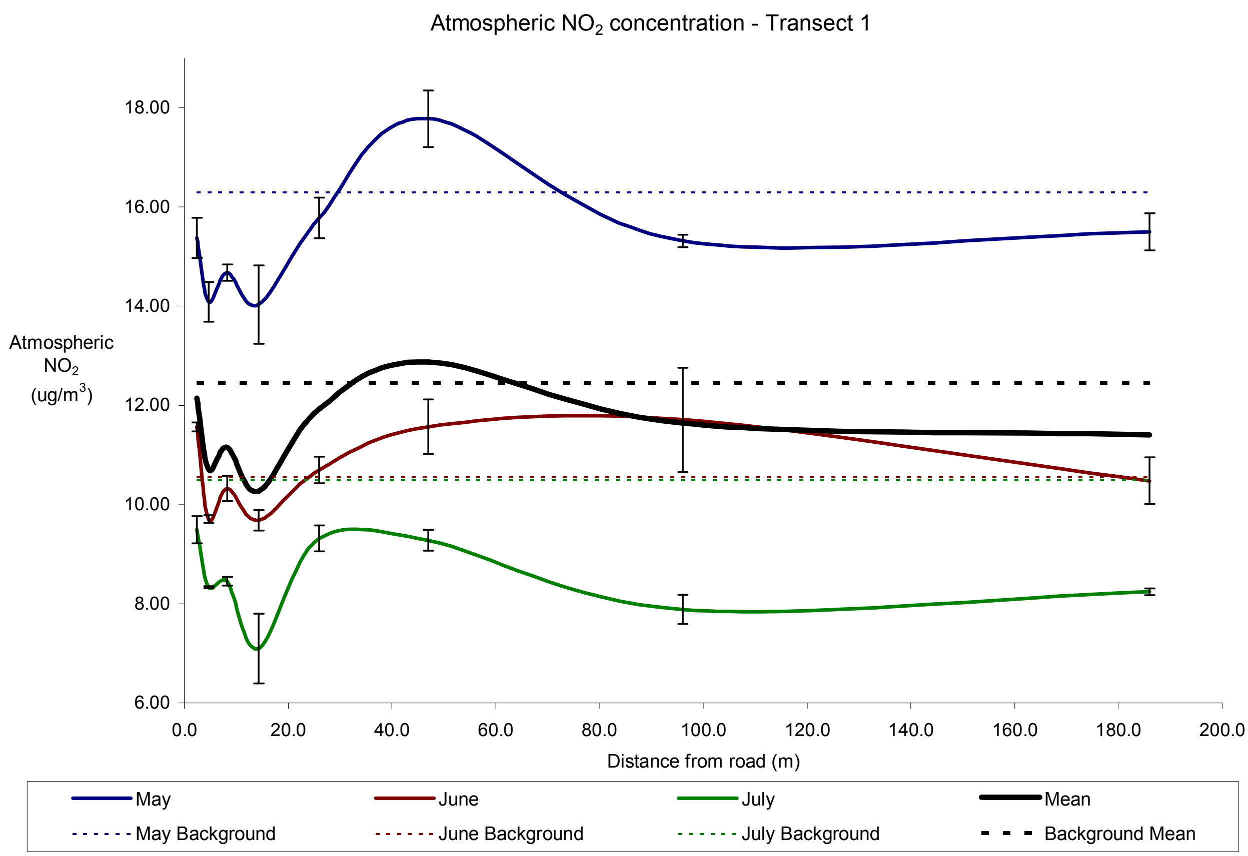
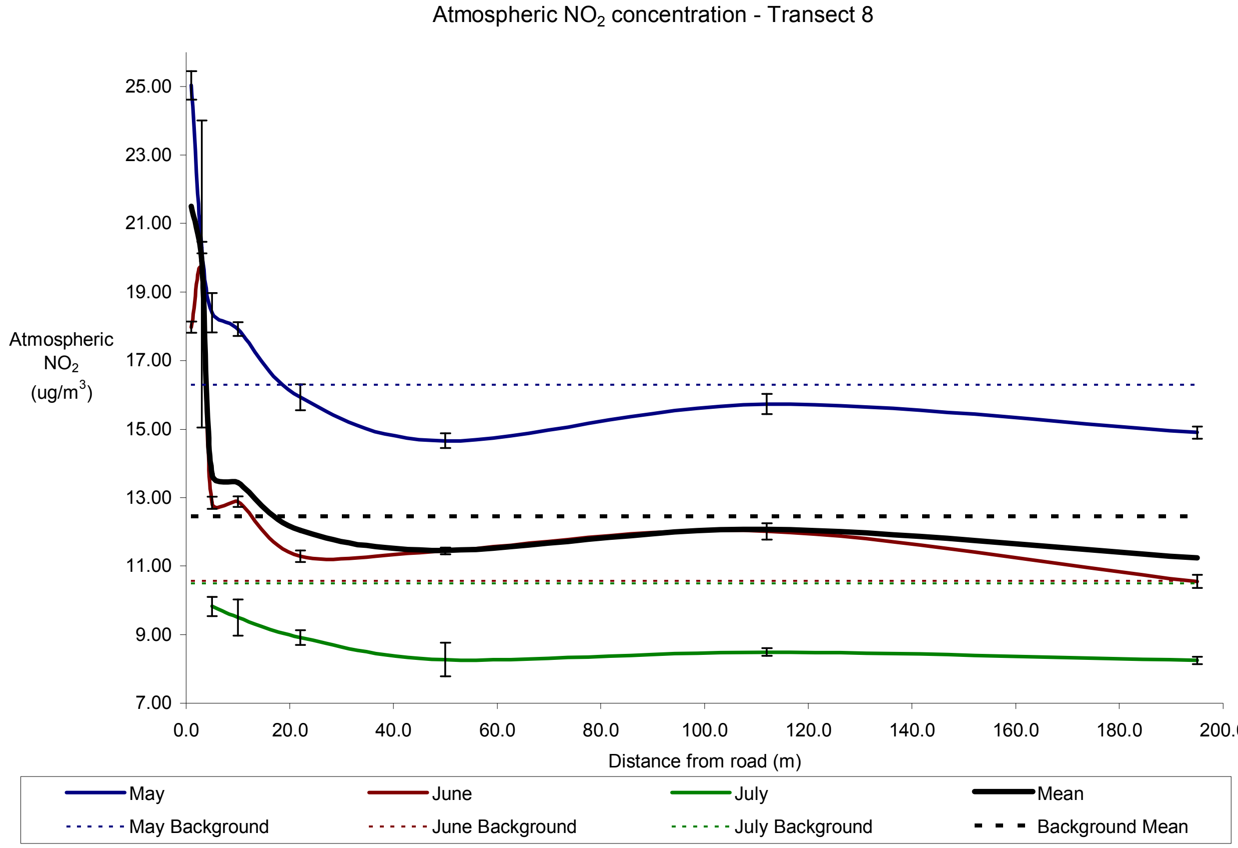


Figure 6.2 - Atmospheric NO_2 - Transect 8.
Error bars show standard error. Note: the y axis does not start at 0



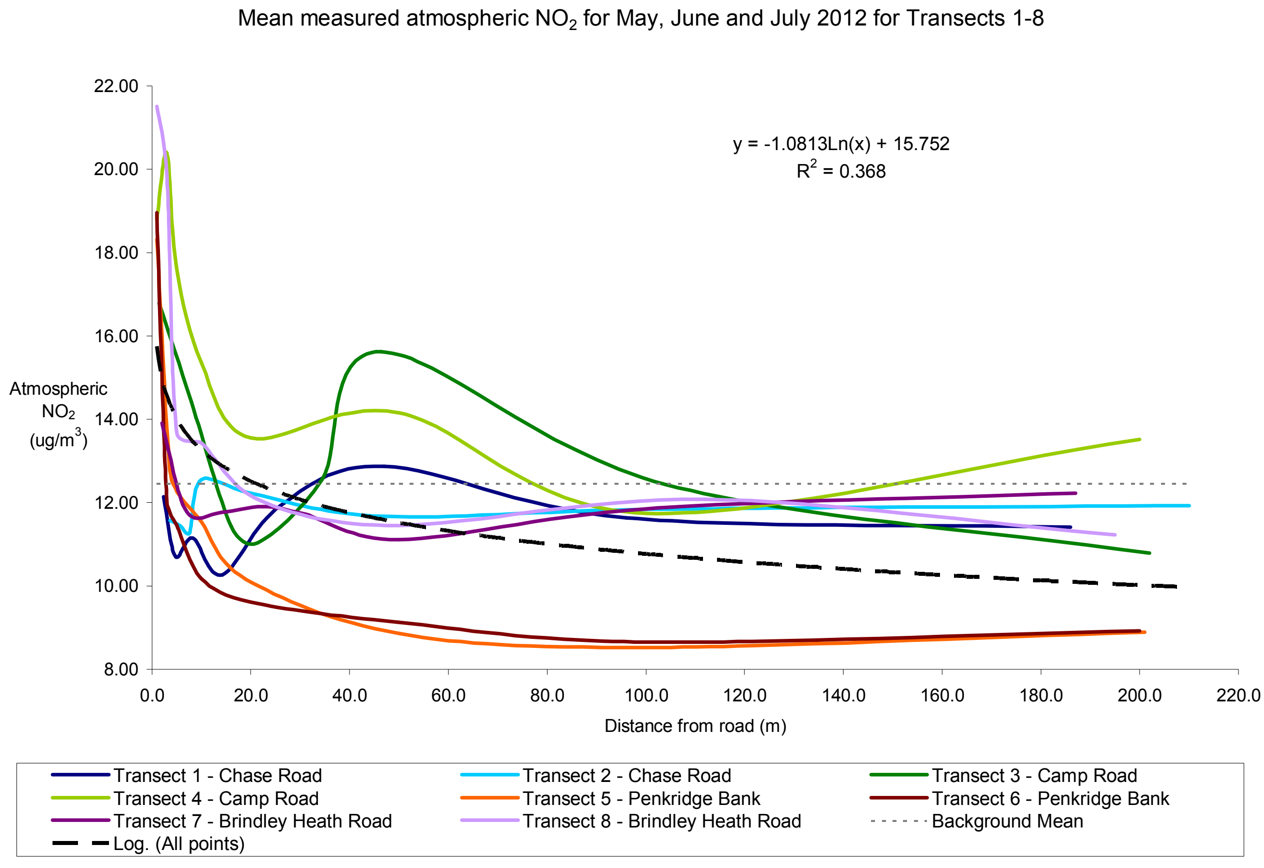
For all triplicate tubes analysed (49 sets) the coefficient of variation, CoV, (relative standard deviation) was <10% except at site 1.7 and 8.2 during June and 1.4 and 8.6 during July where the outliers were identified and removed from the data set prior to further statistical analysis. Less than 10% CoV is considered good precision within the limits of the diffusion tube method (Targa et al, 2008, p. 33).

Figures 6.1 and 6.2 both show a pattern of higher NO_2 concentration during May with levels reducing in June and again in July. This pattern was seen at all of the study sites and also in the mean concentration of the triplicate tubes from the background site - May 16.29µg/m^3 ±0.9, June 10.57µg/m^3 ±0.2 and July 10.49µg/m^3 ±0.4. This gave a background mean for the 3 months of 12.45µg/m^3. This compares well with the 2010 background annual mean concentration of 12.42547µg/m^3 modelled for the nearest coordinate (398500,317500) in Defra's Air Quality Datasets (Defra, 2012). The mean background NO_2 concentrations from this model for the year 2006-2010 indicate that Transects 5 and 6 have the lowest background levels (11.825µg/m^3 ±0.276) and Transect 8 has the highest (13.684µg/m^3 ±0.324).

6.1.2 General observations

Figure 6.3 shows the 3 month mean NO_2 concentrations for each transect. The measured background concentration and the logarithmic regression for all the data points are also shown.

Figure 6.3 - Mean atmospheric NO_2 for May, June and July for all transects. The mean background NO_2 concentration for all 3 months is also shown. The log best fit line is also plotted. Note: the y axis does not start at 0.



Whilst it can be seen from Figure 6.3 that each transect differed from each other in the pattern of mean atmospheric NO_2 with distance from the road, each transect showed a similar pattern each month and showed the same month on month trend that was seen at Transect 1 and 8 in Figures 6.1 and 6.2 (i.e. overall NO_2

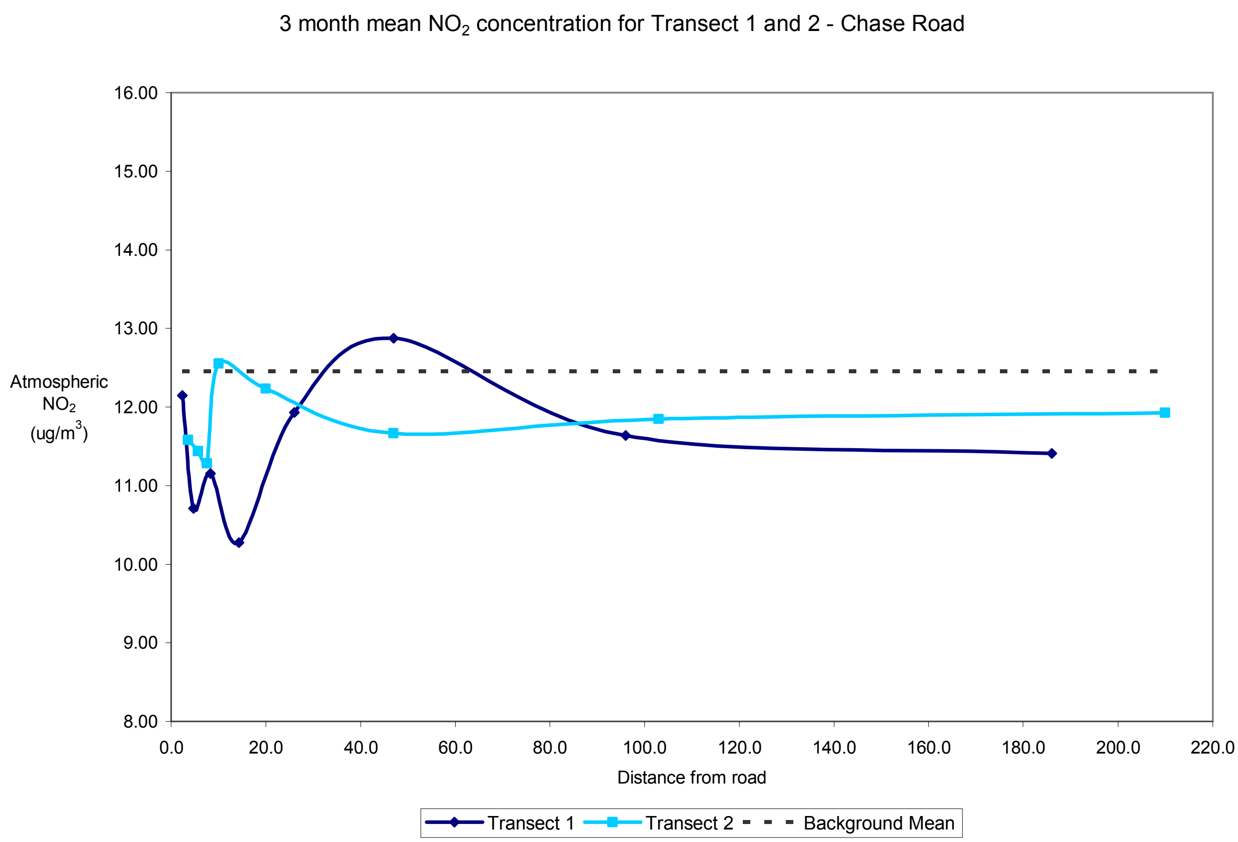
concentrations reduced each month). The mean of all sites during May, June and July was 17.37μg/m^3 ±0.39, 12.12μg/m^3 ±0.34, and 9.32μg/m^3 ±0.26 respectively.

Overall the whole data set showed a statistically significant logarithmic reduction in NO_2 with increasing distance from the road (R^2=0.368, p=<0.001).

6.1.3 Chase Road

Figure 6.4 shows the 3 month mean NO_2 results for transects 1 and 2 adjacent to Chase Road.

Figure 6.4 - 3 month mean NO_2 concentration for Transect 1 and 2.



The measured levels at both these transects were rarely over the background level indicating that the local road traffic is having little impact on the atmosphere in this area. The pattern of variation of NO_2 across the transects (which was seen each month) may be due to other factors such as how sheltered the diffusion tubes were at their exposure sites. For example site 1, 2 and 3 on transect 2 were positioned in trees while site 4 and 5 were on posts (see Figure 5.2).

6.1.4 Camp Road

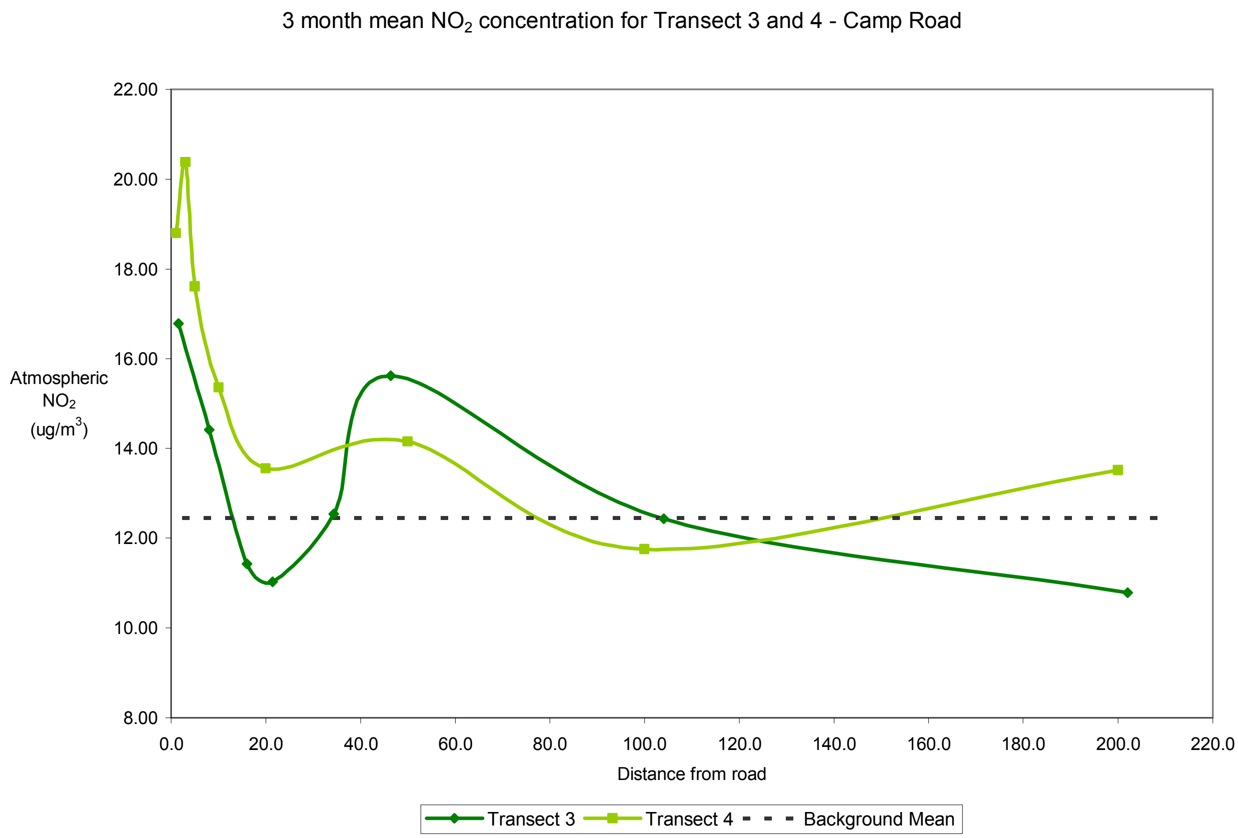
Transects 3 and 4 adjacent to Camp Road differed in terms of topology and vegetation near to the road. Transect 3 had a bank of mixed deciduous trees between 3 and 20m of the road and the site sloped uphill away from the road (see Figure 6.5). Transect 4 was far more exposed and the ground fairly level across the whole transect. As Transect 4 was more open all the NO_2 diffusion tubes were sited onto posts positioned at appropriate distances from the road (see Figure 6.6).

Figure 6.5 - Photograph of Transect 3 viewed from Camp Road

Figure 6.6 - Photograph of Transect 4 viewed from Camp Road.
Note: Posts positioned for NO_2 diffusion tubes exposure.

Figure 6.7 shows the 3 month mean NO_2 concentration for Transects 3 and 4 adjacent to Camp Road.

Figure 6.7 - 3 month mean NO_2 concentration for Transect 3 and 4.



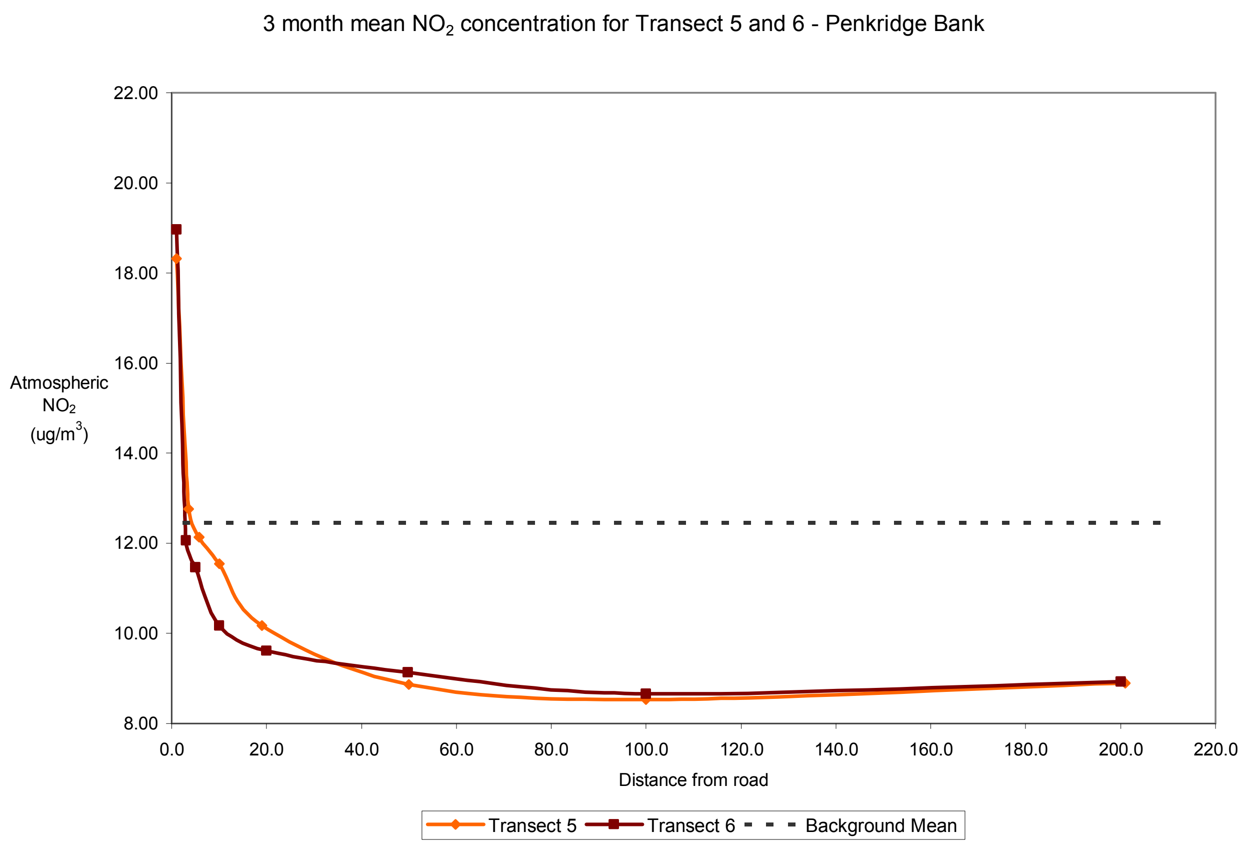
The mean result from site 4.2 on Transect 4 is based on 2 months data (May and June) as the diffusion tube was found on the floor at the end of the third month. As July concentrations were generally lower than May and June this explains the higher mean for this site compared to site 4.1.

Transect 3 shows a decrease in NO_2 concentrations between 1m and 20m from the road and then a rapid increase again up to 50m. This is most likely due to air rising over the bank of trees before sinking again carrying with it NO_2 emissions from the road. Transect 4 in contrast shows higher concentrations at the roadside, a steep decrease within 20m, a slight increase at 50m and then a more gradual decrease up to 100m. Between 100 (site 4.7) and 200m (site 4.8) the concentrations increase again, a pattern seen every month indicating another source of NO_2 influencing this area. Site 4.8 was positioned in an area of *Calluna* close to a rough track which may be used for access to the heathland by park ranger's vehicles.

6.1.5 Penkridge Bank Road

Both transect 5 and 6 shared similar patterns for the two months of measurement across the whole transect, Figure 6.8. The roadside NO_2 levels here were amongst the highest of all the sites but concentrations dropped off sharply to background levels within 5m from the road and beyond 20m levels were consistently well below the background mean.

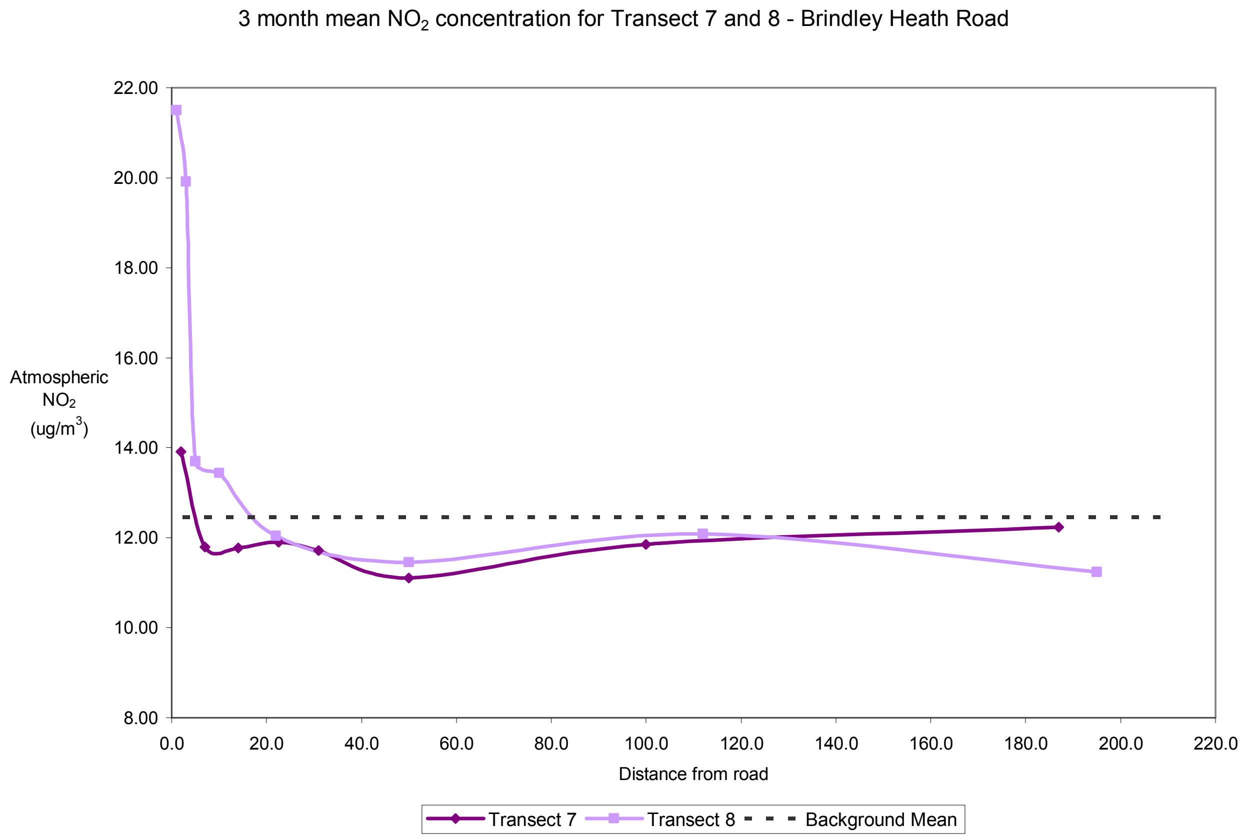
Figure 6.8 - 3 month mean NO2 concentration for Transect 5 and 6.



6.1.6 Brindley Heath Road

Figure 6.9 shows the 3 month mean NO_2 concentration for Transect 7 and 8 adjacent to Brindley Heath Road.

Figure 6.9 - 3 month mean NO2 concentration for Transect 7 and 8.



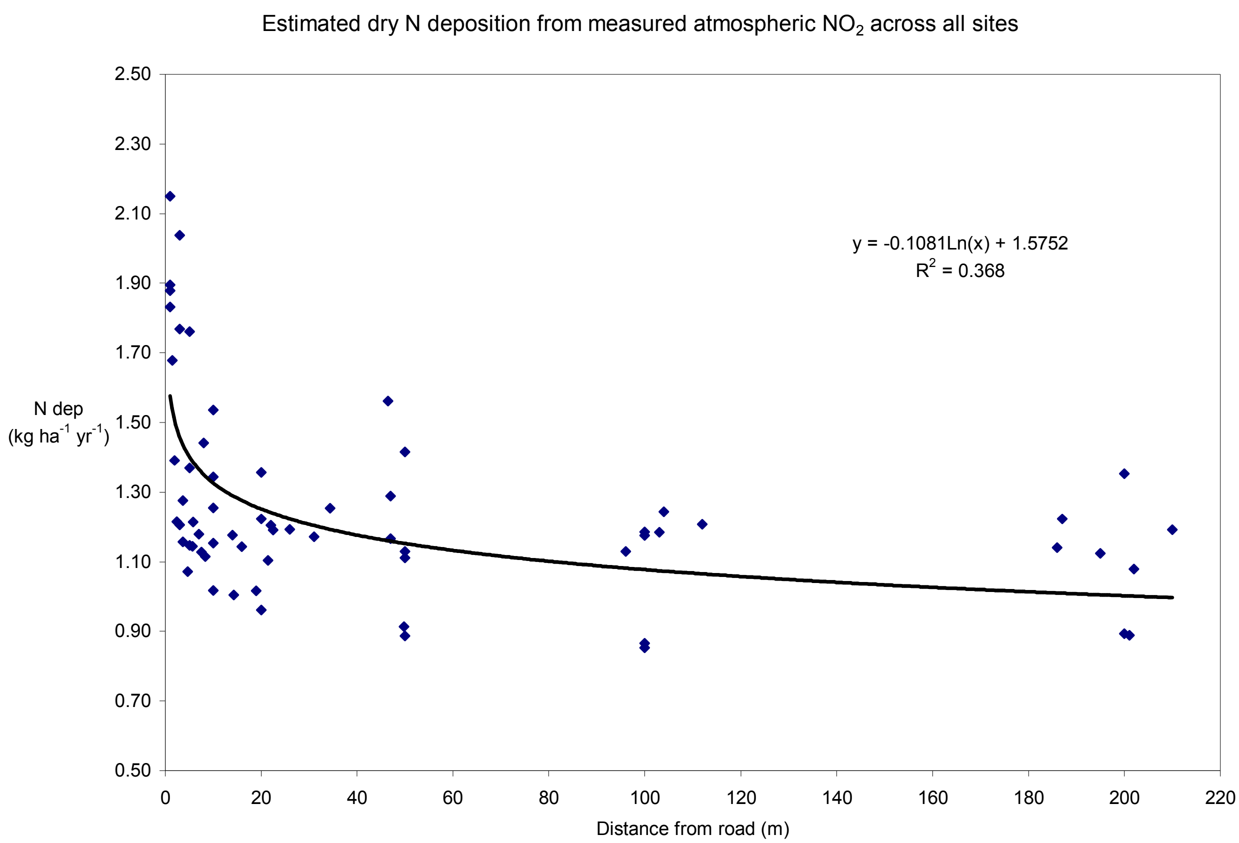
Sites 8.1 and 8.2 results are the mean of May and June as the tubes for July's exposure were missing on collection. This partly explains the higher mean result compared to site 8.3 and the roadside results at Transect 7. However, the roadside concentrations were consistently higher at Transect 8 than Transect 7. One cause of this may be the road layout along this part of Brindley Heath Road which is close to the exit of the one-way access to the Visitor Centre. This may mean that less vehicles pass site 7.1 than 8.1.

Mean NO_2 concentrations at Transect 7 dropped to background levels within 7m of the road whilst at Transect 8 background levels were not reached until approximately 20m from the road.

6.1.7 Estimation of N deposition

The mean atmospheric NO_2 concentrations were used to estimate the amount of dry N deposition occurring at each study site (Figure 6.10). A logarithmic line of best fit is plotted on the figure. Due to the method of estimating N deposition (multiplying by a factor of 0.1 – see Appendix A) although the units are different the overall pattern of change in N deposition from the road is the same as the measured atmospheric NO_2 seen in Figure 6.3 (significant regression R^2=0.368, p=<0.001).

Figure 6.10 - Estimated dry N deposition at all sites.
N deposition calculated from measured atmospheric NO_2. Note: the y axis does not start at 0.



6.2 Vegetation percentage cover

Figures 6.11-6.16 show the percentage cover of *Calluna, Vaccinium, Deschampsia* and competing plants *Molinia*, *Rubus* and *Pteridium* for each site. A line of best fit (logarithmic) is also shown on each graph (note: the y axis scale is not the same for each species).

The figures illustrate that the greatest change in species abundance with distance from the road and the strongest statistically significant trend occurred with an increase in *Calluna.* (R^2=0.3901, p=<0.001). *Vaccinium* and *Deschampsia* also increased in abundance with distance from the road but to a much lesser degree. Of the competing plants *Molinia* slightly increased whilst *Rubus* and *Pteridium* slightly decreased with distance from the road.

Other plant species found at many sites were *Empetrum nigrum, Erica tetralix* and in damper areas *Juncus effusus* and a variety of mosses. At sites within 10m of the road a greater variety of grasses and flowering plants were found including; *Dactylis glomerata; Festuca rubra; Holcus lanatus; Phleum pratense; Cynosurus cristalus; Agropyron repens; Agrostis tenuis; Arrhenatherum elatius;* and *Potentilla erecta; Lotus corniculatus; Trifolium repens; Galium saxatile; Vicia sativa; Lathyrus pratensis; Cirsium arvense; Ranunculus repens; Senecio jacobaea; Plantago lanceolata; Veronica chamaedrys;* and *Epilobium augustifolium*. At all transects *Betula pendula* and *Crategus monogyna* were the most common tree species whilst *Quercus* and *Pinus* were also found in many areas. Transects 5 and 6 had a high cover of *Ulex europaeus* near to the road (Penkridge Bank). Young saplings of *Betula pendula* were common at many sites but particularly at Transect 3 (Rose, 1981)(Sterry, 1997). The complete vegetation survey results can be found in Appendix D.

There was evidence of grazing by deer and rabbits at many of the sites, particularly (in the case of deer) further away from the roads. Most of the sites did not have evidence of recent mowing except for roadside maintenance at transects 3 to 8 (either prior to the start of the study or in the case of Transect 8 during July

2012). Mowing management of the heathland at sites 4.4-4.6 had occurred approximately 5 years previous to the study.

Figure 6.11 - Percentage cover of *Calluna* with distance from the road for all sites.

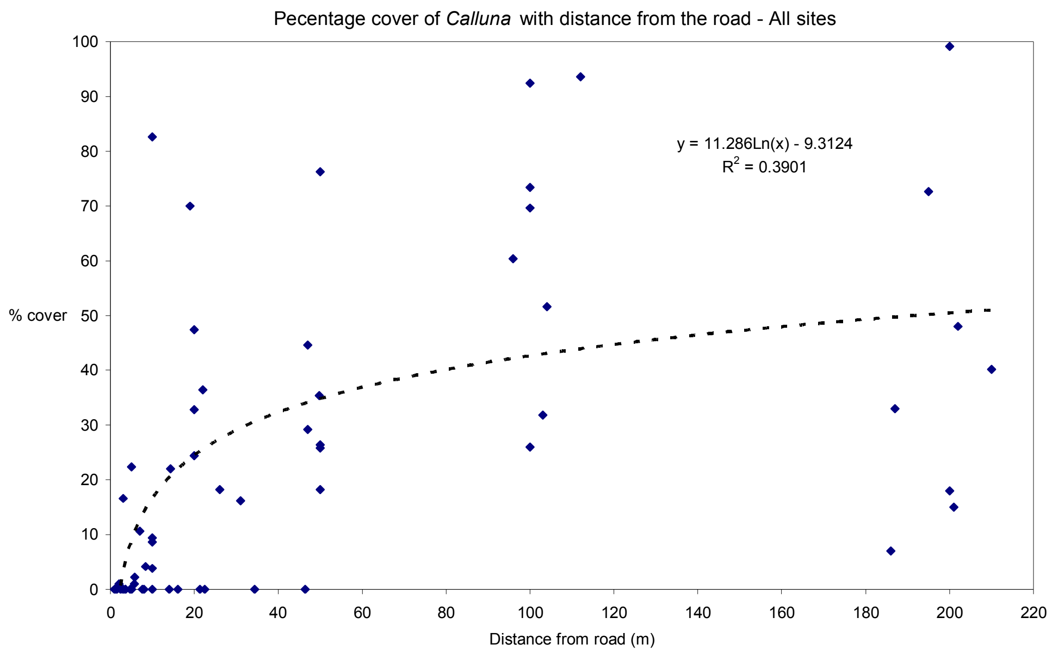


Figure 6.12 - Percentage cover of *Vaccinium* with distance from the road for all sites.

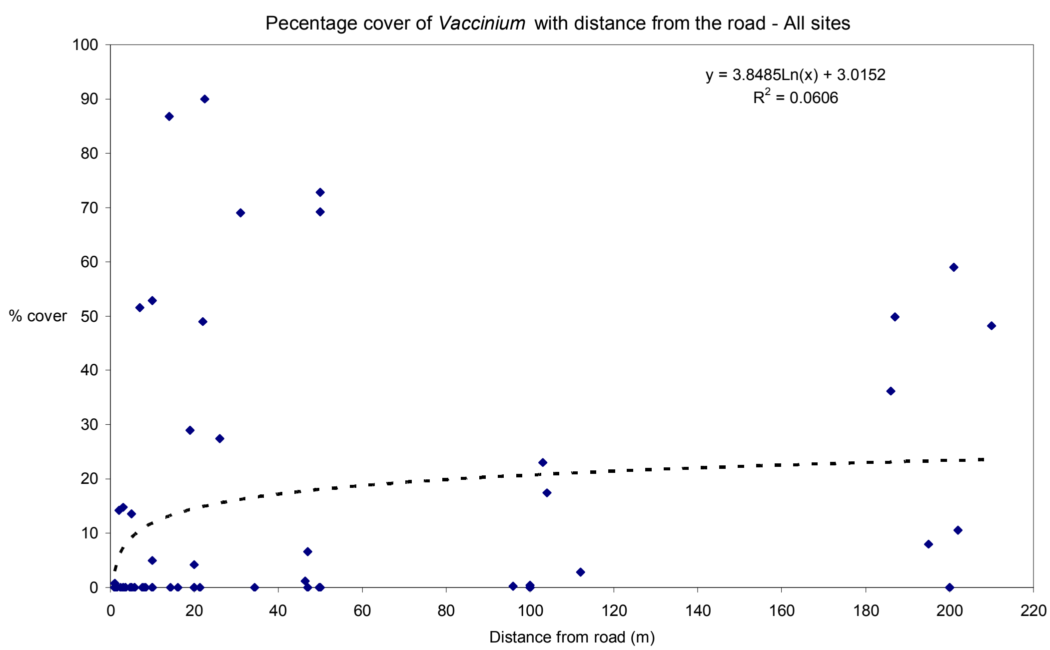


Figure 6.13 - Percentage cover of *Deschampsia* with distance from the road for all sites.

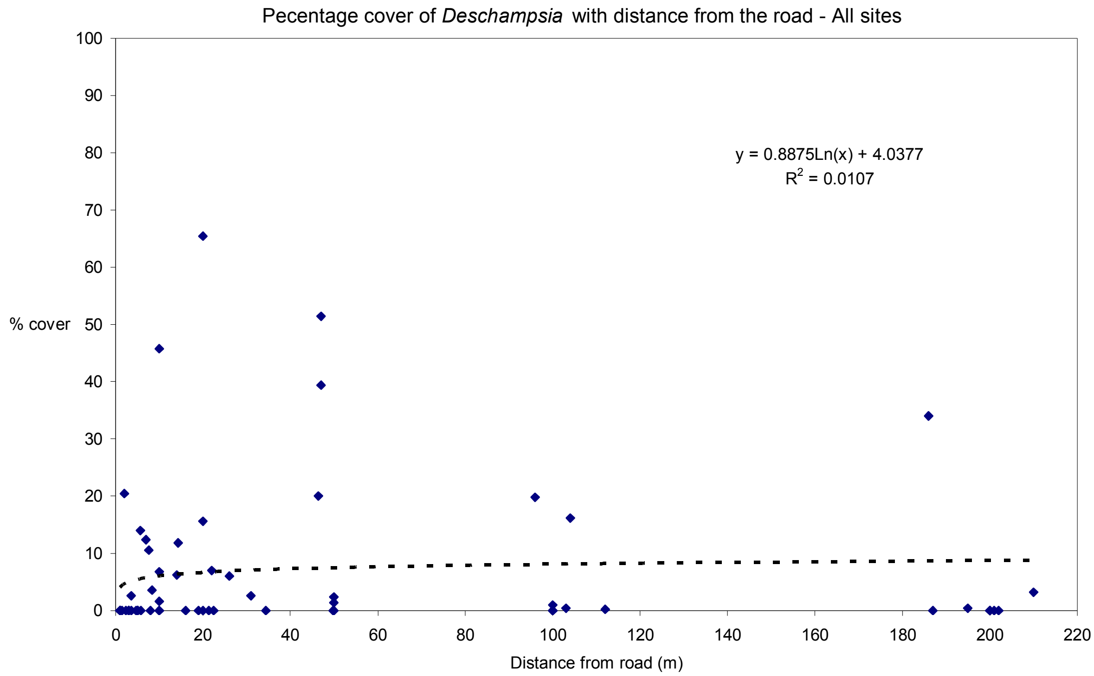


Figure 6.14 - Percentage cover of *Molinia* with distance from the road for all sites.

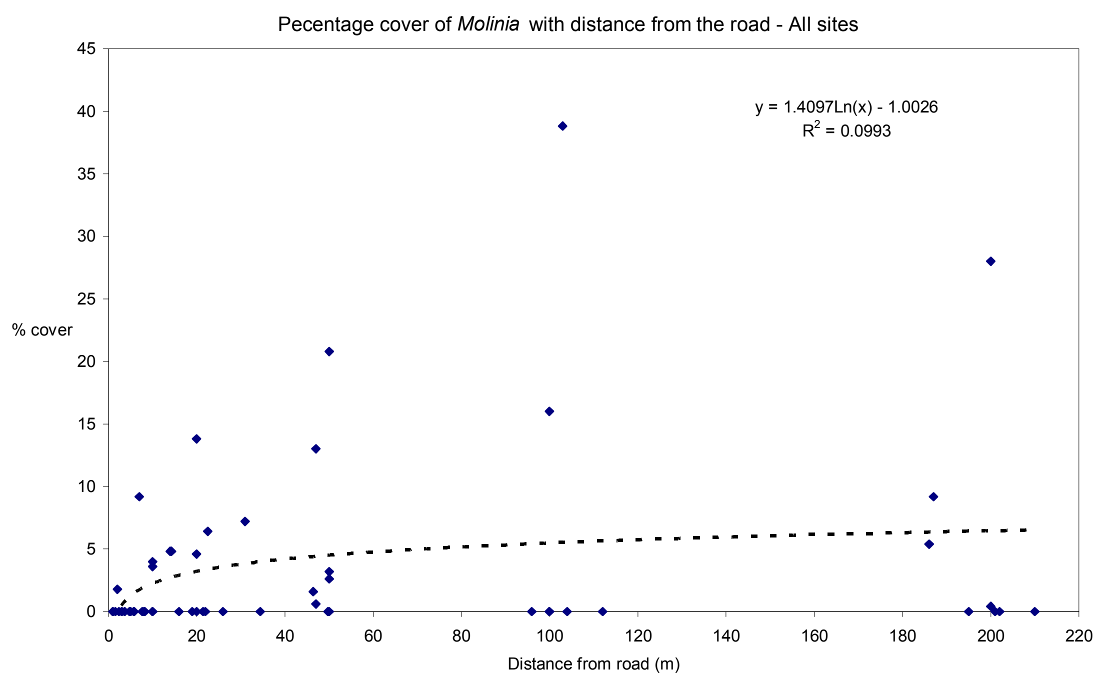


Figure 6.15 - Percentage cover of *Rubus* with distance from the road for all sites.

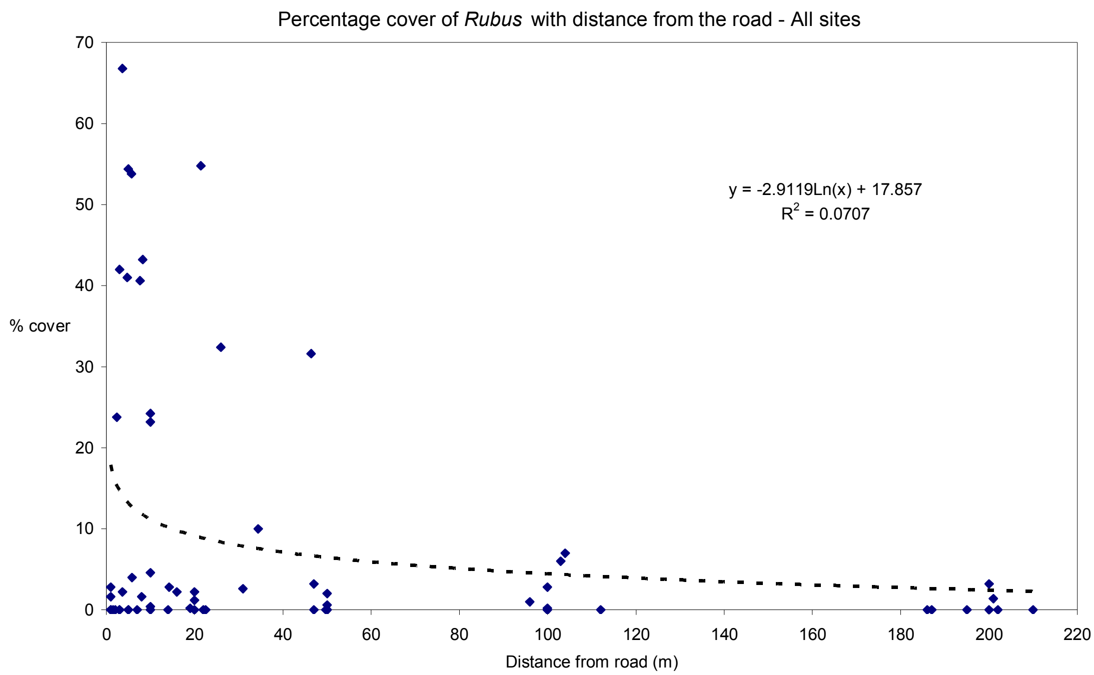
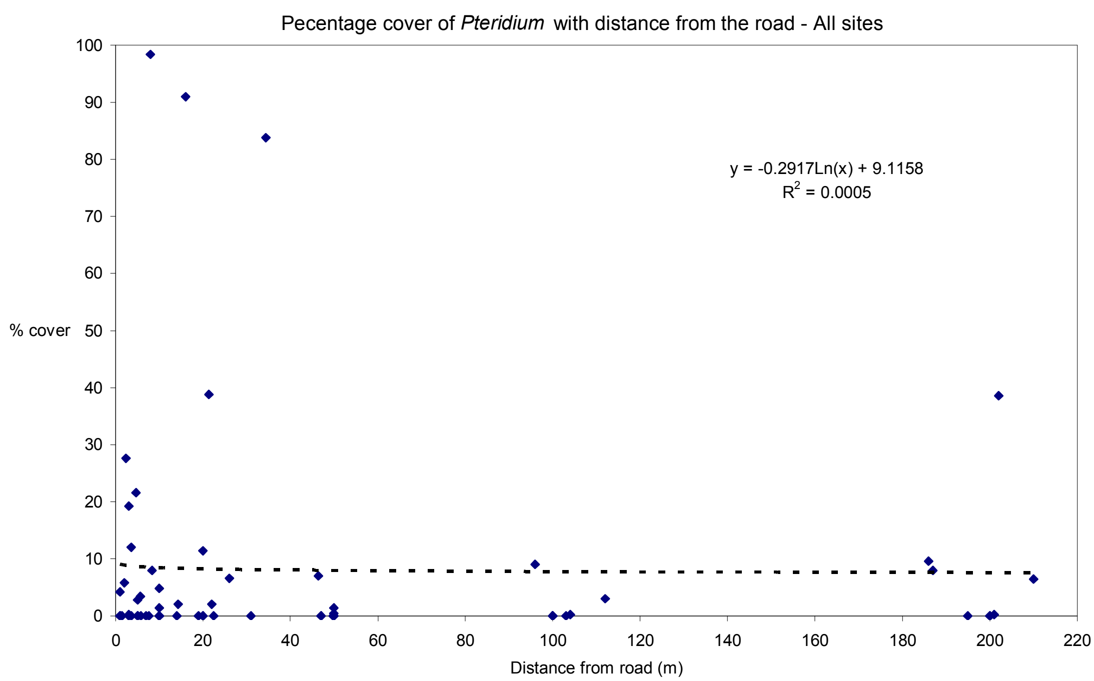


Figure 6.16 - Percentage cover of *Pteridium* with distance from the road for all sites.

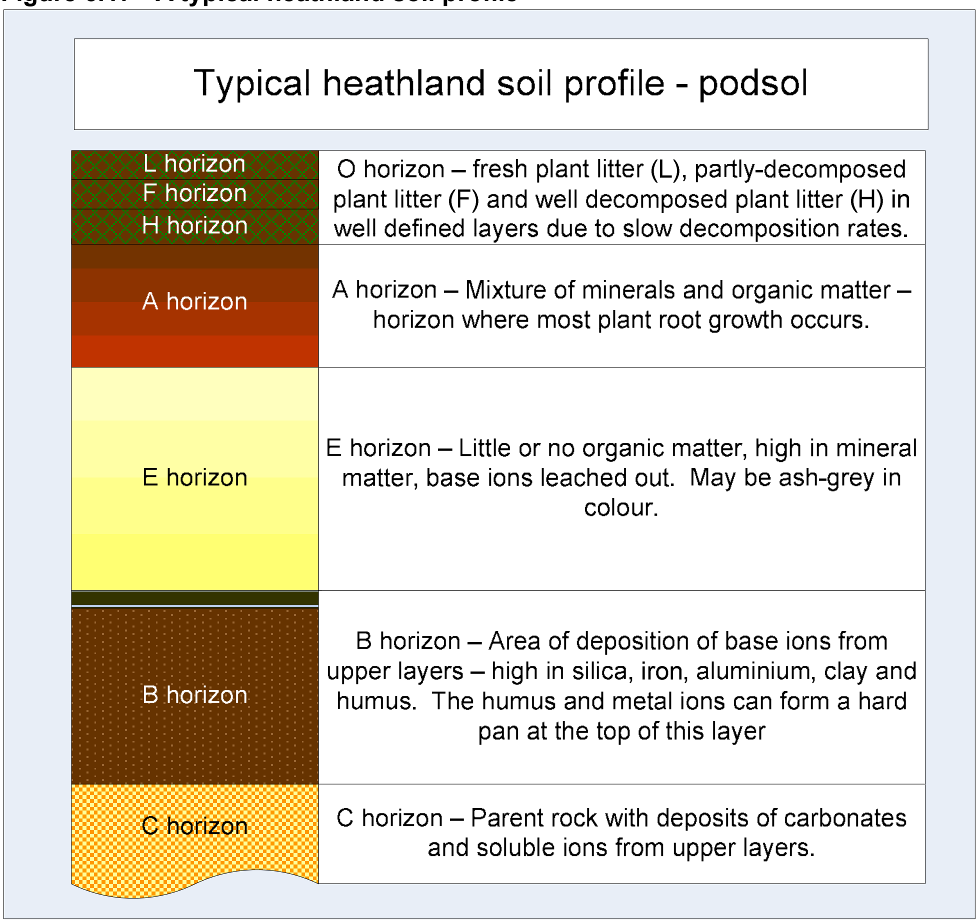


6.3 Soil characteristics

The complete soil analysis data can be found in Appendix E.

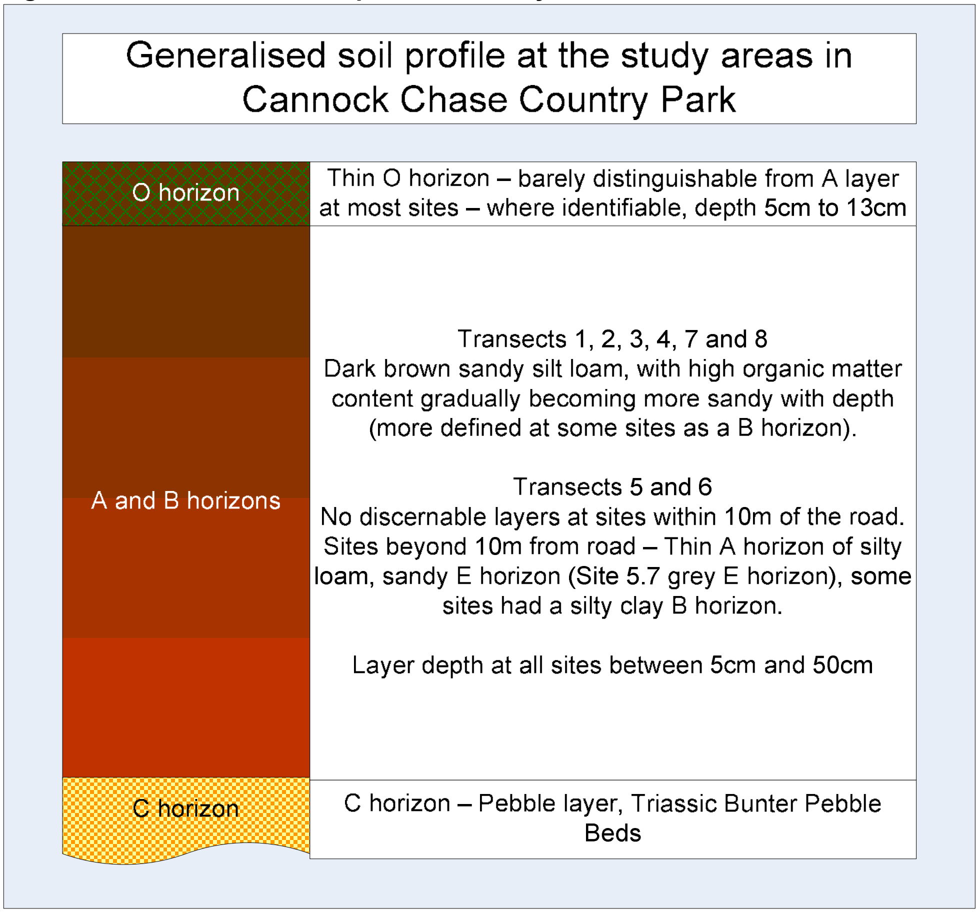
Figure 6.17 shows the soil profile of a typical heathland podsol soil (Webb, 1986; Symes & Day,2003).

Figure 6.17 - A typical heathland soil profile



The soils sampled in this study (generalised profile Figure 6.18) differed from the typical profile in that there was usually no E layer (except at sites 5.5-5.8 and 6.5-6.8) and no accumulation of humus and metal ions at the top of the B horizon forming a hard pan. At most sites the total soil depth was less than 30cm and consisted of well mixed mineral and organic matter (A and B horizons) over a layer of pebbles (underlying geology of Bunter Pebble Beds).

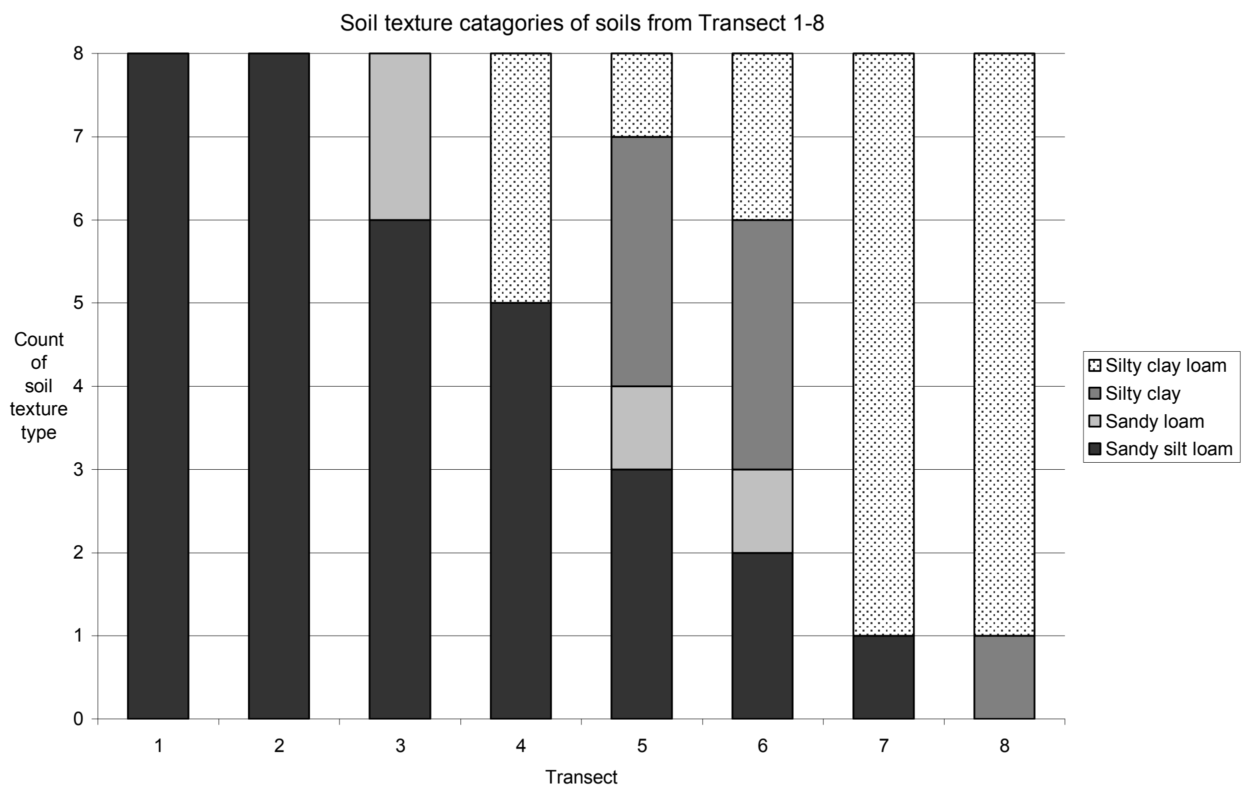
Figure 6.18 - Generalised soil profile at survey sites.



6.3.1 Texture

Figure 6.19 shows the proportion of the soils from each transect catagorised by their soil textures (note – the figure does not indicate from which site in each transect the soil texture came from). The majority of soils (52%) were sandy silt loam and these were mainly from Transects 1-4 while the next most common type (31%) was silty clay loam mainly from transects 7 and 8. The soils from Transects 5 and 6 showed the greatest variation in soil texture being a mixture of sandy silt loam, sandy loam, silty clay loam and silty clay.

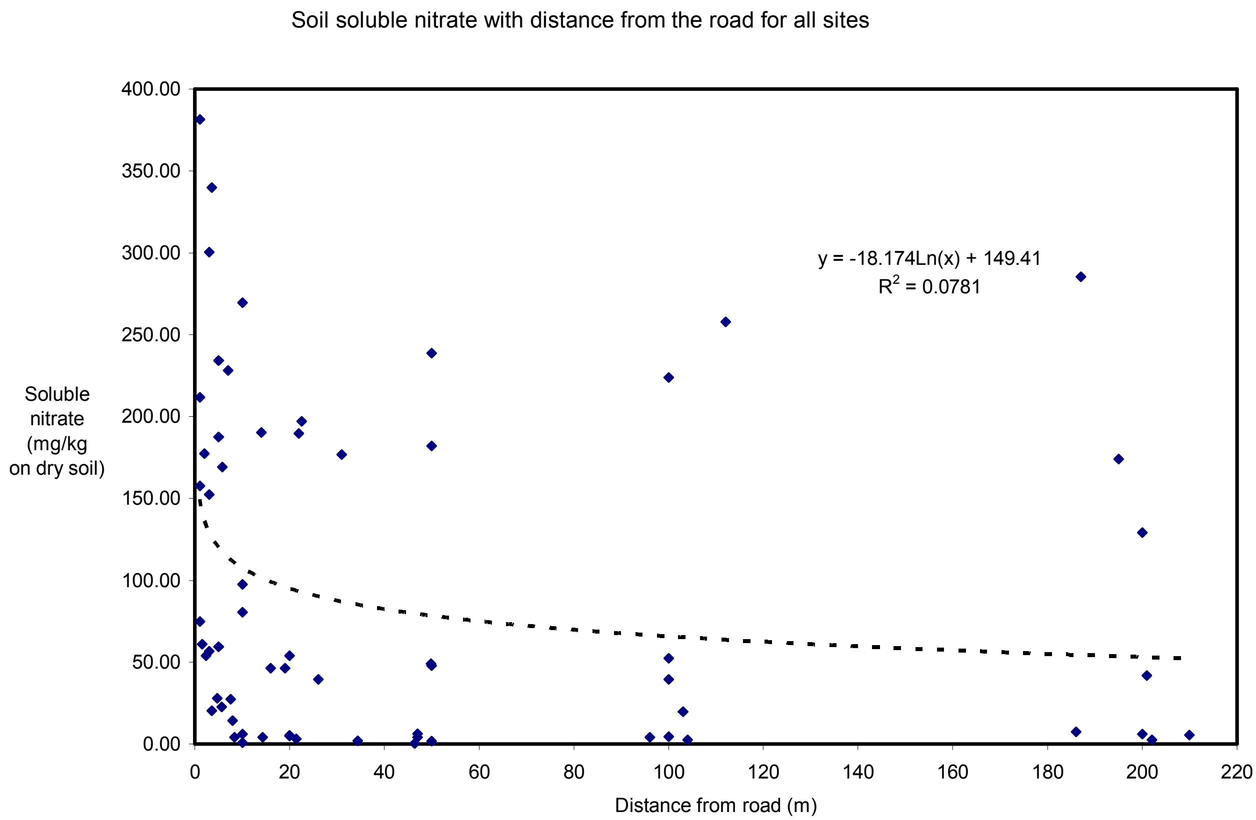
Figure 6.19 - Soil texture catagories of soils in Transects 1-8



6.3.2 Soluble nitrate

Section 3.1 outlined that with increased N deposition it would be expected that the nutrient levels in the soil would increase. Figure 6.20 shows the concentration of soluble nitrate measured in all the soil samples plotted against distance from the road. There is an overall significant pattern of decrease in nitrate concentration away from the road (R^2=0.078, p=0.03) most strongly seen in the first 20m.

Figure 6.20 - Soil soluble nitrate with distance from the road for all sites.



There was considerable variation between transects in nitrate concentrations and patterns of decrease from the road.

Transects 1-4 had the lowest overall concentrations over the whole transect (mean 18.70mg kg^{-1} ±3.9) but did have higher concentrations near to the road (mean up to 10m from road 39.05mg kg^{-1} ±6.4) while beyond 10m concentrations remained fairly consistently low to 200m (mean 6.48mg kg^{-1} ±2).

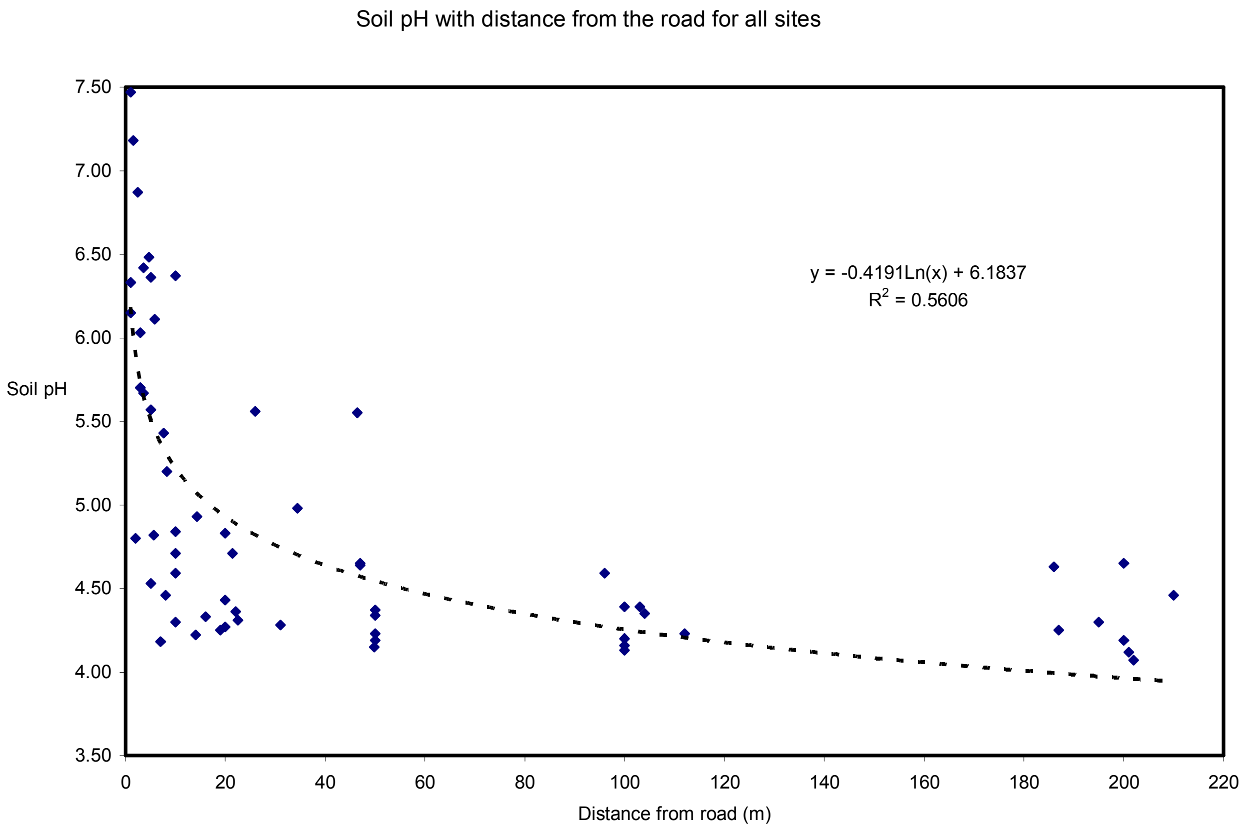
Transects 5 and 6 had high concentrations at the roadside sites (mean up to 6m from road 231.3mg kg^{-}1±41.5) beyond which concentrations dropped sharply and were consistent to 200m (mean 63.72mg kg^{-1}±9.3) except at site 6.8 which showed a 90 mg kg^{-1} increase from 39.3mg kg^{-1} at site 6.7 to 129.3mg kg^{-1}.

Transect 7 and 8 had very high nitrate values across the whole transect (mean 221.0mg kg^{-1} ±10.2) and nitrate concentrations in Transect 7 increased with distance from the road.

6.3.3 pH

As outlined in section 3.1 in areas of increased N deposition it is expected that soil acidity would increase so that close to the road pH would be low and increase with distance from the road. In the soil sampled the opposite was true (R^2=0.5606, p=<0.001). Figure 6.21 shows the pH of all the soil samples with distance from the road. There was a decline in mean pH from 6.35 ±0.30 at roadside sites to 4.33 ±0.08 200m from the road. Importantly this pattern was seen along all transects, even 1 and 2, where it has already been seen that N deposition from atmospheric NO_2 was not higher near to the road. The standard error of the means indicate that there is much greater variation in the soil pH near to the road than at 200m. This pattern of greater variation occurred within 50m of the road beyond which none of the soils had a pH above 4.7. All the soils with the highest pH (between 6 and 7.5) were found within 10m of the road.

Figure 6.21 - Soil pH with distance from the road at all sites.



6.4 Statistical analysis

6.4.1 N deposition and distance from the road.

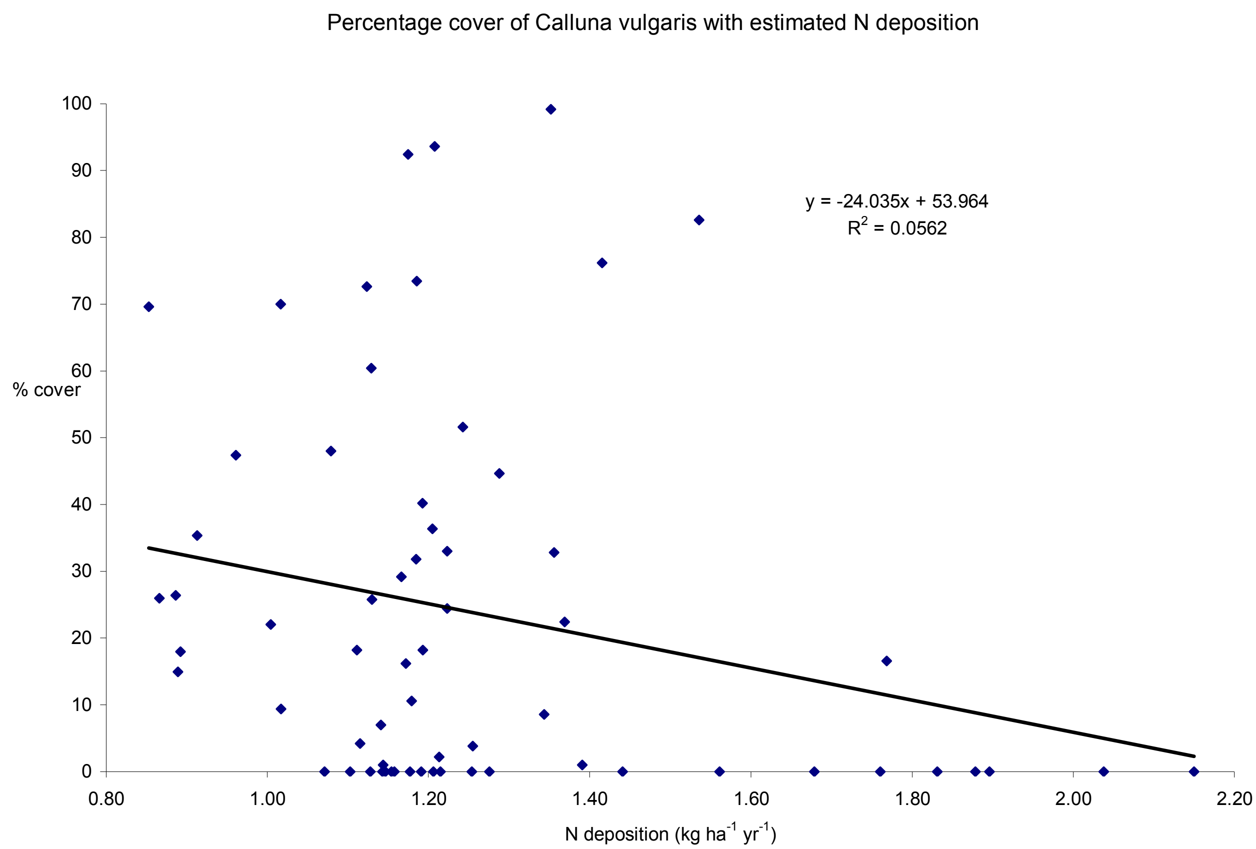
The first hypothesis was to establish whether the dry N deposition (estimated from the measured atmospheric NO_2) decreased with distance from the road. The null hypothesis was, 'that N deposition does not decrease with distance from the road'. Figure 6.10 illustrated the estimated N deposition from the measured atmospheric NO_2 concentration. Linear regression analysis on the estimated N deposition against the log of the distance from the road showed a significant (R^2=0.368, p=<0.001) inverse relationship. The null hypothesis can be rejected and it can be stated that N deposition does decrease with distance from the road.

6.4.2 The abundance of heathland plant species with increased N deposition

The second hypothesis was to identify whether the abundance of three heathland plants was affected by increased N deposition close to the road. The null hypothesis, 'the abundance of heathland plant species does not reduce with increased N deposition' was assessed using linear regression analysis, comparing the percentage cover of each plant species to the estimated N deposition.

It has already been stated that overall, the vegetation survey only found a statistically significant variation in *Calluna* with distance from the road (see section 6.2). However, although there was an inverse relationship between *Calluna* and N deposition (β=-24.03) as seen in Figure 6.22 this was not statistically significant (R^2=0.06, p=0.06). No other plant species had a significantly significant relationship between abundance and N deposition therefore the null hypothesis is not rejected.

Figure 6.22 - Percentage cover of *Calluna* with estimated N depositon for all sites



6.4.3 The abundance of heathland plant species and soil soluble nitrate

The null hypothesis that 'the abundance of heathland plant species does not decrease with increased soil soluble nitrate' was tested using linear regression comparing the mean percentage cover of each plant species with the soil soluble nitrate concentrations. The only plant species that showed a statistically significant relationship was *Vaccinium* (R^2=0.13, p=0.004) but with a very slight positive overall relationship (β=0.08). Further investigation indicated this was a product of the very high nitrate levels at Transects 7 and 8 and there being a high abundance of *Vaccinium* at these sites. Figures 6.23-6.25 illustrate this effect. Separate linear regression analysis of percentage cover of *Vaccinium* and soil nitrate for Transects 1-6 (R^2=0.03, p=0.24) and 7 & 8 (R^2=0.09, p=0.28) were found to be not significant.

Deschampsia also had a significant but weak inverse relationship (β=-0.04) with soil soluble nitrate (R^2=0.10, p=0.01). *Calluna* did not have a significant relationship with soil soluble nitrate (R^2=0.02, p=0.24). The null hypothesis cannot be rejected.

Figure 6.23 - Percentage cover of *Vaccinium* at all sites.

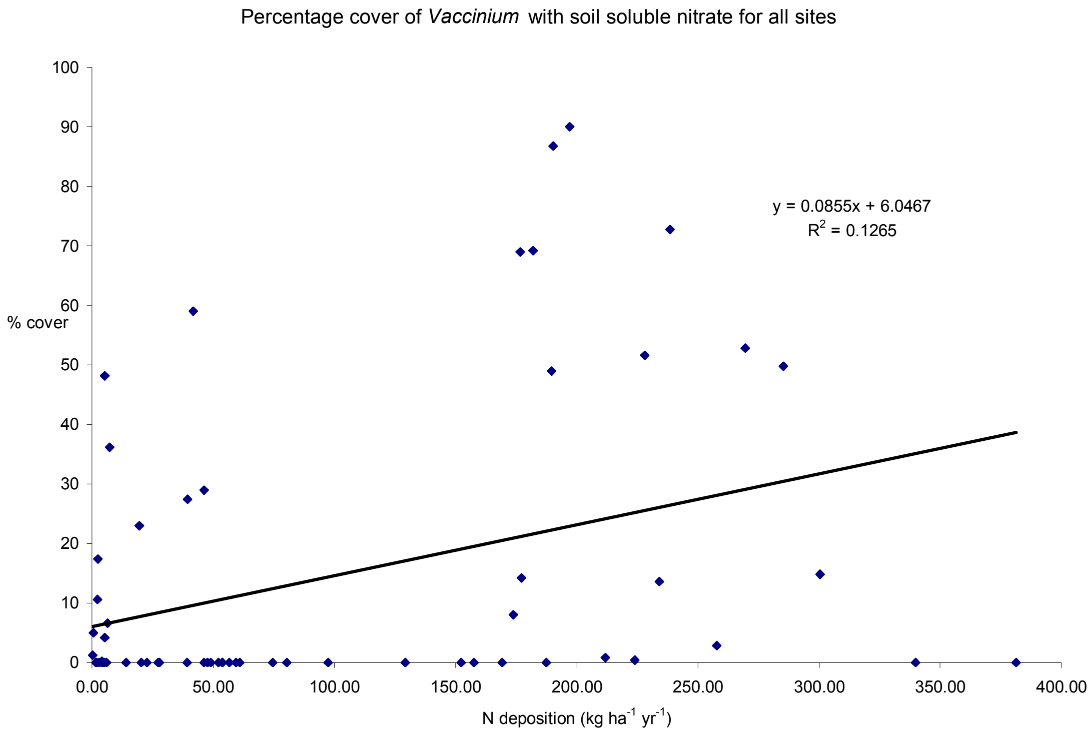


Figure 6.24 - Percentage cover of *Vaccinium* at Transects 1-6.

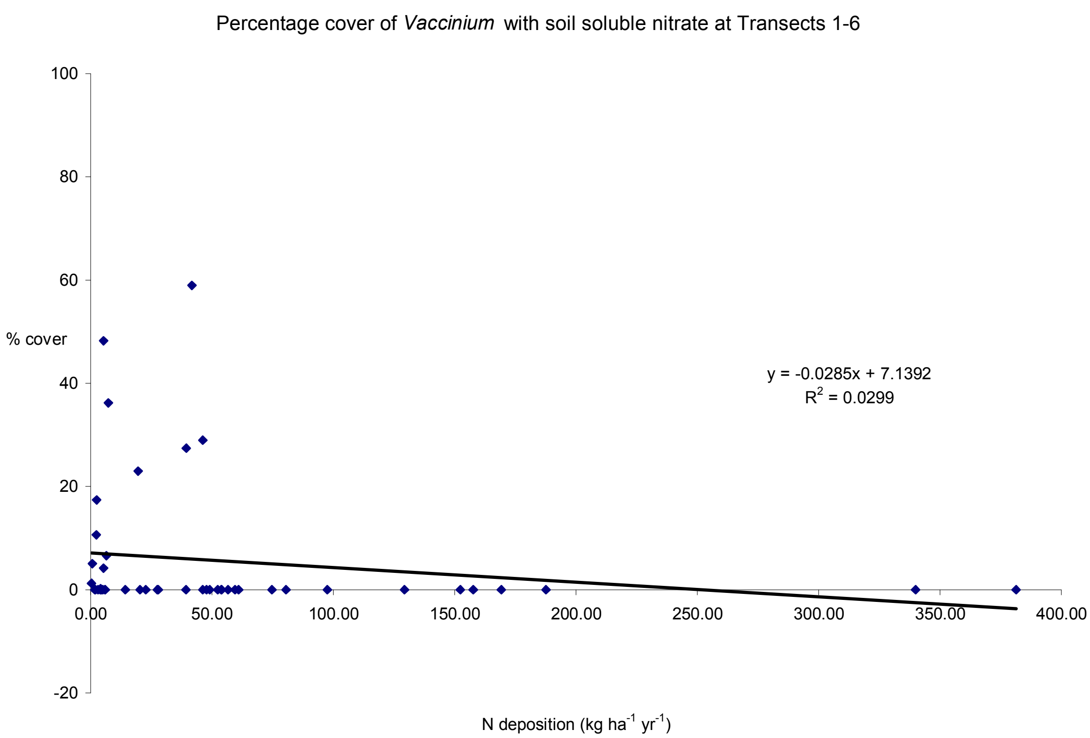
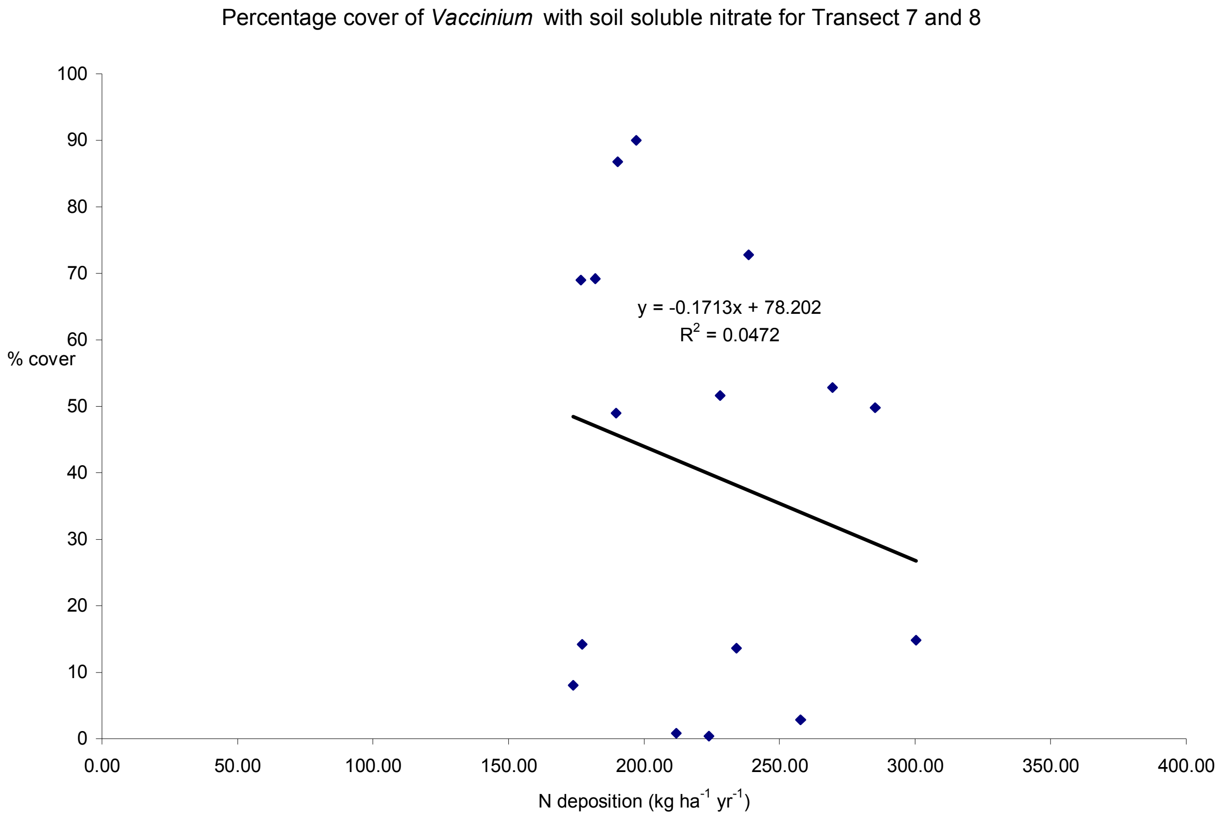


Figure 6.25 - Percentage cover of *Vaccinium* at Transects 7 and 8.



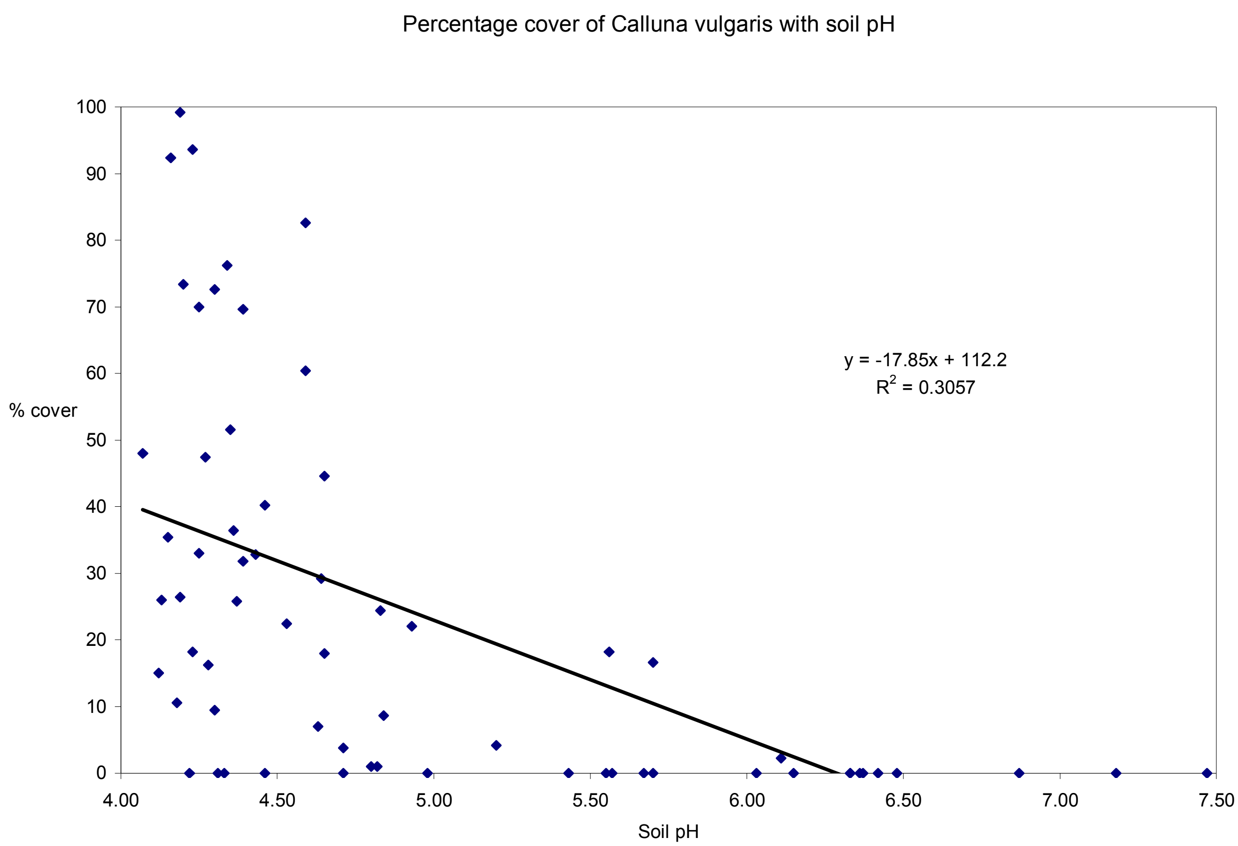
6.4.4 The abundance of heathland plant species and soil acidity

As already stated the soil pH changed with distance from the road in the opposite way to that expected (section 6.3.3). An amended null hypothesis, that the 'abundance of heathland plants does not change with changes to soil acidity' was tested using linear regression comparing the mean percentage cover of the heathland plants with the soil pH at each site. *Calluna* and *Vaccinium* both showed a significant inverse relationship between percentage cover and soil pH.

Calluna and pH

Figure 6.26 shows the significant inverse relationship (β=-17.85) between *Calluna* cover and soil pH (R^2=0.31, p=<0.001). In the case of *Calluna* the null hypothesis is rejected – *Calluna* cover increases with decreasing soil pH.

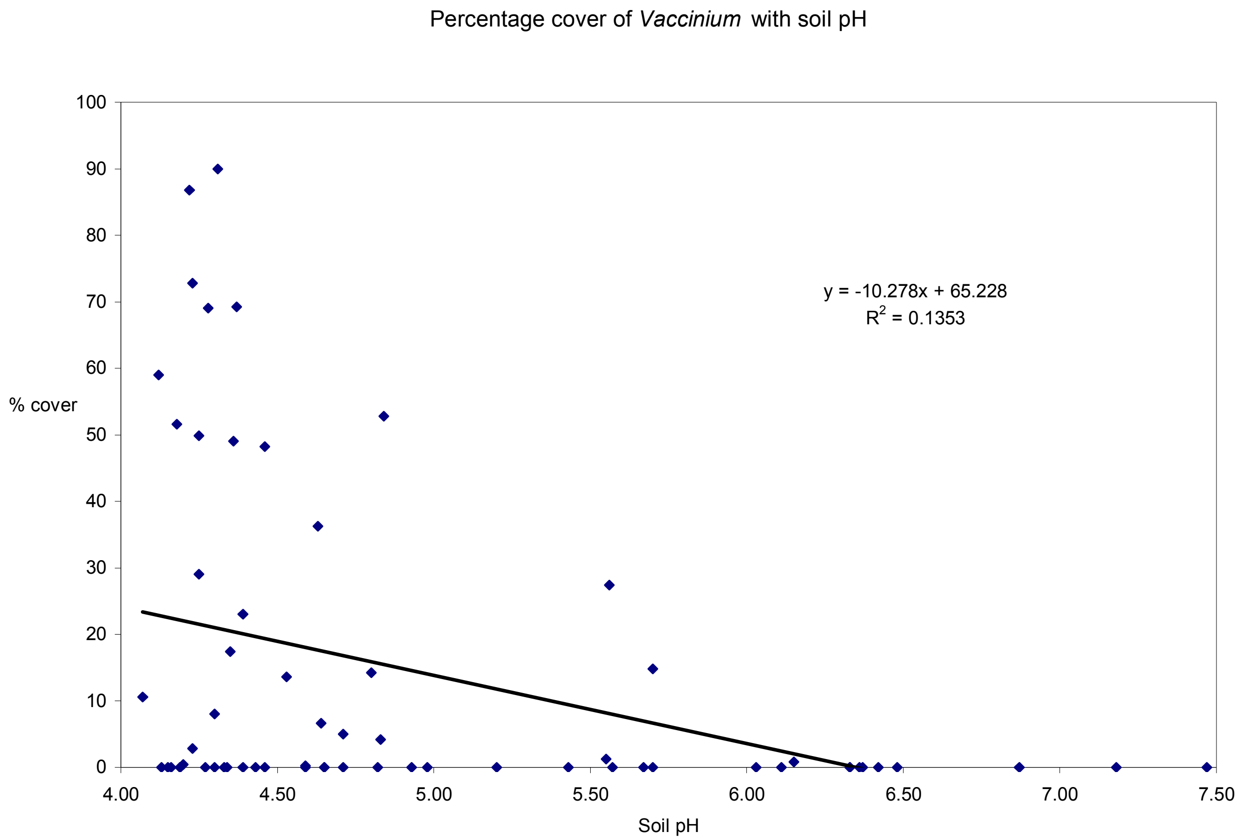
Figure 6.26 - Percentage cover of *Calluna* with soil pH for all sites.



Vaccinium and pH

Figure 6.27 shows the significant inverse relationship (β=-10.29) between *Vaccinium* cover and soil pH (R^2=0.14, p=0.003). In the case of *Vaccinium* the null hypothesis is rejected – *Vaccinium* cover increases with decreasing soil pH.

Figure 6.27 - Percentage cover of *Vaccinium* and soil pH



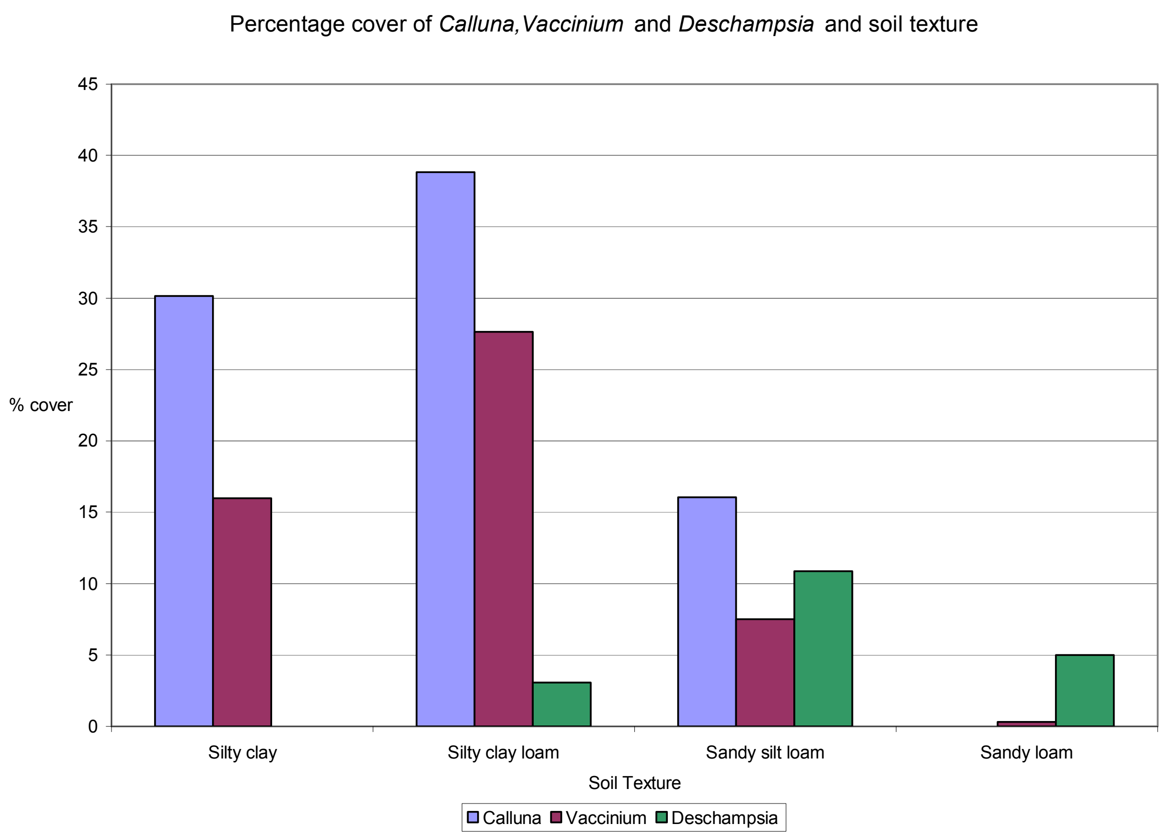
6.4.5 Assessment of other soil parameters on heathland plant species

Soil texture, water content, organic matter content and bulk density were also measured for each site in order to assess the relative importance of other soil characteristics on the vegetation cover.

Soil Texture

Figure 6.28 shows the mean percentage cover of the three heathland plant species studied grouped by soil texture. *Calluna* and *Vaccinium* both had a higher mean percentage cover in soils that had a texture category of ‘silty clay loam’ or ‘silty clay’ indicating a preference for soils with smaller particle size. The highest mean percentage cover for *Deschampsia* occurred on soils of a ‘sandy silt loam’ texture possibly indicating it favours freer draining soils.

Figure 6.28 - Percentage cover of heathland plant species grouped by soil texture.



Soil moisture content

None of the heathland species studied showed any significant relationship with the moisture content of the soils.

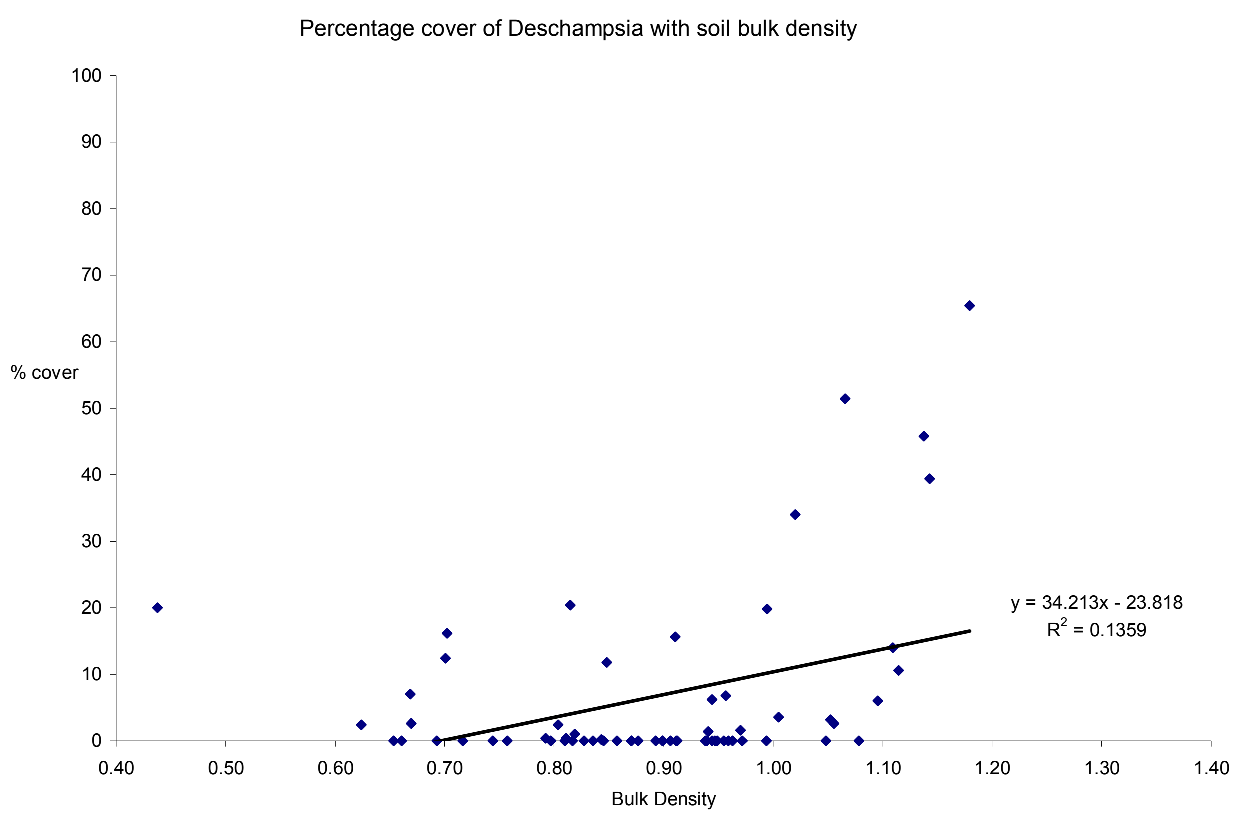
Soil organic matter content

None of the heathland species studied showed any significant relationship with the organic matter content of the soils.

Soil bulk density

Deschampsia was the only species to have a significant relationship with the bulk density of the soils (R^2=0.14, p=0.003) as shown in Figure 6.29.

Figure 6.29 - Percentage cover of Deschampsia and soil bulk density



Competition from other plant species

Linear regression analysis was used to assess the impact on the heathland species from other competing plants, *Molinia*, *Rubus* and *Pteridium*. There were no strongly significant relationships found between the abundance of the competing plants and the heathland plants indicating that not any one species was directly out competing any of the heathland species (*Calluna* and *Rubus* had a significant regression result but this relationship was weak – R^2=0.10, p=0.01).

Table 6.1 shows the results of all the regression analyses for the hypotheses tested and on the impact of other soil properties and competition from invasive plants on all the vegetation studied (significant result at the 95% confidence level p=<0.05).

Table 6.1 - Results of regression analysis.

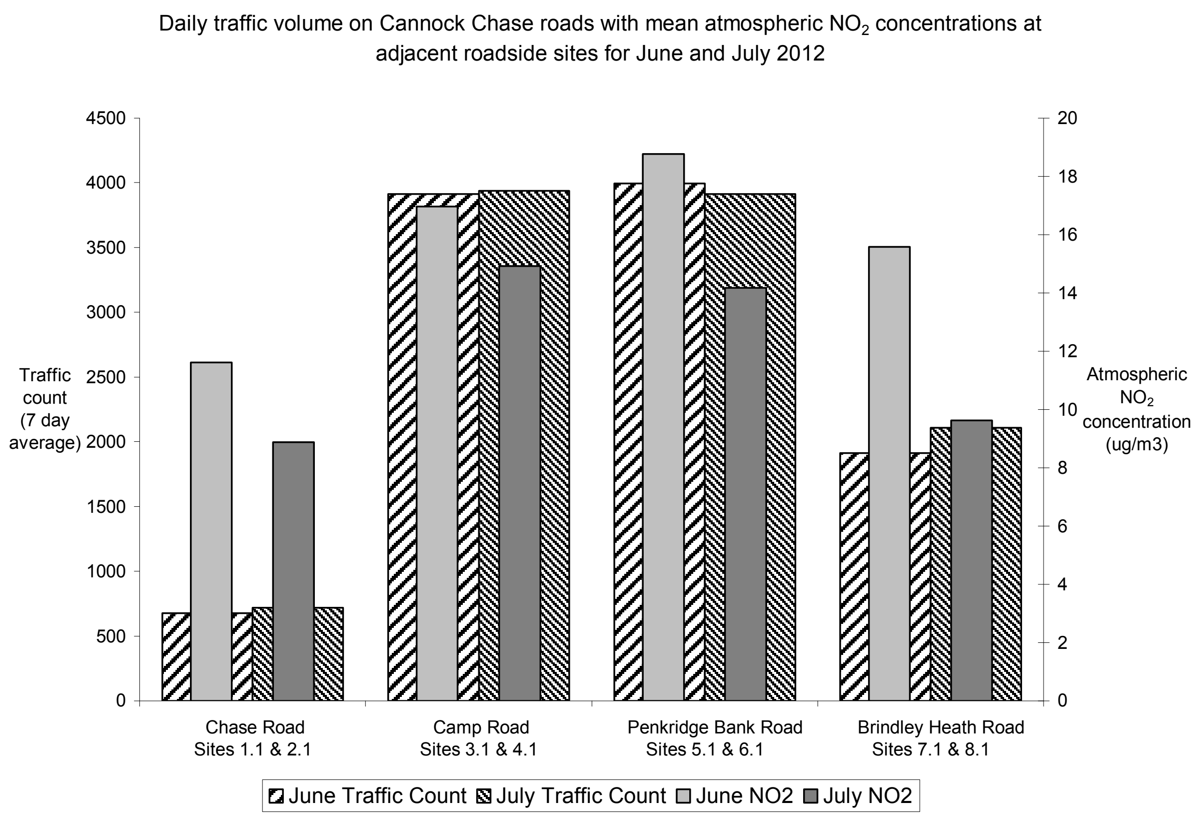
	N deposition		Calluna		Vaccinium		Deschampsia		Molinia		Rubus		Pteridium	
	R^2	P	R^2	P	R^2	P	R^2	P	R^2	P	R^2	P	R^2	P
(Log of) Distance from road	**0.37**	**<0.001**	**0.39**	**<0.001**	**0.06**	**0.05**	0.01	0.41	**0.10**	**0.01**	**0.07**	**0.03**	<0.01	0.86
N deposition	-	-	0.06	0.06	0.03	0.17	<0.01	0.72	0.01	0.40	<0.01	0.86	<0.01	0.99
Soil moisture	-	-	<0.01	0.47	<0.01	0.54	<0.01	0.71	0.06	0.06	0.06	0.06	<0.01	0.50
Soil organic matter	-	-	<0.01	0.78	0.03	0.14	0.02	0.33	0.002	0.73	<0.01	0.47	<0.01	0.44
Soil bulk density	-	-	<0.01	0.68	**0.06**	**0.04**	**0.14**	**0.003**	<0.01	0.94	**0.06**	**0.05**	0.01	0.37
Soil soluble nitrate	-	-	0.02	0.24	**0.13**	**0.004**	**0.10**	**0.01**	<0.01	0.91	0.01	0.37	0.05	0.07
Soil pH	-	-	**0.31**	**<0.001**	**0.14**	**0.003**	0.02	0.31	**0.07**	**0.04**	0.04	0.11	<0.01	0.70
Molinia	-	-	0.03	0.19	0.01	0.42	<0.01	0.69	-	-	0.03	0.19	0.02	0.25
Rubus	-	-	**0.10**	**0.01**	0.02	0.22	<0.01	0.97	-	-	-	-	0.02	0.31
Pteridium	-	-	0.05	0.08	0.03	0.19	0.02	0.33	-	-	-	-	-	-

7 Analysis and discussion

7.1 Atmospheric NO_2 measurements with distance from the road

The measured atmospheric NO_2 concentrations were significantly higher at the roadside sites in transects 3-8 and decreased with distance from the road. In most cases the concentration had reduced to background levels by 20m from the road. Cape et al. (2004) found that the dispersion rate of NO_2 is rapid with 90% being dispersed within a distance of 15m from the road. Gilbert et al. (2007) found there was a strong association with roadside NO_2 concentrations, attenuation away from the road and traffic density on the adjacent roads. Figure 6.1 shows the traffic count and the mean concentrations for each pair of roadside sites for each road.

Figure 7.1 - Daily traffic volume and mean atmospheric NO_2 concentration on the studied roads in Cannock Chase.
Traffic data for June is for the second half of the month only. Traffic data for May is not available.
For Brindley Heath Road June NO_2 data is the mean of sites 7.1 and 8.1 but July is just 7.1 as the tubes at site 8.1 had been removed. Traffic data (SCC, 2012).



The measured NO_2 at the roadside sites showed a significant correlation with the traffic count carried out at the same times (R^2=0.58, p=<0.05). The roadside NO_2 concentrations on Camp Road and Penkridge Bank Road were generally the highest and the corresponding traffic counts are the highest of these roads. The proportionally higher NO_2 concentrations compared to traffic count on Chase Road is due to the traffic density being so low that it is not contributing NO_2 over the background level at these sites (1.1 and 2.1). Brindley Heath Road data for June is anomalous to this pattern. One explanation for this may be where the traffic count was carried out. As mentioned in section 6.1.6 the road layout at the Visitor Centre just off Brindley Heath Road has a one-way system that may mean the traffic passes site 7.1 less often than 8.1. Also, the combined result for Brindley Heath Road in July would probably have been much higher if the diffusion tube as site 8.1 was not missing as this site had consistently higher concentrations than 7.1 for May and June.

The attenuation of NO_2 concentration away from the roads will be influenced by the geography of the site and weather conditions. Gilbert et al. (2003) found that NO_2 concentrations were significantly lower upwind of a road than downwind. Wind speed may also have an impact, Obara et al. (2011) found that reduced windspeed comparatively increased NO_2 concentrations due to less transportation and dispersion of the air. These effects may be further enhanced at some sites depending on the level of exposure of the site both in terms of topography of the ground but also shelter provided by trees. The effectiveness of the diffusion tubes may also be affected by environmental conditions. Some tubes were sited on trees and others on posts making them more exposed. Cape (2009) found that increased wind speed across the open end of the tubes increased the sampling rate of tubes in laboratory conditions. Particularly low or high humidity can also affect the efficiency of the tube absorbent TEA.

7.2 Heathland plant species and N deposition

Figure 6.22 showed the inverse relationship of decreasing N deposition and increasing *Calluna* although this was not statistically significant (R^2=0.056, p=0.06). The greatest estimated N deposition of all the sites surveyed was at 8.1 with 2.15kg ha^{-1} yr^{-1}. However, this study has only estimated the N deposition from NO_2 concentrations while traffic emissions also contain NO, NH_3 and HONO the measurement of which was outside the scope of this project. NO will rapidly react with O_3 in the atmosphere forming NO_2 which it is assumed has been measured by the diffusion tubes. Cape et al. (2004) estimated that the contribution of NH_3 from vehicles would be approximately the same as for NO_2 whilst due to the high solubility of HONO its deposition velocity would be much higher leading to double the deposition of NO_2. Taking all these forms of N_R into account the highest estimated N deposition at the roadside would be 8.6kg N ha^{-1} yr^{-1}. This is well below the critical load for heathland plants of 15-20kg N ha^{-1} yr^{-1} (WHO, 2000). Therefore the amount of N deposition from the road traffic does not appear to directly explain the changes in abundance of *Calluna* or any of the heathland plants with distance from the road.

7.3 Heathland plant species and soil soluble nitrate

Soil soluble nitrate significantly reduced in concentration with distance from the roads (R^2=0.078, p=0.03) particularly in the first 20m from the road. This relationship is improved when only transects 1-6 are considered (R^2=0.246, p=<0.001). The regression analysis of the relationship between N deposition and soluble soil nitrate was not significant in these 6 transects (R^2=0.059, p=0.1). However, transects 5 and 6 had very high nitrate levels in the first 3 sites of each transect (between 152.3 and 381.3mg kg^{-1} on dry soil) which may have been contributed to by the leguminous *Ulex europaeus* which is found at these sites close to the road. Regression on transects 1-4 show a considerable significant positive relationship between N deposition and soluble soil nitrate (R^2=0.324, p=<0.001).

6.4.3

Section 6.4.3 outlined the significant relationship between *Vaccinium* and the soil soluble nitrate was probably influenced by the much higher overall nitrate levels across Transects 7 and 8. Further analysis indicated that this relationship is probably not significant.

Calluna percentage cover and soil soluble nitrate did not show a significant relationship within the whole data set. However, removing the very high data from Transects 7 and 8 and performing regression analysis on data from transects 1-6 comparing *Calluna* percentage cover and soil nitrate concentration showed a significant negative association (R^2=0.121, p=0.02). This indicates that there may be an effect of increased nitrate levels that are impacting on the *Calluna*. Caporn et al. (2000) found that increased nitrogen availability to *Calluna* increased plant shoots by 37% but reduced the plants tolerance to frost. De Graaf et al. (1998) noted a similar result suggesting that a change in the shoot to root ratio led to a higher susceptibility to drought. Plants exposed to higher N_R have been found to have higher nutrient levels in their shoots making them more attractive to grazers, such as deer, sheep (Hartley & Mitchell, 2005) and rabbits, and also insects. The heather beetle, *Lochmaea suturalis*, feeds on *Calluna* and has been a problem in the past in Cannock Chase. As all these grazers and pests open up the heather canopy, grasses such as *Molinia* are allowed to establish (Symes & Day, 2003). In this study however, none of the competing plants appeared to be dominating and pushing out the *Calluna*.

7.4 Heathland plants and soil pH

The results of the soil pH measurements showed that pH significantly decreased with distance from the road (R^2=0.561, p=<0.001). However, this relationship was opposite to that expected if N deposition was affecting soil acidity (section 3.1). Roem et al. (2002) concluded that acidification of the soil was the most important factor in reducing species diversity and seed germination of a number of heathland species. However, this study did not find higher acidity to be the cause of lower *Calluna* abundance. There was a correlation between reduction in pH and increase of percentage cover of *Calluna* (R^2=0.306, p=<0.001, Fig. 5.14). *Calluna* is an ericaceous plant and H9 heathlands normally have a pH of between 3 and 4 so the effect of higher pH in areas alongside the road maybe having an effect on the abundance of *Calluna* but this is not an effect of traffic emissions. The cause of the higher pH near to the road is not within the scope of this investigation but it is suggested that the material the roads are constructed from may contain lime which may leach into the adjacent soils. The more neutral pH soil would then be more favourable to grasses and other calcareous plants.

8 Conclusion

The data showed that on 3 (Camp Road, Penkridge Bank Road and Brindley Heath Road) of the 4 roads studied atmospheric NO_2 was significantly higher within 20m of the road. This reflected the higher traffic levels on these roads. It was assumed that the atmospheric NO_2 directly contributed to N deposition at the site it was measured.

The percentage cover of *Calluna* increased significantly with distance from all roads however there was a great deal of variation between transects.

The variation in abundance of all the heathland plant species was not significantly linked to estimated N deposition but *Calluna* and *Vaccinium* showed a significant positive relationship with soil acidity and at 6 of the 8 transects *Calluna* showed a significant negative relationship with soil soluble nitrate concentrations. Of the other soil properties measured (moisture content, organic content and bulk density) only bulk density appeared to have a significant relationship with the abundance of *Vaccinium* and *Deschampsia*.

It is concluded that at the study sites in Cannock Chase Country Park the NO_2 emissions from road traffic within the park are contributing to higher atmospheric NO_2 within 20m of the road. However, there is no evidence to indicate that this is contributing a significant amount of N_R to the environment to create changes in the abundance of *Calluna, Vaccinium* or *Deschampsia*. This study has identified that the higher pH of the soil near to the road combined with higher nitrate levels may be creating conditions less suitable to *Calluna* and *Vaccinium* allowing other plants to compete and colonise.

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10 Acknowledgements

Acknowledgements and thanks go to:

Ali Glaisher and Sue Sheppard of Staffordshire County Council Environment and Countryside department for permission to carry out the study on Cannock Chase, and for their advice, knowledge and support in the selection of the sites and history of the management of the sites.

Pete Morris of SCC Environment and Countryside for helping with the fieldwork at Penkridge Bank Road.

Shona Frost and Caroline Watterson of Staffordshire County Council for lending me the GPS unit and training in use of the GPS and GIS mapping software.

John Amison at Staffordshire County Council Highways Laboratory for lending me a soil auger.

Mick Payne (Head Ranger at Cannock Chase), rangers and volunteer rangers for help in positioning the posts needed for some of the sites.

Dr Frank Hollywood and my colleagues at Staffordshire County Council Scientific Services for allowing me to use the laboratory facilities.

Special thanks go to my husband Bill for his tremendous help and enthusiasm in collecting samples, surveying sites, carrying equipment, driving me to Cannock Chase and staying with me every weekend for most of the summer. Without his tireless support and patience throughout all of my studies I would not have been able to complete this project.

11 Appendix A – Calculation of Atmospheric NO_2 and Nitrogen Deposition

Calculation of NO_2 diffusion tubes

The concentration of NO_2 in the atmosphere is calculated as:

$$c = \frac{1}{s.rate} x \frac{m}{t}$$

Where:

c is the concentration of NO_2 (µg m^{-3})

$s.rate$ is the sampling rate of NO_2 (m^3 h^{-1})(see below)

m is the mass of nitrate in the diffusion tube in µg (derived from the absorbance reading on the calibrated spectrophotometer compared to a standard graph)

t is the time of exposure (hours)

The sampling rate of NO_2 is calculated as:

$$s.rate = \frac{D_{12} a}{l}$$

Where:

D_{12} is the diffusion coefficient of gas 1 through gas 2 (i.e. NO_2 through air which is 0.05256m^2 h^{-1})

a is the cross sectional area of the tube (m^2)

l is the length of the tube (m)

Calculation of N deposition

The deposition of nitrogen, $N.dep$, (kg N ha-1 yr-1) from atmospheric nitrogen dioxide is calculated as:

$$N.dep = NO_2 x \frac{a}{b} x N_{depvel} x f$$

Where:

NO_2 is the concentration of NO_2 in the atmosphere (µg m^{-3})

a is the molecular weight of nitrogen (14)

b is the molecular weight of NO_2 (46)

N_{depvel} is the deposition velocity of NO_2 (0.001m s^{-1})

f is the factor to change the units from m^2 to ha, from µg to kg and from seconds to years (315.36)

Simplified this equates to:

$$N.dep = NO_2 x 0.1$$

12 Appendix B – Calculation of Soil Parameters

Dry matter
The % dry matter is calculated as:

$$\% \text{ Dry matter} = 100 \times \frac{M_2}{M_1}$$

Where M_1 is the weight of the sample before drying and M_2 is the weight of sample after air drying. The % air dried moisture can also be calculated at this stage.

$$\% \text{ air dry moisture} = 100 \times \frac{M_1 - M_2}{M_1}$$

Or % air dry moisture = 100 - % dry matter

Moisture
The % moisture content is calculated as:

$$\% \text{ Moisture content} = 100 \times \frac{(M_1 - M_2)}{M_1}$$

Where M_1 is the weight of the air dried sample before drying in the oven and M_2 is the weight of the sample after drying.

Organic matter
The % organic matter is calculated as:

$$\% \text{ organic matter} = 100 \times \frac{(M_1 - M_2)}{M_1}$$

Where M_1 is the weight of the air dried sample before drying in the furnace and M_2 is the weight of the sample after drying.

Bulk density
The bulk density is calculated (1ml is equivalent to $1cm^3$):

$$\text{Bulk density (g/cm)} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}}$$

Soluble soil nitrate

The soluble soil nitrate on the dry soil is calculated by:

Soluble soil nitrate on dry soil = Total NO_3 (filtrate) x v/w

Where: total NO_3 (filtrate) is the concentration of NO_3 in the filtrate as analysed by ion chromatography.

V is the volume of deionised water added to the soil to extract the NO_3.

W is the weight of soil used to extract NO_3.

Texture test

Adapted from Chalmers & Parker (1989)

Take a sample of soil and add enough water to moisten it. Follow steps to assign soil texture type.

1 Does the moist soil form a coherent ball?
- Easily (Go to step 2)
- With care **Loamy sand** but check using tests 2 and 3
- No **Sand**

2 When the ball is pressed between thumb and forefinger does it…
- Flatten coherently (3)
- Tends to break up **Sandy Loam** but check using tests 3 and 4

3 Can the ball be rolled into a thick cylinder (5mm thick)?
- Yes (4)
- No **Loamy Sand**

4 Can the cylinder be rolled into a thin thread (2mm thick)?
- Yes (5)
- No **Sandy Loam**

5 Can the thread be bent into a horseshoe shape without cracking?
- Yes (7)
- No (6)

6 Is the feel of the soil…
- Smooth and pasty **Silt Loam**
- Rough and abrasive **Sandy silt loam**

7 Can a ring be formed from the thin thread without cracking?
- Yes (9)
- No (8)

8 Is the feel of the soil…
- Very gritty **Sandy clay loam**
- Moderately rough **Clay loam**
- Doughy **Silty clay loam**

9 On rewetting the soil can the surface be polished with the thumb?
- Yes a high polish like wax with few noticeable particles (10)
- Yes but gritty particles are noticeable **Sandy clay**

10 On wetting thoroughly how strongly does the soil stick together one's fingers?
- Very strongly **Clay**
- Moderately strongly **Silty clay**

13 Appendix C – Atmospheric NO_2 data

The monthly results for Transect 1 and 8 are the mean average of 3 tubes exposed at the same tree or post.

*Sites 5.2-5.8 and 6.2-6.8 not exposed during May.

†Tubes and posts at sites 8.1 and 8.2 had been removed during July's exposure.

Road	Transect	Site	Tree or post	Distance from road (m)	Atmospheric NO_2 (µg/m^3)				
					May	June	July	**Mean**	Standard Deviation
Chase Road	1	**1.1**	Hawthorn	2.4	15.38	11.57	9.49	**12.15**	2.98
		1.2	Hawthorn	4.7	14.09	9.71	8.34	**10.71**	3.00
		1.3	Hawthorn	8.3	14.68	10.32	8.45	**11.15**	3.19
		1.4	Silver birch	14.3	14.03	9.69	7.10	**10.27**	3.50
		1.5	Silver birch	26.0	15.78	10.70	9.32	**11.93**	3.40
		1.6	Silver birch	47.0	17.78	11.57	9.28	**12.88**	4.40
		1.7	Small oak	96.0	15.31	11.71	7.89	**11.64**	3.71
		1.8	Silver birch	186.0	15.50	10.48	8.24	**11.41**	3.72
	2	**2.1**	Hawthorn	3.6	14.84	11.65	8.24	**11.58**	3.30
		2.2	Hawthorn	5.7	14.90	11.00	8.42	**11.44**	3.27
		2.3	Hawthorn	7.6	15.21	10.16	8.47	**11.28**	3.50
		2.4	Post	10.0	17.89	11.12	8.65	**12.55**	4.78
		2.5	Post	20.0	16.57	12.01	8.12	**12.23**	4.23
		2.6	Silver birch	47.0	15.70	11.53	7.77	**11.67**	3.97
		2.7	Silver birch	103.0	16.25	10.70	8.59	**11.85**	3.95
		2.8	Silver birch	210.0	15.82	11.77	8.18	**11.92**	3.82
Camp Road	3	**3.1**	Post	1.5	19.88	15.56	14.91	**16.78**	2.70
		3.2	Silver birch	8.0	19.21	11.88	12.14	**14.41**	4.16
		3.3	Silver birch	16.0	17.04	11.35	5.89	**11.43**	5.58
		3.4	Silver birch	21.4	17.56	11.05	4.48	**11.03**	6.54
		3.5	Silver birch	34.4	17.20	10.63	9.78	**12.54**	4.06
		3.6	Silver birch	46.4	23.10	13.49	10.26	**15.61**	6.68
		3.7	Silver birch	104.0	17.63	11.29	8.37	**12.43**	4.73
		3.8	Silver birch	202.0	15.62	9.68	7.07	**10.79**	4.38
	4	**4.1**	Post	1.0	23.09	18.36	14.91	**18.79**	4.11
		4.2	Post	3.0	22.40	18.36		**20.38**	2.86
		4.3	Post	5.0	18.77	19.61	14.44	**17.60**	2.77
		4.4	Post	10.0	18.77	16.52	10.79	**15.36**	4.11
		4.5	Post	20.0	19.71	12.30	8.67	**13.56**	5.63
		4.6	Post	50.0	18.89	14.50	9.08	**14.16**	4.92
		4.7	Post	100.0	15.95	11.23	8.08	**11.75**	3.96
		4.8	Post	200.0	19.65	12.59	8.31	**13.52**	5.73

Road	Transect	**Site**		Distance from road (m)	**Atmospheric NO_2 (µg/m^3)**				
					May	June	July	**Mean**	Standard Deviation
Penkridge Bank	5	**5.1**	Post	1.0	22.87	17.95	14.12	**18.31**	4.38
		5.2	Hawthorn	3.6	N/A*	14.06	11.45	**12.76**	1.85
		5.3	Gorse	5.8	N/A*	12.76	11.51	**12.13**	0.88
		5.4	Post	10.0	N/A*	12.82	10.26	**11.54**	1.81
		5.5	Silver birch	19.0	N/A*	10.66	9.67	**10.17**	0.70
		5.6	Post	50.0	N/A*	9.42	8.30	**8.86**	0.79
		5.7	Post	100.0	N/A*	8.51	8.54	**8.53**	0.02
		5.8	Silver birch	201.0	N/A*	9.48	8.30	**8.89**	0.84
	6	**6.1**	Post	1.0	23.11	19.56	14.21	**18.96**	4.48
		6.2	Hawthorn	3.0	N/A*	12.34	11.78	**12.06**	0.39
		6.3	Gorse	5.0	N/A*	12.51	10.42	**11.46**	1.48
		6.4	Gorse	10.0	N/A*	10.69	9.65	**10.17**	0.73
		6.5	Post	20.0	N/A*	10.63	8.59	**9.61**	1.45
		6.6	Post	49.8	N/A*	9.44	8.83	**9.13**	0.43
		6.7	Post	100.0	N/A*	9.56	7.76	**8.66**	1.27
		6.8	Post	200.0	N/A*	9.67	8.18	**8.93**	1.06
Brindley Heath Road	7	**7.1**	Post	2.0	18.93	13.18	9.62	**13.91**	4.70
		7.2	Pine	7.0	16.25	10.57	8.55	**11.79**	3.99
		7.3	Pine	14.0	15.12	11.10	9.09	**11.77**	3.07
		7.4	Pine	22.5	16.06	11.75	7.91	**11.91**	4.08
		7.5	Pine	31.0	15.44	11.34	8.38	**11.72**	3.54
		7.6	Pine	50.0	13.14	11.34	8.85	**11.11**	2.15
		7.7	Silver birch	100.0	15.38	9.81	10.37	**11.85**	3.06
		7.8	Silver birch	187.0	16.44	11.24	9.01	**12.23**	3.81
	8	**8.1**	Post	1.0	25.03	17.97	N/A†	**21.50**	4.99
		8.2	Post	3.0	20.30	19.53	N/A†	**19.92**	0.55
		8.3	Silver birch	5.0	18.40	12.85	9.82	**13.69**	4.35
		8.4	Post	10.0	17.92	12.89	9.50	**13.44**	4.24
		8.5	Silver birch	22.0	15.93	11.29	8.92	**12.05**	3.57
		8.6	Silver birch	50.0	14.66	11.44	8.27	**11.46**	3.20
		8.7	Silver birch	112.0	15.73	12.01	8.49	**12.08**	3.62
		8.8	Silver birch	195.0	14.90	10.55	8.25	**11.23**	3.38
Ambient background measurement SJ 98530,17740		**B**	Silver birch	> 500	16.29	10.57	10.49	**12.45**	3.33

Fieldwork: Trish Matthews (except Penkridge Bank sites - Pete Morris).
Laboratory analysis: Trish Matthews at Staffordshire County Council Scientific Services Laboratory.

14 Appendix D – Vegetation survey data

Road	Transect	Site	Distance from road	% cover: *Calluna vulgaris*	*Molinia caerulea*	*Rubus fruticosus*	*Pteridium aquilinum*	*Vaccinium spp.*	*Deschampsia flexuosa*	Other	Comments on vegetation in area (tree cover, other plants identified or bare ground)
Chase Road	1	1.1	2.4	0.00	0.00	23.80	27.60	0.00	0.00	48.6	*Crategus monogyna* (Hawthorn) trees, *Cirsium arvense* (Creeping Thistle), *Arrhenatherum elatius* (False oat grass), *Dactylis glomerata* (Cock's-foot), *Festuca rubra* (Red Fescue).
		1.2	4.7	0.00	0.00	41.00	21.60	0.00	0.00	37.4	*C.monogyna* trees, young *Ulex europaeus* (Gorse), *Cirsium, A.elatius, D.glomerata, F.rubra, Potentilla erecta* (Tormentil), *Crocosmia x crocosmiiflora.*
		1.3	8.3	4.20	0.00	43.20	8.00	0.00	3.60	41	*C.monogyna* trees, young *U.europaeus, F.rubra, P.erecta.*
		1.4	14.3	22.00	4.80	2.80	2.00	0.00	11.80	56.6	*C.monogyna* and *Betula pendula* (Silver Birch) trees, *B.pendula* saplings, *A.elatius, D.glomerata, F.rubra, P.erecta, Juncus effusus* (Soft rush), mosses.
		1.5	26	18.20	0.00	32.40	6.60	27.40	6.00	9.4	*C.monogyna* and *B.pendula* trees, *A.elatius, D.glomerata, F.rubra,* mosses.
		1.6	47	44.60	13.00	0.00	0.00	0.00	39.40	3	*B.pendula* tree, *A.elatius, D.glomerata, F.rubra.*
		1.7	96	60.40	0.00	1.00	9.00	0.20	19.80	9.6	*Quercus petraea* (Sessile Oak) tree and sapling, *A.elatius, D.glomerata, F.rubra,* mosses.
		1.8	186	7.00	5.40	0.00	9.60	36.20	34.00	7.8	*B.pendula* (adult trees and saplings), *A.elatius, D.glomerata, F.rubra, J.effusus.*
	2	2.1	3.6	0.00	0.00	66.80	12.00	0.00	2.60	18.6	*C.monogyna* trees, young *U.europaeus, A.elatius, D.glomerata, F.rubra,* Fungi.
		2.2	5.7	1.00	0.00	53.80	3.40	0.00	14.00	27.8	*C.monogyna* trees, young *U.europaeus, A.elatius, D.glomerata, F.rubra, P.erecta, Lotus corniculatus* (Common Bird's-foot-trefoil), *Digitalis purpurea* (Foxglove).
		2.3	7.6	0.00	0.00	40.60	0.00	0.00	10.60	48.8	*C.monogyna* trees, *A.elatius, D.glomerata, F.rubra, P.erecta, L.corniculatus,* mosses.
		2.4	10	3.80	0.00	23.20	4.80	5.00	45.80	17.4	*A.elatius, D.glomerata, F.rubra, P.erecta, L.corniculatus,* mosses.
		2.5	20	24.40	4.60	1.20	0.00	4.20	65.40	0.2	*A.elatius, D.glomerata, F.rubra.*
		2.6	47	29.20	0.60	3.20	0.00	6.60	51.40	9	*B.pendula* trees, *A.elatius, D.glomerata, F.rubra, J.effusus,* mosses.
		2.7	103	31.80	38.80	6.00	0.00	23.00	0.40	0	*B.pendula* trees, *A.elatius, D.glomerata, F.rubra.*
		2.8	210	40.20	0.00	0.00	6.40	48.20	3.20	2	*B.pendula* trees, *A.elatius, D.glomerata, F.rubra.*

Road	Transect	Site	Distance from road	% cover *Calluna vulgaris*	*Molinia caerulea*	*Rubus fruticosus*	*Pteridium aquilinum*	*Vaccinium spp.*	*Deschampsia flexuosa*	Other	Comments on vegetation in area (tree cover, other plants identified or bare ground)
Camp Road	3	3.1	1.5	0.00	0.00	0.00	0.00	0.00	0.00	100	Road verge had been mown fairly recently - mixed neutral grassland - identified species included *Taraxacum officinale* (Common Dandelion), *Hypochoeris* (Cat's-ear), *Trifolium repens* (White Clover), *L.corniculatus, Urtica dioica* (Common nettle), *Galium saxatile* (Heath Bedstraw).
		3.2	8	0.00	0.00	1.60	98.40	0.00	0.00	0	Edge of area of dense trees - mainly *B. pendula.*
		3.3	16	0.00	0.00	2.20	91.00	0.00	0.00	6.8	*B.pendula*, some grasses, bare ground.
		3.4	21.4	0.00	0.00	54.80	38.80	0.00	0.00	6.4	*B.pendula*, some grasses, bare ground.
		3.5	34.4	0.00	0.00	10.00	83.80	0.00	0.00	6.2	*B.pendula* mature tree and many saplings, some grasses, bare ground.
		3.6	46.4	0.00	1.60	31.60	7.00	1.20	20.00	38.6	*B.pendula* mature tree and many saplings, some grasses, mosses, dead *Rubus fruticosus* and bare ground.
		3.7	104	51.60	0.00	7.00	0.20	17.40	16.20	7.6	*B.pendula* mature tree and many saplings, *U.europaeus*, some grasses, mosses.
		3.8	202	48.00	0.00	0.00	38.60	10.60	0.00	2.8	*B.pendula* mature tree and many saplings, *U.europaeus*, some grasses, mosses.
	4	4.1	1	0.00	0.00	0.00	0.00	0.00	0.00	100	Road verge had been mown recently - mixed neutral grassland - identified species included *T.officinale, Hypochoeris, T.repens, Plantago lanceolata* (Ribwort Plantain).
		4.2	3	0.00	0.00	0.00	0.20	0.00	0.00	99.8	Road verge had been mown recently - mixed neutral grassland - identified species included *T.officinale, Hypochoeris, T.repens, P.lanceolata.*
		4.3	5	0.00	0.00	0.00	0.00	0.00	0.00	100	Road verge had been mown recently - mixed neutral grassland - identified species included *T.officinale, Hypochoeris, T.repens, P.lanceolata.*
		4.4	10	82.60	3.60	0.00	0.00	0.00	6.80	7	Mosses and bare ground.
		4.5	20	32.80	13.80	2.20	11.40	0.00	15.60	24.2	Mosses and bare ground.
		4.6	50	76.20	20.80	0.00	0.00	0.00	1.40	1.6	*B.pendula* saplings.
		4.7	100	92.40	0.00	0.00	0.00	0.00	0.00	7.6	Mosses and bare ground.
		4.8	200	99.20	0.40	0.00	0.00	0.00	0.00	0.4	Mosses.

Road	Transect	Site	Distance from road	% cover: *Calluna vulgaris*	*Molinia caerulea*	*Rubus fruticosus*	*Pteridium aquilinum*	*Vaccinium spp.*	*Deschampsia flexuosa*	Other	**Comments on vegetation in area (tree cover, other plants identified or bare ground)**
Penkridge Bank	5	5.1	1	0.00	0.00	0.00	0.00	0.00	**	100	Dominated by grasses including *D.glomerata, Holcus lanatus* (Yorkshire fog), *Phleum pratense* (Timothy), *Cynosurus cristatus* (Crested Dogstail), and *D.flexuosa plus L.corniculatus, Cirsium, P.lanceolata, T.repens, Urtica dioica* (Common Nettle).
		5.2	3.6	0.00	0.00	2.20	0.00	0.00	0.00	97.8	*B.pendula, C.monogyna* and *Pinus spp., D.glomerata, H.lanatus, A.elatius, F.rubra, Agropyron repens* (Couch), *Cirsium* and dead *Calluna.*
		5.3	5.8	2.20	0.00	4.00	0.00	0.00	0.00	93.8	*U.europaeus, Pinus spp., D.glomerata, H.lanatus, A.elatius, Agrostis tenuis* (Common Bent), plus *Veronica chamaedrys* (Germander Speedwell), *P.lanceolata, Vicia sativa* (Common Vetch), *L.corniculatus, T.repens, C.arvense, Senecio jacobaea* (Common Ragwort) and *C.monogyna* sapling.
		5.4	10	0.00	0.00	0.40	0.00	0.00	0.00	99.6	No trees.*F.repens, H.lanatus, A.elatius, C.arvense, P.lanceolata, T.repens, V.sativa, P.erecta, Lathyrus pratensis* (Meadow Vetchling), *Ranunculus repens* (Creeping Buttercup) and *S.jacobaea.*
		5.5	19	70.00	0.00	0.20	0.00	29.00	0.00	0.8	Small *B.pendula* tree and sapling. *Vaccinium myrtillus* (Bilberry), *V.vitis-idaea* (Cowberry) and *Empetrum nigrum* (Crowberry) and moss with some *Erica tetralix* (Cross-leaved Heath) and *A.repens.*
		5.6	50	26.40	3.20	0.60	1.40	**	0.00	68.4	No trees. *V.myrtillus, V.vitis-idaea, E.nigrum, Erica cinerea* (Bell Heather) with some *G.saxatile*, moss, *F.rubra* and *A.tenuis.*
		5.7	100	69.60	0.00	0.20	0.00	0.00	0.00	30.2	*B.pendula* saplings. *H.lanatus, A.tenuis, A.elatius, S.jacobaea, Epilobium augustifolium* (Rosebay Willowherb), *J.effusus* and moss. Evidence of rabbit grazing on Ragwort.
		5.8	201	15.00	0.00	1.40	0.20	59.00	0.00	24.4	*Sorbus aucuparia* (Rowan) and *Salix caprea* (Goat Willow). *V.myrtillus, E.nigrum* dominant with some *V.vitis-idaea, V.chamaedrys, P.erecta, G.saxatile,* moss, *H.lanatus* and *A.tenuis.*
	6	6.1	1	0.00	0.00	1.60	0.00	0.00	0.00	98.4	*H.lanatus, D.glomerata, T.repens, Equisetum arvense* (Field Horsetail), *Vicia sepium* (Bush Vetch), *P.lanceolata, T.officinale, Cerastium holosteoides* (Mouse Ear), *L.corniculatus* and *S.jacobaea.*
		6.2	3	0.00	0.00	0.00	0.00	0.00	0.00	100	*U.europaeus.*
		6.3	5	0.00	0.00	0.00	0.00	0.00	0.00	100	*U.europaeus.*
		6.4	10	9.40	0.00	4.60	0.00	**	0.00	86	*U.europaeus* and *C.monogyna. H.lanatus, P.erecta, V.myrtillus, V.vitis-idaea, G.saxatile,* and moss.
		6.5	20	47.40	0.00	0.00	0.00	**	0.00	52.6	*Quercus* sapling. *V.myrtillus, V.vitis-idaea, E.nigrum, G.saxatile, E.tetralix, E.cinerea* moss and bare ground.
		6.6	49.8	35.40	0.00	0.00	0.00	**	0.00	64.6	*Quercus* sapling. *V.myrtillus, V.vitis-idaea, E.nigrum, E.tetralix, A.tenuis,* moss.
		6.7	100	26.00	0.00	0.00	0.00	**	0.00	74	*B.pendula* scrub.*V.myrtillus, V.vitis-idaea, E.nigrum* and *A.tenuis.*
		6.8	200	18.00	28.00	3.20	0.00	**	0.00	50.8	*C.monogyna* bush and *B.pendula* scrub. *Molinia caerulea, E.nigrum, V.myrtillus, V.vitis-idaea, E.cinerea, G.saxatile, A.tenuis, H.lanatus.*

** Species present but no figures available

Road	Transect	Site	Distance from road	% cover *Calluna vulgaris*	*Molinia caerulea*	*Rubus fruticosus*	*Pteridium aquilinum*	*Vaccinium spp.*	*Deschampsia flexuosa*	Other	Comments on vegetation in area (tree cover, other plants identified or bare ground)
Brindley Heath Road	7	7.1	2	1.00	1.80	0.00	5.80	14.20	20.40	56.8	50% of area is mown frequently. No trees. Variety of neutral grassland grass species plus *T.repens, G.saxatile, L.corniculatus, V.chamaedrys.*
		7.2	7	10.60	9.20	0.00	0.00	51.60	12.40	16.2	Adult *Pinus sp.* tree. *Pinus sp* and *B.pendula* saplings. *G.saxatile.*
		7.3	14	0.00	4.80	0.00	0.00	86.80	6.20	2.2	*Pinus sp, G.saxatile* and moss.
		7.4	22.5	0.00	6.40	0.00	0.00	90.00	0.00	3.6	*Pinus sp., G.saxatile,* moss and bare ground.
		7.5	31	16.20	7.20	2.60	0.00	69.00	2.60	2.4	*Pinus sp. G.saxatile* and moss.
		7.6	50	18.20	2.60	2.00	0.00	72.80	2.40	2	*Pinus sp.* and moss.
		7.7	100	73.40	16.00	2.80	0.00	0.40	1.00	6.4	*B.pendula* tree. Moss.
		7.8	187	33.00	9.20	0.00	8.00	49.80	0.00	0	*B.pendula* tree.
	8	8.1	1	0.00	0.00	2.80	4.20	0.80	0.00	92.2	Road verge had been mown recently - mixed neutral grassland - identified species included *L.corniculatus.*
		8.2	3	16.60	0.00	42.00	19.20	14.80	0.00	7.4	Ground cover dominated by *Calluna, Rubus* and *Pteridium* and some *Vaccinium.* Some grasses present including *A.tenuis.*
		8.3	5	22.40	0.00	54.40	2.80	13.60	0.00	6.8	*B.pendula* tree. Ground cover dominated by *Rubus, Calluna* and *Vaccinium.* Some of the *Rubus* was dead, some bare ground.
		8.4	10	8.60	4.00	24.20	1.40	52.80	1.60	7.4	Ground cover dominated by *Calluna, Rubus* and *Vaccinium. A.tenuis,* mosses and bare ground.
		8.5	22	36.40	0.00	0.00	2.00	49.00	7.00	5.6	*B.pendula* tree. Ground cover dominated by *Calluna* and *Vaccinium. Pinus sp.* sapling, mosses and *A.tenuis.*
		8.6	50	25.80	0.00	0.00	0.40	69.20	2.40	2.2	*B.pendula* tree. *Pinus sp.* sapling, mosses and areas of bare ground.
		8.7	112	93.60	0.00	0.00	3.00	2.80	0.20	0.4	*B.pendula* tree. Ground cover dominated by mature *Calluna.* Some moss and small areas of bare ground.
		8.8	195	72.60	0.00	0.00	0.00	8.00	0.40	19	*B.pendual* tree and sapling. Ground cover dominated by *Calluna.* Also some mosses and *A.tenuis.*

Fieldwork: Trish Matthews (except Penkridge Bank sites - Pete Morris).

15 Appendix E – Soil analysis data

Road	Transect	Site	Distance from road	Texture	pH	Total moisture % in original sample	% organic matter in air dry soil (Loss at 500°C)	Bulk density of air dry soil (g/cm3)	Nitrate mg/kg (in air dry soil)
Chase Road	1	1.1	2.4	Sandy silt loam	6.87	22.54	8.94	1.05	53.95
		1.2	4.7	Sandy silt loam	6.48	25.31	9.07	0.96	27.88
		1.3	8.3	Sandy silt loam	5.20	23.57	7.95	1.00	4.18
		1.4	14.3	Sandy silt loam	4.93	30.48	11.98	0.85	4.23
		1.5	26	Sandy silt loam	5.56	19.57	5.92	1.10	39.45
		1.6	47	Sandy silt loam	4.65	22.12	4.74	1.14	3.98
		1.7	96	Sandy silt loam	4.59	25.61	8.06	0.99	4.08
		1.8	186	Sandy silt loam	4.63	29.39	7.01	1.02	7.34
	2	2.1	3.6	Sandy silt loam	5.67	19.33	6.49	1.06	20.36
		2.2	5.7	Sandy silt loam	4.82	19.87	6.68	1.11	22.76
		2.3	7.6	Sandy silt loam	5.43	17.24	4.43	1.11	27.42
		2.4	10	Sandy silt loam	4.71	22.04	4.46	1.14	0.74
		2.5	20	Sandy silt loam	4.83	20.15	5.24	1.18	5.32
		2.6	47	Sandy silt loam	4.64	26.13	9.04	1.07	6.42
		2.7	103	Sandy silt loam	4.39	39.71	18.63	0.81	19.59
		2.8	210	Sandy silt loam	4.46	21.87	8.66	1.05	5.38
Camp Road	3	3.1	1.5	Sandy loam	7.18	20.48	1.48	0.94	60.95
		3.2	8	Sandy silt loam	4.46	22.85	11.95	0.91	14.16
		3.3	16	Sandy silt loam	4.33	29.58	16.84	0.69	46.21
		3.4	21.4	Sandy silt loam	4.71	18.46	9.27	0.89	2.92
		3.5	34.4	Sandy silt loam	4.98	33.54	17.62	0.74	2.03
		3.6	46.4	Sandy loam	5.55	41.37	42.15	0.44	0.34
		3.7	104	Sandy silt loam	4.35	30.92	20.12	0.70	2.52
		3.8	202	Sandy silt loam	4.07	22.13	10.14	0.80	2.39
	4	4.1	1	Sandy silt loam	6.33	20.20	9.97	0.90	74.62
		4.2	3	Sandy silt loam	6.03	22.86	12.14	0.87	56.70
		4.3	5	Sandy silt loam	6.36	29.24	17.64	0.81	59.48
		4.4	10	Silty clay loam	4.59	25.42	10.50	0.96	5.93
		4.5	20	Sandy silt loam	4.43	24.55	11.98	0.91	4.94
		4.6	50	Silty clay loam	4.34	29.25	11.99	0.94	1.73
		4.7	100	Sandy silt loam	4.16	22.33	7.18	0.99	4.34
		4.8	200	Silty clay loam	4.19	25.08	7.18	1.08	5.97

Road	Transect	Site	Distance from road	Texture	pH	Total moisture % in original sample	% organic matter in air dry soil (Loss at 500°C)	Bulk density of air dry soil (g/cm3)	Nitrate mg/kg (in air dry soil)
Penkridge Bank	5	5.1	1	Sandy loam	7.47	17.88	7.07	0.94	381.32
		5.2	3.6	Sandy silt loam	6.42	34.64	20.11	0.72	339.86
		5.3	5.8	Sandy silt loam	6.11	18.81	8.02	0.97	169.20
		5.4	10	Sandy silt loam	6.37	23.05	8.56	0.95	97.46
		5.5	19	Silty clay loam	4.25	28.38	9.65	0.84	46.21
		5.6	50	Silty clay	4.19	19.56	5.66	0.96	47.75
		5.7	100	Silty clay	4.39	23.79	6.46	0.91	52.26
		5.8	201	Silty clay	4.12	36.58	18.22	0.66	41.73
	6	6.1	1	Sandy loam	6.33	18.35	8.76	0.95	157.57
		6.2	3	Sandy silt loam	5.70	22.94	9.20	0.87	152.29
		6.3	5	Sandy silt loam	5.57	19.14	8.77	0.91	187.54
		6.4	10	Silty clay loam	4.30	40.69	21.47	0.65	80.46
		6.5	20	Silty clay	4.27	27.82	8.40	0.83	53.79
		6.6	49.8	Silty clay loam	4.15	29.92	10.49	0.76	49.01
		6.7	100	Silty clay	4.13	23.12	6.99	0.88	39.30
		6.8	200	Silty clay	4.65	27.55	8.07	0.90	129.26
Brindley Heath Road	7	7.1	2	Silty clay loam	4.80	20.82	10.13	0.81	177.16
		7.2	7	Silty clay loam	4.18	25.54	13.12	0.70	228.14
		7.3	14	Silty clay loam	4.22	15.62	8.15	0.94	190.23
		7.4	22.5	Silty clay loam	4.31	17.36	13.18	0.82	197.04
		7.5	31	Sandy silt loam	4.28	23.26	21.83	0.67	176.76
		7.6	50	Silty clay loam	4.23	18.82	13.10	0.80	238.54
		7.7	100	Silty clay loam	4.20	21.78	10.50	0.82	223.88
		7.8	187	Silty clay loam	4.25	20.82	7.85	0.95	285.23
	8	8.1	1	Silty clay loam	6.15	12.26	14.01	0.86	211.79
		8.2	3	Silty clay loam	5.70	13.67	10.98	0.85	300.33
		8.3	5	Silty clay loam	4.53	12.67	9.73	0.94	234.09
		8.4	10	Silty clay	4.84	12.08	6.67	0.97	269.46
		8.5	22	Silty clay loam	4.36	27.28	19.72	0.67	189.64
		8.6	50	Silty clay loam	4.37	31.52	22.66	0.62	182.03
		8.7	112	Silty clay loam	4.23	23.22	16.59	0.84	257.74
		8.8	195	Silty clay loam	4.30	14.84	18.49	0.79	173.88