Ecological Monitoring at Ashdown Forest: Considering the Current and Future Impacts on the SAC caused by Air Quality and Nitrogen Deposition.

Wealden District Council
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Summary

Ashdown Forest is located within the north-western part of Wealden District, East Sussex and comprises one of the best areas of lowland heath in the United Kingdom. As a consequence it is designated as a Site of Special Scientific Interest (SSSI) and a Special Area of Conservation (SAC).

The integrity of heathland habitats at Ashdown Forest is threatened by a number of factors, including elevated rates of nitrogen deposition arising from increased road vehicle exhaust emissions. Fundamental shifts in the composition and structure of heathland vegetation communities are known to occur under conditions of elevated nitrogen deposition. This is because many of the characteristic plants, mosses and lichens of heathland habitats are adapted to nutrient poor conditions and any extra input of nitrogen (which acts as a fertiliser but may also be toxic) disadvantages these characteristic species in favour of other species with greater tolerance of higher nitrogen levels. As a result, nitrogen-sensitive species may be lost from the community and a general decline in biodiversity observed. In many cases, including that of Ashdown Forest, much change is already likely to have happened but lack of systematic baseline records make this change difficult to quantify. In fact, there are few records that have been maintained even from recent decades.

Here, we report results from the first three years of a study examining the impacts of elevated nitrogen deposition on heathland habitats and vegetation communities at Ashdown Forest. This work was commissioned by Wealden District Council as part of a long-term monitoring programme to inform a Habitats Regulations Assessment of the risk to Ashdown Forest from increased road traffic emissions, associated with proposed development in their Local Plan.

Fifteen transects were established perpendicular to roads around Ashdown Forest. Vegetation community composition and structure in quadrats along each transect was monitored in 2014, 2015 and 2016. Samples of soil and foliage were also taken for measurement of nitrogen content. Modelled values for nitrogen deposition and air pollution at each quadrat were estimated by Air Quality Consultants Ltd (AQC) (full details of this complimentary aspect of the study are provide in AQC (July, 2018)).

Our findings include:

- All quadrats along all transects represent significantly degraded heathland habitat.
- Modelled rates of annual mean total nitrogen deposition were consistently above the critical load for all quadrats, but were highest closest to a road.
- Quadrats further from a road hosted a suite of species more typical of nitrogen-poor conditions compared with quadrats closer to a road, implying a species distribution strongly influenced by rates of nitrogen deposition.
- Species richness was low overall and declined with distance from a road.
- Nitrogen index values (e.g. Ellenberg N values) declined with distance from a road. The contribution made by dwarf shrubs to these overall nitrogen index values increased with distance from a road and the contributions made by graminoids and forbs decreased. There was no statistically significant pattern shown by bryophytes and lichens.
• Concentrations of foliar nitrogen and amino acids in *Hypnum jutlandicum* (a moss) and *Calluna vulgaris* (heather) were relatively high but did not display any relationship with distance from a road. This may be because plants are already nitrogen saturated along the entire length of the transects.

• Soil total nitrogen levels were variable but generally high. There was no correlation between soil total nitrogen and distance from a road even though we may have anticipated a negative relationship. This was a puzzle and we do not currently have an explanation for this observation.

• A positive relationship was apparent between soil carbon:nitrogen ratio and distance from a road. This provides some evidence to suggest that soil nitrogen levels do indeed decline with distance from a road, contrary to the observation outlined under the previous bullet point.

• Ordination, which helps to elucidate patterns in the distribution of ecological communities, showed that the distribution of graminoids could be quite well explained in terms of Ellenberg N values but was less successful in explaining patterns observed for other plant groupings (e.g. dwarf shrubs, bryophytes and lichens, forbs and woody species).

Our recommendations for further monitoring and study include:

• The continued yearly monitoring of quadrats for the presence of all vegetation species and their percentage cover.

• The continued yearly monitoring of soils to determine carbon:nitrogen ratios.

• An effort to determine whether foliar nitrogen concentrations are saturated.

• Review current heathland management practises and how they might best be applied to the conservation and restoration of Ashdown Forest,
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1. Introduction

1.1 Background To Study

1.1.1 Ashdown Forest is located within the north-western part of Wealden District, East Sussex and comprises one of the best areas of lowland heath in the United Kingdom. It is therefore recognised as an important site for nature conservation at both a national and international level.

1.1.2 The Forest was notified as a Site of Special Scientific Interest (SSSI) in 1986, a Special Protection Area (SPA) in 1996 and a Special Area of Conservation (SAC) in 2005. SACs and SPAs are known collectively as European Sites and are part of the Natura 2000 network.

1.1.3 European sites are protected in law by EC Directive 92/43/EEC 1992 (the Habitats Directive) and EC Directive 2009/147/EC (the Birds Directive). These directives are transposed into UK law by the Conservation of Habitats and Species Regulations 2017 (the Habitats Regulations).

1.1.4 The condition of European Sites is considered against site-specific Conservation Objectives, which are measured via Common Standards Monitoring (CSM), typically undertaken on a 6-year cycle. Currently, Ashdown Forest’s lowland heath is categorised as being in an ‘unfavourable-recovering’ condition by Natural England. There are a number of reasons why this may be the case but adverse impacts from airborne pollutants have been identified as of potential significance on the Ashdown Forest Natura 2000 standard data form.

1.1.5 New development that may affect the conservation status of European Sites must be subject to ‘appropriate assessment’ by a ‘competent authority’ and will not be permitted unless any adverse effects can be avoided or mitigated or if there are no alternative feasible solutions. If adverse effects cannot be avoided, for a development to go ahead, there must be imperative reasons of overriding public interest and it must be demonstrated that appropriate compensatory measures will be provided to off-set any negative effects.

1.1.6 Therefore, through the process of Habitats Regulations Assessment (HRA), Wealden District Council, acting as the ‘competent authority’, is required to determine whether future development set out in their Local Plan is likely to result in significant adverse effects on the ecological integrity of Ashdown Forest.

1.2 Purpose of This Study

1.2.1 In April 2014 Wealden District Council commissioned Ecus Ltd to provide a programme of air quality and ecological monitoring to assist the Council in more accurately determining the effects of atmospheric pollution on the Ashdown Forest SAC. This will help the Council ensure that Ashdown Forest SAC conservation objectives are not compromised as a result of development according to their Local Plan.

1.2.2 The project is being undertaken by Ecus Ltd in association with Air Quality Consultants Ltd (AQC).
1.3 Scope of Works

1.3.1 The scope of this study as provided to Ecus Ltd by Wealden District Council was to:

"..provide the necessary detail and finalise the methodology and implement and manage a monitoring, modelling, assessment and reporting programme to determine more accurately the atmospheric concentrations of relevant pollutants and the effects of these on the Ashdown Forest Special Area of Conservation (SAC)". The scope of the study includes to:

- regularly monitor relevant air pollutants along certain road corridors within and adjacent to the SAC;
- research and monitor the potential onsite effects of atmospheric pollution on habitat and vegetation diversity;
- model current and future impacts on ambient concentrations and nitrogen deposition from road traffic in the vicinity of the SAC;
- calculate future impacts on ambient concentrations and nitrogen deposition from road traffic in the vicinity of the SAC based on development scenarios and resulting traffic movements provided by the Client;
- analyse the results from the monitoring and modelling programme, and
- report on the results of the monitoring and modelling programme including bringing both the air quality and ecological elements of the project together.

1.3.2 An initial methodology for undertaking the above works was developed for Wealden District Council by Mott MacDonald in July 2013, based on consultation with Natural England, the Conservators of Ashdown Forest, the Centre for Ecology and Hydrology (CEH) and Wealden District Council. Works undertaken in respect of this contract have been based on this methodology with some variation where agreed with Wealden District Council (Appendix 1).

1.4 This Report

1.4.1 This report has been produced following three years of air quality and ecological monitoring and seeks to provide information to inform the HRA for the Wealden Local Plan (full details of the air quality monitoring are provided in a separate report (AQC, 2018).

1.4.2 Regular monitoring of concentrations of the following nitrogenous air-bourne pollutants has been undertaken along road corridors within and adjacent to the SAC:

- nitric oxide (NO), nitrogen dioxide (NO₂), nitric acid (HNO₃), nitrate (NO₃⁻);
- ammonia (NH₃), ammonium (NH₄⁺).

Data obtained from this monitoring were then used to calculate rates of nitrogen deposition in the SAC.
1.4.3 Research into and monitoring of the onsite effects of nitrogen deposition on habitat and vegetation species diversity of the heathland has been undertaken.

1.4.4 The report also provides information that can be used to assist Wealden District Council in determining planning applications with regard to its duty under the Habitat Regulations. The Council must decide whether growth proposed within the Wealden Local Plan will result in an adverse impact and whether suitable mitigation or compensatory measures, as relevant, can be applied to mitigate or offset any adverse impact to allow development proposed in the Wealden Local Plan to proceed.
2. Planning Policy History

2.1 Core Strategy Local Plan

2.1.1 Wealden District Council adopted its Core Strategy in February 2013. A major consideration in the development of the Core Strategy was the effect of atmospheric pollution on Ashdown Forest SAC through traffic growth. The HRA concluded that development proposed in the Core Strategy was considered to have neutral / no adverse effect on site integrity. However, the findings of the assessment identified that a section of the A26 would have an additional Annual Average Daily Traffic (AADT) of 950 as a result of the Core Strategy. This meant that, when considered with a number of additional identified housing sites already granted planning permission, the A26 was very close to being an 'affected road' as defined by the Design Manual for Roads and Bridges screening methodology.

2.1.2 In addition, it was recognised using information from Air Pollution Information System (APIS) that nitrogen deposition has already exceeded a critical threshold for Ashdown Forest SAC and that additional traffic from new development will lead to increases in air pollution which could ultimately lead to an increase in nitrogen deposition. The effect of this is likely to be more severe in close proximity to busy road corridors (within 200 metres). At the time of the Core Strategy, nitrogen deposition for Ashdown Forest SAC was modelled as a 5 km x 5 km average, too coarse a scale to be representative of site-specific conditions near to any roads. Furthermore, the nearest monitoring station to the SAC was located at Barcome Mills, approximately 12 km to the south. Therefore, at the time of producing the Core Strategy, the level of nitrogen deposition close to existing roads was unknown. The effect of nitrogen deposition is considered likely to be more severe in close proximity to busy road corridors (within 200 m) and may therefore exceed the critical load by a higher margin. Accordingly, it could not be concluded on a precautionary basis that more growth (in addition to that identified in the Core Strategy) would not result in a significant adverse effect.

2.1.3 Core Strategy Policy WSC12 required the Council to ‘undertake further investigation of the impacts of nitrogen deposition on Ashdown Forest SAC, so that its effects in the longer term can be more fully understood and mitigated, if appropriate’. The purpose of this is to establish a better scientific understanding of the situation to see if additional growth can be accommodated.

2.2 Wealden Local Plan

2.2.1 The Wealden Local Plan put forward in March 2017 seeks to allocate 14,250 new homes and up to 22,500 m² additional employment floor space (B1/B2/B8) and 4,350 m² additional retail floor space in Wealden District over the period 2013 to 2028. As identified during the production of the Core Strategy, new development in the district has the potential to result in an increase in air pollution from increased traffic on the roads through Ashdown Forest. Any changes in traffic could increase air pollution such as nitrogen oxides and ammonia that could ultimately lead to an increase in nitrogen deposition and could potentially adversely affect the Conservation Objectives of the SAC.

2.2.2 The SAC designation relates to the protection of habitat types which have
been shown through various academic studies to be affected by nitrogen deposition from traffic. There is also the potential for direct effects from exposure to elevated ambient concentrations. Therefore additional information is needed, taking into account the precautionary principle, to establish whether there would be a likely significant effect on the SAC as a result of delivering the Local Plan, taking into account the ‘in combination’ assessment required by the Habitats Regulations 2017.
3. Ashdown Forest SAC/SSSI

3.1 Background

3.1.1 Ashdown Forest is approximately 900 years old and originated as a medieval hunting forest managed for deer and for grazing livestock. The first mention of the Forest as heathland was made in 1500. Since this time wood from the Forest supplied local blast furnaces. In 1693, much of the Forest was sold to private landowners, which now includes the Ministry of Defence. By the early 1900s the Forest was dominated by heathland, with less than 10% woodland by 1947.

3.1.2 Following the Second World War, a reduction in grazing and the outbreak of myxomatosis provided an opportunity for natural succession and woodland cover increased to 40% of the total Forest area, with the remaining 60% consisting of lowland heath. The Forest comprises the largest area of open access land in the south-east.

3.2 Special Area Of Conservation

3.2.1 Ashdown Forest contains one of the largest blocks of continuous lowland heath in south-east England, with the SAC covering an area of 2715 hectares. Annex I habitats that are a primary reason for the SAC designation include both wet heath and dry heath. The specific habitat types as listed on the Natura 2000 data form are:

- 4010 Northern Atlantic wet heaths with Erica tetralix;
- 4030 European dry heaths.

4010 Northern Atlantic Wet Heaths with Erica Tetralix

3.2.2 North Atlantic wet heath is a natural or semi-natural habitat that occurs on acidic, nutrient-poor soils, typically either shallow peats or sandy soils with impeded drainage and the water table generally at or above ground level for at least part of the year. Vegetation is dominated by dwarf shrub species including cross-leaved heath (Erica tetralix). Four National Vegetation Classification (NVC) types in Britain meet the definition of this habitat type. Of these, Ashdown Forest supports M16 Erica tetralix – Sphagnum compactum wet heath.

M16 Erica tetralix – Sphagnum compactum wet heath

3.2.3 M16 heath is dominated by variable mixtures of cross-leaved heath, heather (Calluna vulgaris) and purple moor grass (Molinia caerulea). Western gorse (Ulex gallii) and dwarf gorse (Ulex minor) may also occur. Other consistent associate vascular species are few but may include deer grass (Trichophorum cespitosum (Scirpus cespitosus)), common cottongrass (Eriophorum angustifolium), bog asphodel (Narthecium ossifragum), common sundew (Drosera rotundifolia) and bog myrtle (Myrica gale). Frequently occurring non-vascular plants include mosses such as Sphagnum compactum and Sphagnum tenellum and lichens such as Cladonia impexa and Cladonia uncialis.

3.2.4 Nearly all wet heath is semi-natural, being derived from wetter areas of woodland through a history of grazing and burning. In the absence of burning
and grazing, eventual succession of wet heath to woodland is expected.

3.2.5 The description of this habitat in relation to Ashdown Forest, as given by the Joint Nature Conservation Committee (JNCC), is presented below.

“The M16 Erica tetralix – Sphagnum compactum wet heath element provides suitable conditions for several species of bog-mosses Sphagnum spp., bog asphodel Narthecium ossifragum, deergass Trichophorum cespitosum, common cotton-grass Eriophorum angustifolium, marsh gentian Gentiana pneumonanthe and marsh clubmoss Lycopodiella inundata. The site supports important assemblages of beetles, dragonflies, damselflies and butterflies, including the nationally rare silver-studded blue Plebejus argus, and birds of European importance, such as European nightjar Caprimulgus europaeus, Dartford warbler Sylvia undata and Eurasian hobby Falco Subbuteo.”

4030 European Dry Heaths

3.2.6 European dry heaths typically occur on freely-draining, acidic to circumneutral soils with generally low nutrient content. Ericaceous dwarf-shrubs dominate the vegetation. Twelve NVC types meet this definition. Of these, Ashdown Forest supports H2 Calluna vulgaris – Ulex minor heath.

H2 Calluna vulgaris – Ulex minor heath

3.2.7 H2 heath is dominated by heather but with significant presence of both bell heather (Erica cinerea) and dwarf gorse (Ulex minor). Wavy hair-grass (Deschampsia flexuosa) and purple moor-grass are often patchily present but there are few other consistent associate vascular species. Bracken (Pteridium aquilinum) is occasional and scattered plants of tormentil (Potentilla erecta) or heath bedstraw (Galium saxatile) may be found in more open areas.

3.2.8 Nearly all dry heath is semi-natural, being derived from woodland through a history of grazing and burning. Most dry heaths are managed as grazing for livestock or, in upland areas, as grouse moors. In the absence of burning, mosses and lichens may be common. Heath plait-moss (Hypnum jutlandicum) and broom fork-moss (Dicranum scoparium) are often present, along with lichens such as Cladonia arbuscula and Cladonia furcata. In the absence of burning and grazing, succession of dry heath to woodland is expected.

3.2.9 The JNCC description of this habitat in relation to Ashdown Forest is:

“The dry heath in Ashdown Forest is an extensive example of the south-eastern H2 Calluna vulgaris – Ulex minor community. This vegetation type is dominated by heather Calluna vulgaris, bell heather Erica cinerea and dwarf gorse Ulex minor, with transitions to other habitats. It supports important lichen assemblages, including species such as Pycnothelia papillaria. This site supports the most inland remaining population of hairy greenweed Genista pilosa in Britain”.

Ashdown Forest SAC Conservation Objectives

3.2.10 As required through Article 6(3) of the Habitats Directive and therefore through the Habitats Regulations, the Conservation Objectives for Ashdown Forest must ensure that the Qualifying Features of the SAC (i.e. those features for which the site was designated) are maintained at Favourable
Conservation Status or returned to Favourable Conservation Status by maintaining or restoring:

- the extent and distribution of qualifying natural habitats and habitats of qualifying species;
- the structure and function (including typical species) of qualifying natural habitats;
- the structure and function of the habitats of qualifying species;
- the supporting processes on which qualifying natural habitats and the habitats of qualifying species rely;
- the populations of qualifying species;
- the distribution of qualifying species within the site.

### 3.3 Site Of Special Scientific Interest

#### 3.3.1 The Ashdown Forest Site of Special Scientific Interest (SSSI) covers 3144.6 hectares and includes the area of the SAC. A description of the designated heathland plant communities is given below (the full citation may be found at [http://www.sssi.naturalengland.org.uk/citation/citation_photo/1001983.pdf](http://www.sssi.naturalengland.org.uk/citation/citation_photo/1001983.pdf)).

"Ashdown Forest is an extensive area of common land lying between East Grinstead and Crowborough. The soils are derived from the predominantly sandy Hastings Beds. It is one of the largest single continuous blocks of heath, semi-natural woodland and valley bog in south-east England, and it supports several uncommon plants, a rich invertebrate fauna, and important populations of heath and woodland birds.

#### 3.3.2 Although the area of heathland has declined in recent years due to cessation of grazing and frequent fires, there remain extensive areas of dry heath dominated by ling *Calluna vulgaris*, with bell heather *Erica cinerea* and dwarf gorse *Ulex minor*. This heathland supports important lichen communities including species such as *Pycnothelia papillaria*. Bracken *Pteridium aquilinum* is now dominant over large areas.

#### 3.3.3 On the damper heath, cross-leaved heath *Erica tetralix* becomes dominant with deer-grass *Trichophorum cespitosum*. The heath and bracken communities form a mosaic with acid grassland dominated by purple moor-grass *Molinia caerulca* with species such as the local petty whin *Genista anglica*. Wet areas provide suitable conditions for several species of sphagnum moss, together with which are found bog asphodel *Narthecium ossifragum*, common cotton-grass *Eriophorum angustifolium* and specialities such as marsh gentian *Gentiana pneumonanthe*, ivy-leaved bell flower *Wahlenbergia hederacea*, white-beaked sedge *Rhynchospora alba* and marsh clubmoss *Lycopodiella indundata*.

#### 3.3.4 Gorse *Ulex europaeus*, silver birch *Betula pendula*, pedunculate oak *Quercus robur* and Scots pine *Pinus sylvestris* are scattered across the heath, and in some areas form extensive secondary woodland and scrub."

### 3.4 Site Condition

#### 3.4.1 The condition of nationally and internationally important sites for nature conservation is typically monitored every six years following CSM guidance,
developed by the JNCC as a result of The Environmental Protection Act 1990.

3.4.2 For Lowland Heath plant communities there are 11 attributes that are assessed in an attempt to judge the condition and conservation status of the site. These include the percentage cover of heathers, mosses and lichens, as well as bare ground, the presence of negative indicator species and signs of disturbance.

3.4.3 In 2015, 66 out of 71 of the SSSI units comprising the Ashdown Forest heath habitat were assessed as being in ‘unfavourable-recovering’ condition, primarily due to their failure to meet vegetation composition and structure targets. Reasons for failure highlighted by Natural England include above target cover of purple moor-grass, above target cover of heather, below target cover of forbs, below target cover of dwarf shrubs and below target cover of various growth stages of heather.

3.4.4 It should be noted, however, that whilst CSM has been used in this study as a proxy for heathland health, the JNCC states that the condition assessment process was not designed for identifying the effects of nitrogen deposition impacts. The limitations of this approach are further discussed in section 5.8.

3.5 Threats And Pressures

3.5.1 The Natura 2000 Standard Data Form lists a number of likely sources of negative impact to the lowland heath habitats of Ashdown Forest. These are as follows:

- H04, air pollution, air-borne pollutants;
- J02, human induced changes in hydraulic conditions;
- A02, modification of cultivation practices;
- G01, outdoor sports and leisure activities, recreational activities.

3.5.2 It should be noted that these influences are not listed in order of potential importance. It should also be recognised that they will combine to produce a complicated suite of ecosystem drivers. For example, high visitor pressure and certain management practises may obscure more subtle effects on vegetation produced by air pollution.
4. Effects Of Nitrogen Deposition On Heathlands

4.1 Nitrogen Deposition

4.1.1 Nitrogen is an essential element for all living things because it is a key component of proteins. For terrestrial plants it is often the limiting nutrient for growth, a fact that farmers have long recognised. If moderate levels of nitrogen-based fertilisers are added to a crop, yields may almost certainly be increased.

4.1.2 Plants may be expected, therefore, to be highly sensitive to changes in concentrations of available nitrogen. Although gaseous nitrogen (N$_2$) is by far the most abundant of our atmospheric gases it is highly unreactive and not readily available to plants. What plants are principally after is nitrogen in the form of nitrate (NO$_3^-$) and ammonium (NH$_4^+$) ions. Naturally occurring sources of these nutrients are limited. However, recent human activities have vastly increased their availability and nitrogen now acts as a pollutant, driving biodiversity change across the globe (Sala et al., 2000).

4.1.3 Figure 4.1 shows sources of pollutant nitrogen and how it may reach plant communities. Most oxidised nitrogen (NO$_x$, for example NO and NO$_2$) comes from the exhaust emissions of motor vehicles and most reduced nitrogen (NH$_3$) from the intensive production of livestock. However, vehicle emissions may also be a significant source of ammonia-based pollution (Tengyu et al., 2014; Suarez-Bertoa & Astaga, 2016; Schoonejongen, 2017; Sun et al., 2017). After entering the atmosphere, these gases may reach plants directly in the process known as dry deposition, or may reach plants by first dissolving in rain to form NO$_3^-$ and NH$_4^+$ in the process known as wet deposition.

![Figure 4.1: Pollutant nitrogen emission and deposition processes](www.apis.ac.uk/starters-guide-air-pollution-and-pollution-sources, accessed October 2017).

4.1.4 We expect then, that the principal impact of elevated nitrogen deposition on plant communities is a fertilization effect. Certain species (particularly graminoids) are better able to assimilate nitrogen than others and may therefore gain competitive advantage under conditions where nitrogen availability is increased. Changing competitive relationships between individual species may consequently result in changing species richness and
species composition of the community.

4.1.5 Other effects of elevated nitrogen deposition may relate more directly to toxicity. For example, ammonia (NH₃) has been shown to cause necrosis and growth reduction in a number of agricultural crops (van der Eerden, 1982; van der Erden et al., 1998) and acidification of soils by acid rain (containing nitric acid, HNO₃) can release usually mineral-bound toxic metals such as aluminium, iron and manganese (Blake & Goulding, 2002). Again, such effects have the potential to alter the competitive relationships between plant species and ultimately to shape plant communities.

4.2 Effects On Heathland Vegetation

4.2.1 Different species of vascular plants, bryophytes and lichens will respond to elevated levels of available nitrogen in differing ways and the threshold above which an increasing nitrogen load becomes pollutant will also vary in a species-specific way. Effects of elevated nitrogen may be direct or indirect and will operate in conjunction with a wide range of other abiotic and biotic factors influencing the growth of the plant (Heil & Diemont, 1983; Heil & Bruggink, 1987; Aerts et al., 1990). The effects of even moderately low levels of nitrogen deposition on heathland communities may persist for many years and may be reversible only through the use of specific management practises.

4.2.2 As a consequence of their species composition, characterised by low growing and non-vascular species (i.e. bryophytes and lichens) with limited ability to assimilate nitrogen, heathland habitats are particularly vulnerable to nitrogen deposition (Bobbink & Heil, 1993). Nitrogen deposition typically has a fertilising effect on vegetation allowing taller and more competitive species to dominate the sward with a resulting decline in community species-richness and structural diversity.

4.2.3 One of the first effects of increased availability of nitrogen deposition in heathlands is an increase in overall plant biomass, which typically manifests itself as increased above ground growth of heather. Lower-growing species, especially mosses and lichens, may then be negatively affected through increased shading and reduction of bare ground. They are also particularly susceptible to the direct effects of nitrogen deposition because they may absorb nutrients / pollutants through their entire body surfaces.

4.2.4 Once the productivity of heather is no longer limited by nitrogen, increased nitrogen concentrations may be seen in leaf tissue and soil. Where a plant cannot properly assimilate nitrogen because of toxic effects of deposition, damage to tissues can occur leading to increased sensitivity to pathogens, herbivores such as the heather beetle (Lochmaea suturalis) and environmental stressors such as frost or drought. In terms of lowland heath, this would be expected to manifest in the increased cover of degenerate or dead heather plants and ultimately in the reduction of heather cover and the encroachment of other more competitive species such as bracken and purple moor-grass.

4.2.5 Even under moderate levels of stress plant communities do not change rapidly. We would therefore expect that neither an upward nor downward change in rate of nitrogen deposition would immediately affect heathland plant communities in terms of species richness and / or composition (Caporn
et al., 2016). This is because currently extant communities are a reflection of the historic accumulation of nitrogen in ecosystems over many years, if not decades.

4.3 **Critical Loads And Critical Levels**

Critical loads and critical levels are used for assessing the risk of air pollution impacts to ecosystems (www.apis.ac.uk, accessed October 2017). Critical Loads are defined as: "a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge". Critical levels are defined as: "concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur according to present knowledge".

4.3.1 Critical loads differ from critical levels, in that critical loads relate to the quantity of pollutant deposited from air to ground and critical levels relate to the gaseous concentration of a pollutant in the air.

4.3.2 The critical load for both wet and dry heathland across the UK is 10-20 kg N/ha/yr (www.apis.ac.uk). Defra further recommend that the lower-bound of the published national critical loads (i.e. 10 kg N/ha/yr) is used in air pollution impact assessments.

4.3.3 For heathland, the critical level for oxidised nitrogen (NO₃) is an annual mean of 30 µg/m². Similarly, the critical level for reduced nitrogen (NH₃) is 1 µg/m². The critical levels for NO₃ and NH₃ are not habitat-specific and have been applied, following advice from CEH, across the entire SAC. Some of the potential consequences for heathland plant communities of exceeding these critical levels are shown in Table 4.1.

<table>
<thead>
<tr>
<th>NOₓ, NO₃</th>
<th>NH₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased foliar nitrogen concentration. Community composition changes in favour of taller, nitrophilous species.</td>
<td>Bleaching on sensitive species, usually occurs first on lichens; damage to heather foliage and canopy breakdown; increase in grass cover; increase in nitrophilic species; absence of habitat constants; increase in Ellenberg N; increase in foliar N; more pests and pathogens.</td>
</tr>
</tbody>
</table>

4.3.4 Changes in both species composition and ecosystem function indices have been identified at lower thresholds of nitrogen deposition (5-10 kg N/ha/yr) (Emmott et al., 2012) and, as species differ in their sensitivity to nitrogen, some may be affected at deposition rates below formally defined critical loads. Indeed, in their comprehensive review of the effects of elevated nitrogen deposition on a range of habitats of conservation importance Caporn et al. (2016) found that, for heathland, there is a 'substantial reduction' in species richness above the critical load and that 'where curvilinear responses in species richness are described the greatest decline in richness is below the critical load'.

4.3.5 In many areas in the UK and Europe, the critical load is already exceeded and habitats are already significantly impacted by nitrogen deposition (Caporn
et al., 2016).
5. Ecology Monitoring Methodology

5.1 Overview

5.1.1 A programme of ecological monitoring has been designed to research and monitor the potential onsite effects of atmospheric pollution on habitat and vegetation diversity. Data collected is correlated, amongst other things, with modelled nitrogen deposition parameters from the air quality monitoring program in an attempt to relate changes in habitat and vegetation diversity with distance from a road (and therefore, by implication, with a gradient in nitrogen deposition). Monitoring comprises the following elements of work:

- the production of a large-scale habitat map of Ashdown Forest SAC every three years and identifying any significant changes to relevant habitat areas;
- monitoring the structure and composition of heathland communities along 15 transects;
- analysing foliar nitrogen content of a non-vascular and a vascular plant across three of the transects;
- analysing amino acid content of both a non-vascular and a vascular plant across three of the transects;
- analysing nitrogen content of soil from each quadrat along all 15 transects.

5.1.2 The ecological monitoring is based on a review of methodologies undertaken by Mott MacDonald in 2013 (Mott MacDonald, 2013) as a precursor to this project. Variations to the Mott MacDonald methodology were proposed by ECUS and based on the advice provided were implemented with the agreement of Wealden District Council and are summarised in Appendix 11.

5.1.3 The ecological monitoring programme was undertaken during the botanical survey periods of 2014, 2015 and 2016 and provides information on the ecological condition of the site.

5.1.4 The individual transect data are used together with the air quality monitoring data to run multi-parameter analyses in an attempt to identify the key pressures that are influencing species community composition. We do not attempt to identify long-term trends in vegetation change. Typically, to detect such change would require persistent monitoring for a period of at least 10 years, if not a number of decades. Our multi-year data-set reduces the uncertainty inherent in monitoring over even shorter periods of time and adds robustness to the identification of baseline conditions.

5.2 Habitat Mapping

5.2.1 Analysis of habitat mapping within the SAC boundary based on aerial imagery was undertaken by Environment Systems Ltd, firstly in 2014 and again in 2017. The distribution of major habitat types was plotted using photochromatic analysis of imagery obtained from two satellites, SPOT5 and Worldview2, using specialist software. The mapping focusses primarily on wet and dry heath, which comprise the qualifying features of the SAC, however woodland and other habitats present were also mapped.

5.2.2 Mapping was compared between years and also to other sources of habitat...
information, including an existing habitat map provided by the Conservators of Ashdown Forest and to the citation for the SAC. Historic internet-based aerial imagery and old maps from online sources (www.oldmaps.co.uk), which date back to 1874, were also reviewed with the aim of identifying any obvious changes in habitat extent.

5.2.3 Ground truthing of the habitat maps was undertaken by Ecus Ltd to verify the habitat types and their extent and also to investigate any areas of habitat change between years.

5.2.4 In 2014, a general walkover of 20% of heathland within 250 m of a road was undertaken to verify the habitat map. In 2016, a more detailed approach was adopted with focus on investigating areas of apparent habitat change identified by Environment Systems using a change analysis. The criteria for this ground truthing included:

- areas to be ground truthed to fall within the SAC boundary;
- areas to be ground truthed to fall within 250 m of a road;
- areas to be ground truthed to be spread across both unfavourable and unfavourable-recovering SSSI units;
- all areas of change within 250 m of a road to be ground truthed to determine what the change was and any apparent cause;
- 20% of the area of each heathland type present to be ground truthed.

5.3 Vegetation Survey

Transect Selection and Establishment

5.3.1 Fifteen 250 m transects were established as specified by Mott MacDonald (2013). These transects were labelled A through to O. Nine quadrats were permanently fixed along each transect at the following distances from a road: 10 m (Q1), 25 m (Q2), 50 m (Q3), 75 m (Q4), 100 m (Q5), 150 m (Q6), 200 m (Q7), 250 m (Q8) and a control at 400 m (Q9). Each quadrat was 2 x 2 m² and was marked with a survey pin in two opposite corners to aid future location. The rationale provided by Mott MacDonald for the spacing was that most change as a result of nitrogen deposition is expected to occur within 100 m of a road (Bignal et al., 2007; Ricardo-AEA, 2016). In 2016 two additional quadrats were added to each transect at 1 m (QA) from the road and 5 m (QB) from the road. Quadrats are referred to as QA, QB, Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9 in terms of their distance from the road.

5.3.2 Transect selection aimed to incorporate the following elements:

- orientation - all transects to be located perpendicular to major roads;
- traffic flow – transects to be established near roads with different AADT flows;
- vegetation type - dwarf shrub heath to be present along at least 50% of each transect length;
- woodland belt – a woodland belt to be present between the road and heathland habitats in a minimum of three transects;
- grazing - transects to be located in both grazed and non-grazed areas;
• visitor pressure – a minimum of two transects to be located within 500 m of high visitor pressure car parks and the remainder more than 1 km from car parks with high or medium visitor pressure.

5.3.3 Traffic flows (AADT) thus linked to individual transects are shown below:

- AADT 1444, transects A and B;
- AADT 1839, transects L and M;
- AADT 3221, transects G, H, I and O;
- AADT 5078, transect F;
- AADT 5526, transects C, D and N;
- AADT 5648, transect E;
- AADT 12042, transect J and K.

5.3.4 Based on an initial site scoping visit at the start of the project, it became apparent that it was not possible to select 15 transect locations starting at the roadside with dwarf shrub cover along 50% of their lengths. The transects pass through a mosaic of habitats, including grass, bracken and gorse-dominated areas, rather than large expanses of heather and other dwarf shrubs. Transects B, H, N and O have the highest occurrence of dwarf shrubs with between 9 and 10 quadrats out of 11 supporting these species. Transect A has the lowest occurrence of dwarf shrubs with only one of the 11 quadrats containing these species. The majority of transects have dwarf shrubs in between four and six of the 11 quadrats.

5.3.5 Six transects (A, F, H, I, L, M) were located so as to have woodland/tree belts at their starts, the idea being that a barrier of trees may buffer the effects of elevated nitrogen deposition for the heathland beyond.

5.3.6 Four transects are considered to be located in ungrazed areas (B, E, K, N) with the other 11 in areas grazed by livestock. This reckoning is based on evidence collected on site during the three years of survey, including presence of fencing, livestock, droppings and grazed vegetation. Limitations associated with assigning transects as grazed or ungrazed are discussed in section 5.8.

5.3.7 It was not possible to locate transects more than 1 km from moderate or high visitor pressure car parks due to the overall high frequency of car parks along the major roads. Furthermore, as locating transects between car parks would add further variability to transect locations (i.e. level of visitor pressure and distance from that pressure) all transects were located within 50 m of car parks with a range of known visitor pressures. As the transect locations were determined in 2014, levels of visitor pressure were taken from a study by U.E. Associates in 2008. This study was updated in 2016 by Footprint Ecology, which found that the busiest car parks were similar to those reported in 2008. Maps 1 – 3 (Appendix 1) show quadrant locations, traffic flows and visitor pressure. Appendix 3 gives full descriptions of each transect.

Vegetation Data

5.3.8 Monitoring of vegetation communities was undertaken in 2014, 2015 and 2016 along 15 transects. The times and dates of the surveys, and the surveyors involved, are summarised in Table 5.1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Dates</th>
<th>Staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>11.08.14 – 15.08.14</td>
<td>ER/JH</td>
</tr>
<tr>
<td></td>
<td>18.08.14 – 21.08.17</td>
<td>TS/LLH</td>
</tr>
<tr>
<td></td>
<td>01.09.14 – 05.01.14</td>
<td>ER/DB</td>
</tr>
<tr>
<td>2015</td>
<td>15.08.15 – 22.08.15</td>
<td>ER/SU</td>
</tr>
<tr>
<td>2016</td>
<td>04.07.16 – 13.07.16</td>
<td>ER/SU</td>
</tr>
</tbody>
</table>

5.3.9 Vegetation data in the quadrats along each transect were recorded in accordance with standard NVC methodology (Rodwell, 2006). The following variables were recorded in each year:

- percentage cover of all ground-dwelling vascular plants, bryophytes and lichens;
- percentage cover of dwarf shrubs;
- total percentage cover of vegetation;
- mean vegetation height;
- percentage cover of bare ground;
- details of any surface water present;
- any evidence of management or dog fouling.

5.3.10 All quadrats located between 10 m and 400 m from the road were assessed against a total of 25 condition assessment targets (seven targets tested in 2014 and nine targets tested in both 2015 and 2016) according to CSM methodology (JNCC, 2009). However, as quadrats QA and QB were only set up and sampled during 2016, they were only tested against the nine targets once. Table 5.2 shows the attributes considered (the full condition assessment attributes and targets table is provided in Appendix 4). Attribute selection and limitations surrounding the use of CSM in this study are discussed in section 5.8.

Table 5.2. CSM attributes and targets assessed.

<table>
<thead>
<tr>
<th>CSM Attribute</th>
<th>Dry Heath Target</th>
<th>Wet Heath Target</th>
<th>Years in which attribute was assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare ground (%)</td>
<td>Bare ground 1-10% Disturbance, erosion or</td>
<td>Bare ground 1-10% Disturbance, erosion or</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td></td>
<td>paths &lt;1 %</td>
<td>paths &lt;1 %</td>
<td></td>
</tr>
<tr>
<td>Vegetation structure: growth phase</td>
<td>Pioneer ericaceous cover: 10-40 %</td>
<td>Pioneer ericaceous cover: 10-40 %</td>
<td>2015, 2016</td>
</tr>
<tr>
<td>composition of ericaceous cover</td>
<td>Building/mature phase: 20-80- %</td>
<td>Building/mature phase: 20-80- %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Degenerate phase: &lt;30 %</td>
<td>Degenerate phase: &lt;30 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dead: &lt;10 %</td>
<td>Dead: &lt;10 %</td>
<td></td>
</tr>
<tr>
<td>Vegetation structure: where bryophyte</td>
<td>At least 50 % to comprise pioneer heather,</td>
<td>At least 50 % to comprise pioneer heather,</td>
<td>2015, 2016</td>
</tr>
<tr>
<td>species of lowland</td>
<td>degenerate heather or vegetation less than 15 cm</td>
<td>degenerate heather or vegetation less than 15 cm</td>
<td></td>
</tr>
<tr>
<td>CSM Attribute</td>
<td>Dry Heath Target</td>
<td>Wet Heath Target</td>
<td>Years in which attribute was assessed</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------</td>
<td>-----------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>heathland with bare ground that is winter-wet, summer droughted with light disturbance</td>
<td>At least two species of dwarf shrubs present and at least frequent. Dwarf shrub cover 25-90% Total <em>Ulex</em> spp. cover &lt;50%, with <em>Ulex europaeus</em> &lt;25%</td>
<td>At least two species of dwarf shrubs present and at least frequent. Dwarf shrub cover 25-90% Total <em>Ulex</em> spp. cover 50%, with <em>Ulex europaeus</em> &lt;10%</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td>Vegetation composition: dwarf shrubs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation composition: graminoids</td>
<td>At least 1 graminoid species frequent and 2 species occasional. <em>Deschampsia flexuosa</em> and <em>Nardus stricta</em> no more than occasional and &lt;25% cover</td>
<td>At least 1 graminoid species frequent and 2 species occasional.</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td>Vegetation composition: desirable forbs</td>
<td>At least two desirable forb species occasional (from specific species list)</td>
<td>At least two desirable forb species occasional (from specific species list)</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td>Negative indicators: exotic species</td>
<td>&lt;1% exotic species &lt;10% bracken (dense canopy) Acrocarpous mosses &lt;occasional</td>
<td>&lt;1% exotic species &lt;5% bracken (dense canopy) Acrocarpous mosses &lt;occasional</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td>Negative indicators: herbaceous species</td>
<td>&lt; 1 % ragwort, nettle, thistles and other herbaceous species specific to dry heath.</td>
<td>&lt; 1 % ragwort, nettle, thistles and other herbaceous species specific to wet heath.</td>
<td>2014, 2015, 2016</td>
</tr>
<tr>
<td>Negative indicators: tree and shrub species</td>
<td>&lt; 15% trees &amp; scrub</td>
<td>&lt; 10% trees &amp; scrub</td>
<td>2014, 2015, 2016</td>
</tr>
</tbody>
</table>

### 5.4 Foliar Nitrogen

5.4.1 Heath plait-moss (*Hypnum jutlandicum*) and heather (*Calluna vulgaris*) were chosen for foliar nitrogen analysis. The moss is relatively abundant across the whole of the SAC and has been used in previously published nitrogen studies (Leith et al., 2005). Moss is also considered a potentially good indicator of recent, direct, nitrogen deposition (rather than cumulative deposition) because moss obtains little or no nitrogen from the soil (Rowe et al., 2014). Heather is a good indicator of heathland health and studies have found that
an increase in nitrogen content in heather correlates to an increase in nitrogen deposition, particularly relating to \( \text{NH}_3 \) (Carfrae et al., 2004).

5.4.2 Samples of heath plait-moss and heather were taken, where possible, from all quadrats along three transects: B, L and O. These transects were selected because of the relatively consistent presence of both species along their lengths. However, in some quadrats the target species were absent or there was a dense cover of gorse. Under these circumstances, if the target species were present within 10 m either side of the transect (at the relevant distance from the road), then substitute samples were taken.

5.4.3 Samples were analysed for foliar nitrogen concentration through thermal combustion by Scientific Analysis Laboratories Ltd (SAL) and for foliar amino acid concentration through acid hydrolysis by Alta Bioscience.

5.4.4 Unfortunately, discrepancies in foliar nitrogen concentration results became apparent in 2016. The 2014 and 2016 samples were subcontracted for analysis by SAL to NRM Laboratories, whilst SAL themselves analysed the 2015 samples. The two laboratories did not use the same sample preparation methodology and we consider this factor to be the cause of the discrepancies. The implications of this are discussed in section 5.8.

5.4.5 The initial methodology review by Mott MacDonald suggested that plant samples should be taken every year until a baseline has been established. It was considered that yearly results for the first three years would identify any significant short term trends (increase or decrease in nitrogen with distance from road) across the first three years. If there is a significant relationship between foliar nitrogen concentrations and nitrogen deposition, this analysis will be continued as part of the longer term study.

5.5 Soil Nitrogen

5.5.1 In 2014, 2015 and 2016, soil samples were taken along all transects for determination of total nitrogen content. In 2016, after discussion with CEH, C:N ratio was also analysed.

5.5.2 The aim was to take 3 sub-samples from all quadrats along each transect, to give a combined overall sample of soil of approximately 0.5 litres per quadrat. Where this was not directly possible (for example where quadrats fell within an area of dense gorse) similar samples were taken at the relevant distance from the road, within 10 m of the quadrat. Samples were kept refrigerated and then sent for analysis in cool boxes.

5.5.3 Samples were analysed by SAL using thermal combustion. However, as noted above, SAL subcontracted the analyses to NRM Laboratories in 2014 and 2016, directly carrying out the work themselves only in 2015. Discrepancies in soil nitrogen results became apparent in 2016 and it seems likely that, as for the foliar nitrogen results, they stem from differences in preparation methodology between the two laboratories. The implications of this are discussed in section 5.8.

5.6 Modelled Nitrogen Deposition

5.6.1 AQC provided modelled values for air pollution parameters based on the two years of air quality data available for calibration. The values represent
theoretical concentrations of pollutants at the distance of each quadrat from a road. Data from a custom model developed by AQC are used throughout the report except in section 6.10, where data obtained using the latest Environment Agency model are also presented for comparison. Parameters are shown in Table 5.3.

5.7 Statistical Analysis

Quadrat Composition

5.7.1 Stacked bar graphs were used to provide a visual representation of the vegetation composition of each quadrat. Mean percentage cover was calculated across the three years of data to give a robust baseline to assess any differences between vegetation composition with distance from a road.

5.7.2 Vegetation cover may exceed more than 100 % of the quadrat area, due to the layered structure of vegetation within a quadrat. For example, a quadrat may be dominated by bryophytes at ground level, with dwarf shrubs above and graminoids or bracken growing through the shrub layer (Rodwell, 2006).

Grass:Forb Ratio

5.7.3 Grass:forb ratio was calculated for a particular quadrat at a particular time using the percentage cover of all grass species and the percentage cover of all forb species in that quadrat, according to the formula grass:forb ratio = cover of grass / cover of forbs. This metric may be responsive to changes in available nitrogen and therefore indicative of a gradient associated with elevated nitrogen deposition (Emmett et al., 2011; Rowe et al., 2014; Stevens et al., 2011).

5.7.4 Grass:forb ratio is an indicator of habitat health, with different habitat types having different characteristic ratios. A ratio of 1 for heath habitats and 2.5 for bog habitats can be considered as indicative of good habitat quality (Emmett et al., 2012). Higher ratios for these habitats would typically be indicative of degradation. These figures are not available in the floristic tables in the NVC books (e.g. Rodwell, 1991) and have been calculated using multiple studies of large data sets.

Species-richness

5.7.5 Species-richness is simply the total number of recorded species in a particular quadrat at a particular time. Increases in nitrogen deposition have been shown to correlate with a decrease in species-richness (Rowe et al., 2014; Caporn et al., 2016).

5.7.6 Details in Rodwell (1991) suggest that healthy examples of M16 Erica tetralix – Sphagnum compactum wet heath and H2 Calluna vulgaris – Ulex minor dry heath habitats should be expected to contain an average of 13 species. We have therefore used this value of 13 as a benchmark against which to compare our species-richness observations.

Plant Nitrogen Index

5.7.7 Ellenberg N values for vascular plants (Hill et al., 1999) and similar N values for lichens and bryophytes (Wirth, 1991; Siebel, 1993) were obtained for all species recorded. Index values range from 1 – 9. For example, species such as cross-leaved heath and the lichen Cladonia portentosa tend to be found in
extremely nitrogen poor situations and have index values of 1. Other species such as false oat grass (*Arrhenatherum elatius*) and nettle (*Urtica dioica*) tend to be found in nitrogen rich situations and have index values of 7 and 8, respectively. Cover-weighted index means were calculated for each quadrat along each transect. To do this, the fractional contribution of a particular species to the total percentage cover (of all species) in a particular quadrat was first calculated. These fractions were then multiplied by the relevant Ellenberg N value for each species and then summed to give a weighted mean for that quadrant.

**Error Bars, Simple Regression and Significance Levels**

5.7.8 Error bars presented in figures represent +/- 1 standard error in all cases.

5.7.9 Correlation was used to examine potential relationships between distance from a road and variables measured along the transects such as species-richness, grass:forb ratio, soil nitrogen content and so on. Power functions, exponential functions, log functions and linear functions were all explored as lines of best fit with the most suitable model for particular data sets being chosen through a combination of objective examination of summary statistics and subjective judgement.

5.7.10 Significance levels are indicated as follows: * p < 0.05, ** p < 0.01, *** p < 0.001, ns = not significant.

**Ordination**

5.7.11 Variation in plant community composition can be investigated using a family of statistical techniques collectively known as ordination. In particular, ordination diagrams can help us visualise relationships between individual species and environmental gradients. Although such diagrams may often appear complicated, the basic principle is simple: proximity implies similarity. In other words, species that are close to each other will have more similar environmental niches than species that are far apart in the diagram. Samples that are close to each other will be more similar in terms of occurring species than samples far apart, and so on. We must then use our knowledge of the ecology of individual species to help in the ecological interpretation of the gradients represented by the axes.

5.7.12 Here, we first use detrended correspondence analysis (DCA) to examine the length of environmental gradients potentially associated with each data set. DCA is an example of indirect gradient analysis. It uses only a single species by sample matrix and so, if there is any available information about the environment it must be applied as an interpretive tool after the analysis.

5.7.13 We then use canonical correspondence analysis (CCA) to further investigate possible relationships between occurrence of species and measured environmental gradients. CCA is an example of direct gradient analysis and is a marriage between correspondence analysis and multiple regression because sample scores are constrained to be linear combinations of explanatory variables. It attempts to identify associations between two sets of matrices, one containing species abundances and the other containing measured or modelled environmental variables.

5.7.14 No ordination techniques provide a true measure of the significance of the relationships they illustrate because unexplained variance is usually a source
of confounding influences. Interpreting patterns therefore relies on the knowledge and experience of the person running the analysis. However, CCA does provide an idea of how much species variance (total inertia) is explained by each environmental variable and can help in deciding which variables seem to be the most important in shaping particular plant communities.

5.7.15 It is useful to appreciate that in a CCA diagram, the length of environmental vectors (arrows) indicates their importance to the ordination and the direction of the vectors indicates their correlation with each of the axes (or, put another way, vectors pointing in the same direction are correlated).

5.7.16 Environmental variables used in our DCA and CCA are shown in Table 5.3. The statistical package used for these analyses was Canoco.

<table>
<thead>
<tr>
<th>Environmental Variable</th>
<th>Code</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from road (DR)</td>
<td>1</td>
<td>Distance of quadrat to nearest road</td>
</tr>
<tr>
<td>Grazing (GRZ)</td>
<td>2</td>
<td>Whether the quadrat is grazed or not (based on site evidence including fencing, grazed plants, presence of stock and droppings)</td>
</tr>
<tr>
<td>Visitor pressure (VP)</td>
<td>3</td>
<td>Low, medium or high pressure (based on U.E. Associates study in 2008 and Footprint Ecology in 2016)</td>
</tr>
<tr>
<td>Woodland/tree belt (W)</td>
<td>4</td>
<td>Presence of a tree belt at the beginning of the transect</td>
</tr>
<tr>
<td>AADT (AADT)</td>
<td>5</td>
<td>Annual Average Daily Traffic Flow as determined in 2016</td>
</tr>
<tr>
<td>Sum (modelled N) (TN)</td>
<td>6</td>
<td>Value modelled for each quadrat (based on the two years of air quality data available to calibrate the model)</td>
</tr>
<tr>
<td>Annual mean NH₃ (ug/m³) (AvNH₃)</td>
<td>7</td>
<td>Value modelled for each quadrat (based on the two years of air quality data available to calibrate the model)</td>
</tr>
<tr>
<td>Annual mean NOₓ (ug/m³) – as NO₂ (AvNOₓ)</td>
<td>8</td>
<td>Value modelled for each quadrat (based on the two years of air quality data available to calibrate the model)</td>
</tr>
<tr>
<td>Maximum 24h mean NOₓ Concentration (ug/m³) – as NO₂ (24NOₓ)</td>
<td>9</td>
<td>Value modelled for each quadrat (based on the two years of air quality data available to calibrate the model)</td>
</tr>
</tbody>
</table>

5.8 Limitations

Habitat Mapping

5.8.1 The images used in aerial habitat mapping are gathered from above and therefore are best at identifying plant communities which have a distinctive appearance from above. Communities that are characterised by the presence of small sized plants occurring at low frequencies cannot be mapped with great accuracy. Scattered vegetation and habitat mosaics may also be problematic to map. Mapping provided by remote sensing will therefore not completely equate to the reality that a botanist would observe on the ground.

5.8.2 Small changes in habitat area between maps produced at different times may be due to inaccuracies in the mapping technique rather than actual habitat change on the ground. Ground truthing is undertaken to verify if this is the
5.8.3 The total area of Ashdown Forest SAC calculated in the 2014 and 2017 habitat maps differs from that stated in the Natura 2000 data form. The Natura form states 2715 ha, the 2014 map measures 2725 ha and the 2017 map measures 2728 ha. The habitat mapping in 2014 and 2017 used the base map provided by Natural England for the SAC. When the currently available base map was checked in 2017, it was confirmed to measure 2728 ha in area. The discrepancy in mapped area represents a 0.1% change between 2014 and 2017 and is not considered significant to the results of this study. The discrepancy is most likely to have arisen due to the publically available base map provided by Natural England.

Vegetation Survey

Transect Location and Quadrat Size

5.8.4 Choosing quadrat size and transect location is always problematic at the design stage of any vegetation survey, with many trade-offs between the accuracy required and the effort possible. Ideally, a large number of large, permanent, quadrats would be established across the area of interest using a randomised design and regular sampling would be undertaken over a period of many years. Clearly, such effort is rarely possible.

5.8.5 Our survey design closely follows the methodology of Mott MacDonald (2013), as agreed with the Council in the project brief. However, there are a number of limitations inherent in this design. Firstly, transect locations were chosen to represent a suite of desirable factors, including significant presence of dwarf shrub dominated heathland. This non-random placing of transects may bias interpretation of results towards a more favourable picture of the condition of the SAC as a whole because the poorer areas were not sampled in the first place. Secondly, although the use of 2 m² quadrats is relatively standard, using small sampling areas to characterise larger areas of habitat can result in rare species or other features being missed or infrequently recorded.

‘Grazing’

5.8.6 Assigning transects as either ‘grazed’ or ‘ungrazed’ is largely subjective. Furthermore, adding two additional quadrats to all transects in 2016 has resulted in the first two quadrats of ‘grazed’ transects being largely ‘ungrazed’. All transects are likely to be grazed to some extent by wildlife (e.g. deer and rabbits), a factor that is not accounted for in this study. Livestock grazed transects are likely to experience varying pressures dependent on animal type, stocking density and seasonal regime. The only way to truly have grazed and ungrazed quadrats is to use herbivore-proof fencing.

Surveyor Bias

5.8.7 Surveyor bias is a commonly acknowledged source of error in botanical recording (Rich & Woodruff, 1992). To minimise this error, surveyors recorded several quadrats together at the beginning of the survey to standardise species percentage cover estimation and the same surveyors have worked on the project, where possible, to reduce variation between years.

CSM

5.8.8 Collection of data to specifically test CSM attribute targets was not part of the
originally agreed vegetation survey methodology. However, the data that was collected in 2014 was suitable for measurement against 7 attributes. On perusal of this data it was decided to modify survey protocol so that a further two attributes could be tested in 2015 and 2016. Attributes that were not included in the new protocol were: niche diversity; vegetation composition of bryophytes and lichens; indicators of local distinctiveness; and signs of disturbance as negative indicators.

5.8.9 The JNCC states that the condition assessment process was not designed for identifying the effects of nitrogen deposition impacts and Critical Load is not measured as part of the Common Standards Monitoring (CSM) assessment i.e. it is not an attribute in the assessment process. Furthermore, the majority of CSM targets either do not describe ecosystem components sensitive to nitrogen deposition or are worded such that any impacts cannot be reliably attributed to nitrogen. Although nitrogen deposition and exceedance of the Critical Load has the potential to affect vegetation composition and thus has the potential to affect site condition, changes in vegetation composition may also be influenced by many other factors such as management or visitor pressure.

5.8.10 The JNCC published guidance on attributing nitrogen deposition as a threat to or cause of unfavourable habitat condition of protected sites in February 2016 (Jones et al., 2016). The JNCC notes that there is a basic requirement for greater knowledge about nitrogen impacts in habitats and that there are very few useable strong nitrogen indicators, with only a small number of habitats with one or more strong nitrogen indicators and many habitats have no useable nitrogen indicators at all. Each CSM target assessed is given a rating of how strongly linked this may be to nitrogen and also a rating of how much confidence there is in this correlation.

5.8.11 An initial application of this process to the Ashdown Forest SSSI attributes and targets indicates only two of the eleven attributes for the Forest have a strong association with nitrogen deposition and only one of these has a high level of confidence. The two attributes are:

- vegetation composition – graminoids (strong indicator for nitrogen, strong confidence) and
- vegetation composition – bryophytes and lichens (strong indicator for nitrogen, weak confidence).

5.8.12 ‘Vegetation composition: graminoids’ was assessed using the data collected as part of this study, however ‘vegetation composition: bryophytes and lichens’ was not assessed.

5.8.13 Case studies of individual sites have shown that changes as a consequence of N deposition are very unlikely to be detected using CSM (Caporn et al., 2016). Monitoring of changes in vegetation species composition, species richness and Ellenberg N scores over time was able to detect more subtle changes at individual sites, suggesting that damage is occurring even in sites judged to be in favourable condition.

**Foliar Nitrogen and Soil Nitrogen**

5.8.14 SAL were contracted to provide analysis of foliar and soil nitrogen levels.
However, it came to light in 2016 that NRM laboratories had been subcontracted by SAL to undertake these analyses in 2014 and 2016 and that there were differences in preparation of the samples between the two laboratories. Without further, independent, testing of samples it is not possible for us to determine which laboratory has provided results most reflective of the real situation. Nevertheless, 2014 and 2016 represent two years of consistent sampling and we use these results for the focus of our analysis. It should be noted that differences in the data between years caused by methodology should be relative and that underlying spatial patterns, if present, should not be affected.

**Statistical Analysis**

5.8.15 It should be recognised that data analysis in studies of community ecology deals largely with correlation. Efforts are made to determine how variation in one variable may be explained by variation in another variable. However, cause and effect are not implicit and explanation of any apparent relationships relies on subjective judgement. The only way to determine cause and effect with great certainty is through the design and implementation of controlled experiments.
6. Ecology Monitoring Results

6.1 Habitat Mapping Results

Conservators Map

6.1.1 The Conservators of Ashdown Forest produced a habitat map for the Forest in 2005. The total area mapped by the Conservators is 2472 ha, which is smaller than the total area of the Ashdown Forest SAC listed within the Natura 2000 data form. This discrepancy in total area arises as the Conservators are not responsible for the management of the entire SAC.

6.1.2 The 2005 map differentiates between wet heath, dry heath and ‘other’ types of heath, including grass-dominated, bracken-dominated and gorse-dominated, which is likely to be useful to inform management actions. Habitat details according to this map are provided in Table 6.1.

Table 6.1. Habitat area according to the 2005 Conservators map.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-natural Woodland</td>
<td>995</td>
</tr>
<tr>
<td>Wet lowland heath</td>
<td>288</td>
</tr>
<tr>
<td>Dry lowland heath</td>
<td>300</td>
</tr>
<tr>
<td>Other heathland</td>
<td>777</td>
</tr>
<tr>
<td>Other habitats</td>
<td>112</td>
</tr>
<tr>
<td>Total</td>
<td>2472</td>
</tr>
</tbody>
</table>

6.1.3 Whilst the 2005 map does not cover the full extent of the SAC, the proportionate coverage of woodland and heathland habitat types shown is similar to that listed in the Natura 2000 data form, with woodland equating to 40%, heathland to 55% and other habitats to 5%. The ‘other habitats’ category includes habitats such as hardstanding, bare ground, open water and amenity grassland.

Aerial Mapping

6.1.4 The full results of aerial imagery analysis undertaken by Environment Systems Ltd are given in Appendix 2. A breakdown of habitat types based on 2014 and 2017 aerial imagery analysis is given in Table 6.2. These maps define wet and dry heathland as being dominated by the appropriate species of dwarf shrubs, with areas of bracken, gorse and grassland-dominated heath mapped as separate categories.

Table 6.2. Habitat details from 2014 and 2017 aerial mapping.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>2014 Aerial Imaging Map (ha)</th>
<th>2017 Aerial imaging Map (ha)</th>
<th>Difference between 2014 and 2017 (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-natural Woodland</td>
<td>1180</td>
<td>1179</td>
<td>-1</td>
</tr>
<tr>
<td>Dry dwarf shrub heath</td>
<td>283</td>
<td>293</td>
<td>+10</td>
</tr>
<tr>
<td>Wet dwarf shrub heath</td>
<td>308</td>
<td>307</td>
<td>-1</td>
</tr>
<tr>
<td>Grassland</td>
<td>108</td>
<td>108</td>
<td>0</td>
</tr>
<tr>
<td>Bracken</td>
<td>236</td>
<td>238</td>
<td>+2</td>
</tr>
<tr>
<td>Scattered bracken</td>
<td>455</td>
<td>446</td>
<td>-9</td>
</tr>
<tr>
<td>Ephemeral / short perennial</td>
<td>52</td>
<td>52</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 6.1: Habitat Change 2014-2017

<table>
<thead>
<tr>
<th>Habitat</th>
<th>2014 Aerial Imaging Map (ha)</th>
<th>2017 Aerial Imaging Map (ha)</th>
<th>Difference between 2014 and 2017 (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Built-up Areas</td>
<td>82</td>
<td>85</td>
<td>+3</td>
</tr>
<tr>
<td>Bare ground</td>
<td>15</td>
<td>14</td>
<td>-1</td>
</tr>
<tr>
<td>Total</td>
<td>2725</td>
<td>2728</td>
<td></td>
</tr>
</tbody>
</table>

6.1.5 The total area of woodland recorded is almost identical between the 2014 and 2017 analysis, with 1 ha less being evident in 2017. The same pattern exists for wet heath, with 1 ha less in 2017. An increase in 10 ha of dry heath is shown in 2017, relative to 2014, equating to an increase of approximately 3.5%. Whilst this may indicate a small increase in heathland habitats within the SAC, the area affected is very small relative to the entire SAC. This may represent a small increase in the cover of heathland, which may be due to management practices, although further investigation would be needed to confirm this. However, the difference could also be an artefact of the habitat mapping and care should be taken when looking at small changes in large scale mapping and inferring habitat/community change.

6.1.6 As the Natura 2000 data form only separates the habitats within the Forest into woodland and wet and dry heathland it is apparent that potentially degraded heathlands (including grassland, dense gorse and continuous bracken) are included within habitat area totals. Nevertheless, it is not clear how these have been apportioned to each type of heathland. A comparison of the percentage cover of heathland and woodland between the Natura 2000 data form and the 2014 and 2017 maps can be made by combining the areas of heathland dominated by habitats other than dwarf shrub with the areas of wet and dry dwarf shrub heath on the 2014 and 2017 maps. This results in the following habitat coverage:

- **2014:** 43% woodland, 53% heathland, 4% other habitats
- **2017:** 43% woodland, 53% heathland, 4% other habitats

6.1.7 The data from 2014 and 2017 show that habitats such as hardstanding, bare ground and open water contribute ≤ 5% of the SAC. These habitats are not specifically detailed in the Natura 2000 data form. The cover of woodland and heathland in 2014 and 2017 indicates a similar (although not the same) 40/60 split between woodland and lowland heathland as suggested by the Natura 2000 data form.

#### Areas Of Change

6.1.8 An analysis of areas of change between 2014 and 2017 identified 14 areas where habitat had altered within 250 m of the roads (Table 6.3; see Appendix 1, Map 4). These areas of change are limited in extent and total 0.63 ha.

**Table 6.3: Areas of Habitat Change between 2014 and 2017.**

<table>
<thead>
<tr>
<th>Area of Change</th>
<th>Habitat on 2014 Map</th>
<th>Habitat on 2017 Map</th>
<th>Ground Truthing Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Semi-natural woodland</td>
<td>Dry dwarf shrub heath</td>
<td>Ordnance Survey grid reference: TQ494324. An area of dense bracken with cleared areas of short gorse (&gt;10 cm) and dry dwarf shrub heath and acid grassland. The area appeared to...</td>
</tr>
<tr>
<td>Area of Change</td>
<td>Habitat on 2014 Map</td>
<td>Habitat on 2017 Map</td>
<td>Ground Truthing Notes</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>have been subject to bracken management, however there was no evidence of tree felling. Based on ground truthing, 2017 map is considered accurate.</td>
</tr>
<tr>
<td>2</td>
<td>Bare ground</td>
<td>Built up</td>
<td>TQ461286. An area of rushes and short acidic grassland within the western end of Ellison's Pond car park. Neither bare ground nor built up are considered accurate and this area should be mapped as grassland.</td>
</tr>
<tr>
<td>3</td>
<td>Semi-natural woodland</td>
<td>Built up</td>
<td>TQ438298. This area is located at the edge of the woodland at the northern edge of Millbrook West car park. Habitats comprise dense scrub with semi-improved grassland and tall ruderal vegetation. This area would best be retained as semi-natural woodland as it comprises woodland edge.</td>
</tr>
<tr>
<td>4</td>
<td>Scattered bracken</td>
<td>Bracken</td>
<td>TQ436300. An area of acid grassland with areas of bracken. The area has signs of recent bracken removal with ploughing ridge and furrows. There are several areas of bare ground present throughout the area. This area would be best mapped as scattered bracken as the bracken is evidently being managed.</td>
</tr>
<tr>
<td>5</td>
<td>Semi-natural woodland</td>
<td>Bare ground</td>
<td>TQ425311. A large hole (&gt;10 m deep) with signs of recent excavation by heavy machinery. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>6</td>
<td>Open water</td>
<td>Built up</td>
<td>TQ419314. This area is located at the edge of the reservoir. Scattered trees and dense scrub are present on the southern side of the reservoir boundary fence. This area would be best retained as open water on the map.</td>
</tr>
<tr>
<td>7</td>
<td>Open water</td>
<td>Built up</td>
<td>TQ419315. This area is located at the edge of the reservoir. An area of tall ruderal vegetation/dense scrub along the western boundary fence of the reservoir. This area would be best retained as open water on the map.</td>
</tr>
<tr>
<td>8</td>
<td>Semi-natural woodland</td>
<td>Grassland</td>
<td>TQ421335. This area is located at the edge of the woodland and comprises bracken and an area of managed acidic grassland. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>9</td>
<td>Dry dwarf heath</td>
<td>Grassland</td>
<td>TQ423335. An area of acid grassland adjacent to a small tree line and an active golf course. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>Area of Change</td>
<td>Habitat on 2014 Map</td>
<td>Habitat on 2017 Map</td>
<td>Ground Truthing Notes</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>10</td>
<td>Dry dwarf heath</td>
<td>Grassland</td>
<td>TQ424335. An area of short acidic grassland on the golf course. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>11</td>
<td>Dry dwarf heath</td>
<td>Grassland</td>
<td>TQ424336. An area of short acidic grassland on active golf course. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>12 and 13</td>
<td>Scattered bracken</td>
<td>Grassland</td>
<td>TQ447325. A triangle of acidic grassland outside Gosple Oak, Sandy Lane. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
<tr>
<td>14</td>
<td>Scattered bracken</td>
<td>Bracken</td>
<td>TQ448326. A hedgerow and an area of Rhododendron and bracken scrub to the west and east of a residential garden gate. Based on ground truthing, the 2017 map is considered accurate.</td>
</tr>
</tbody>
</table>

6.1.9 Many of the areas of change appear to have resulted from management activities, such as mowing and bracken cutting. Of the 14 areas of change, two areas (2,3) had been incorrectly identified by both the 2014 and the 2017 mapping. Three of the areas (4, 6, 7) had been accurately identified by the 2014 map but mis-identified by the 2017 map and nine areas had been mis-identified by the 2014 map but had been accurately identified by the 2017 map. These include areas where the habitat has changed due to management or ground works (5,8,9,10,11) or where the habitats have been more accurately identified during the mapping process (1,12,13,14).

**Discussion**

6.1.10 It is clear that current and recent management activities impact the heathland habitats across the Forest. Intensive mowing, such as that observed on the golf course, can cause damage to grassland and open up patches of bare ground. Moderate grazing pressure may open up the sward and promote species diversity, whereas intense grazing pressure may promote dominance by a few, grazing resistant species. Management to reduce the cover of bracken can promote growth of dwarf shrubs and other desirable heathland species. How such drivers of community composition and change interact with other potential drivers such as elevated nitrogen deposition is likely to be complex, largely site-specific and difficult to ascertain.

6.1.11 It is much more difficult to determine how historical management has shaped the Forest habitats at anything but a coarse level. This is for two reasons: lack of detailed management records and lack of detailed aerial imagery. However, understanding the historical management of the site and how this management shaped site habitats is clearly important and should be addressed at a future stage in the monitoring program.

6.1.12 Mapping appears to be relatively consistent and accurate. Analysis of aerial imagery is a useful tool in the construction of habitat maps for large areas of land. The accuracy of the 2014 and 2017 mapping is high and the change between years very low. Nevertheless, there is no substitute for feet on the ground, especially when a fine level of detail is required and evidence of
recent management practice needs to be documented. To this end, it is suggested that more extensive ground truthing could be conducted during future monitoring, in consultation with Environmental Systems Ltd and as appropriate to the long-term monitoring requirements of the study.

6.2 Vegetation Survey

Results

Site Overview

6.2.1 Land within 250 m of key roads typically supports a mosaic of habitats, including dwarf shrub heath, interspersed with stands of bracken and European gorse, dry acid grassland and wetter purple moor-grass tussocks. The dwarf shrub heath is frequently found towards the middle or end of transects, with many transects beginning in either strips of gorse, stands of bracken or heavily grazed grassland. Indeed, the general picture is of better quality heathland towards the centre of Ashdown Forest. Even so, a number of the 400 m quadrats are not dominated by dwarf heath and some fall wholly in gorse, bracken or a tree belt (e.g. B, K, M).

6.2.2 Eight transects (A, B, C, D, H, I, J, L) include areas of H2 dry heath (see section 3.2 and Appendix 4 for descriptions of the desirable characteristic species composition of this habitat type). Purple moor grass is a common component of the heathland, along with other grasses including mat grass (Nardus stricta), bents (Agrostis spp.) and fescues (Festuca spp.). Bryophytes and lichens were not frequently recorded, being prevalent only in areas around transects B, E and H. Areas of dense European gorse and bracken were present along some transects (B, J, K) limiting the establishment of a quadrat in these areas.

6.2.3 Only four transects included M16 wet heath (D, E, G, O) because wet heath habitats are not typically located in close proximity to the roads (see section 3.2 and Appendix 4 for descriptions of the desirable characteristic species composition of this habitat type). These areas were typically dominated by purple moor grass, with cross-leaved heath and bell heather. Species of sphagnum were present in some hollows along with deer sedge (Trichophorum cespitosum) and common cotton-grass (Eriophorum angustifolium).

6.2.4 Grasses are prevalent in many quadrats and dominant in grazed quadrats in close proximity to car parks or public entrances to the Forest (C, D). However they are also prevalent along transects containing an abundance of dwarf shrubs (e.g. B, O), as grasses such as purple moor grass and wavy hair grass (Deschampsia flexuosa) grow up through the shrub layer. Therefore grasses are present in most quadrats across all transects and the presence of grasses in general (i.e. as a taxonomic group) does not necessarily correlate with a decrease in dwarf shrubs in this study.

6.2.5 Ashdown Forest SAC does not support many large expanses of dwarf shrub heath. Species such as bracken and gorse are prevalent across the Forest and areas of purple moor-grass appear rank and species-poor. In areas close to car parks, the grassland is cropped short by sheep and cattle and trampled by the public, giving rise to grassy ‘lawns’ interspersed by gorse bushes.

6.2.6 Some of the larger expanses of ling-dominated dry heath were found to the
north of Coleman’s Hatch Road, close to the Ashdown Forest Visitor Centre (in the area of Transects L and M). Another expanse was found to the west of the B2026 (in the area of Transect B). Dwarf shrubs dominated here and *Cladonia portentosa* was frequently occurring. The area of heathland around Transect H also comprised a large expanse dominated by dwarf shrubs, with numerous species of *Cladonia*.

6.2.7 A notably good example of wet heath is present close to Transect O, approximately 200 m from Crowborough Road. The land slopes downwards away from Crowborough Road, with abundant dwarf shrubs. A localised wet area was noted, where water pools and sphagnum growth is abundant. Sundew (*Drosera rotundifolia*) is present, along with bog asphodel (*Narthecium ossifragum*), cross-leaved heath and heath spotted orchids (*Dactylorhiza maculata*) on drier hummocks.

6.2.8 Maps 1 and 2 (Appendix 1) show the locations of the transects. Further description of each transect is provided in Appendix 3. A full species list for the transects is provided in Appendix 9 and the raw data is provided in Appendix 10.

**Transect Composition and Condition Assessment**

6.2.9 If the Ashdown Forest heathland was in good condition (in relation to the criteria outlined in section 3.2 and Appendix 4) we would expect to find that the majority of quadrats along all transects contained dwarf shrubs (i.e. heather and dwarf gorse), along with various forbs and a representation of non-vascular plants and lichens. Grasses such as purple moor-grass and heath grass would be frequent but have combined covers of less than about 25%. Bracken and European gorse would be infrequent and trees very occasional. Percentage cover of vegetation would probably be greater than 100%, indicating that a number of different vegetation layers are present, for example a ground-layer of bryophytes and lichens, with taller layers of heather and other flowering plants above. Such spatial complexity is an important ecosystem component. However, percentage cover values are rather meaningless without consideration of exactly which species are present: it may be the case that there are a number of canopy layers of ‘undesirable’ species (for example, a stand of bracken with continuous grass cover underneath).

**Transect A**

6.2.10 Transect A comprises a high proportion of grasses, forbs and bracken (Figure 6.1). Dwarf shrubs and bryophytes are only occasionally present and bare ground is prevalent in the quadrats at 250 and 400 m. The percentage of habitat covered exceeds 100% in many quadrats, indicating that several canopy layers are present.

6.2.11 Species-richness ranged from 1 to 13, with an average value of 5.3 across all quadrats and survey years (standard deviation 3.7, n = 29). On average, all quadrats along transect A achieved less than 4 of the yearly condition assessment targets they were assessed against (Figure 6.2). According to these criteria, we consider that the overall picture along transect A is one of very degraded heathland habitat.
Transect B

6.2.12 Grasses are prevalent along transect B, with 25 – 100 % cover in the majority of quadrats (Figure 6.3). However, dwarf shrubs also make up more than 30% cover in eight of the quadrats and bryophytes are consistently present. European gorse dominates Q8 and Q9. The percentage of habitat covered
exceeds 140% in many quadrats, indicating that several canopy layers are present.

6.2.13 Species-richness ranged from 1 to 24, with an average value of 5.4 across all quadrats and survey years (standard deviation 4.0, n = 29). On average, all quadrats along transect B achieved less than 5 of the yearly condition assessment targets they were assessed against (Figure 6.4). According to these criteria, we consider that the overall picture along transect B is one of very degraded heathland habitat.

Figure 6.3. Vegetation composition along transect B (data are values averaged over the three survey years).
6.2.14 All quadrats along transect C contain 50 to 100% cover of grasses (Figure 6.5). Forbs are frequent over the first seven quadrats, with European gorse prevalent in Q2, Q3 and Q4. Bryophytes are relatively frequent throughout. Dwarf shrubs are prevalent in Q7 and Q9. The percentage of habitat covered consistently exceeds 120%, indicating that several canopy layers are present.

6.2.15 Species-richness ranged from 3 to 26, with an average value of 10.7 across all quadrats and survey years (standard deviation 5.6, n = 29). On average, all quadrats along transect C achieved less than 4 of the yearly condition assessment targets they were assessed against (Figure 6.6). According to these criteria, we consider that the overall picture along transect C is one of degraded heathland habitat.
**Transect C - Quadrat Vegetation Composition**

![Graph showing vegetation composition along transect C](image)

Figure 6.5. Vegetation composition along transect C (data are values averaged over the three survey years).

**Transect C**

![Graph showing mean number of condition assessment targets met along transect C](image)

Figure 6.6. Mean number of condition assessment targets met by quadrats along transect C (data are values averaged over the three survey years).

**Transect D**

6.2.16 The majority of quadrats along transect D comprise over 40% cover of grasses; only Q3 and Q7 have a lower coverage (Figure 6.7). There is a decrease in the proportion of forb coverage with distance from the road, in favour of dwarf shrubs, European gorse and bracken. The percentage of
habitats covered consistently exceeds 100%, indicating that several canopy layers are present.

6.2.17 Species-richness ranged from 2 to 26, with an average value of 12.5 across all quadrats and survey years (standard deviation 6.3, n = 29). On average, all quadrats along transect D achieved less than 4 of the yearly condition assessment targets they were assessed against (Figure 6.8). According to these criteria, we consider that the overall picture along transect D is one of degraded heathland habitat.

Figure 6.7. Vegetation composition along transect D (data are values averaged over the three survey years).
Figure 6.8. Mean number of condition assessment targets met by quadrats along transect D (data are values averaged over the three survey years).

**Transect E**

6.2.18 Bracken is dominant in the first four quadrats of transect E (Figure 6.9). This dominance is given over to grasses along the rest of the transect. Dwarf shrubs are sparsely present in Q5 to Q9, as are bryophytes. The percentage of habitat covered exceeds 100% for the majority of quadrats, indicating that several canopy layers are present.

6.2.19 Species-richness ranged from 3 to 20, with an average value of 7.8 across all quadrats and survey years (standard deviation 4.3, n = 29). On average, all quadrats along transect E achieved less than 4 of the yearly condition assessment targets they were assessed against (Figure 6.10). According to these criteria, we consider that the overall picture along transect E is one of very degraded heathland habitat.
Figure 6.9. Vegetation composition along transect E (data are values averaged over the three survey years).

Figure 6.10. Mean number of condition assessment targets met by quadrats along transect E (data are values averaged over the three survey years).

*Transect F*

6.2.20 Quadrats along transect F display a wide range of vegetation compositions (Figure 6.11). Grasses are consistently present and dominant in QA, Q2, Q7
and Q9. Bracken is dominant in Q1 and Q6; and Q4 is largely bare ground.
Dwarf shrubs and bryophytes are only sparsely present. The percentage of
habitat covered does not much exceed 100% across all quadrats, indicating
that layering of canopies is limited.

6.2.21 Species-richness ranged from 2 to 16, with an average value of 8.3 across all
quadrats and survey years (standard deviation 3.5, n = 29). On average, all
quadrats along transect F achieved 4 or less of the yearly condition
assessment targets they were assessed against (Figure 6.12). According to
these criteria, we consider that the overall picture along transect F is one of
very degraded heathland habitat.

Figure 6.11. Vegetation composition along transect F (data are values averaged
over the three survey years).
**Transect F**

Figure 6.12. Mean number of condition assessment targets met by quadrats along transect F (data are values averaged over the three survey years).

**Transect G**

6.2.22 Grasses are prevalent, and often dominant, in all quadrats of transect G (Figure 6.13). Bracken is dominant in QB and Q1 and European gorse in Q2. Dwarf shrubs and bryophytes are generally sparsely present but are prevalent in Q8. The percentage of habitat covered exceeds 100% for all quadrats, indicating that several canopy layers are present (this is particularly the case for Q2 and Q8).

6.2.23 Species-richness ranged from 2 to 16, with an average value of 6.7 across all quadrats and survey years (standard deviation 3.0, n = 29). On average, all quadrats along transect G achieved 4 or less of the yearly condition assessment targets they were assessed against (Figure 6.14). According to these criteria, we consider that the overall picture along transect G is one of very degraded heathland habitat.
Figure 6.13. Vegetation composition along transect G (data are values averaged over the three survey years).

Figure 6.14. Mean number of condition assessment targets met by quadrats along transect G (data are values averaged over the three survey years).

**Transect H**

6.2.24 Grasses are dominant in only 3 quadrats (Q1, Q3, Q6) of transect H (Figure 6.15). Q2 is covered almost entirely by European gorse, but dwarf shrubs and bryophytes dominate in quadrats further from the road (Q5, Q7, Q8 and Q9). The percentage of habitat covered exceeds 100% for all quadrats, indicating that several canopy layers are present.
6.2.25 Species-richness ranged from 4 to 25, with an average value of 7.7 across all quadrats and survey years (standard deviation 4.5, n = 29). On average, all quadrats along transect H achieved less than 5 of the yearly condition assessment targets they were assessed against (Figure 6.16). According to these criteria, we consider that the overall picture along transect H is one of very degraded heathland habitat.

![Transect H - Quadrat Vegetation Composition](image)

**Figure 6.15.** Vegetation composition along transect H (data are values averaged over the three survey years).

![Transect H](image)

**Figure 6.16.** Mean number of condition assessment targets met by quadrats along transect H (data are values averaged over the three survey years).
Transect I

6.2.26 Grasses are prevalent in all quadrats of transect I and were dominant from Q4 to Q9 (Figure 6.17). Bracken was relatively abundant in Q1 and Q2. Dwarf shrubs were generally sparsely present in quadrats further from the road and were prevalent in Q3, Q6 and Q7. Bryophytes were relatively frequent but prevalent only in Q3. Canopy layering, as indicated by total percentage vegetation cover in each quadrat, was most developed further from the road.

6.2.27 Species-richness ranged from 3 to 18, with an average value of 6.8 across all quadrats and survey years (standard deviation 3.3, n = 29). On average, all quadrats along transect I achieved 4 or less of the yearly condition assessment targets they were assessed against (Figure 6.18). According to these criteria, we consider that the overall picture along transect I is one of very degraded heathland habitat.

![Transect I - Quadrat Vegetation Composition](image)

Figure 6.17. Vegetation composition along transect I (data are values averaged over the three survey years).
Transect J

6.2.28 Dominance of quadrats along transect J is shared by bracken, forbs, European gorse and, particularly, grasses (Figure 6.19). Dwarf shrubs are generally infrequent, although in Q5 they are dominant. Bryophytes are also generally infrequent, except in Q4 where they contribute 38% of the cover. The percentage of habitat covered exceeds 100% for the majority of quadrats, indicating that several canopy layers are present. This was particularly the case for those quadrats closest to the road.

6.2.29 Species-richness ranged from 1 - 17, with an average value of 8.2 across all quadrats and survey years (standard deviation 4.6, n = 29). On average, all quadrats along transect J achieved less than 5 of the yearly condition assessment targets they were assessed against (Figure 6.20). According to these criteria, we consider that the overall picture along transect J is one of very degraded heathland habitat.
Transect J - Quadrat Vegetation Composition

![Graph showing vegetation composition along transect J.](chart)

**Figure 6.19.** Vegetation composition along transect J (data are values averaged over the three survey years).

Transect J

![Graph showing mean number of condition assessment targets met by quadrats along transect J.](chart)

**Figure 6.20.** Mean number of condition assessment targets met by quadrats along transect J (data are values averaged over the three survey years).

**Transect K**

6.2.30 Grasses were prevalent across most quadrats of transect K and were dominant in QB, Q1 and Q5 (Figure 6.21). Bracken was dominant in Q3 and the quadrats towards the end of the transect. Dwarf shrubs were dominant in Q4 but otherwise infrequent. Bryophytes provided 10% cover in Q4 but were otherwise rare. The percentage of habitat covered exceeds 100% for all quadrats, indicating that several canopy layers are present.

6.2.31 Species-richness ranged from 0 to 20, with an average value of 5.9 across all
quadrats and survey years (standard deviation 4.8, n = 29). On average, all quadrats along transect K achieved 4 or less of the yearly condition assessment targets they were assessed against (Figure 6.22). According to these criteria, we consider that the overall picture along transect K is one of very degraded heathland habitat.

Figure 9.21. Vegetation composition along transect K (data are values averaged over the three survey years).

Figure 6.22. Mean number of condition assessment targets met by quadrats along transect K (data are values averaged over the three survey years).
Transect L

6.2.32 Grasses were dominant in QA, Q3, Q7 and Q9 of transect L (Figure 6.23). Dwarf shrubs and bryophytes were dominant in Q4, Q5, Q6 and Q8 and prevalent in Q7 and Q9. The presence of a tree belt is indicated by the high proportion of leaf litter in QB, Q1 and Q2. Layering of the canopy was mainly seen as bryophytes growing under dwarf shrubs and grasses in quadrats further from the road.

6.2.33 Species-richness ranged from 4 to 16, with an average value of 6.6 across all quadrats and survey years (standard deviation 2.4, n = 29). On average, all quadrats along transect L achieved less than 5 of the yearly condition assessment targets they were assessed against (Figure 6.24). According to these criteria, we consider that the overall picture along transect L is one of very degraded heathland habitat.

Figure 6.23. Vegetation composition along transect L (data are values averaged over the three survey years).
Transect M

6.2.34 Grasses were prevalent across the quadrats of transect M (Figure 6.25) and were dominant in Q3, Q4, Q5, Q6, Q7 and Q9. Bracken was dominant in QA, QB and Q8. However, dwarf shrubs and bryophytes were occasionally prevalent (Q3, Q5, Q9). The percentage of habitat covered exceeds 100% for the majority of quadrats, indicating that several canopy layers are present. This was not the case for Q1 and Q2 where the occurrence of significant leaf litter indicated the presence of a tree belt.

6.2.35 Species-richness ranged from 1 to 12, with an average value of 5.5 across all quadrats and survey years (standard deviation 3.0, n = 29). On average, all quadrats along transect M achieved less than 4 of the yearly condition assessment targets they were assessed against (Figure 6.26). According to these criteria, we consider that the overall picture along transect M is one of very degraded heathland habitat.
Figure 6.25. Vegetation composition along transect M (data are values averaged over the three survey years).

Figure 6.26. Mean number of condition assessment targets met by quadrats along transect M (data are values averaged over the three survey years).

Transect N

6.2.36 Grasses were dominant in the majority of quadrats along transect N (Figure 6.27). Nevertheless, dwarf shrubs and bryophytes were prevalent from Q2 (where they were dominant) to the end of the transect. Bracken significantly occurred in Q7 and Q8. The cover in all quadrats exceeded 100%, indicating that a number of vegetation layers were present.
Species-richness ranged from 3 to 15, with an average value of 8.1 across all quadrats and survey years (standard deviation 4.0, n = 29). On average, all quadrats along transect N achieved less than 5 of the yearly condition assessment targets they were assessed against (Figure 6.28). According to these criteria, we consider that the overall picture along transect N is one of very degraded heathland habitat.

![Figure 6.27](image1.png)

**Figure 6.27.** Vegetation composition along transect N (data are values averaged over the three survey years).

![Figure 6.28](image2.png)

**Figure 6.28.** Mean number of condition assessment targets met by quadrats along transect N (data are values averaged over the three survey years).
Transect O

6.2.38 Although grasses were prevalent across transect O (Figure 6.29), they were nowhere dominant. Bracken was sparsely present throughout and European gorse occasional. Dwarf shrubs and bryophytes were present to varying extents from 10 m to the end of the transect and were dominant in Q1 and Q6. Bare ground was significant in Q3, Q4 and Q5 but, otherwise, cover exceeded 100% indicating that a number of vegetation layers were present.

6.2.39 Species-richness ranged from 4 to 25, with an average value of 9.4 across all quadrats and survey years (standard deviation 5.2, n = 29). On average, all quadrats along transect O achieved 5 or less of the yearly condition assessment targets they were assessed against (Figure 6.30). According to these criteria, we consider that the overall picture along transect O is one of very degraded heathland habitat.

<table>
<thead>
<tr>
<th>Transect O - Quadrat Vegetation Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from road (m)</td>
</tr>
<tr>
<td>Percentage cover of quadrat</td>
</tr>
<tr>
<td>Leaf litter</td>
</tr>
<tr>
<td>Other forbs</td>
</tr>
<tr>
<td>Bryophytes</td>
</tr>
<tr>
<td>Sedge rush</td>
</tr>
<tr>
<td>Dwarf shrubs</td>
</tr>
<tr>
<td>Bare ground</td>
</tr>
<tr>
<td>European gorse</td>
</tr>
<tr>
<td>Bracken</td>
</tr>
<tr>
<td>Grasses</td>
</tr>
</tbody>
</table>

Figure 6.29. Vegetation composition along transect O (data are values averaged over the three survey years).
**Discussion**

6.2.40 As species richness was lower than that expected for healthy heathland (c.13 species) and as few condition assessment targets were met, all quadrats along all transects represent degraded heath habitat. It is highly likely that, if fully assessed against all CSM attributes, all quadrats/SSSI units sampled would be judged to be in unfavourable condition.

6.2.41 The number of targets achieved by each quadrat averaged over the three survey years was used to explore possible patterns in the data. Vegetation community composition and structure rarely changes rapidly and how a particular quadrat scores against a particular target in one year is probably how it is going to score in the following year. This means that it is not fruitful to compare data between years at this early stage of the project.

6.2.42 There is an indication that fewer targets were met by quadrats within 25 m of a road as exemplified by transects A, B, E, H, J (and tentatively by C, G, N) and it is tempting to relate this to elevated nitrogen deposition closer to a road. However, it is important to note that this pattern is not conclusive. Firstly, other transects did not display discernible patterns with distance from a road (D, F, I, K, L, M, O); secondly, there is only a single years data for quadrats QA and QB; thirdly, the JNCC states that the condition assessment process was not designed for identifying the effects of nitrogen deposition impacts; and fourthly, other negative pressures are likely to be higher near to a road and separating out the contribution of these effects to habitat degradation (as measured by CSM) may be difficult.

6.2.43 Are particular condition assessment targets being consistently failed? This is an interesting question that has potential for focussed future investigation, particularly with regard to the possible implementation of management practise to attempt to reverse heathland decline. Our data show that some targets are very rarely or never achieved, such as those relating to the vegetation composition of dwarf shrubs, graminoids and desirable forbs.
Other targets are frequently achieved, but these relate to negative indicators including the presence of exotic and herbaceous species and trees and scrub (Table 6.4). This means that most quadrats do not contain non-native invasive plant species or too much cover of other ‘undesirable’ herbaceous plants, scrub or trees.

Table 6.4. Numbers of quadrats meeting attribute targets each year (out of a possible total of 135 in 2014 and 165 in 2015 and 2016).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
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<tbody>
<tr>
<td>Bare ground</td>
<td>28</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Ericaceous cover</td>
<td>N/A</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Bryophytes</td>
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<td>49</td>
</tr>
<tr>
<td>Dwarf shrubs</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Graminoids</td>
<td>2</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Desirable forbs</td>
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<td>0</td>
</tr>
<tr>
<td>Exotic species</td>
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<td>93</td>
<td>102</td>
</tr>
<tr>
<td>Herbaceous species</td>
<td>118</td>
<td>115</td>
<td>130</td>
</tr>
<tr>
<td>Trees and scrub</td>
<td>134</td>
<td>131</td>
<td>158</td>
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</tbody>
</table>

### 6.3 Grass:forb Ratio

**Results**

6.3.1 Grass:forb ratio varied widely both between quadrats along individual transects, as well as between the different transects themselves. The overall mean was 3.5 (standard deviation 8.1, n = 363), indicating that grass cover in the vegetation was relatively high compared with that of other herbaceous flowering plants.

6.3.2 There was no significant correlation between grass:forb ratio and distance from a road. Table 6.5 shows summary statistics for correlations performed for each transect and each year. Figures 6.31 – 6.33, which we consider to best represent the current situation at the site, show mean grass:forb ratio with distance from a road across all transects for each year.
Table 6.5. Summary statistics from correlation of grass:forb ratio with distance from a road for all transects and all years.

<table>
<thead>
<tr>
<th>Transect</th>
<th>2014</th>
<th></th>
<th></th>
<th></th>
<th>2015</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>2016</th>
<th></th>
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<td>p</td>
<td>slope</td>
<td>R²</td>
<td>p</td>
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<td>-</td>
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<td>-</td>
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<td>0.495</td>
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<td>-</td>
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<td>0.424</td>
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</tr>
</tbody>
</table>

Figure 6.31. Grass:forb ratio versus distance from all roads (m), mean across all transects, 2014.

\[
y = -0.0059x + 3.6575 \\
R^2 = 0.3048 \\
p = 0.123 \text{ ns}
\]
Figure 6.32. Grass:forb ratio versus distance from all roads (m), mean across all transects, 2015.

Figure 6.33. Grass:forb ratio versus distance from all roads (m), mean across all transects, 2016.

Discussion

6.3.3 Grass:forb ratio can provide an indication of heathland quality. Nitrogen deposition has been shown to influence vegetation community composition in British heathlands, with increases in nitrogen deposition contributing to changes to the grass:forb ratio and an overall reduction in species richness (Bobbink et al., 2010; Defra, 2008). Grass species more able to assimilate nitrogen under conditions of higher nutrient availability have been shown to increase in cover as a result of elevated nitrogen deposition, at the expense of other shrub and forb species, including heather (Maskell et al., 2010; Edmondson, 2007). Increased nitrogen deposition may lead to an increase in primary productivity whereby grass species can outcompete shrubs and forbs. An NVC H2 dry heathland would be expected to have a grass:forb ratio
of 1 and NVC M16 wet heathland would be expected to have a value of 2.5 (Emmett et al., 2012). According to these criteria, if the Ashdown Forest heathland was in an excellent state of health we would have expected to record values mainly around 1 and occasionally up to 2.5. (This is because wet heath was recorded in 4 transects only). This was not the case. The values observed in this study were generally high. This suggests degradation of habitat across all transects through an increased dominance of grasses and, by implication, across the SAC as a whole.

6.3.4 There was little indication that grass:forb ratio decreased with distance from a road and no significant correlation to this effect. Indeed, Figures 6.31 – 6.33 nominally suggest that values were highest between 25 and 75 m distance from a road, an observation that may warrant some future investigation.

6.4 Species-richness

Results

6.4.1 Species-richness ranged from 1 to 25 species per quadrat, with an overall average of 7.7 (standard deviation 4.6, n = 435).

6.4.2 There was little significant correlation between species-richness and distance from a road when data for each transect and year were examined (Table 6.6 shows summary statistics). In the 9 instances where significant correlation was demonstrated, the relationship was negative. We therefore consider figures 6.34 – 6.36, which show mean species-richness with distance from a road across all transects for each year, to best illustrate overall patterns displayed by species richness to date. When the data are examined at this resolution, species richness clearly declines with distance from a road.

Table 6.6. Summary statistics from correlation of species-richness with distance from a road for all transects and all years.

<table>
<thead>
<tr>
<th>Transect</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>slope</td>
<td>R²</td>
<td>p</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>0.01</td>
<td>0.767</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>0.56</td>
<td>0.020*</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>0.60</td>
<td>0.014*</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>0.49</td>
<td>0.035*</td>
</tr>
<tr>
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<td>0.893</td>
</tr>
<tr>
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<td>0.055</td>
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<tr>
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<td>K</td>
<td>-</td>
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<tr>
<td>O</td>
<td>-</td>
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<td>0.996</td>
</tr>
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</table>
Figure 6.34. Relationship between species-richness and distance from all roads (m), mean across all transects, 2014.

Figure 6.35. Relationship between species-richness and distance from all roads (m), mean across all transects, 2015.
6.4.3 To investigate patterns in species richness further, the data used to produce figures 6.34 – 6.36 were split into two groups to produce species richness values for ‘nitrophobe’ species (those species with a nitrogen index value of 1-4) and for ‘nitrophile’ species (those species with a nitrogen index value of 5-9). This split was entirely arbitrary but serves to illustrate patterns in the distribution of typical heathland species (nitrophobes) compared with other species (nitrophiles) that have colonised the habitat because, at least in part, of their higher tolerance of elevated nitrogen deposition.

6.4.4 There was no significant relationship between number of nitrophobe species and distance from a road in any year (Figures 6.37 – 6.39). However, nitrophile species were more prevalent closer to a road (Figures 6.40 – 6.42), particularly in quadrats QA at 1 m distance and quadrats QB at 5 m distance (Figure 6.42). Logarithmic or exponential functions best fitted the data in figures 6.40 – 6.42 because of the curvi-linear decrease in nitrophile species with increasing distance from a road.
Figure 6.37. Relationship between nitrophobe species-richness and distance from all roads (m), mean across all transects, 2014.

\[ y = -0.0019x + 6.2791 \]
\[ R^2 = 0.0952 \]
\[ p = 0.419 \text{ ns} \]

Figure 6.38. Relationship between nitrophobe species-richness and distance from all roads (m), mean across all transects, 2015.

\[ y = -0.0034x + 7.032 \]
\[ R^2 = 0.4022 \]
\[ p = 0.067 \text{ ns} \]
Figure 6.39. Relationship between nitrophobe species-richness and distance from all roads (m), mean across all transects, 2016.

Figure 6.40. Relationship between nitrophile species-richness and distance from all roads (m), mean across all transects, 2014.
Discussion

6.4.5 Species richness provides an indication of habitat quality by assessing the number of species recorded against the number of species that would be expected for that habitat type. Increases in nitrogen deposition have been shown to correlate with a decrease in species-richness in certain habitats (Rowe et al., 2014) and reductions in species richness may occur below the empirical critical load (Ricardo-AEA, 2016).

6.4.6 Species richness was, overall, low and consistently below the value of 13 expected for heathland habitats. This indicates general degradation of habitat across all transects.
6.4.7 We might anticipate species-richness to decline with increasing nitrogen deposition as fewer, more nitrogen tolerant, species come to dominate the community. We would therefore expect to see lower species richness next to a road, with this improving with distance. However, we found that overall species richness declined with distance from the road.

6.4.8 Why should a negative relationship between species-richness and distance from a road be apparent? Evidence strongly suggests that this pattern is largely due to additional nitrophile species being present in the vegetation communities closer to a road. Nevertheless, we must recognise that other factors may also be operating to promote these patterns.

6.4.9 Moderate levels of disturbance (for example from grazing, mowing and trampling) can promote species-richness by opening gaps for colonisation by competitive species and preventing dominance by species that would otherwise be competitively superior in a heathland environment. It is possible that this effect is operating at Ashdown Forest: species-richness is higher closer to a road because these areas experience higher levels of moderate disturbance of all types, not just nitrogen deposition which allows a higher number of competitor species to colonise.

6.4.10 It is also possible that species-richness appears higher closer to a road because species found in these locations are more visible and / or easier to identify due to the composition of quadrats in these areas and percentage of cover. Mosses and lichens, perhaps more likely to occur at distance from a road, are small, difficult to identify and are relatively easy to overlook especially when there is a high percentage of vegetation cover. However, they are considered to be key diagnostic components of heathland communities. Continued monitoring, perhaps with occasional intensive searching for rarer or more difficult species, should help to clarify this picture.

6.5 Plant Nitrogen Index

Results

6.5.1 Plant nitrogen index values ranged from 1.6 to 6.1, with an overall average of 2.7 (standard deviation 0.9, n = 432).

6.5.2 Figures 6.43 – 6.45, which show mean plant nitrogen index values with distance from a road across all transects for each year, best illustrate the general patterns displayed by overall plant community nitrogen index. It is apparent that there is a strong negative curvi-linear relationship, across the transects, between plant nitrogen index and distance from a road.
Figure 6.43. Relationship between plant nitrogen index and distance from all roads (m), mean across all transects, 2014.

\[ y = -0.276\ln(x) + 3.8395 \]
\[ R^2 = 0.9283 \]
\[ p < 0.001 *** \]

Figure 6.44. Relationship between plant nitrogen index and distance from all roads (m), mean across all transects, 2015.

\[ y = -0.267\ln(x) + 3.8143 \]
\[ R^2 = 0.952 \]
\[ p < 0.001 *** \]
6.5.3 To further investigate how plant nitrogen index values might vary according to distance from a road the data sets were split to represent dwarf shrubs, bryophytes and lichens, graminoids and forbs.

6.5.4 Nitrogen index values for dwarf shrubs are shown across all transects, for each year, in Figures 6.46 to 6.48. These figures demonstrate a statistically significant positive curvi-linear relationship between dwarf shrub nitrogen index value and distance from a road. This means that dwarf shrubs contributed a greater proportion to the overall plant community nitrogen index value further away from a road.

Figure 6.45. Relationship between plant nitrogen index and distance from all roads (m), mean across all transects, 2016.

\[ y = -0.313\ln(x) + 4.0835 \]
\[ R^2 = 0.9578 \]
\[ p < 0.001 *** \]

Figure 6.46. Relationship between plant nitrogen index and distance from all roads (m) for dwarf shrubs, mean across all transects, 2014.

\[ y = 0.1131x^{0.2535} \]
\[ R^2 = 0.6917 \]
\[ p < 0.01 ** \]
6.5.5 Nitrogen index values for bryophytes and lichens are shown across all transects, for each year, in Figures 6.49 to 6.51. There were no statistically significant relationships between these values and distance from a road. This means that bryophytes and lichens contributed a consistent (and low) proportion to the overall plant community nitrogen index value regardless of distance from a road.
Figure 6.49. Relationship between plant nitrogen index and distance from all roads (m) for bryophytes and lichens, mean across all transects, 2014.

y = 0.2273e^{-0.003x}
R² = 0.447
p = ns

Figure 6.50. Relationship between plant nitrogen index and distance from all roads (m) for bryophytes and lichens, mean across all transects, 2015.

y = 0.2472e^{-0.003x}
R² = 0.4229
p = ns
6.5.6 Nitrogen index values for graminoids are shown across all transects, for each year, in Figures 6.52 to 6.54. On balance, the evidence would suggest a negative curvi-linear relationship between graminoid nitrogen index value and distance from a road. This means that graminoids contributed a lower proportion to the overall plant community nitrogen index value further away from a road.
Nitrogen index values for forbs are shown across all transects, for each year, in Figures 6.55 to 6.57. It would appear that there is probably a negative curvi-linear relationship between forb nitrogen index value and distance from a road. Why this pattern was not apparent in 2015 is not known but in 2014 and 2016 the relationship was strongly statistically significant. This means that graminoids contributed a lower proportion to the overall plant community nitrogen index value further away from a road, at least in 2014 and 2016.
Figure 6.55. Relationship between plant nitrogen index and distance from all roads (m) for forbs, mean across all transects, 2014.

\[ y = -0.115\ln(x) + 0.6634 \]
\[ R^2 = 0.7613 \]
\[ p < 0.001 *** \]

Figure 6.56. Relationship between plant nitrogen index and distance from all roads (m) for forbs, mean across all transects, 2015.

\[ y = 0.4674e^{-0.002x} \]
\[ R^2 = 0.2747 \]
\[ p = \text{ns} \]
Discussion

6.5.8 Use of nitrogen indices are a tried and tested way of demonstrating vegetation community responses to changes in environmental nitrogen gradients (e.g. JNCC, 2004; Leith et al., 2005; Carly et al., 2011).

6.5.9 We have shown that average plant nitrogen index values for the vegetation communities along the transects decline with distance from a road. This reflects an increase in the percentage cover of nitrophilous plants towards a road and / or a decline in those species requiring nutrient poorer conditions. The implication here is that elevated nitrogen deposition from motor vehicle emissions is the principal driver of this change. Nevertheless, it is possible that increased nutrient loading from animal waste (dogs and livestock) could also be playing a part in determining these patterns.
6.6 Foliar Nitrogen

Results

Heath plait-moss

6.6.1 Foliar nitrogen concentrations (mg kg\(^{-1}\)) in heath plait-moss did not show any consistent significant correlation with distance to a road. As measured levels were obviously lower in 2015 relative to either 2014 or 2016 (likely due to differences in sample preparation before analysis, as discussed in section 5.8), it is considered that Figure 6.58 represents the clearest picture to date of how these concentrations vary. Data from 2014 and 2016 showed a range of 1.3 to 2.5 % but were relatively uniform (mean 1.6 %, standard deviation 0.2 %, n = 37). Figures 6.59 – 6.67 show data for each transect in each year.

6.6.2 Appendix 5 contains all foliar nitrogen raw data (SAL laboratory analysis report).

![Heath plait-moss, all 2014 and 2016 data](image)

Figure 6.58. Relationship between heath plait-moss mean foliar nitrogen concentration and distance from all roads (m) for transects B, L and O in 2014 and 2016.
Figure 6.59. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect B, 2014.

Figure 6.60. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect B, 2015.

Figure 6.61. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect B, 2016.
Figure 6.62. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect L, 2014.

Figure 6.63. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect L, 2015.

Figure 6.64. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect L, 2016.
Figure 6.65. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect O, 2014.

Figure 6.66. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect O, 2015.

Figure 6.67. Relationship between heath plait-moss foliar nitrogen concentration and distance from all roads (m) for transect O, 2016.
Heather

6.6.3 Foliar nitrogen concentrations (mg kg⁻¹) in heather did not show any consistent significant correlation with distance to a road. Measured levels in 2015 were obviously lower than those in either 2014 or 2016 (likely due to differences in sample preparation before analysis, as discussed in section 7.8). Figure 6.68 is therefore considered to represent the clearest picture to date of how these concentrations vary. Data from 2014 and 2016 showed a range of 1.1 to 2.0 % but were relatively uniform (mean 1.4 %, standard deviation 0.2 %, n = 38). Figures 6.69 – 6.77 show data for each transect in each year.

6.6.4 Appendix 5 contains all foliar nitrogen raw data.

![Figure 6.68. Relationship between heather mean foliar nitrogen concentration and distance from all roads (m) for transects B, L and O in 2014 and 2016.](image)

\[ y = -4.3546x + 14637 \]
\[ R^2 = 0.3775 \]
\[ p = 0.078 \text{ ns} \]
Figure 6.69. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect B, 2014.

Figure 6.70. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect B, 2015.

Figure 6.71. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect B, 2016.
Figure 6.72. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect L, 2014.

Figure 6.73. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect L, 2015.

Figure 6.74. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect L, 2016.
Figure 6.75. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect O, 2014.

Figure 6.76. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect O, 2015.

Figure 6.77. Relationship between heather foliar nitrogen concentration and distance from all roads (m) for transect O, 2016.
Discussion

6.6.5 Foliar nitrogen concentrations in bryophytes and heather may be used to indicate nitrogen deposition (Pitcairn et al., 2003), especially where deposition rates are below 25 kg N/ha/yr (Rowe et al., 2014). The nitrogen deposition values modelled along the survey transects range between 12.1 and 37.5 kg N/ha/yr. As only 11 of the 165 vegetation sampling quadrats and two of the quadrats sampled for bryophyte tissue have modelled deposition values exceeding 25 N/ha/yr, foliar analysis was considered likely to be of value.

6.6.6 It was anticipated that vegetation subject to greater levels of nitrogen deposition close to a road would have a greater foliar nitrogen content than vegetation located further away from the road. Our data from heath plait-moss and heather do not back this supposition. It is possible that our samples represented tissue already saturated with nitrogen. Plant tissue cannot continue assimilating nitrogen indefinitely and the response curve showing the relationship between increasing rates of nitrogen deposition and tissue nitrogen content is curvi-linear (Rowe et al., 2014).

6.7 Foliar Amino Acids

Results

Heath plait-moss

6.7.1 Foliar amino acid concentrations ranged from 0.5 to 3.2 g/100 g (mean 1.5, standard deviation 0.5, n = 51). There was no significant correlation between these concentrations and distance from a road. It is therefore considered that Figure 6.78, which shows overall mean foliar concentrations across all transects and all years, provides the best representation of this aspect of the study to date. Figures 6.79 – 6.87, which show data for each transect and each year, are included for the sake of completeness.

6.7.2 Appendix 6 contains all foliar amino acid raw data (Alta Biosciences laboratory analysis report).

![Heath plait-moss, all data](image)

Figure 6.78. Relationship between heath plait-moss mean foliar amino acid concentration (g/100g) and distance from all roads (m) across all transects and all years (all data).
Figure 6.79. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2014.

Figure 6.80. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2015.

Figure 6.81. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2016.
Figure 6.82. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2014.

Figure 6.83. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2015.

Figure 6.84. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2016.
Figure 6.85. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2014.

Figure 6.86. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2015.

Figure 6.87. Relationship between heath plait-moss foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2016.
Heather

6.7.3 Foliar amino acid concentrations ranged from 1.0 to 2.6 g/100 g (mean 2.0, standard deviation 0.3, n = 57). With one exception, there were no significant correlations between these concentrations and distance from a road. The exception was transect L in 2014 where a significant positive correlation was evident. However, this pattern was not repeated and it is therefore considered that Figure 6.88, which shows overall mean foliar concentrations across all transects and all years provides the best representation of this aspect of the study to date. Figures 6.89 – 6.97, which show data for each transect and each year, are included for the sake of completeness.

6.7.4 Appendix 6 contains all foliar amino acid raw data (Alta Biosciences laboratory analysis report).

Figure 6.88. Relationship between heather mean foliar amino acid concentration (g/100g) and distance from all roads (m) across all transects and all years.
Figure 6.89. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2014.

Figure 6.90. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2015.

Figure 6.91. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect B, 2016.
Figure 6.92. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2014.

Figure 6.93. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2015.

Figure 6.94. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect L, 2016.
Figure 6.95. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2014.

Figure 6.96. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2015.

Figure 6.97. Relationship between heather foliar amino acid concentration (g/100g) and distance from all roads (m) for transect O, 2016.
**Discussion**

6.7.5 Amino acids may be found in significantly greater quantities in plants subjected to increased nitrogen deposition as the available nitrogen exceeds the capacity of the plant to assimilate the nitrogen to growth. Consequently surplus nitrogen is accumulated as amino acids (Pitcairn *et al.*, 2003; Nordin *et al.*, 2011). It is therefore expected that vegetation subject to greater levels of nitrogen deposition i.e. vegetation located closer to a road, will have greater amino acid content relative to vegetation located further from a road. However, this anticipated relationship has not been observed here.

6.7.6 When compared to national values, the nitrogen content of vegetation is high. The majority of foliar nitrogen concentrations for heath plait-moss were between 1.5 - 2 % of total dry matter. Concentrations for heather were between 1.2 – 1.8 %. Where nitrogen deposition is low (<10 kg N ha\(^{-1}\)year\(^{-1}\)) total tissue nitrogen is typically around 0.7 – 1 % (Pitcairn *et al.*, 2006). Pitcairn *et al.* (2006) conclude that ‘tissue N concentration in mosses provides a good indication of N deposition at sites where deposition is dominated by NH\(_3\), and is also valuable in identifying vegetation exposed to large concentrations of NH\(_4\)\(^+\) or NO\(_3\)\(^-\), in wet deposition dominated areas, such as hilltops and wind exposed woodland edges’. Whilst their study shows that the extent of increase in foliar tissue concentrations is dependent on regional context, the foliar nitrogen concentrations at Ashdown Forest provide a clear indication that the vegetation is affected by nitrogen deposition, with concentrations characteristic of a nitrogen rich site. However, we are reluctant to conclude whether our transects are dominated by NH\(_3\) or NH\(_4\)\(^+\) / NO\(_3\)\(^-\) deposition at this stage of the study and, therefore, whether heath plait-moss is a particularly useful indicator of elevated nitrogen deposition in this context. Ideally, future study would include improved methodology, greater sampling effort and sampling of a wider range of species in an effort to better elucidate the distribution of foliar nitrogen concentrations along the transects.

6.8 Soil Nitrogen

**Results**

6.8.1 There was wide variation in measured soil total nitrogen levels between quadrats along individual transects, between transects and between years (range 100 to 21100 mg/Kg; mean 4770 mg/Kg; standard deviation 4094 mg/Kg, n = 406). This variation was somewhat reduced when data from 2015 were not considered (range 200 to 13500 mg/Kg; mean 3506 mg/Kg, standard deviation 2563 mg/Kg, n = 156), for reasons outlined in section 5.8 and below.

6.8.2 It might reasonably be anticipated that levels of soil total nitrogen would decrease with distance from a road. However, no such correlation was evident in this study.

6.8.3 Starting with an examination of mean nitrogen concentrations across all transects within years (Figures 6.98 to 6.100), it may be noted that correlations are non-significant and that year 2 values are higher than those of year 1 or year 3. Indeed, this second observation is statistically significant (t-tests comparing paired means between 2014 and 2015 and between 2015 and 2016 were significant at p > 0.05 in all cases except one: the control quadrats in 2014 and 2015). As there is no reason to suppose that soil total nitrogen really was higher during the second year it seems likely that this
anomaly was due to the differing methods of analysis outlined in section 5.8. As a result, Figure 6.101, which shows mean nitrogen concentration averaged over 2014 and 2016 across all transects, is considered to present the most informative picture of the soil total nitrogen situation for the study so far.

Figure 6.98. Relationship between mean soil total nitrogen and distance from all roads (m) across all transects, 2014.

Figure 6.99. Relationship between mean soil total nitrogen and distance from all roads (m) across all transects, 2015.
Figure 6.100. Relationship between mean soil total nitrogen and distance from all roads (m) across all transects, 2016.

Figure 6.101. Relationship between mean soil total nitrogen and distance from all roads (m) across all transects, averaged over 2014 and 2016.

6.8.4 A full compliment of soil samples were collected and analysed for transects C, E, F, G, I, L, N and O. For these transects relationships between soil nitrogen and distance from a road were further investigated. Results are summarised in Table 6.7. This table is included simply to illustrate the lack of correlation at any spatio-temporal scale for all the transects.

6.8.5 Appendix 7 contains all soil total nitrogen raw data (SAL laboratory analysis reports).
Table 6.7. Coefficient of correlation ($R^2$) and significance level ($p$) from simple linear regression of soil total nitrogen content on distance from a road for raw data from transects within years and averaged across 2014 and 2016 (ns = not statistically significant, * = significant at the $p < 0.05$ level).

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<td>2014</td>
<td>0.03</td>
<td>0.638, ns</td>
</tr>
<tr>
<td>O</td>
<td>2015</td>
<td>0.06</td>
<td>0.514, ns</td>
</tr>
<tr>
<td>O</td>
<td>2016</td>
<td>0.34</td>
<td>0.060, ns</td>
</tr>
<tr>
<td>O</td>
<td>2014 &amp; 2016</td>
<td>&lt;0.01</td>
<td>0.979, ns</td>
</tr>
</tbody>
</table>

Discussion

6.8.6 Soil total nitrogen levels were variable but generally high. There was no correlation between soil total nitrogen level and distance from a road even though we may have anticipated a negative relationship. This is rather a puzzle. It may be that gradients in soil nitrogen caused by elevated deposition from motor vehicles are subtle at Ashdown Forest and easily masked by input from other sources. This would especially be the case if nitrogen inputs were high across the entire SAC, regardless of source. For example, input from animal excreta may be locally significant. It may also be the case that cycling of nitrogen varies widely across the SAC and therefore input and rate of flow need to be taken into consideration. Finally, sampling methodology may need to be adjusted. Variation in depth of soil sampled, and how much root material each sample contained, may cause considerable unwanted variation over the length of a transect.

6.8.7 Should soil total nitrogen levels continue to be assessed as part of the ongoing program of monitoring and study? This is a point that needs to be
discussed but, based on the usefulness of data collected so far, there would seem little value in continuing along the same vein. If anything, it would perhaps be fruitful to more intensively sample soil along sections of transect closer to the roads.

6.9 C:N Ratio

Results

6.9.1 Analysis of C:N ratio was undertaken in 2016 only. Heathland soils may be expected to have C:N ratios of between 20 and 24 (Certini et al., 2015) and a study by Neilson et al. (2011) suggests that the C:N threshold in topsoil to achieve favourable condition for dry heathland is > 30.

6.9.2 C:N ratios in this study varied between 7 and 51 (mean 22.2, standard deviation 7.6, n = 157).

6.9.3 When data was averaged across all transects a significant positive curvilinear relationship was apparent between C:N ratio and distance from a road (Figure 6.102). This was not reflected in a reciprocal negative relationship between C:N ratio and modelled total nitrogen deposition at the distance of the quadrats from a road (Figure 6.103), but was reflected by patterns in NO₂ deposition (Figure 6.104), NH₃ deposition (Figure 6.105) and atmospheric concentrations of NH₃ (Figure 6.106) and NOₓ (Figures 107 and 108).

6.9.4 When each transect was examined separately, data from five transects (C, D, E, H, M) showed significant positive correlation with distance from a road (Table 6.8). Of the remaining transects, there was a general tendency towards positive correlation, with a further 6 positively inclined slopes (Table 6.8).

6.9.5 Appendix 7 contains all soil C:N raw data (2016 SAL laboratory analysis reports).
Figure 6.102. Relationship between soil carbon:nitrogen ratio (C:N) and distance from all roads (m). Data averaged across all transects.

Figure 6.103. Relationship between soil carbon:nitrogen ratio (C:N) and modelled total nitrogen deposition (kg N/ha/yr) at the distance of the quadrats from a road. Data averaged across all transects.

Figure 6.104. Relationship between soil carbon:nitrogen ratio (C:N) and modelled NO$_3$ deposition (kg N/ha/yr) at the distance of the quadrats from a road. Data averaged across all transects.
Figure 6.105. Relationship between soil carbon:nitrogen ratio (C:N) and modelled NO$_3$ deposition (kg N/ha/yr) at the distance of the quadrats from a road. Data averaged across all transects.

Figure 6.106. Relationship between soil carbon:nitrogen ratio (C:N) and modelled annual mean NH$_3$ (µg/m$^3$) at the distance of the quadrats from a road. Data averaged across all transects.

Figure 6.107. Relationship between soil carbon:nitrogen ratio (C:N) and modelled annual mean NO$_x$ (µg/m$^3$) at the distance of the quadrats from a road. Data averaged across all transects.
Figure 6.108. Relationship between soil carbon:nitrogen ratio (C:N) and modelled annual 24 h mean NOx (µg/m²) at the distance of the quadrats from a road. Data averaged across all transects.

Table 6.8. Coefficient of correlation ($R^2$) and significance level ($p$) from simple linear regression of soil carbon:nitrogen ratio on distance from a road for individual transects, 2016 (ns, not statistically significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

<table>
<thead>
<tr>
<th>Transect</th>
<th>slope</th>
<th>$R^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+</td>
<td>0.088</td>
<td>0.404  ns</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>0.037</td>
<td>0.621 ns</td>
</tr>
<tr>
<td>C</td>
<td>+</td>
<td>0.789</td>
<td>0.003  ***</td>
</tr>
<tr>
<td>D</td>
<td>+</td>
<td>0.444</td>
<td>0.025  *</td>
</tr>
<tr>
<td>E</td>
<td>+</td>
<td>0.582</td>
<td>0.006  **</td>
</tr>
<tr>
<td>F</td>
<td>-</td>
<td>0.202</td>
<td>0.166  ns</td>
</tr>
<tr>
<td>G</td>
<td>+</td>
<td>0.059</td>
<td>0.471  ns</td>
</tr>
<tr>
<td>H</td>
<td>+</td>
<td>0.752</td>
<td>0.0005 ***</td>
</tr>
<tr>
<td>I</td>
<td>+</td>
<td>0.288</td>
<td>0.089  ns</td>
</tr>
<tr>
<td>J</td>
<td>-</td>
<td>0.001</td>
<td>0.941  ns</td>
</tr>
<tr>
<td>K</td>
<td>+</td>
<td>0.121</td>
<td>0.445  ns</td>
</tr>
<tr>
<td>L</td>
<td>+</td>
<td>0.047</td>
<td>0.522  ns</td>
</tr>
<tr>
<td>M</td>
<td>+</td>
<td>0.600</td>
<td>0.009  ***</td>
</tr>
<tr>
<td>N</td>
<td>-</td>
<td>0.204</td>
<td>0.163  ns</td>
</tr>
<tr>
<td>O</td>
<td>+</td>
<td>0.028</td>
<td>0.623  ns</td>
</tr>
</tbody>
</table>
Discussion

6.9.6 Soil C:N values appear to be in the expected range for heathland soils based on Certini et al. (2015). However, they are generally lower than the value of >30 suggested by Nielson et al. (2011).

6.9.7 If levels of nitrogen deposition are negatively correlated with distance from a road and by implication so are levels of soil nitrogen, then we might expect to see a positive correlation between C:N ratio and distance from a road (and a negative correlation with modelled total nitrogen deposition). There is reasonably strong suggestion that this was the case in 2016. The fact that our measurements of soil total nitrogen currently confound this picture is difficult to explain. It could be that the accuracy of laboratory analysis of C:N ratio is less sensitive to the methodology used for sample collection because relative values are involved and because unintended contamination by vegetative matter (e.g., fine root material) will affect both the level of carbon and the level of nitrogen. It would seem that continuing a program of soil analysis to determine C:N ratio may provide useful and illuminating results. Clearly, to establish a robust estimate of baseline conditions, sampling along these lines should continue for at least another 2 years.

6.10 Modelled Nitrogen Deposition

Results

6.10.1 Modelled total nitrogen deposition values obtained from AQC show that it is likely that the lower limit of the critical load (i.e. 10 kg N/ha/yr) is consistently exceeded at all distances from a road across all transects (Figures 6.109 and 6.110). Two graphs are shown in Figures 6.109 and 6.110, representing results from two slightly different modelling procedures: results using the current Environment Agency (EA) model; and results using a custom model developed by AQC. In both, a polynomial function best described patterns in the data. Values of total nitrogen deposition are highest within 25 m of a road, drop to a consistent lower level between 50 and 200 m and then rise again slightly at 400 m (probably due to the presence of trees).

![Annual Mean Total Nitrogen Deposition (EA)](image)

Figure 6.109. Relationship between modelled total nitrogen deposition (kg N/ha/yr) and distance from all roads (m) across all transects. EA model. Error bars are too small to be visible for a number of points.
6.10.2 In terms of concentrations of pollutants in the air, modelled annual mean NO\textsubscript{2} and NH\textsubscript{3} values across all transects were consistently below their critical levels of 30 µg/m\textsuperscript{3} and 1 µg/m\textsuperscript{3}, respectively. There is a clear curvi-linear relationship between levels of both pollutants and distance from a road (Figure 6.111 & 6.112), with levels dropping quickly within the first 50 m and then remaining consistent to 400 m.

\begin{align*}
\text{Annual Mean Total Nitrogen Deposition (AQC)}
\end{align*}

\begin{align*}
y &= 9E^{-0.05}x^2 - 0.0403x + 17.595 \\
R^2 &= 0.7405 \\
p &< 0.01 \text{ **}
\end{align*}

\begin{align*}
\text{Annual Mean NO}_2 (\text{AQC})
\end{align*}

\begin{align*}
y &= 25.627x^{0.148} \\
R^2 &= 0.9582 \\
p &< 0.001 \text{ ***}
\end{align*}
Discussion

6.10.3 Ashdown Forest clearly experiences significantly elevated rates of nitrogen deposition and it would seem that emissions from motor vehicles using the surrounding road network are a probable significant source of this pollution. Although the upper boundaries for critical loads and levels are not generally exceeded according to Figures 6.109 and 6.110, species richness, species composition and other vegetation community indices have been shown to be negatively affected by elevated deposition at levels well below these upper boundaries (Emmett et al., 2012). We would expect, therefore, that the vegetation communities along our transects are subject to significant pressure from elevated nitrogen deposition as a driver of ecological change.

6.11 Ordination

Results

DCA

6.11.1 Detrended correspondence analysis (DCA) was performed on subsets of the species cover data for each quadrat (averaged across all transects and years). In this analysis we attempt to address the following questions:

- Are quadrat samples aligned in an explicable way with the gradient represented by axis 1? In other words, can we explain how quadrats are ordered in terms of their distance from a road?
- Are quadrat samples in any way similar to each other?
- Are species aligned with the gradient represented by axis 1? Can we
Explain their positions in terms of distance from a road?

**Graminoids**

6.11.2 The proportion of species variance explained by axis 1 in this model was high, at 51.8% (Table 6.9).

<table>
<thead>
<tr>
<th></th>
<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
<th>Axis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eigenvalue</strong></td>
<td>0.395</td>
<td>0.044</td>
<td>0.016</td>
<td>0.014</td>
</tr>
<tr>
<td><strong>Length of gradient</strong></td>
<td>1.811</td>
<td>0.810</td>
<td>0.826</td>
<td>0.813</td>
</tr>
<tr>
<td><strong>Cumulative percentage variance explained</strong></td>
<td>51.8</td>
<td>57.5</td>
<td>59.8</td>
<td>61.4</td>
</tr>
</tbody>
</table>

(sum of all eigenvalues = 0.763)

Samples were reasonably well aligned with axis 1, although not quite in order of distance from a road (Figure 6.113). Sample 1 was clearly dissimilar to all other samples. Similarity between the remaining samples increased along the axis, with 8 and 9 (quadrats Q6 and Q7) and 10 and 11 (quadrats Q8 and Q9) being particularly similar. This suggests that, according to graminoid species composition, quadrats do broadly fall along some gradient based on distance from a road, and that quadrats closer to a road are more dissimilar than those further away (i.e. a greater range of different species are found in quadrats closer to a road).
6.11.3 Figure 6.114 shows the species data plotted for the ordination (Table 6.10 lists the species). It appears that species towards the right of the plot are generally those with a lower Ellenberg N value (for example fine-leaved sheep’s-fescue, bulbous rush, mat grass and deer grass). Species towards the left of the plot are generally those with a higher Ellenberg N value (for example false oat-grass, red fescue, Yorkshire fog, perennial rye-grass and Timothy). Species with intermediate Ellenberg N values are generally found towards the centre of the plot. A notable exception to the above pattern is cotton sedge (species 14) which has an N value of 1 but is found towards the centre of the plot.
Figure 6.114. Distribution of species: DCA, graminoids.

Table 6.10. Species included in graminoid DCA.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ellenberg N value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common bent</td>
<td><em>Agrostis capillaris</em></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Creeping bent</td>
<td><em>Agrostis stolonifera</em></td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Brown bent</td>
<td><em>Agrostis vinealis</em></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Sweet vernal grass</td>
<td><em>Anthoxanthum odoratum</em></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>False oat-grass</td>
<td><em>Arrhenatherum elatius</em></td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Green-ribbed sedge</td>
<td><em>Carex binevis</em></td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Common yellow sedge</td>
<td><em>Carex demissa</em></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Carnation sedge</td>
<td><em>Carex panicea</em></td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Crested dog's tail</td>
<td><em>Cynosurus cristatus</em></td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Cock's foot</td>
<td><em>Dactylis glomerata</em></td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Heath grass</td>
<td><em>Danthonia decumbens</em></td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Tufted hair grass</td>
<td><em>Deschampsia cespitosa</em></td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Common Name</td>
<td>Scientific Name</td>
<td>Number</td>
<td>Ellenberg N value</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------</td>
<td>--------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Wavy hair-grass</td>
<td>Deschampsia flexuosa</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Cotton grass</td>
<td>Eriophorum angustifolium</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Fine-leaved sheep’s fescue</td>
<td>Festuca tenuifolia</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Red fescue</td>
<td>Festuca rubra</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Sheep’s fescue</td>
<td>Festuca ovina</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Yorkshire fog</td>
<td>Holcus lanatus</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Creeping soft-grass</td>
<td>Holcus mollis</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>Sharp-flowered rush</td>
<td>Juncus acutiflorus</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Bulbous rush</td>
<td>Juncus bulbosus</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Toad rush</td>
<td>Juncus bufonius</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Compact rush</td>
<td>Juncus conglomeratus</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>Soft rush</td>
<td>Juncus effusus</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Heath rush</td>
<td>Juncus squarosus</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Slender rush</td>
<td>Juncus tenuis</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>Perennial rye-grass</td>
<td>Lolium perenne</td>
<td>27</td>
<td>6</td>
</tr>
<tr>
<td>Purple moor grass</td>
<td>Mollinia caerulea</td>
<td>28</td>
<td>2</td>
</tr>
<tr>
<td>Mat grass</td>
<td>Nardus stricta</td>
<td>29</td>
<td>2</td>
</tr>
<tr>
<td>Timothy</td>
<td>Phleum pratense</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Annual meadow-grass</td>
<td>Poa annua</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td>Rough meadow-grass</td>
<td>Poa trivialis</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>Deer grass</td>
<td>Trichophorum cespitosum</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>Squirrel-tail fescue</td>
<td>Vulpia bromides</td>
<td>35</td>
<td>3</td>
</tr>
</tbody>
</table>

**Dwarf Shrubs**

6.11.4 The proportion of species variance explained by axis 1 in this model was very high, at 66.9% (Table 6.11). However, samples were not well aligned with axis 1 according to distance from a road (Figure 6.115). Samples 3 (quadrat Q1) and 9 (quadrat Q7) in particular are confounding. This means that we may only tentatively link the gradient represented by axis 1 with a gradient based on distance from a road. Sample 1 (quadrat 1) was dissimilar to all other samples.

**Table 6.11. Summary statistics for dwarf shrubs DCA model.**

<table>
<thead>
<tr>
<th></th>
<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
<th>Axis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>0.117</td>
<td>0.020</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Length of gradient</td>
<td>1.278</td>
<td>0.550</td>
<td>0.455</td>
<td>0.377</td>
</tr>
<tr>
<td>Cumulative percentage variance explained</td>
<td>66.9</td>
<td>78.1</td>
<td>79.7</td>
<td>80.2</td>
</tr>
</tbody>
</table>

(sum of all eigenvalues = 0.175)
Figure 6.115. Distribution of samples: DCA, dwarf shrubs.

Figure 6.116 shows the species data plotted for the ordination (Table 6.12 lists the species). There is no apparent association between the 5 species and they are not strongly associated with any particular sample. These species all have low Ellenberg N values and would be expected to occur in similar areas of the plot if axis 1 could be related to a gradient in nitrogen deposition in this model.
Figure 6.116. Distribution of species (unnumbered samples also shown: DCA, dwarf shrubs.

Table 6.12. Species included in dwarf shrubs DCA.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ellenberg N Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heather</td>
<td>Calluna vulgaris</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Bell heather</td>
<td>Erica cinerea</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cross-leaved heath</td>
<td>Erica tetralix</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Dwarf gorse</td>
<td>Ulex minor</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Bilberry</td>
<td>Vaccinium myrtillus</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Forbs and Woody Species

6.11.5 The proportion of species variance explained by axis 1 in this model was relatively high, at 41.8% (Table 6.13). However, samples were poorly aligned with axis 1 (Figure 6.117). It would seem therefore, that the gradient represented by axis 1 cannot be well linked with a gradient based on distance from a road.
Table 6.13. Summary statistics for forbs and woody species DCA model.

<table>
<thead>
<tr>
<th></th>
<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
<th>Axis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>0.155</td>
<td>0.027</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Length of gradient</td>
<td>1.228</td>
<td>0.663</td>
<td>0.375</td>
<td>0.383</td>
</tr>
<tr>
<td>Cumulative percentage</td>
<td>41.8</td>
<td>49.2</td>
<td>50.0</td>
<td>50.2</td>
</tr>
<tr>
<td>variance explained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sum of all eigenvalues = 0.370)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9.117. Distribution of samples: DCA, forbs and woody species.

Figure 6.118 shows the species data plotted for the ordination (Table 6.14 lists the species). Bracken (species 12) appears to be closely associated with samples 1 and 3 (quadrats QA and Q1) but there are no other close species-sample associations. The distribution of the species cannot be strongly related to Ellenberg N values. Whilst the nitrophilous silverweed, dandelion and creeping buttercup are found towards the left of the plot, so are bird’s-foot trefoil and tormentil, both with N values of 2. Scot’s pine and lesser spearwort with N values of 2 and 3 respectively are found towards the right of the plot.
but so are downy birch, oak and hawthorn with respective N values of 4, 4 and 6.

Figure 9.118. Distribution of species (unnumbered samples also shown): DCA, forbs and woody species.

Table 9.14. Species included in forbs and woody species DCA.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ellenberg N Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downy birch</td>
<td><em>Betula pubescens</em></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Silver birch</td>
<td><em>Betula pendula</em></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Common mouse-ear</td>
<td><em>Cerastium fontanum</em></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Heath bedstraw</td>
<td><em>Galium saxatile</em></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Common cat's-ear</td>
<td><em>Hypochaeris radicata</em></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Autumn hawkbit</td>
<td><em>Leontodon autumnalis</em></td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Bird's-foot trefoil</td>
<td><em>Lotus corniculatus</em></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Scot's pine</td>
<td><em>Pinus sylvestris</em></td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Silverweed</td>
<td><em>Potentilla anserina</em></td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Tormentii</td>
<td><em>Potentilla erecta</em></td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Common Name</td>
<td>Scientific Name</td>
<td>Number</td>
<td>Ellenberg N Value</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------</td>
<td>--------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Potentilla reptans</td>
<td>Creeping cinquefoil</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Bracken</td>
<td>Pteridium aquilinum</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Oak</td>
<td>Quercus robur</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Creeping buttercup</td>
<td>Ranunculus repens</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>Lesser spearwort</td>
<td>Ranunculus flaminula</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Sheep's sorrel</td>
<td>Rumex acetosella</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Dandelion</td>
<td>Taraxacum officionale agg</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>European gorse</td>
<td>Ulex europaeus</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Hawthorn</td>
<td>Crataegus monogyna</td>
<td>19</td>
<td>6</td>
</tr>
</tbody>
</table>

*Bryophytes and Lichens*

6.11.6 The proportion of species variance explained by axis 1 in this model was relatively high, at 44.5% (Table 6.15). However, samples were not very well aligned with axis 1 (Figure 6.119). Samples 1 and 2 were clearly much different to the rest of the samples, which were jumbled and all rather closely associated with one another, although samples 9, 10 and 11 were located furthest to the right of the plot as might be anticipated. It would seem that axis 1 may be somewhat representative of a gradient based on distance from a road but this representation is far from perfect.

**Table 6.15. Summary statistics for bryophytes and lichens DCA model.**

<table>
<thead>
<tr>
<th></th>
<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
<th>Axis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>0.314</td>
<td>0.068</td>
<td>0.022</td>
<td>0.003</td>
</tr>
<tr>
<td>Length of gradient</td>
<td>2.377</td>
<td>0.925</td>
<td>0.491</td>
<td>0.677</td>
</tr>
<tr>
<td>Cumulative variance explained</td>
<td>44.5%</td>
<td>54.2%</td>
<td>57.2%</td>
<td>57.7%</td>
</tr>
</tbody>
</table>

(sum of all eigenvalues = 0.706)
6.11.7 Figure 6.120 shows the species data plotted for the ordination (Table 6.16 lists the species). The distribution of species cannot be well related to N values. *Brachythecium rutabulum*, *Rhytidiadelphus squarrosus*, *Kindbergia praelonga* and *Pseudoscleropodium purum*, all with high N values, are found at the left side of the plot with the first two species being associated with sample 1 (quadrat QA). *Cladonia cervicornus*, *Cladonia polydactyla* and *Cladonia portentosa*, all with very low N values, are found towards the right side of the plot. However, many of the other species do not fit this anticipated pattern of higher N values towards the left and lower N values towards the right. *Hypnum jutlandicum* for example, with an N value of 2, is located close to the axis but around the mid-point of the gradient.
Figure 6.120. Distribution of species (unnumbered samples also shown): DCA, bryophytes and lichens.

Table 6.16. Species included in bryophytes and lichens DCA.

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Number</th>
<th>N Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aulacomnium palustre</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Brachythecium rutabulum</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Calygonella cuspidata</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Brachythecium albicans</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Calypogea arguta</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Calypogea fissa</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Calypogea muelleriana</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Campylopus flexuosus</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Campylopus introflexus</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Campylopus pyriformis</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Cephalozia bicuspidata</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Cephalozia connivens</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Cephalozia lenifolia</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>
6.11.8 Canonical correspondence analysis (CCA) was performed for graminoids. This data set was chosen because DCA indicated that distribution of graminoids, in particular, was potentially explicable in terms of a decreasing gradient of nitrogen deposition with distance from a road. In this analysis we attempt to address the following questions:

- Which of our measured environmental variables are most important in affecting graminoid distribution?
- Can further patterns in individual species distributions be ascertained with respect to our measured environmental variables?

6.11.9 Initially, data for each survey year were analysed separately (results are shown in Appendix 8). However, this approach was not particularly enlightening because of a lack of consistent pattern between years. It was therefore considered that using data averaged over all survey years provides the most interpretable picture for the study so far.

6.11.10 Summary statistics for the analysis are shown in Table 6.17. Axis 1 of the model explained a slightly low, but acceptable, proportion of the variance in the species data (8.3%) and a Monte Carlo test demonstrated significant
linear relationships between the samples / species data and the environmental data. The triplot is shown in Figure 6.121. It is a crowded figure, and sample and species labels are not shown for clarity. The most important vector for this ordination appears to be 7 (AvNH₃), followed closely by 1 and 2 (DR and GRZ and then 6, 8 and 9 (TN, AvNOₓ, 24NOₓ). Vectors 8 and 9 are very closely correlated. Vectors 3, 4 and 5 (VP, W, AADT) are of lesser importance. Environmental variables represented by these vectors are shown in Table 5.3.

6.11.11 The majority of samples are clustered towards the lower left of the plot (Figure 6.121) and seem, at least partially, to be aligned with vector 4 (W) and vector 2 (GRZ). However, there is no obvious alignment with the ordination axes or with other vectors and individual samples are distributed widely throughout the plot. It would seem, then, that the graminoid species composition of many of the quadrats was relatively similar although the data set as a whole showed considerable heterogeneity.

Table 6.17. CCA summary statistics: graminoids, average across all years.

<table>
<thead>
<tr>
<th></th>
<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
<th>Axis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>0.366</td>
<td>0.212</td>
<td>0.076</td>
<td>0.047</td>
</tr>
<tr>
<td>Species-environment correlation</td>
<td>0.672</td>
<td>0.583</td>
<td>0.494</td>
<td>0.422</td>
</tr>
<tr>
<td>Cumulative percentage variance explained (species data)</td>
<td>8.3</td>
<td>13.2</td>
<td>14.9</td>
<td>16.0</td>
</tr>
<tr>
<td>Cumulative percentage variance explained (species-environment relation)</td>
<td>48.4</td>
<td>76.5</td>
<td>86.6</td>
<td>92.8</td>
</tr>
</tbody>
</table>

(sum of all eigenvalues = 4.390; sum of all canonical eigenvalues = 0.755; Monte Carlo test of significance of all canonical axes: trace = 0.755, F = 3.369, p = 0.0020)
Figure 6.121. CCA triplot: graminoids, average over all years (circles = samples, triangles = species, vectors = environmental variables (1 = DR, distance of quadrat to nearest road; 2 = GRZ, whether the quadrat is grazed or not; 3 = VP, low, medium or high pressure; 4 = W, presence of a tree belt at the beginning of the transect; 5 = AADT, annual average daily traffic flow as determined in 2016; 6 = TN, modelled total nitrogen for each quadrat; 7 = AvNH$_3$, modelled annual mean NH$_3$; 8 = AvNO$_x$, modelled annual mean NO$_x$; 9 = 24NO$_x$, modelled 24h mean NO$_x$; see Table 5.3)).

6.11.12 The distribution of certain species appeared to be particularly influenced by certain environmental variables (Figure 6.122, species labels in Table 6.10). For example, squirrel-tail fescue (34) was closely associated with moderate grazing; red fescue (16) was closely associated with relatively high AvNH$_3$; heath grass (11) and annual meadow grass (31) were closely associated with moderate to high AADT, respectively; and sheep's fescue (17) and mat grass (29) with higher levels of visitor pressure. Nevertheless, there was general lack of pattern and further elucidation of species distributions based on Ellenberg N values and position in relation to vectors representing nitrogen deposition is elusive. This is illustrated by those species clustered around the increasing ends of vectors 7, 8 and 9, which are
Yorkshire fog (18, N value = 5), sweet vernal grass (4, N value = 3), green-ribbed sedge (6, N = 2), red fescue (16, N = 5) and Timothy (30, N = 6). Some have higher N values, some have lower N values. Similarly, cotton sedge (14, N = 1), compact rush (23, N = 3), perennial rye grass (27, N = 6) and soft rush (24, N = 4) are located towards the mid- to lower ends of vectors 7, 8 and 9. Species did not tend to be principally affected by vector 6, representing total nitrogen.

Figure 6.122. CCA plot showing species and environmental variables: graminoids, average over all years (1 = DR, distance of quadrat to nearest road; 2 = GRZ, whether the quadrat is grazed or not; 3 = VP, low, medium or high pressure; 4 = W, presence of a tree belt at the beginning of the transect; 5 = AADT, annual average daily traffic flow as determined in 2016; 6 = TN, modelled total nitrogen for each quadrat; 7 = AvNH\textsubscript{3}, modelled annual mean NH\textsubscript{3}; 8 = AvNO\textsubscript{x}, modelled annual mean NO\textsubscript{x}; 9 = 24NO\textsubscript{x}, modelled 24h mean NO\textsubscript{x}; see Table 5.3). Table 6.10 gives species labels.

Discussion

6.11.13 Ordination suggested that patterns in the distribution of graminoids
may be explicable in terms of their Ellenberg N values and distance from a road. As modelled nitrogen deposition values decrease with distance from a road and Ellenberg N values of graminoids also tend to decrease, we may reasonably conclude that there is a causal relationship between the two variables. However, it seems that decrease in nitrogen deposition with distance from a road is likely to be non-linear and therefore a simple relationship between nitrogen deposition and graminoid distribution may not exist at Ashdown Forest. Moreover, it is clear that a number of other environmental variables, as might be expected, are influential in determining graminoid distribution. These include grazing and visitor pressure. More effort will be needed in future study if the precise effects of these different influences are to be separated and fully determined.

6.11.14 As patterns in the distribution of dwarf shrubs, forbs and woody species, and bryophytes and lichens were elusive, the focus on graminoids as indicator species for the presence of potential nitrogen deposition gradients would seem the most promising line to pursue. In particular, focus on identifying the rarer and often more difficult species (e.g. sedges and rushes) may shed further light on the picture, because many of these species have low Ellenberg N values and are presumably most sensitive to change.
7. Conclusions And Recommendations

7.1 Conclusions

7.1.1 Heathland is a semi-natural environment that, to a large extent, exists only because of the activities of human beings. Traditional management practises such as burning, grazing and cutting, periodically removed nutrients from the habitat allowing plant species characteristic of nutrient-poor soils to thrive. However, in many areas traditional management is no longer practised and heathland is experiencing strong negative pressures from various new ecological drivers.

7.1.2 One of the principal drivers implicated in causing negative change to heathland is increased nitrogen deposition from atmospheric pollution. Nitrogen acts largely as a nutrient, stimulating the production of plant biomass, although some nitrogenous compounds can be toxic and cause direct damage to tissues and even death of the whole plant. The critical load at which nitrogen deposition becomes a problem for heathland has been determined as 10-20 kg N/ha/yr. Nevertheless, some evidence suggests that much lower loading can have significant negative impacts (Emmett et al., 2012; Caporn et al., 2016).

7.1.3 A change in heathland plant community composition and structure is expected as a result of elevated nitrogen deposition. Nitrophilious species may become increasingly prevalent and nitrogen-sensitive species may decrease in prevalence or even disappear altogether. This means that grass cover is likely to increase and cover of dwarf shrubs, other forbs, bryophytes and lichens to decrease. At higher rates of deposition overall species richness is likely to decline.

7.1.4 We can therefore identify, in theory, a number of observable outcomes of elevated nitrogen deposition on heathland. However, there are a number of reasons why some expected effects may not be observed on the ground. Firstly, plant communities typically respond slowly to change and documenting these changes can take many years: for most studies, time is a commodity in very short supply. Secondly, the effects of elevated nitrogen deposition are cumulative, may be subtle, and probably impact on the most sensitive species first. These sensitive species are also likely to be inherently rarer within the community and often more difficult to study. Thirdly, disentangling the effects of subtle drivers of ecological change from the effects of other, stronger, or more pervasive, drivers is a challenge and usually requires dedicated experimental manipulation.

7.1.5 In our study we have determined that all quadrats along all transects represent degraded heathland habitat. This is not surprising because Natural England currently considers Ashdown Forest SSSI to be in an 'unfavourable-recovering' condition, and an experienced ecologist would reach a similar conclusion with just a cursory visit to the site. It is interesting to note here, too, that applying the decision framework proposed by Jones et al. (2016) to attribute atmospheric nitrogen deposition as a threat to, or cause of, unfavourable habitat condition on protected sites (a report commissioned by the JNCC) would most likely classify Ashdown Forest into at least the ‘orange outcome category’. This suggests that the site is ‘not recovering’ and ‘requires action to reduce N deposition impacts at national or site-level’.
7.1.6 So, this is our current starting point and it should be appreciated that it may be difficult to detect potentially subtle change in plant communities where significant change has clearly already taken place. Having said this, current understanding has identified that subtle changes in nitrogen deposition can result in further species loss or can inhibit successful habitat restoration.

7.1.7 The aim of our monitoring over the first three years of this study was to establish a baseline for current habitat conditions at Ashdown Forest. It would be nice if three years worth of data produced a range of easily explainable patterns with regard to elevated nitrogen deposition. However, this was not strongly anticipated. Detecting significant change in vegetation communities is known to be a long-term process (e.g. 10+ years) and, therefore, attaching reasonable certainty to the validity of observed trends also takes a long time. It was not our purpose to look for long-term trends; and three years worth of data are not appropriate for time-series analysis in this instance. Instead, we feel that our baseline is robust and that this study has begun to uncover informative patterns in the composition of the vegetation community that are worthy of continued investigation.

7.1.8 Grass:forb ratios did not significantly decrease with increasing distance from a road as might have been anticipated. There was some indication that ratios were highest at distances of 25 – 75 m from a road (and variation between quadrats at these distances was certainly higher) which may warrant future investigation. However, Emmett et al. (2011) note that the efficacy of use of this index for detecting change is limited and, moreover, even if grass:forb ratios do show change across a habitat, it is difficult to determine the ultimate cause of this change using this indicator on its own.

7.1.9 For most quadrats species richness was low and well beneath the figure of 13 we chose to be representative of average healthy heathland. In addition, it seems likely that species richness actually declines with distance from a road. Other increased pressures closer to a road (such as verge maintenance and visitor pressure) are probably allowing the colonisation of these areas by non-heathland ruderals tolerant of greater levels of disturbance and these ruderals inflate the species richness of those quadrats closer to a road.

7.1.10 There was a strong negative relationship across the transects between plant nitrogen index values and distance from a road. On average, quadrats further from a road hosted a suite of species more typical of nitrogen poor conditions compared with quadrats closer to a road and we can imply from this data that this is due to variance in nitrogen deposition. Indeed, this is our principle evidence that a gradient in nitrogen deposition is effectual along the length of the transects.

7.1.11 If it is given that there is some tendency for species to be distributed according to their tolerance to different levels of nitrogen, the matter of exactly which species occur where then arises. Attempting to answer this question is a job for ordination. Patterns in species distributions elucidated by DCA were particularly helpful because it would seem that graminoids (grasses, sedges, rushes) are most likely to be indicative, according to their N values, of a gradient in nitrogen deposition at Ashdown Forest. CCA did not shed much further light on how graminoids may be influenced by nitrogen deposition but it did highlight the importance of other environmental variables in also influencing graminoid distribution (e.g. grazing and visitor pressure).
7.1.12 Foliar nitrogen concentrations and foliar amino acid concentrations in heath plait-moss and heather did not show any consistent significant correlation with distance from a road. It is unlikely that this plant tissue is unaffected by elevated nitrogen deposition and so it would seem that levels of nitrogen are already at high, saturation levels at all distances along the transects, and/or sampling methodology is not accurate enough to pick up subtle changes between quadrats.

7.2 Recommendations

7.2.1 It is recommended that the aim of the project is redefined and the project is subsequently re-scoped to ensure that suitable data is collected in future years to meet the stated aims of the study. If the project’s objective remains to monitor the ecological condition and nitrogen deposition on the heath, then minor revisions may be required. However, it should be noted that determining a direct causal relationship between elevated nitrogen deposition and plant community change will not be possible using this information and if the project aims to research the likely effects of nitrogen deposition on plant and habitat physiology, this is likely to require the design and implementation of controlled experiments as other negative influences are undoubtedly operating to cause change to Ashdown Forest (e.g. grazing and visitor pressure). The relative influence of these pressures is unknown and difficult to separate from potential effects of elevated nitrogen deposition without significant effort to determine their precise magnitude along the transects (ideally by including quadrats with no visitor pressure and no grazing).

7.2.2 Quadrat location should be reviewed, to ensure that heath that is currently significantly degraded is not under-represented. Furthermore, by selecting all transects within a 250 m band of a road it is likely that all transects are located in areas that have already undergone significant change, including that induced by higher nitrogen deposition. As mentioned above, detecting further subtle change caused by a particular driver in communities that have already potentially been strongly changed by that driver may be difficult. Emmett et al. (2011) discuss problems associated with choosing quadrat locations and make the following recommendation: ‘any surveillance schemes for detecting N impacts at site level would ideally incorporate complete floristic monitoring of replicate permanent quadrats located at random within fixed areas (e.g. a habitat area as initially mapped) over a number of years’.

7.2.3 We have established a robust baseline with a detailed database documenting species distributions across all transects, along with parameters associated with nitrogen deposition. We have also demonstrated how a modelled gradient in nitrogen deposition may be related to the distribution of species, and graminoids in particular. From our experience so far we particularly recommend the continuation of the elements of study outlined below.

1. Continue yearly monitoring of quadrats for all species present with emphasis on the detection and recording of rarer species (particularly bryophytes and lichens). Do not include CSM-type assessment.

2. Continue with yearly monitoring of soil C:N ratio. Do not include total soil nitrogen.

7.2.4 It is also recommended that samples of heather and heath plait-moss are taken from as wide a range of locations across the SAC as possible, in a one-
off effort to determine whether levels of foliar nitrogen in these plants have reached saturation level along the transects. Sampling methodology should be examined and a greater number of samples collected.

7.2.5 If it is decided that greater effort should be made to disentangle effects of other negative influences (e.g. visitor pressure and grazing) then consideration should be given to excluding these influences from certain quadrats or even from certain transects. Consideration should also be given to the establishment of other quadrats, at random (as far as this is possible), in more central areas of the SAC, away from the roads.

7.2.6 Finally, as the ultimate aim of this study is to enhance the conservation prospects of Ashdown Forest, consideration of how heathland restoration practises may interact with elevated nitrogen deposition to influence plant communities would be of interest. It is quite possible that targeted experimental regimes of burning, cattle grazing and or reduction in visitor pressure could ameliorate some of the negative effects of elevated nitrogen deposition by reducing the overall stress experienced by heathland plants. Clearly, this would be an involved process and would require different quadrats to receive different management treatments. However, results may be illuminating and may provide a practical demonstration of mitigation for nitrogen deposition.
References


