Lichen surveys to investigate ammonia impacts

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Natural Resources Wales

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Crynodeb Gweithredol

Mae'r Adroddiad Tystiolaeth hwn yn dwyn ynghyd chwe adroddiad mewnol a baratowyd gan Sam Bosanquet, Ecolegydd Planhigion Anfasgwlaidd CNC, yn dilyn gwaith maes yn 2017, ac un adroddiad a gomisiynwyd gan arbenigwr allanol ar gennau. Roedd pob un o'r adroddiadau hyn yn darparu tystiolaeth annibynnol o effeithiau negyddol amonia ar gennau ar Safleoedd o Ddiddordeb Gwyddonol Arbennig (SoDdGAau) yng Nghymru. Roedd canlyniadau pob arolwg yn sail i'r gweddill, felly mae ailadrodd yn y nodau, y dulliau a'r drafodaeth, ond mae pob un eisoes wedi cael ei ryddhau o fewn CNC ac yn allanol ac felly heb ei newid yma. Ychwanegwyd cyflwyniad trosfwaol at bwnc effaith amonia ar gennau - 'cefndir gwyddonol' - ar gais dau adolygydd cymheiriaid.

Mae dull cyson o asesu safleoedd, yr Arolwg o Gen ar Frigau, sy'n darparu mesuriad effaith ar bedair lefel, wedi ei ddatblygu gan academyddion a chenegwyr (http://www.apis.ac.uk/lichen-app-monitoring-nitrogen-air-quality-using-lichens), ac fe'i defnyddir yma ar dair SoDdGA yn Ne-orllewin a Chanolbarth Cymru. Mae'n dangos pa safleoedd sydd â 'Llygredd N Uchel', pa rai sydd â 'Llygredd N', a'r safleoedd sydd 'Mewn perygl' neu'n 'Lân,' yn nhrefn ddisgynnol eu heffaith.

Mae amonia yn llygrydd sylweddol, ynghyd â chyfansoddion eraill o Nitrogen, ac mae'n effeithio’n sylweddol ar ecosystemau naturiol, fel y trafodwyd yn y **Cefndir Gwyddonol** trosfwaol i'r adroddiad hwn:

- Yn wahanol i'r rhan fwyaf o fathau eraill o lygredd atmosfferig, sy'n cael eu rheoli gan newid technolegol a rheoleiddio effeithiol, mae allyriadau amonia yn cynyddu ym Mhrydain

- Mae ffynonellau amonia wedi eu crynhoi mewn ardaloedd gwledig ac mae llygredd amonia yn cael effeithiau dwys iawn yn agos i'r ffynhonnell, yn wahanol i fathau eraill o lygredd N sy'n crynhoi ar hyd rhwydweithiau trafnidiaeth neu sydd ag effeithiau ymhellach o'r ffynhonnell, er bod amonia gwledig hefyd yn cyfrannu at effeithiau ymhellach i ffwrdd;
- Mae gwyddoniaeth gadarn yn cysylltu llygredd amonia ac N â newidiadau yng nghyfansoddiad rhywogaethau cen, gan gynnwys colli rhywogaethau sensitif a'u disodli gan rywogaethau sy'n oddefgar.
- Gostyngwyd Lefelau Critigol ar gyfer amonia ym Mhrydain yn 2007, yn dilyn argymhellion gan UNECE, i ddiogelu ecosystemau sy'n gyfoethog o ran cennau a bryoffytau.
- Mae cennau yn elfennau allweddol o lawer o gynefinoedd Ardaloedd Cadwraeth Arbennig (ACA), yn enwedig Hen Goedwigoedd Derw Digoes, ac mae cennau yn nodweddion o 85 SoDdGA yng Nghymru; Mae gan CNC ddyletswydd statudol i ddiogelu'r cennau hyn. Llwyddodd y rhan fwyaf o safleoedd gwarchodedig gyda nodweddion cennau i ddianc rhag llygredd SO_2 hanesyddol oherwydd eu bod yn bell o ddiwydiant, ond gallai ffynonellau amonia fod wedi eu gwasgaru dros ardal lawer ehangach.
- Nid newid esoterig yn unig yw newid/colled epiffytau a achosir gan lygredd awyr - mae'n effeithio ar swyddogaethau'r ecosystemau hefyd:
  - Mae cennau'n amsugno dŵr glaw ac yn helpu i leihau dŵr ffo mewn coetir cefnforol;
  - Mae cennau yn chwarae rhan mewn cylchu maetholion mewn ecosystemau coedwig naturiol;

- Mae cennau'n darparu cartrefi ar gyfer anifeiliaid di-asgwrn-cefn, sydd yn eu tro yn darparu bwyd i adar a bioamrywiaeth coetiroedd arall.

Mae cennau epiffytig (cennau sy'n tyfu ar goed) nid yn unig yn cael eu heffeithio gan weithgareddau yn y coetir neu'r parcdir y maent yn tyfu ynddo, maent hefyd yn ymateb i ddefnydd tir mewn caeau cyfagos. Mae **Adroddiad 1** yn cofnodi colli rhywogaethau sensitif o barcdir SoDdGA yn dilyn 20 mlynedd o chwistrellu slyri ar y cae silwair cyfagos, tra bod **Adroddiad 2** yn defnyddio'r Arolwg o Gen ar Frigau i ddangos graddiant o goed â 'Llygredd N Uchel' i 'Mewn perygl' o'r cae silwair cyfagos i mewn i'r SoDdGA hwn.

Mae amonia'n gweithredu'n bennaf ar raddfa ychydig gannoedd o fetrau, felly gall parthau o gwmpas safleoedd allweddol lle na chaniateir unrhyw ffynonellau amonia ac na wasgerir unrhyw wastraff (ee tail, slyri neu weddillion treuliad) roi rhywfaint o ddiogelwch; mae angen i'r rhain fod yn ddigon llydan i gadw amonia rhag ymledu i'r safle. Mae **Adroddiad 3** yn cyflwyno enghraifft o barth tua 500m o led lle nad oes gwastraff yn cael ei ledaenu yn gwarchod calon parcdir SoDdGA (lle mae'r coed yn cael eu hasesu fel 'Glân') ond yn cofnodi gorfaethu gan amonia ar ymylon y SoDdGA (mae'r coed 'Mewn perygl').Mewn cyferbyniad, mae gan y SoDdGA parcdir yn **Adroddiad 4** gaeau silwair a phorfa maetholion uchel yn gyfagos i'r SoDdGA, a thair sied ieir o fewn 2.2 km; mae'r SoDdGA cyfan yn dioddef 'Llygredd N' neu 'Mewn perygl’. Mae angen asesu'r cyfraniad at grynodiadau amonia ar y SoDdGA o allyriadau o'r siediau cyw iâr o gymharu â ffermydd llaeth agosach.

Mae SoDdGA cennau parcdir iseldirol yn arbennig o agored i orfaethu gan amonia, ond mae effeithiau hefyd i'w gweld mewn ACA coetir cefnforol. Mae **Adroddiad 5** yn disgrifio cennau brigau niferus yn rhan isaf un coetir ACA, yn cael eu disodli gan gennau brigau tila a 'slwj algaidd' (tyfiant rhemp o algâu a/neu cyanobacteria sy'n mogi planhigion eraill) yn rhan uchaf y goedwig, nid nepell o gaeau a reolir yn ddwys ac o fewn 4 km i fferm ieir.

Rhoddir golwg ehangach ar effeithiau ar SoDdGA ym Mhowys yn **Adroddiad 6**, gydag Arolygon o Gen ar Frigau yn cwmpasu ucheldiroedd 'glân' Mynyddoedd Cambria a'r iseldiroedd lle mae mwy o lygredd N. Yn olaf, mae **Adroddiad 7** yn cofnodi dirywiad gwirioneddol mewn tri chen sy'n sensitif i amonia yng Nghymru, gan gynnwys lleihad sylweddol (rhwng 31% a 57%) yn nifer y safleoedd a feddiannir ac arwynebedd meddiannaeth *Bryoria fuscescens*.

Thema gyffredin yn yr adroddiadau yw'r amrywiad mewn llygredd amonia a arsylwyd ar draws safleoedd - o 'Glân' i 'Llygredd N Uchel' dim ond 200-300m ar wahân - er bod www.apis.ac.uk yn rhoi un gwerth am grynodiad amonia, wedi'i fodelu gan ddefnyddio CBED (Amcangyfrif o Ddyddodiad ar Sail Crynodiad), ym mhob sgwâr 5x5km a archwiliwyd. Mae modelau, cyfartaleddau a rhagdybiaethau yn cael eu defnyddio ar hyn o bryd drwy gydol proses CNC ar gyfer asesu effaith:

- Cymerir y crynodiad amonia cyfredol ar gyfer safle o APIS, sydd fel arfer yn cyflwyno data ar fanylrwydd 5x5km tra bod amonia yn gweithredu dros bellter llawer byrrach;
- Ffitiad gorau'r Lefel Gritigol ar gyfer amonia mewn cynefinoedd cennau a bryoffytau yw 1 µg / m^3, ond mae rhai rhywogaethau cen yn sensitif i grynodiadau llawer is;
- Mae'r modelau'n amcangyfrif crynodiad blynyddol cyfartalog ar gyfer y sgwâr grid 5x5km, ond mae llawer o genegwyr yn ystyried bod dosau uchel ysbeidiol o amonia yn wenwynig (mae angen mwy o ymchwil);

- Nid yw adroddiadau sgrinio yn cyfrif am effeithiau tywydd, fel gwrthdroadau tymheredd, a all achosi i golofnau o amonia hongian dros SoDdGA am sawl diwrnod.

O ystyried bod difrod i nodweddion SoDdGA/ACA eisoes i'w weld yn y pedair safle a ddisgrifir yn **Adroddiadau 1 i 5**, bod effeithiau amonia i'w gweld yn fwy eang yn SoDdGAau Powys (**Adroddiad 6**), a bod rhai epiffytau o bwysigrwydd ecolegol wedi dirywio'n sylweddol (**Adroddiad 7**), mae angen i CNC fabwysiadu gweithdrefnau cadarnach i atal difrod pellach.

Mae'r adroddiadau gyda'i gilydd yn darparu tystiolaeth o ddifrod i nodweddion SoDdGA/ACA sy'n gyson â llygredd amonia y dylid ei reoleiddio drwy'r cyfundrefnau trwyddedu cyfredol a weithredir gan CNC. Mae rheolaeth a diogelwch parhaus SoDdGAau sy'n gyfoethog o ran cennau yn gyfle gwych i ddangos Rheolaeth Gynaliadwy o Adnoddau Naturiol yn ymarferol trwy addasu'r asesiadau rheoleiddio mae Cyfoeth Naturiol Cymru yn eu cynnal wrth benderfynu ar geisiadau, i ystyried sensitifrwydd y safleoedd hyn yn briodol i fygythiadau cyfredol a rhai'r dyfodol:

- Mae ACAau a SoDdGA â nodweddion sy'n gyfoethog o ran cennau neu fryoffytau yn amlach na pheidio ar wahân ac o faint cyfyngedig, ac mae hyn yn cyfyngu cymhwyso'r gyfundrefn reoleiddio ddiwygiedig i ardaloedd cyfyngedig o Gymru. I'r gwrthwyneb, dylai fod llawer o leoliadau amgen addas ar gyfer datblygiadau;
- Llygrydd pellter byr sy'n effeithio ar y rhywogaethau, felly gellir nodi 'mannau diogel' lle mae effeithiau'n annhebygol;
- Mae lle i ddatrysiadau technolegol, er mwyn caniatáu datblygu siediau amaethyddol dwys hyd yn oed yn gymharol agos at SoDdGA sy'n gyfoethog o

ran cennau, gan leihau'r risg i'r nodweddion sensitif o'i defnyddio ar cyd â threfniadau monitro priodol. Fodd bynnag, byddai angen adnoddau i fynd i'r afael â phob ffynhonnell bresennol o lygredd amonia o amgylch y SoDdGAau hyn, a byddai angen atebion technolegol yn arbennig ar gyfer slyri gwartheg.

Argymhellion

A. Diwygio gweithdrefnau gweithredol CNC i ddarparu amddiffyniad cadarn ar gyfer SoDdGAau/ACA sy'n gyfoethog o ran cennau gan gynnwys parthau dim mewnbwn o amgylch y safleoedd pwysicaf;

B. Diwygio gweithdrefnau sgrinio CNC fel bod crynodiadau amonia yn cael eu hasesu'n gywir (peidio â defnyddio modelau 5x5km), ac atal unrhyw fewnbwn amonia ychwanegol i SoDdGA sy'n gyfoethog o ran cennau yn agos at Lefel Gritigol yr amonia;

C. Datblygu haen GIS i ganiatáu defnyddio'r Lefel Gritigol seiliedig ar gennau, sy'n is, ar Goetiroedd Hynafol sydd â chofnodion diweddar o gennau sy'n sensitif i N;

D. Comisiynu astudiaeth o docsisedd llygredd amonia acíwt i gyfres o gennau epiffytig, a diwygio gweithdrefnau yng ngoleuni'r canlyniadau;

E. Ei gwneud yn ofynnol i ddatblygwyr gomisiynu arolwg o gen ar frigau ar SoDdGA sy'n gyfoethog o ran cennau fel rhan safonol o'r broses asesu ar gyfer cynigion amaethyddiaeth ddwys yn agos at y safleoedd gwarchodedig hyn;

F. Ychwanegu *Bryoria fuscescens* a *B. subcana* i Adran 7 o Ddeddf yr Amgylchedd (Cymru) a defnyddio eu presenoldeb fel arwydd o sensitifrwydd eithafol;

G. Dangos SMNR gan ddefnyddio SoDdGAau/ACA sy'n gyfoethog o ran cennau, gan dalu ffermwyr i fabwysiadu technolegau fydd yn lleihau llygredd amonia.

Risgiau

Mae risgiau allweddol yn wynebu'r amgylchedd a CNC:

- Mae colledion rhywogaethau yn parhau, ac mae llywodraethau'r DU a Chymru wedi nodi ei fod yn fygythiad i genedlaethau'r dyfodol;
- Bydd strwythur, swyddogaeth a gwytnwch ecosystemau yn dirywio wrth i epiffytau gael eu colli;
- Mae risg enw da'r sefydliad a mwy o fewnbwn gan swyddogion yn bosibl os na fydd Cyfoeth Naturiol Cymru yn rhoi sylw dyledus i nodweddion safleoedd gwarchodedig;

Gallai achosion llys am dorcyfraith ddeillio o ddifrod heb ei reoleiddio i nodweddion ACA.

Executive Summary

This Evidence Report brings together six internal reports prepared by Sam Bosanquet, NRW Non-vascular Plant Ecologist, following fieldwork in 2017, and one report commissioned from an external lichen expert. Each of these reports provided stand-alone evidence of the negative impacts of ammonia on lichens on Sites of Special Scientific Interest (SSSIs) in Wales. The results of each survey helped to inform the others, so there is repetition in the aims, methods and discussion, but each has already been released within NRW and externally and therefore remain unchanged here. An over-arching introduction to the subject of ammonia impacting on lichens – ‘scientific background’ – was added at the request of two peer reviewers.

A consistent approach to site assessment, the Twig Lichen Survey which provides a four level measure of impact, has been developed by academics and lichenologists (http://www.apis.ac.uk/lichen-app-monitoring-nitrogen-air-quality-using-lichens), and is applied here at three SSSI in South-west and Mid Wales. It shows which sites are ‘Very N polluted’, which are ‘N polluted’, which are ‘At risk’ and which are ‘Clean’ in declining order of impact.

Ammonia is a significant pollutant, along with other compounds of Nitrogen, with profound effects on natural ecosystems, as discussed in the overarching **Scientific Background** to this report:

- In contrast to most other forms of atmospheric pollution, which are being controlled by technological change and effective regulation, ammonia emissions are increasing in Britain
- Ammonia sources are concentrated in rural areas and ammonia pollution has profound short-range effects, in contrast to other forms of N pollution which are concentrated along transport networks or have long-range impacts, although rural ammonia does also contribute to long-range impacts;
- Robust science links ammonia and N pollution to changes in lichen species composition, including loss of sensitive species and their replacement by N-tolerant species
- Critical Levels for ammonia were reduced in Britain in 2007, following recommendations from UNECE, to protect lichen- and bryophyte-rich ecosystems.
- Lichens are key components of many Special Areas of Conservation (SAC) habitats, notably Old Sessile Oakwood, and lichens are features of 85 SSSIs in Wales; NRW has a statutory duty to protect these lichens. Most protected sites

with lichen features escaped historical SO_2 pollution because they were remote from industry, but ammonia sources are potentially much more widespread.

- Epiphyte change/loss caused by air pollution is not simply an esoteric change – it affects ecosystem function as well:
    - Lichens absorb rainwater and help to reduce run-off in oceanic woodland;
    - Lichens play a role in nutrient cycling in natural forest ecosystems;
    - Lichens provide homes for invertebrates which in turn provide food for birds and other woodland biodiversity.

Epiphytic lichens (lichens that grow on trees) are not only affected by activities in the woodland or parkland in which they grow, they also react to landuse in adjacent fields. **Report 1** documents loss of sensitive species from a SSSI parkland following 20 years of slurry spraying on the adjacent silage field, whilst **Report 2** uses the Twig Lichen Survey to show a gradient from ‘Very N polluted’ to ‘At risk’ trees running into this SSSI from the adjacent silage field.

Ammonia operates primarily at a scale of a few hundred metres, so zones around key sites where no ammonia sources are allowed and no waste (e.g. manure, slurry or digestate) is spread may provide protection; these need to be sufficiently wide to avoid incursions of ammonia into the site. **Report 3** presents an example of a *ca.* 500m wide zone where no waste is spread protecting the heart of a SSSI parkland (where the trees are assessed as ‘Clean’) but records ammonia enrichment on the edges of the SSSI (trees are ‘At risk’). In contrast, the parkland SSSI covered by **Report 4** has silage fields and high-nutrient pasture adjoining the SSSI, and three chicken sheds within 2.2 km; the entire SSSI is ‘N polluted’ or ‘At risk’. The contribution to ammonia concentrations at the SSSI from emissions from the chicken sheds compared to closer dairy farms requires assessment.

Lowland parkland lichen SSSI are especially vulnerable to ammonia enrichment, but impacts are also visible in oceanic woodland SAC. **Report 5** describes abundant twig lichens in the lower part of one SAC woodland, replaced by scanty twig lichens and locally abundant ‘algal gunk’ (rampant growth of algae and/or cyanobacteria that smothers other plants) in the upper part of the wood, a short distance from intensively managed fields and within 4 km of a chicken farm.

A wider view of impacts on SSSI in Powys (eastern mid Wales) is given in **Report 6**, with Twig Lichen Surveys covering the ‘clean’ uplands of the Cambrian Mountains and the more N-polluted lowlands. Finally, **Report 7** documents real declines in three ammonia-sensitive lichens in Wales, including a significant (between 31% and 57%) reduction in number of occupied sites and area of occupancy of *Bryoria fuscescens*.

A common theme of the reports is the variation in observed ammonia pollution across sites – from ‘Clean’ to ‘Very N polluted’ just 200-300 m apart – despite www.apis.ac.uk presenting a single value for ammonia concentration, modelled by CBED (Concentration Based Estimation Deposition), within each 5x5km square investigated. Models, averages and assumptions are currently used throughout NRW’s process for impact assessment:

- Current ammonia concentration for a site is taken from APIS, which generally presents data at a 5x5km resolution whilst ammonia operates at much shorter ranges;
- The Critical Level for ammonia in lichen- and bryophyte-rich habitats is a best fit 1 µg/m^3, but some lichen species are sensitive to much lower concentrations;

- The models estimate an average annual concentration for the 5x5km grid square, but intermittent high doses of ammonia are considered toxic by many lichenologists (more investigation is needed);
- Screening reports do not account for weather effects, such as temperature inversions, that may cause ammonia plumes to hang over a SSSI for several days.

Given that damage to SSSI/SAC features is already visible at the four sites described in **Reports 1 to 5**, that ammonia impacts are visible more widely in Powys SSSIs (**Report 6**), and that some ecologically important epiphytes have declined significantly (**Report 7**), NRW needs to adopt more robust procedures to prevent further damage.

The reports collectively provide evidence of damage to SSSI/SAC features that is consistent with ammonia pollution which should be regulated through the current permitting regimes enacted by NRW. The continued management and protection of lichen-rich SSSI provides an excellent opportunity to demonstrate practical Sustainable Management of Natural Resources through modifying the regulatory assessments NRW undertakes when determining applications, to take proper account of the sensitivity of these sites to current and future threats:

- SACs and SSSI with lichen- or bryophyte-rich features are mostly discrete and of limited extent, thus restricting the application of the modified regulatory regime to limited areas of Wales. Conversely there should be many suitable alternative locations for developments;
- The species are affected by a short-range pollutant, so ‘safe areas’ where impacts are unlikely can be identified;

- There is scope for technological solutions, to allow development of intensive agricultural sheds even relatively close to lichen-rich SSSI, minimising the risk to the sensitive features if coupled with appropriate monitoring regimes. However, resources would be needed to address all current sources of ammonia pollution around these SSSI, with technological solutions required for cattle slurry in particular.

Recommendations

H. Revise NRW's operational procedures to provide robust protection for lichen-rich SSSI/SAC including zero-input zones around the most important sites;

I. Revise NRW's screening procedures so that ammonia concentrations are accurately assessed (not using 5x5km models), and prevent any additional ammonia inputs to lichen-rich SSSI close to the ammonia Critical Level;

J. Develop a GIS layer to allow application of the lower, lichen-based Critical Level to Ancient Woodlands with recent records of N-sensitive lichens;

K. Commission a study of the toxicity of acute ammonia pollution to a suite of epiphytic lichens, and revise procedures in light of the results;

L. Require developers to commission twig lichen survey at lichen-rich SSSI as a standard part of the assessment process for intensive agriculture proposals close to these protected sites;

M. Add *Bryoria fuscescens* and *B. subcana* to Section 7 of the Environment (Wales) Act and use their presence as an indication of extreme sensitivity;

N. Demonstrate SMNR using lichen-rich SSSI/SAC, paying farmers to adopt technologies that will reduce ammonia pollution.

Risks

Key risks face both the environment and NRW:

- Species loss is ongoing, and has been identified by the UK and Welsh governments as a threat to future generations;
- Ecosystem structure, function and resilience will decline as epiphytes are lost;
- Organisational reputation risk and increased officer time input are possible if NRW does not take propoer account of protected site features;
- Infraction procededings could result from unregulated damage to SAC features.

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Contents

Scientific background

Report 1) Parc Pont-faen SSSI – a visit to assess slurry impacts in 2017

Report 2) Parc Pont-faen SSSI – twig lichen survey 2017

Report 3) Dinefwr Park SSSI - a transect recording twig lichens to investigate current ammonia levels

Report 4) Gregynog SSSI – three transects recording twig lichens to investigate current ammonia levels

Scientific background

I. Ammonia and N pollution

a) Nitrogen in natural ecosystems

Nitrogen (N_2) is the most abundant gas in earth's atmosphere, but its tight triple bond renders it largely unreactive and unavailable as a plant nutrient. Certain cyanobacteria, bacteria and archaea have evolved to 'fix' nitrogen, converting it to ammonia and related molecules, and these molecules then become available for uptake by plants. However, most natural ecosystems have very low levels of fixed nitrogen in the soil, and plants have evolved strategies for scavenging N, including symbiotic N-fixing bacteria in the root nodules of many leguminous plant species, and a range of complex mycorrhizal associations between many plant roots and fungi (Lilleskov *et al.*, 2011). Nitrogen is an essential plant nutrient (Marschner, 2005), as it is a component of proteins, nucleic acids, chlorophyll and many other complex macromolecules.

Most terrestrial and aquatic ecosystems have limited available N, although some swamps where plant material gathers and decays can have naturally high levels of N, as can areas where animals congregate, such as sea cliffs or bat caves. As a consequence, most species that make up natural, biodiverse ecosystems have evolved to cope with N being a limited resource, although some plants (e.g. stinging nettle *Urtica dioica* and cleavers *Galium aparine*) and lichenised fungi (e.g. the orange lichen *Xanthoria parietina*) – thrive where N levels are high. Human activities have altered environmental N levels for centuries at a local scale, by spreading animal manure on farmed land, and this was scaled-up in the 19th century by using mined nitre or harvested guano as fertiliser. However, the invention of the Haber Process in the early 20th century provided an industrial source of 'fixed' nitrogen and led to an ever-increasing landscape of artificially fertilised land.

The increased availability of artificial fertilisers, often including phosphorus (P) and potassium (K) as well as N (EFMA, 2000), allowed scientists to selectively breed crops that thrive in highly fertile environments and produce nutrient-rich forage. Hay was replaced by silage as the principal winter feed for cattle on many farms during the late 20th century, with the latter being formed of grass from highly fertile leys or from maize, and nutrition has been supplemented by feed concentrates that regularly include constituents imported from other parts of the world (Musel, 2009). Poultry units in Wales, with current estimates of more than 7.5 million birds (Statistics for Wales, 2017), use a mix of locally grown (DEFRA, 2018) and imported feeds, with soy protein sourced in the southern hemisphere being a significant, if now moderated, constituent (e.g. Cargill, 2017). Imported nutrients are contributing to increasing levels of N pollution in much of the UK (DEFRA, 2016): nitrogen levels in our environment are now typically significantly higher than in natural ecosystems.

b) Sources of N pollution

Although nitrogen is an essential plant nutrient, excessive N compounds affect the composition and functioning of both terrestrial and aquatic ecosystems. Nitrogen pollution occurs when the levels of N compounds are raised by human activity and has various sources and expressions. Asman *et al.* (1998) describe how ammonia (NH_3), nitric oxide (NO) and nitrogen dioxide (NO_2) are the principal emitted sources of N pollution, and how reactions in the atmosphere lead rapidly to the production of ammonium ions ($NH4^{+}$), gaseous nitric acid (HNO_3), and particulate NO_3^-. Deposition of these N compounds is described below in section c).

Nitric oxide (NO) and nitrogen dioxide (NO_2), collectively known as nitrogen oxides (NO_x), are produced by combustion processes, partly from nitrogen compounds in the fuel, but mostly by direct combination of atmospheric oxygen and nitrogen in flames. According to DEFRA (2016), the UK emits about 2.2 million tonnes of NO_2 each year, and emissions are falling, albeit more slowly than those of some other major pollutants such as SO_2. Of this, about half is from motor vehicles, a quarter from power stations, and the rest from other industrial and domestic combustion processes (www.apis.ac.uk). Emission sources for NO_x are therefore concentrated in urban areas or along road networks (Fig. I1), although rural settlements, rural industry and installations such as farm biomass boilers can be major local sources in rural areas.

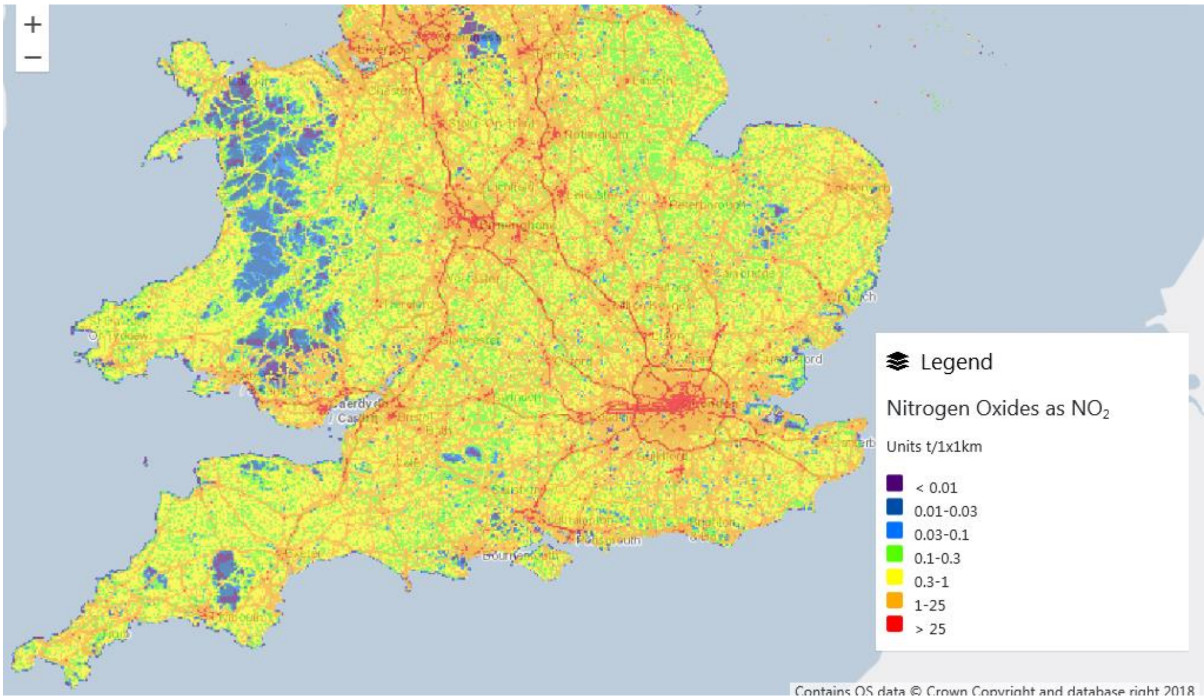


Figure I1: map of NOx emissions in the southern part of the UK for 2015 (http://naei.beis.gov.uk/emissionsapp/). The Critical Load for dry acid and neutral grassland of 10-15 kg N/ha (the Critical Loads scale) equates to 1-1.5 t/1x1km (the mapped scale).

In contrast to NO_x, ammonia is predominantly a rural pollutant (Fig. I2) resulting primarily from agriculture (Fig. I3), although it also affects urban areas with increasing evidence of rural ammonia being deposited in urban areas as ammonium sulphate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3) and causing human health problems (DEFRA 2019). At the turn of the 21st century, total ammonia emissions in the UK were estimated to be 283 kt N yr-1 (Sutton et al. 2000) with 228 kt coming from agricultural sources. Ammonia emissions declined slightly since 2000 in the UK and Wales (Fig. I3), but the decline has recently been reversed and emissions have increased in GB and Wales since 2014 (DEFRA 2016). Emissions of ammonia are higher now in Wales than they were in 2010 (Jones *et al.*, 2017a).

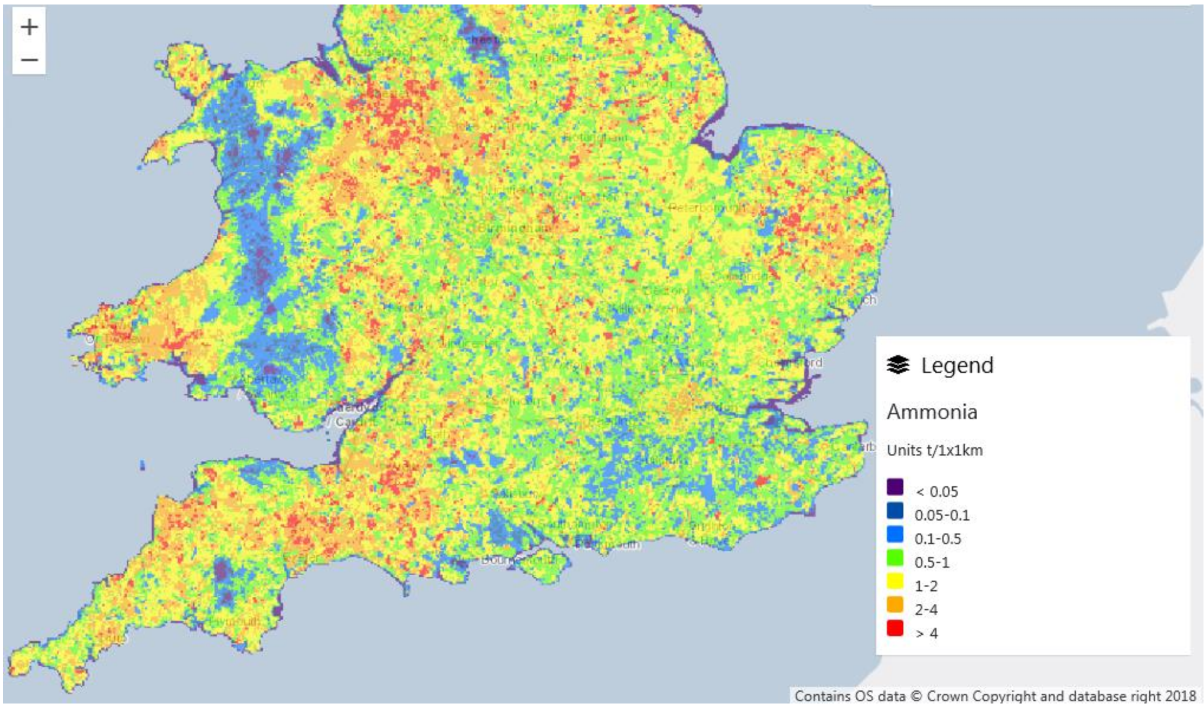


Figure I2: map of ammonia (NH_3) emissions in the southern part of the UK for 2015 (http://naei.beis.gov.uk/emissionsapp/) (note the different colour scale to the NO_x map, with 0.1-0.5 t/1x1km being blue on the ammonia map and 0.1-0.3 t/1x1km being green on the NO_x map, making rural NO_x emissions appear higher at first glance than they actually are).

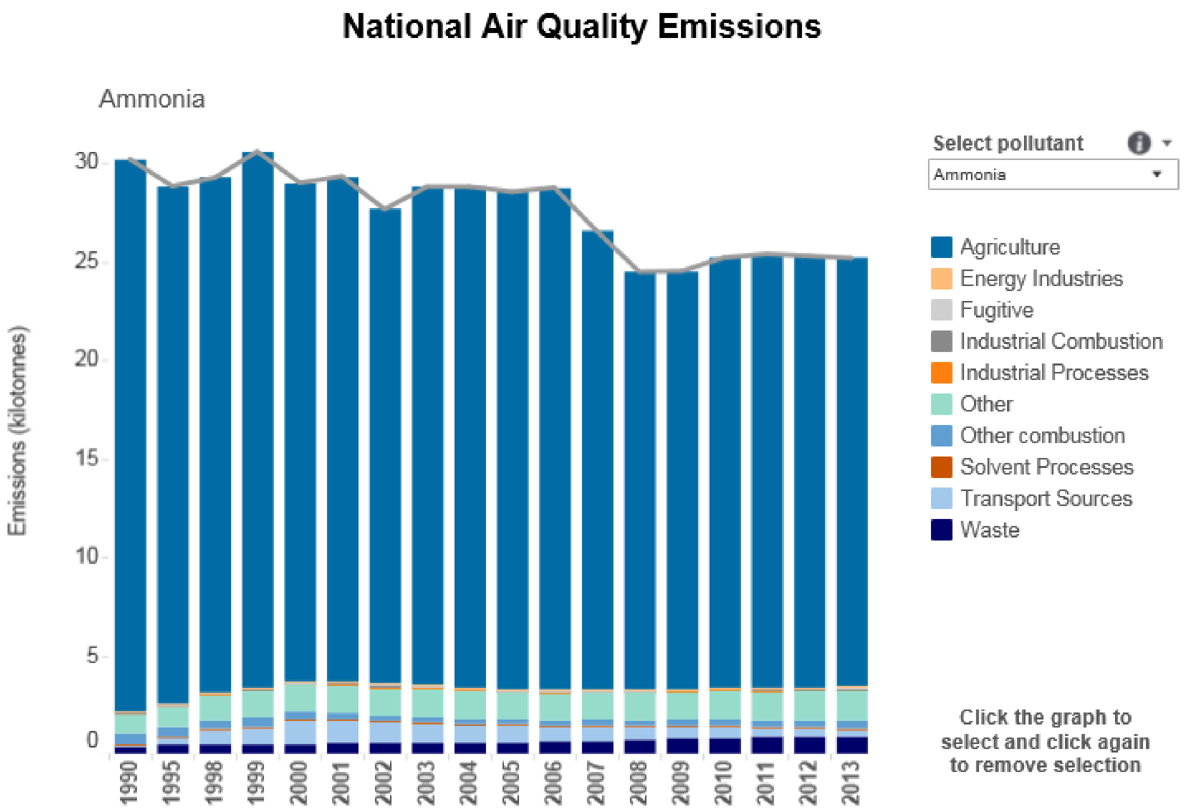


Figure I3: emissions of ammonia in Wales between 1990 and 2013 by sector (https://airquality.gov.wales/maps-data/emissions/national-air-quality).

c) Movements of N pollution

As discussed above, chemical reactions in the atmosphere convert emitted ammonia and NOx to ammonium ions, nitric acid and NO_3^-. Some of the emitted ammonia and NOx are deposited on to vegetation close to the pollution source in what is termed ‘dry deposition’, but estimates indicate that up to 60% can move through the atmosphere to more distant areas and fall as ‘wet deposition’ (Tony Dore, CEH, pers. comm. 18th April 2019). N deposition and ammonia concentrations are calculated from emissions data and climate data using the CBED (Concentration Based Estimated Deposition) model, which takes UK national measurement site concentration data and uses rainfall data and “*transfer rates from the atmosphere to the canopy surface and then the uptake by various mechanisms within the plant canopy*” (www.apis.ac.uk/popup/cbed) to present modelled deposition levels across the country (Fig. I3). The CBED model is informed by monitoring data, although there are currently just seven monitoring sites for NO_x in Wales (www.uk-air.defra.gov.uk) and just five for ammonia (Fig. I4).

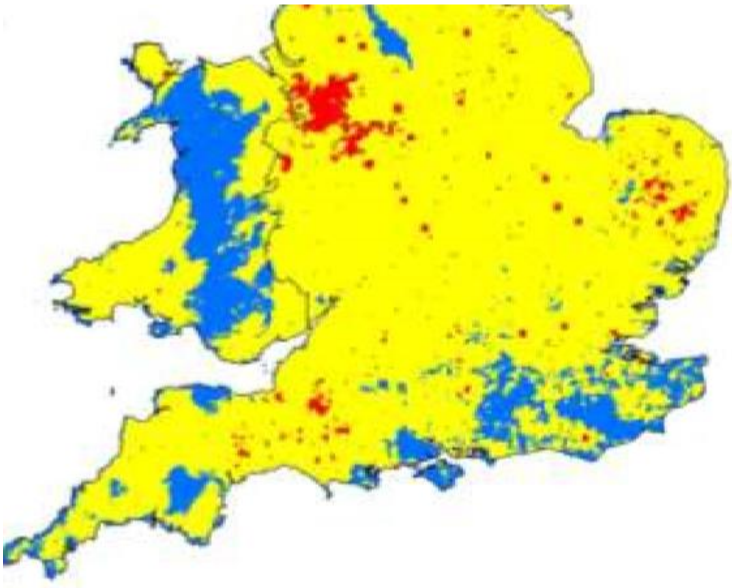


Figure I3: map of ammonia (NH_3) concentrations in the southern part of the UK for 2012-2014 using the CBED model (from Hall *et al.*, 2017); blue: <1 µg/m^3; yellow: 1-3 µg/m^3; red: >3 µg/m^3.

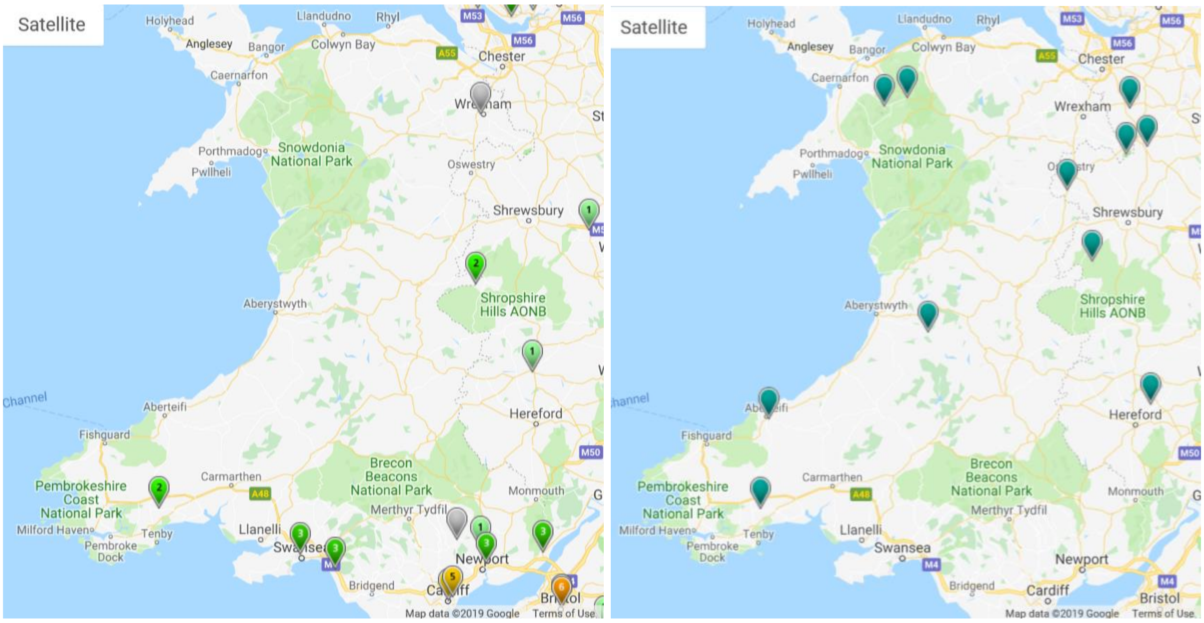


Figure I4: NOx (left) and ammonia (right) monitoring stations in Wales (www.uk-air.defra.gov.uk).

Dry deposition of nitrogen oxides is greatest within large conurbations and close to major highways because nitrogen dioxide (NO_2) is mostly emitted from motor vehicles and heating sources. Some of this NO_2 is deposited close to these sources, but much reaches the atmosphere. Atmospheric oxidation produces nitric acid and particulate and aqueous NO_3^-: the main NO_y components of wet deposition. These can move in the atmosphere over great distances, causing long-range ecological effects (e.g. van Herk *et al.*, 2003).

Reduced nitrogen (NH_x) pollution comprises mainly gaseous ammonia NH_3, and fine ammonium NH_4^+ salts. The latter have a long atmospheric residence time, and can be deposited in remote ecosystems through rainfall, termed 'wet deposition' (Asman *et al.*, 1998). In contrast, 'dry' deposition of ammonia usually takes place in close proximity to ammonia sources, although Aazem & Bareham (2015) show increased concentrations of ammonia through dry deposition more than 1km from poultry farms in central Powys, with a landscape-scale increase in ammonia resulting from a cluster of poultry farms north-east of Newbridge-on-Wye.

Although RoTAP (DEFRA, 2012) reported that ammonia emissions had peaked in the UK in the 1980s and that wet ammonium deposition has decreased by 35% since 1986, the decline is small compared with those of SO_2 and NO_x. The increase in ammonia emissions since 2014 (Jones *et al.*, 2017a) means that short-range 'dry deposition' of ammonia is also likely to be increasing, whilst longer-range 'wet deposition' with contributions from NO_x as well as ammonia may also be increasing.

II. Effects of ammonia pollution on biodiversity

d) Assessment with Critical Loads and Critical Levels

The impact of air pollution on ecosystems is assessed using two principal metrics: Critical Loads and Critical Levels. These two metrics are defined on www.apis.ac.uk.

- 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 Loads relate to the quantity of a pollutant deposited from air to ground, and are often assessed as a cumulative mass of the pollutant deposited during a year.
- 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.*" Critical Levels relate to the concentration of a pollutant in the air, and are often assessed as annual means.

N deposition is assessed using habitat-specific Critical Loads, which are presented on www.apis.ac.uk as ranges that account for variation within habitats across Europe. If the annual load of N deposited to the habitat is lower than the Critical Load, then significant harmful effects are unlikely to occur. Empirical critical loads for nutrient nitrogen are set under the Convention on Long-Range Transboundary Air Pollution and are based on empirical evidence, mainly observations from experiments and gradient studies. The latest revision of European Critical Loads for N was carried out in 2010 (UNECE, 2010), during which many Critical Loads were revised downwards because of improved evidence of impacts. For example, the Critical Load for valley mires, poor fens and transition mires was reduced from 10-20 kg N ha^{-1}yr^{-1} to 10-15 kg N ha^{-1}yr^{-1}. According to one analysis, 63% of all nitrogen-sensitive habitats across the UK receive higher nitrogen deposition rates than they are able to tolerate (Hall *et al.*, 2016).

Ammonia pollution and NO_x are assessed using Critical Levels, which are usually assessed as annual mean concentrations. When lichens and bryophytes form a key part of the ecosystem integrity, a Critical Level of 1µg NH_3 m^{-3} is used, whereas a Critical Level for ecosystems in which lichens and bryophytes are not key components are assessed with a Critical Level of 3 µg NH_3 m^{-3}. There are many ways that a receptor can experience an annual mean concentration of 1µg NH_3 m^{-3}, especially given variation in wind direction and changing activities at a pollution source (such as cleaning manure out of a shed), and Critical Levels for ammonia have also been defined with monthly, daily or hourly means (hourly: 3300 µg m^{-3}, daily: 270 µg m^{-3}, monthly: 23 µg m^{-3}). However, the Critical Level for ecosystems with lichens or bryophytes as key components was reduced from 8 µg NH_3 m^{-3} to 1 µg NH_3 m^{-3} by UNECE (2007) but there was not thought to be sufficient evidence to allow reductions in the shorter period Critical Levels. Furthermore, the 1 µg NH_3 m^{-3} Critical Level was considered to be the ‘best fit’ value in a continuum of sensitivities, and some lichens and bryophytes are damaged by lower concentrations of ammonia (e.g. McCune & Geiser, 2009; Johansson *et al.*, 2012).

e) Effects of N pollution on ecosystems

Nitrogen pollution has been identified as a significant threat to Biodiversity (Sala *et al.*, 2000; Dise *et al.*, 2011), and has profound direct and indirect effects on many species that make up both terrestrial and aquatic ecosystems. Phosphorus pollution has also been identified as reducing plant species richness in terrestrial ecosystems, but Soons *et al.* (2017) show that N is a much more significant driver of species loss than P, including when N and P are combined. Different forms of N pollution have different effects, but the differences are complex, and responses may be species specific or not apparent (*i.e.* species are insensitive to the form of N, and only the N dose matters) (Sheppard *et al.*, 2014). Experimental release of ammonia over Whim bog (e.g. Sheppard *et al.*, 2011) provides the strongest UK evidence of direct impacts on a range of vegetation, including bryophytes and lichens, whilst studies at the national scale have shown how these observed impacts and others are altering many ecosystems. Both reduced nitrogen (ammonia NH_3 and ammonium NH_4^+) and oxidised nitrogen (nitric acid and particulate and aqueous NO^{3-}) affect plant growth and consequently the survival of other species, and in some cases are directly toxic to plants and fungi. The precise causes of observed effects can be difficult to ascertain because a site may be impacted by dry ammonia deposition, dry NO_X deposition, wet ammonium deposition and wet deposition of oxidised N, whilst effects are often cumulative (Payne *et al.*, 2019). However, Sheppard *et al.* (2011) showed experimentally that dry deposition of ammonia gas caused a more rapid reduction in species diversity at Whim Bog than wet deposition of ammonium ions.

There are three principal causes of species loss in grasslands due to N deposition (Stevens *et al.*, 2006): N favours the growth of some grass species rather than other herbs, bryophytes and lichens causing competitive exclusion; forb cover and flower abundance decline (O’Sullivan, 2008); and direct N toxicity damages some terricolous lichens and bryophytes. Furthermore, Basto *et al.* (2014) showed additional long-term impacts because of significantly reduced soil seed bank levels after 13 years of N enrichment, even when forb cover and flowering appeared relatively unaffected. Management such as grazing, mowing or burning can hide the effects of N deposition in grasslands, and indeed can mitigate some of the enrichment effects if cut material is removed (Jones *et al.*, 2017b), but direct toxicity to some plants, bryophytes and lichens will still cause species loss even if competitive exclusion is reduced, and spring/summer mowing also prevents flowering and seed production in later-flowering plants.

Wooded ecosystems including forests and parkland are also impacted negatively by N deposition, although timber productivity is considered not to be affected (UKreate, 2019). N deposition has been linked to reduced species diversity on the forest floor, reduced tree root growth, increased sensitivity to natural stresses and an unbalanced nutritional status due to eutrophication and acidification (Erisman & de Wries, 2000). UKreate (2019) report a study showing increased insect damage to Scots pine, as well as increased abundance of the N-tolerant plants bramble *Rubus fruticosus* and nettle *Urtica dioica*. Changes in mycorrhizal fungal community composition have been linked to N deposition (Lilleskov *et al.*, 2011), with the genera *Cortinarius*, *Tricholoma*, *Piloderma* and *Suillus* particularly negatively impacted by high levels of N, and a general shift from mycorrhiza that scavenge for rare soil N ("*medium- to long-distance exploration types*") to mycorrhiza that take in more abundant soil nitrogen ("*contact, short-distance, and medium-distance smooth types*"). These changes in mycorrhiza have potential implications for tree growth and leaf nutritional value, although more research is required. Mitchell *et al.* (2005) show that Atlantic Oakwoods – the typical woodland type found in much of Wales – are especially vulnerable to N deposition because of their high diversity and biomass of lichens and bryophytes.

Some of the changes to the plants and fungi that make up terrestrial ecosystems, described above, result in changes to the fauna of those ecosystems as well. Kurze *et al.* (2018) demonstrated significantly lower survival of six common grassland butterflies and moths to adulthood under conditions of raised N. Their N treatments are consistent with direct fertiliser application but also match deposition levels close to some agricultural ammonia sources. Their paper "*contradicts the well-accepted nitrogen-limitation hypothesis, which predicts a positive response in species performance to dietary nitrogen content*" and provides "*the first evidence that current fertilization quantities in agriculture exceed the physiological tolerance of common Lepidoptera species.*" The reduced survival of common lepidoptera is consistent with the changes in butterfly abundance and diversity observed over recent decades in the Netherlands, where a longterm trend towards an N-tolerant guild of butterflies has recently been reversed, in parallel to recent N pollution reduction in that country, leading to slight recovery of some declining species (Wallis de Vries & van Swaay, 2017). The links between changes in lichen abundance and invertebrate abundance are still only partially investigated, although Pescott *et al.* (2015) showed significant increases in lichen-feeding moth species in parallel with increases in lichen abundance following reductions in SO_2 pollution. However, the complex interplay between SO_2 reduction and N increase – causing some invertebrate species to increase and others to decline – remains an evidence gap requiring research.

Large declines in woodland birds over recent decades are believed to be caused by a suite of different factors, including climate change, habitat modification by deer, predation pressure by squirrels, corvids and great spotted woodpeckers, and a reduction in invertebrate food numbers (Fuller *et al.*, 2005). If the declines in common grassland lepidoptera reported by Kurze *et al.* (2018) are replicated in woodlands (a subject of ongoing research) then N deposition may also be a contributory factor to woodland bird decline. Fuller *et al.* (*loc. cit.*) also consider a reduction in lichen abundance as a potential factor in woodland bird declines, but rule it out because declines are also ongoing in areas of Britain with historically low lichen abundance; however, the dominance of other factors in some areas does not mean that lichen abundance is never a contributory factor. Lichen-rich forests do support a greater abundance of invertebrate prey (Petterson, 1996), especially spiders that form a significant part of birds' diets in winter (Norberg, 1978) and damage to epiphytic lichen communities by N deposition is therefore likely to contribute to woodland bird declines in those areas where lichens are currently abundant.

Although biodiversity loss is viewed by many people as undesirable, N pollution also causes fundamental changes to the ability of ecosystems to provide services to the population. Jones *et al.* (2014) show that reductions in N pollution in Britain between 1987 and 2005 led to a slight loss in provisioning services (crop growth and timber growth) but that this was outweighed by improved cultural services (water quality in upland streams and biodiversity). The net benefit (as Equivalent Annual Value) due to declining N deposition was £65m (range £5m to £123m, 95% confidence intervals).

f) Effects of N pollution on lichens

The ecosystem changes described above demonstrate why control of N pollution is essential and backs up current evidence-based regulation. However, lichens are especially sensitive to N pollution and require enhanced protection. The current Evidence Report focusses on lichens for a suite of reasons:

- there is a strong scientific evidence base surrounding the effects of N on lichens;
- lichens have been shown to be among the most sensitive of all organisms to N pollution;
- lichens have a direct link to the atmosphere because they are poikilohydric (their water and nutrients are taken in directly from the atmosphere and rainfall rather than through a root system);
- many lichens react rapidly to environmental change, either increasing or declining when conditions are suitable;
- effects on lichens can be observed macroscopically, whereas more detailed study is needed to determine changes in diatom abundance or grass biomass;
- lichens are a key part of ecosystem integrity in many terrestrial and freshwater environments.

The role of lichens in terrestrial ecosystems is varied and often highly important. In upland areas they are the key colonists of exposed rock, along with bryophytes, and play a role in soil formation. Larger lichens in watercourses trap sediment, whilst lichens provide significant cover in many dry grassland and heathland ecosystems. Lichen cover in the built environment accumulates particulates (Bergamaschi *et al.*, 2007) and aesthetically provides 'cultural' services. Epiphytic lichens play perhaps the most obvious role in ecosystems because of their structural diversity and sheer biomass (Ellis *et al.*, 2015): a "*community of epiphytic lichens may be viewed as a* *miniature woodland on the surface of a tree itself (Shorrocks et al., 1991)*". As stated above, they provide key habitat for invertebrates (Gunnarson et al. 2004) and thus increase the food resource for birds (Norberg, 1978). Epiphytic lichens and bryophytes may increase canopy water uptake by around 50% (Knops et al. 1996), increasing rainfall interception and thus reducing erosion and flash-flooding. In a natural, unpolluted forest, cyanobacteria in lichens make nitrogen biologically available in the forest ecosystem (Antoine, 2004).

Stevens *et al.* (2012) showed that changes in the distribution of some terricolous lichens across Britain correlate with the national pattern of N deposition (Fig. I5), and that N deposition is causing changes in species composition in lichen-rich grassland, heathland and bog habitats. Their research also analysed the effects of climate change, changes in SO_2 pollution and land use change, and concluded that "*even low levels of nitrogen deposition could be damaging terricolous lichen communities*". The *New Forest Lichen Survey* (Sanderson, 2017) discusses air pollution effects on heathland lichens (pp. xi–xii), and highlights competition from the non-native moss *Campylopus introflexus* as a cause of lichen decline, along with direct reduction in the survival of some *Cladonia* species (Sparrius, 2011). However, Sanderson found no correlation between the generally low ammonia levels in the New Forest (0.72 µg/m^3 to 1.51 µg/m^3) and terricolous lichen diversity and considered management history to be a much more significant factor. Monitoring of Thursley Common (Nisbet *et al.*, 2017) has shown terricolous lichens are recovering well from a fire there in 2006, despite spring ammonia concentrations being as high as 1.6 µg/m^3, although the relative frequency of different *Cladonia* species has not yet been established. Different N sensitivities between species, difficulties over the identification of many *Cladonia* species and the relative restriction of terricolous lichens to semi-natural habitats have all led to limited use of terricolous lichens for pollution monitoring in the UK, and the focus has instead been on epiphytic species.

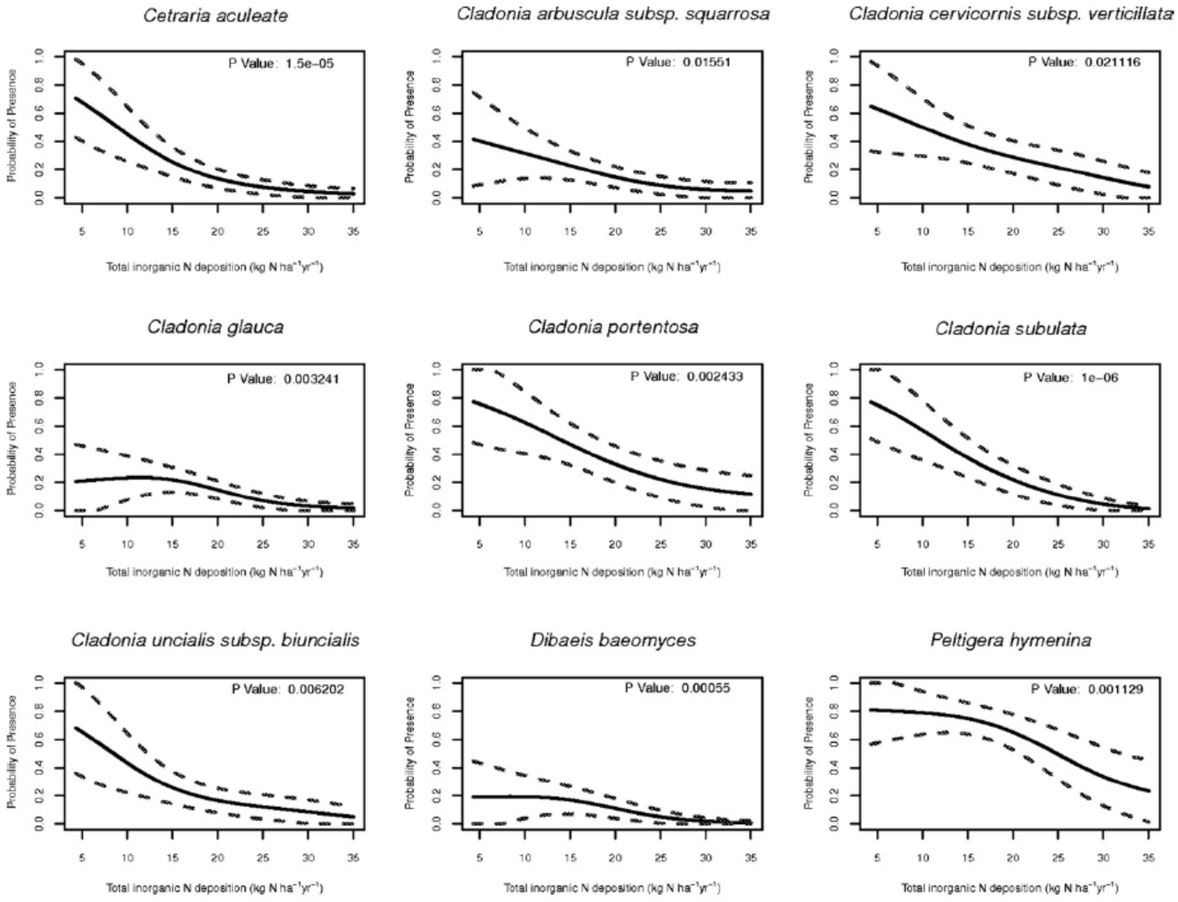


Figure I5: curves of probability of presence (vertical) against total N deposition (horizontal) for nine terricolous lichens that show significant negative relationships to N deposition (from Stevens *et al.*, 2012).

Until relatively recently, the use of epiphytic lichens to study air pollution focussed on the effects of SO_2. Sulphur Dioxide pollution had profound effects on much of southern Britain during the 19th and 20th centuries and governed the distribution of lichens to such an extent that many species of epiphyte were restricted to north-western areas that were remote from industrial SO_2 sources, and heavily polluted urban and industrial areas almost entirely lacked lichen epiphytes

(Hawksworth & Rose, 1976). The 'Hawksworth-Rose Scale' of lichen pollution tolerance focussed on SO_2 and was used to demonstrate both the distribution of 'clean air' and SO_2-tolerant lichens, and recolonisation of polluted areas as SO_2 levels fell in the late 20th century (Hawksworth & McManus, 1989).

Lichenologists in the Netherlands were among the first to document a rise in nitrophilous (N-loving) lichens alongside a return of species that had been lost because of SO_2 pollution (van Dobben & de Bakker, 1996). At this stage, British lichenologists were focussing more on the recovery in urban areas (e.g. Seaward, 1997) than on changes in rural landscapes where N levels were increasing. Van Herk (1999) developed a system for mapping ammonia pollution effects in the Netherlands using nitrophilous (N-loving) and acidophilous (N-sensitive) lichens, and this was used to inform the selection of species for lichen-based ammonia monitoring in Britain. Recording macrolichens on the trunks and twigs of oak or birch was found to be a consistent way of determining ammonia concentrations, with twig lichens being especially sensitive and able to "*act as a sensitive early warning system of changes in atmospheric* NH_3" (Wolseley *et al.*, 2009). Increasing ammonia levels caused changes in lichen community composition, including significant loss of N-sensitive species, as described for Coed Ty Canol NNR in west Wales over eight years (Larsen Vilsholm *et al.*, 2009). However, despite documentation of loss of N-sensitive species and an increase in N-tolerant species, there was no assessment of overall lichen biomass change or epiphyte structure change in the aforementioned studies.

Research in the Netherlands (van Herk, 2017) has shown an overall increase in lichen diversity, but the increase in diversity has been among crust-forming species that perform little in the way of ecosystem services, whilst there has been a significant decline larger lichens such as *Evernia prunastri* (from occurrence in 86% of samples to 59% of samples in 25 years). Van Herk (*loc. cit.*) also reports recent declines in N-loving lichen species in response to reductions in N pollution following regulation by the Dutch government, but no reduction in the loss of the larger N-sensitive species such as *Evernia* in his study area. Sparrius (2007) documented "*massive*" die-off of N-loving lichens following 7 years of ammonia reduction in another area of the Netherlands, but little recovery among N-sensitive species, although many N-tolerant (as opposed to N-loving) lichens did recolonise and overall lichen biomass increased.

Much experimental work on N pollution has been carried out in bog ecosystems, and the work of Wolseley *et al.* (2003) and van Herk (2017) focussed on differences in lichen abundance at areas of known N concentration or where N deposition was known. Experiments carried out by Johansson *et al.* (2012) in naturally N-poor spruce forest in Sweden is therefore powerful evidence of epiphytic lichen community change being caused by N deposition. They dosed spruce trees daily with N at concentrations equivalent to 0.6, 6, 12.5, 25 and 50 kg N ha^{-1} yr^{-1} (roughly equivalent to concentrations of 0.08, 0.77, 1.60, 3.21 and 6.41 µg/m^3 and therefore comparable to concentrations found in Welsh ecosystems), during four consecutive growing seasons (2006–2009), and found significant changes in the abundance of certain lichens including *Alectoria sarmentosa*, *Bryoria* spp. and *Hypogymnia physodes*. Overall lichen biomass fell substantially over the four seasons under the two highest doses, whilst biomass stayed roughly stable or increased at the lower three doses, but with species compositional change. They concluded that "*the significant changes in lichen community composition recorded even at 6 kg N* ha^{-1} yr^{-1} *[the second lowest dose] after only 4 years indicate that this moderate treatment is above the critical load of N* *deposition for boreal epiphytic lichen communities. This has not been experimentally demonstrated previously, but it strongly supports previously determined critical loads and confirms that lichen communities are among the most sensitive communities to N deposition*".

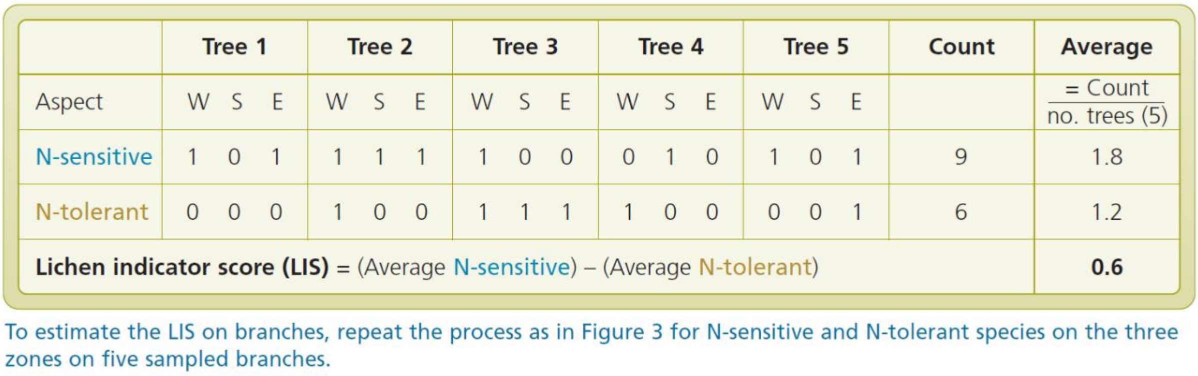
The Critical Level against which lichen-rich habitats are assessed is an annual mean, because there is robust science to demonstrate changes in lichen community composition and overall lichen biomass decline above the concentration of 1µg/m^3. However, Paoli *et al.* (2015) showed that both the photobiont (alga) and mycobiont (fungus) of the moderately N-sensitive *Flavoparmelia caperata* were damaged by acute three week periods at 100 µg/m^3 or 300 µg/m^3 ammonia, whilst the N-tolerant *Xanthoria parietina* was unaffected by the 100 µg/m^3 peak and only had its photobiont damaged during the period at 300 µg/m^3. *Flavoparmelia* is less N-sensitive than the species used as indicators by Wolseley *et al.* (2009), whilst the 100 µg/m^3 dose is higher than the current monthly 27 µg/m^3 Critical Level for ammonia; further work is needed to test the effects of acute ammonia exposure on more sensitive species.

III. Recent observations of ammonia impacts on lichens in Wales

g) The Twig Lichen Survey approach

Four of the surveys included in this report used the 'Twig Lichen Survey' methodology, which has been adapted slightly in terms of recording detail from the Field Studies Council 'Lichen App.' approach (Wolseley et al., 2019) but retains the same scoring system as that robust, peer-reviewed approach. This involves recording the presence of nitrogen-tolerant and nitrogen-sensitive lichens on three zones of the twigs of oak or birch trees: zone 1 is the relatively mature part of a twig, >100cm from the tip; zone 2 is 50-100cm from the tip; and zone 3 is the youngest part, <50cm from the twig's tip. The lichen species involved are all easy to identify, without the need for specimen collection or microscope work. The methodology has been adapted slightly for use in Wales: the presence of every N-sensitive or N-tolerant lichen within each twig zone, rather than the presence of any N-sensitive or N-tolerant species being recorded, and *Platismatia glauca* was recorded whenever present, but did not contribute to scoring because it was not included in the original 'Lichen App.'

Every zone that holds at least one N-sensitive lichen contributes 1 to an N-sensitive count, and every zone that holds at least one N-tolerant lichen contributes 1 to an N-tolerant count. There are three zones on each twig, and a survey comprises five twigs on an oak/birch or a group of oaks/birches; average N-tolerant and N-sensitive counts are therefore calculated for a twig by dividing the overall counts by five (Fig. I6). A 'Lichen Indicator Score' (LIS) for the tree/group is then calculated by subtracting the average N-tolerant count from the average N-sensitive count, and that LIS is then converted to a Nitrogen Air Quality Index (NAQI) using a regression line (Fig. I7). The NAQI allows trees or groups of trees to be assigned to one of four N pollution bands: 'Clean air' trees show very few signs of N pollution; 'At risk' trees show a mix of N-tolerant lichens and N-sensitive lichens; 'N-polluted' trees have their branches dominated by N-tolerant species but retain some N-sensitive lichens; and 'Very N-polluted' trees generally lack N-sensitive lichens entirely, and may have macrolichens replaced by a thin layer of algae and crustose lichens, or may even lack epiphytic lichens entirely.



	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Count	Average
Aspect	W S E	W S E	W S E	W S E	W S E		= Count / no. trees (5)
N-sensitive	1 0 1	1 1 1	1 0 0	0 1 0	1 0 1	9	1.8
N-tolerant	0 0 0	1 0 0	1 1 1	1 0 0	0 0 1	6	1.2
Lichen indicator score (LIS) = (Average N-sensitive) – (Average N-tolerant)							**0.6**

To estimate the LIS on branches, repeat the process as in Figure 3 for N-sensitive and N-tolerant species on the three zones on five sampled branches.

Figure I6: an example of how to calculate a Lichen Indicator Score, from Wolseley *et al.* (2019).

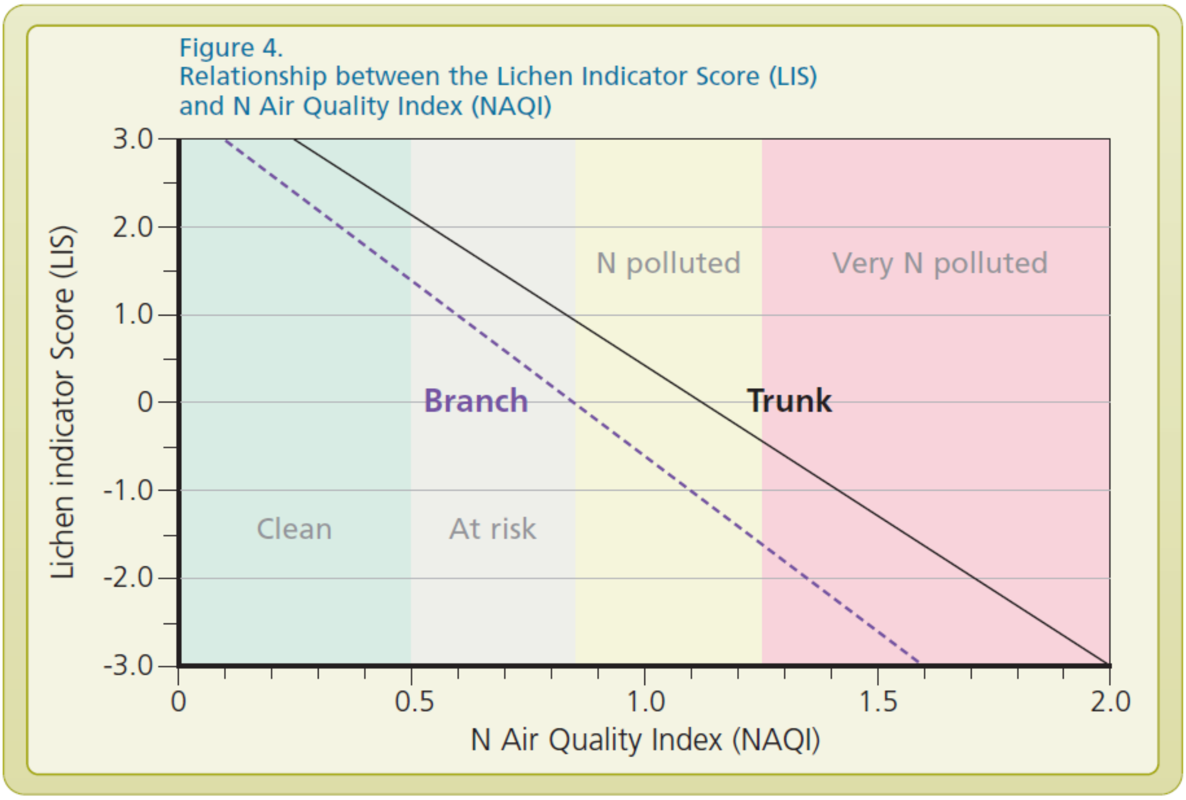


Figure I7: regression line for converting Lichen Indicator Scores to Nitrogen Air Quality Index figures, from Wolseley *et al.* (2019).

h) Observations covered in Reports 1 to 7 of Evidence Report 298

Epiphytic lichens are not only affected by activities in the woodland or parkland in which they grow, they also react to landuse in adjacent fields. Report 1 documents loss of sensitive species from a SSSI parkland following 20 years of slurry spraying on the adjacent silage field, although an unfortunate lack of monitoring means that the timing of this loss – rapid loss within a few years of the commencement of slurry spreading or slow loss over a decade or more – is not known. Report 2 uses the Twig Lichen Survey approach to show a gradient from 'Very N-polluted' to 'At risk' trees running into this SSSI from the adjacent silage field. The 'At risk' oak trees within the SSSI support more diverse and abundant lichen epiphytes than the 'Very N-polluted' oaks – indeed some of the latter support just a thin crust of lichens and algae on their twigs and lack macrolichens entirely – but have N-tolerant lichen species growing alongside N-sensitive species, with complete loss of N-sensitive epiphytes on some branches.

Dry deposition of ammonia occurs within a few hundred metres of ammonia sources, although long-distance wet deposition also arises from ammonia pollution. 'Zero-input zones' where there are no agricultural sources of ammonia (e.g. livestock sheds, manure stores or manure spreading) can provide protection for sites where sensitive ecosystems occur, although these need to be sufficiently wide to avoid incursions of ammonia. Report 3 presents an example of a ca. 500m wide 'zero-input zone' protecting the heart of a SSSI parkland (where the trees are assessed as 'Clean air') but records ammonia enrichment on the edges of the SSSI (trees are 'At risk'). In contrast, the parkland SSSI covered by Report 4 has silage fields and high-nutrient pasture adjoining the SSSI, along with three poultry sheds within 2.2 km; the entire SSSI is 'N-polluted' or 'At risk'. The relative roles played by the poultry sheds and closer dairy farms require further assessment and modelling.

Impacts of increased N on epiphytic lichens are found in oceanic woodland habitats as well as parklands. Report 5 describes abundant twig lichens in the lower part of an SAC woodland in north-western Powys, replaced by scanty twig lichens and locally abundant ‘algal gunk’ (rampant growth of algae and/or cyanobacteria that smothers other plants) in the upper part of the wood, a short distance from intensively managed fields and within 4 km of a poultry farm.

A wider view of impacts on SSSI in Powys (eastern mid Wales) is given in Report 6, with Twig Lichen Surveys covering the ‘Clean air’ uplands of the Cambrian Mountains and the more N-polluted lowlands. Powys is the area of Wales in which poultry developments are most abundant, although Fig. I2 shows that ammonia sources are greater in Dyfed (eastern Pembrokeshire and western Carmarthenshire), and further investigation is required in that area. Finally, Report 7 documents real declines in three ammonia-sensitive lichens in Wales, including a significant (between 31% and 57%) reduction in number of occupied sites and area of occupancy of the robust epiphytic lichen *Bryoria fuscescens*.

Figure I8: map of the sites covered by reports 1 to 6.

i) Other recent observations from Wales

Ongoing studies of epiphytic lichens in Wales reinforce the picture presented in reports 1 to 7. Volunteers from the *CENNAD* lichen apprenticeship scheme (run by Tracey Lovering from Plantlife and supported by experts from the British Lichen Society) have carried out Twig Lichen Surveys of 85 trees or groups of trees across Wales since late 2017. These largely back up modelled ammonia concentrations presented on www.apis.ac.uk, but in some cases show local variation in ammonia levels that is too fine-scale to be apparent in the CBED modelling presented by APIS.

At Coed Ty Canol NNR, the site studied by Larsen Vilsholm *et al.* (2009), some trees indicate 'Clean air' conditions whilst locally frequent nitrophiles show that others nearby are 'At risk', reinforcing the observations from 2009 that N pollution from surrounding landuse is affecting this lichen-rich SSSI. At Bradnant and Brynposteg in Powys, there is variation between 'Clean' and 'N-polluted' according to location, in an area where www.apis.ac.uk reports ammonia concentrations as being below the Critical Level for lichen-rich ecosystems. Birch trees on the eastern edge of Gilfach Nature Reserve in Powys – just to the west of the Powys Pilot Area study of Aazem & Bareham (2015) – all support nitrophilous species alongside N-sensitive lichens and are 'At risk'. True 'Clean air' areas have been demonstrated by *CENNAD* Twig Lichen Surveys in the Woodland Trust's Coed Dolifor reserve (SN9665) near Rhayader, the 'waterfalls' area in the Brecon Beacons National Park (SN9110), near Llyn Alwen (SH9651) in north-east Wales and at Cwm Fron (SN9680) near Llanidloes, and doubtless remain widespread in the more remote parts of Wales.

Twig Lichen Survey demonstrates the high levels of N at two of the most important SSSI for plants and bryophytes in Powys: Stanner Rocks NNR and Roundton Hill Nature Reserve. At Stanner Rocks, all surveyed oak twigs support nitrophilous lichens, including abundant *Physcia* and *Xanthoria*, and almost entirely lack N-sensitive species, leading to their classification as 'Very N-polluted'; even mature branches hold few N-sensitive lichens. This indicates that N levels at Stanner are already so high that lichens are being adversely affected, and implications for its mosses, liverworts and flowering plants – including three species found nowhere else in Britain and several others with fewer than 10 known British colonies – are dire, both because of direct N toxicity and because of enhanced vascular plant growth. The same is true at Roundton Hill, which supports two mosses listed on Section 7 of the Environment (Wales) Act 2016: abundant nitrophilous lichens on oak twigs indicate 'N-polluted' conditions, and 'algal gunk' encrusts cushions of the Section 7 moss *Weissia levieri*.

The decline of *Bryoria fuscescens* in Wales (Report 7) is paralleled by a decline in the N-sensitive lichen *Cetraria sepincola*, which is very rare in Britain south of Scotland and has its last remaining Welsh site at Cors y Llyn NNR. Monitoring of this lichen commenced in 1998, and repeat monitoring in 2019 (Bosanquet, 2019) showed significant declines in almost every part of the reserve. The only area in which *C. sepincola* continues to thrive is sheltered from surrounding agricultural land use by a band of conifers, wheras the remainder of the site – which appears to have 'Clean air' according to the Twig Lichen Survey method – receives some ammonia drift and has abundant algae on almost all birch twigs. The decline of *C. sepincola* even when other N-sensitive lichens such as *Usnea* spp. and *Evernia prunastri* are abundant is a reflection of the difference in N tolerance even among N-sensitive species.

Agriculture is not the only source of ammonia, and a study by Bosanquet (2018) showed that thousands of pheasants released in one area of Allt y Gest SSSI in south-wetern Powys for a season between 2016 and 2017 caused localised N enrichment, leading to 'free' algae covering crustose lichens and algal encrustation of larger lichens. Other than this localised enrichment, Twig Lichen Survey showed Allt y Gest SSSI, near Beulah, to have 'Clean air'.

Natural Resources Wales continue to record and monitor epiphytic lichens across Wales, and use the Twig Lichen Survey method to demonstrate ongoing impacts from N pollution and to identify areas that are particularly sensitive to N pollution.

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Report 1) Parc Pont-faen SSSI – a visit to assess slurry impacts in 2017

1.1 Introduction

1.1.1 Background

Parc Pont-faen SSSI was notified in 1979 and renotified in 1983. The citation describes the site as "an old parkland containing many ancient trees, mainly sessile oak Quercus petraea, rich in epiphytic lichens", and says that "the lichen flora includes the tree lungwort 'Lobarion' community which, in mid Wales, only occurs on old trees in ancient woodland and parkland." The citation explicitly states that "of particular interest is the lichen *Anaptychia ciliaris*".

A 1998 report by Steve Chambers – a national lichenexpert and county lichen recorder for Cardiganshire – said that *Anaptychia ciliaris* had been found on a single tree: an oak close to the main Lampeter to Aberaeron road in the north-western field of the SSSI (Chambers, 1998). But "neither Ray Woods nor Steve Chambers [could] refind the species here (or indeed the tree Ray climbed to discover it on in1975) beside the main road close to a style or gate" according to the Lichens of Wales Website (http://wales-lichens.org.uk/species-account/anaptychia-ciliaris-subsp-ciliaris accessed 10th March 2017). A 2016 survey by national lichen expert Alan Orange did not relocate the *Anaptychia* and included the observation that "*Ramalina* species on this tree were well-grazed by molluscs, and it is possible that *Anaptychia* has been grazed away" (Orange, 2016). Several other notable lichens recorded from the site in the 1970s, such as *Lobaria scrobiculata* and *Nephroma laevigatum*, were not relocated in either 1998 or 2016. Orange (*loc. cit.*) said that "there have been no drastic changes in the site or its lichen flora" since 1998, and that the reason for the [apparent] loss of *Anaptychia* "cannot be attributed to any aspect of management." He also noted that "*Diploicia canescens* may be an indicator of nutrient-enrichment; it is less abundant in the wood pasture than in the valley, and is absent from some trees, but locally abundant on others".

In late February 2017, Natural Resources Wales were alerted to slurry spreading within the SSSI boundary. A visit by Miguel Ortuno (NRM Officer for North Ceredigion) confirmed that slurry spreading had taken place and that there was slurry on the base of the tree on which Steve Chambers had seen *Anaptychia ciliaris* in 1998. The Site Management Statement states that "Spraying of herbicides and fertilizers should be avoided within close proximity to the parkland trees and where possible, should be discouraged on adjacent fields", whilst the 1983 PDO list said that site managers should contact CCW (a predecessor body of NRW) if there were any changes in management including "Dumping, spreading or discharging of any waste materials".

1.1.2 Methods

Sam Bosanquet visited Parc Pont-faen SSSI with Miguel Ortuno on 3rd March 2017 in order to assess whether the slurry spreading was likely to have affected the SSSI lichen feature. The two trees that MO had seen slurry on were examined for approximately 40 minutes, with most time spent on the tree nearest to the road as that was where *Anaptychia ciliaris* had previously been seen. The lowest part of each trunk was examined, and SB also climbed carefully on to the lowest branches of the roadside tree in order to check above head height. Notes and photographs were taken, but no specimens were collected because of Alan Orange's thorough 2016 survey.

1.2 **Results**

1.2.1 Observations in 2017

The tree closest to the road (1/1 in Orange, 2016) retains a good cover of lichens on its lower trunk, branches and canopy. The lichen assemblage is similar to that noted by Orange (*loc. cit.*), as would be expected, with species such as *Schismatomma decolorans*, *Chrysothrix candellaris*, *Parmelia* spp. (recorded as *P. ernstiae* by Orange, 2016) and *Pertusaria hymenea*. The nitrophilous *Diploicia canescens* was locally frequent on the west side of the trunk (Figs. 1.1 & 1.2), but was otherwise sparsely distributed; a single tiny thallus of the nitrophilous *Xanthoria parietina* was noted (Fig. 1.3). The lichen identified by Orange (*loc. cit.*) as *Dirinia massiliensis* grows on the base of the oak (Fig. 1.4), where it was partly buried by remnants of slurry (Fig. 1.5) and was covered by a thin film of green algae (Fig. 1.6).

Figures 1.1 & 1.2: *Diploicia canescens* on the Oak where *Anaptychia ciliaris* grows at Parc Pont-faen SSSI.

There was no *Anaptychia ciliaris* visible below head height on the roadside oak, but careful climbing on to the lowest branches allowed access to a higher section of the trunk where a 20x20cm patch of moribund *Anaptychia* was found and photographed (Figs. 1.7–10). Further examination of the middle trunk of the oak produced a few more scraps of *Anaptychia* about 20 cm at 2 o'clock from the main patch. A ladder would be needed to establish whether additional patches are present higher up the trunk.

Figure 1.3: *Xanthoria parietina* at Parc Pont-faen SSSI; Figure 1.4: putative *Dirinia massiliensis*.

Figure 1.5: *Dirinia massiliensis* spattered with slurry; Figure 1.6: *Dirinia massiliensis* with a film of algae.

The tree closest to the one on which *Anaptychia ciliaris* grows – tree 1/2 of Orange (2016) – is further from the field boundary and closer, therefore, to the edge of the SSSI. It supports abundant *Diploicia canescens* and has a limited lichen assemblage, although small patches of *Pertusaria* and *Parmelia* were seen on the south side of the trunk. Slurry was more extensively present on the base of this tree (Figs 1.11 & 1.12), overlapping some of the *Diploicia*; there was a strong smell of slurry.

Figures 1.7 & 1.8: location and extent of the main patch of *Anaptychia ciliaris* at Parc Pont-faen SSSI.

Figures 1.9 & 1.10: moribund *Anaptychia ciliaris* at Parc Pont-faen SSSI in March 2017.

Figure 1.11: slurry on the in-field tree (1/2) at Parc Pont-faen; Figure 1.12: slurry on *Diploicia canescens*.

Only one tree in the remainder of the SSSI was examined by SB because of AO’s recent survey. This was an Oak where MO had noted a pile of cut branches stacked against the trunk (Fig. 1.13). SB examined the lichens on the branches and found only common species such as *Parmelia sulcata* and species of *Ramalina* (Fig. 1.14).

Figure 1.13: branch pile by oak at Parc Pont-faen; Figure 1.14: *Parmelia sulcata* on the branch pile.

1.3 Discussion & conclusions

1.3.1 Impacts of slurry on the lichen assemblage

Cattle slurry was seen and photographed on the base of two trees – 1/1 and 1/2 of Orange (2016) – overlying lichens such as *Diploicia canescens* and *Dirinia massiliensis*. Slurry is a highly effective fertiliser and produces Nitrogen compounds that are beneficial to silage crop grasses but have been shown to profoundly alter lichen assemblages, for example replacing the Parmelion and Usneion communities with the nitrophilous Xanthorion (Wolseley *et al.* 2003). "Sensitive lichen species, such as *Usnea*, *Bryoria*, and *Cladonia* were found to be lost at even modest ammonia concentrations, while nitrogen loving species, particularly *Xanthoria* increased at their expense" (Sutton *et al.* 2009). The thin film of algae overlying lichens close to the remaining slurry (Fig. 1.6) is considered to be a direct result of the slurry application and is similar to the rapid algal blooms visible in waterbodies that receive a sudden, large input of ammonia and related Nitrogen compounds. A repeat visit later in the season will be needed to assess whether this short-term bloom of algae on the lichens has resulted in long-lasting damage or not.

The discovery that *Anaptychia ciliaris* is still present on the tree where it was seen in 1998 is encouraging, although its moribund appearance is of significant concern. Steve Chambers (pers. comm.) considered that the tips of the thalli appear alive in the photograph, so there are "grounds for hope" that this rare lichen will continue to survive. It was present for three years in Aberystwyth, where it was accidentally introduced on an imported oak, but declined to extinction there by 2017. The Parc Pont-faen colony is therefore still the only extant one in Cardiganshire.

Scattered populations elsewhere in Wales are in decline according to http://wales-lichens.org.uk/species-account/anaptychia-ciliaris-subsp-ciliaris (accessed 10th March 2017) because of atmospheric pollution. Ray Woods (pers. comm.) said that the strongest population has become overwhelmed by algae since the construction of a chicken unit very near by. It is quite possible that the moribund appearance of the Parc Pont-faen SSSI population is a direct result of ammonia enrichment from slurry spreading immediately adjacent to the SSSI, as this has taken place annually since 1992 according to the farmer (J. David pers. comm.). However, mollusc grazing may be partly or even entirely at fault.

The branches piled against a parkland tree in the eastern part of the SSSI did not support any lichens of note, and no damage to the SSSI lichen feature had taken place when the fallen branch was cut up. Piling fallen wood close to tree bases is often considered good management practise in parklands, although this particular pile of wood was too close to the trunk.

1.3.2 Implications for site management

Evidence shows that ammonia has severe negative impacts on populations of lichens other than a small number that are nitrophilous. Slurry applications have taken place annually adjacent to Parc Pont-faen SSSI since 1992 and two lichens that are known to be sensitive to atmospheric pollution – *Lobaria amplissima* and *Nephroma laevigatum* – have been lost from the site, whilst *Anaptychia ciliaris* has become moribund. There is no direct evidence to link these two occurrences, and the loss of *Lobaria* and *Nephroma* may have resulted from Sulphur Dioxide pollution before the change from farmyard manure to slurry had even taken place. A good number of other notable lichens, many of which are considered to be nutrient intolerant, are still present on the site (Orange, 2016).

The changes caused by ammonia to lichen populations are so profound, however, that continuing slurry applications adjacent to the SSSI are highly likely to cause (further) damage. The Site Management Statement suggests that there should be no inputs of fertiliser on the SSSI and that ideally there should be no inputs nearby, and the PDO list identifies “Dumping, spreading or discharging of any waste materials” as a Potentially Damaging Operation (now an Operation Likely to Damage the Special Interest; OLDSI). Somehow, these requirements have gradually morphed from zero inputs via inputs of farmyard manure to annual slurry applications, with supplementary stock feeding photographed by Orange (1998); unless this trend is reversed, it is highly likely that the lichen assemblage which makes this SSSI special will continue to deteriorate. A clearly marked boundary for slurry application is needed immediately, but thought should also be given to removing slurry applications entirely from the field that is part SSSI; direct drilling of slurry or spreading when the wind is north-easterly might slightly reduce impacts, but high levels of ammonia will still result from the presence of slurry in the field.

1.4 References

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Report 2) Parc Pont-faen SSSI – twig lichen survey 2017

2.1 Introduction

2.1.1 Background

Parc Pont-faen SSSI was notified in 1979 and renotified in 1983. The citation describes the site as “an old parkland containing many ancient trees, mainly sessile oak Quercus petraea, rich in epiphytic lichens”, and says that “the lichen flora includes the tree lungwort ‘Lobarion’ community which, in mid Wales, only occurs on old trees in ancient woodland and parkland.” The citation explicitly states that “of particular interest is the lichen *Anaptychia ciliaris*”.

Following concerns over the condition of the lichen SSSI, NRW commissioned a full survey of epiphytic lichens in 2016 (Orange, 2016). Some of the notable species recorded by previous visitors, including *Anaptychia ciliaris*, *Lobaria scrobiculata* and *Nephroma laevigatum* were not relocated, but old woodland lichens such as *Cresponea premnea*, *Pachyphiale carneola* and *Schismatomma cretaceum* remained, and Orange (*loc. cit.*) concluded that “there have been no drastic changes in the site or its lichen flora” since 1998. Both the *Lobaria* and *Nephroma* had already been lost by 1998 (Chambers, 1998), but the loss of *Anaptychia* at its only Ceredigion site was a significant problem. Bosanquet (2017) relocated the *Anaptychia* colony in March 2017 but found it moribund; a return visit in August 2017 showed no improvement in the condition of the remaining scraps of *Anaptychia*.

Ongoing increases in ammonia concentrations in Wales combine with ever-expanding intensive agriculture – increased use of cattle slurry in silage fields and increased development of large poultry sheds – to present significant threats to lichens in Wales. Increased concentrations of ammonia have been demonstrated to cause wholesale changes in epiphyte composition (Wolseley *et al.*, 2003; Sutton *et al.*, 2009), including loss of many sensitive species. The loss of *Lobaria* and *Nephroma* from Parc Pontfaen SSSI prior to 1998 might be the result of ammonia pollution, although Sulphur Dioxide pollution is believed to have caused the loss of *Lobaria* on other Welsh sites in that period; the moribund nature of the *Anaptychia ciliaris* colony was also tentatively linked to slurry applications that have taken place adjacent to the SSSI since 1992. A visit by SB to Parc Pontfaen SSSI on 23rd August 2017 focussed on assessing the ammonia pollution levels across the SSSI, to elucidate whether there are likely to be links between slurry applications adjacent to the site and epiphyte loss within the SSSI.

Figure 2.1: a group of oaks on the banc at Parc Pontfaen.

2.1.2 Methods

Wolseley et al. (2017) have produced a standard method for measuring impacts on a site’s lichens from ammonia. This tried and tested method, accessible from the www.apis.ac.uk website, was used at Parc Pontfaen. The survey method involves recording the presence of nitrogen-tolerant and nitrogen-sensitive lichens on tree trunks or twigs on groups of five oak or birch trees. The lichen species involved are all easy to identify, without the need for specimen collection or microscope work. Five oak trees in three areas of Parc Pontfaen SSSI were selected, giving a rough transect from the heart of the SSSI ‘banc’, where there have been no direct nutrient inputs for many years, to the northern field where manure has been spread in the past and thence to the north-western field where slurry spreading has taken place since 1992 (J. David pers. comm.). Only twig lichens were recorded, because a similar survey at Dinefwr Park SSSI (Bosanquet, 2017b) found that the twig results showed more clear-cut patterns than trunk results, with sensitive species apparently surviving in deep bark crevices on trunks that were already showing significant signs of enrichment.

2.2 Results

2.2.1 The 2017 twig lichen survey

Recording of twig lichens at five locations across the SSSI allowed calculation of Lichen Indicator Scores for these trees (see Appendix 1 for full data). The lowest LIS score was -2.0, for the twigs in the north-west field, whilst the highest was 0.0 for one tree on the banc. Wolseley et al. (2017) give a system for converting these LIS values to a Nitrogen Air Quality Index (NAQI), based on their UK-wide survey (Fig. 2.2). The NAQI for the trees shows a range from ‘At risk’ to ‘Very N polluted’ (Table 2.1; Fig. 2.3).

Table 2.1: Lichen Indicator Scores (LIS) and Nitrogen Air Quality Indices (NAQI) for trees at Dinefwr Park and nearby farms, using the methodology of Wolseley et al. (2017) (see Appendix 1 for full data). NAQI are coloured to match Figure 5: green=Clean; blue=At Risk; yellow=N Polluted; red=Very N Polluted.

Tree	Notes	LIS	NAQI	Pollution level
Pontfaen 1	Banc (zero input)	-0.8	1.0	N polluted
Pontfaen 2	Banc (zero input)	-1.8	1.3	Very N polluted
Pontfaen 3	Banc (zero input)	0.0	0.8	At risk
Pontfaen 4	N Field (regular manure)	-1.8	1.3	Very N polluted
Pontfaen 5	NW Field (regular slurry)	-2.0	1.4	Very N polluted

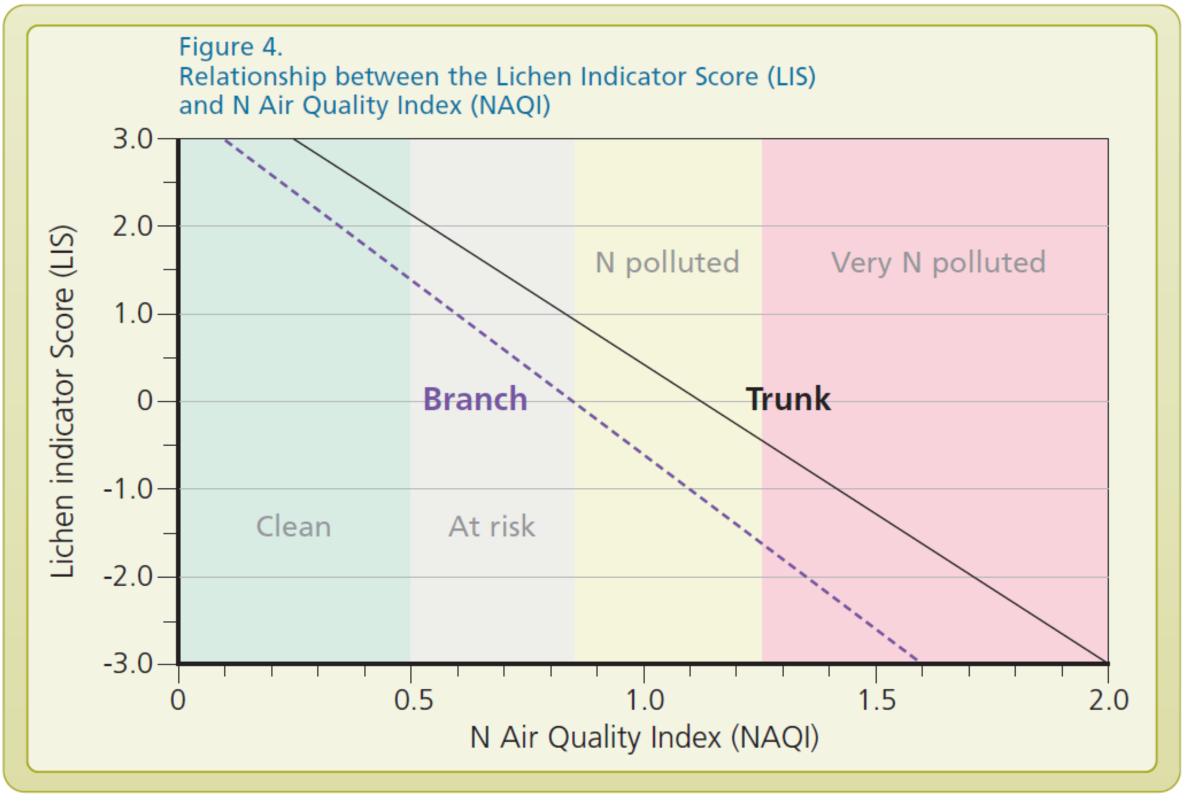

Figure 2.2: the Nitrogen Air Quality Index derived from the LIS score according to Wolseley et al. (2017).

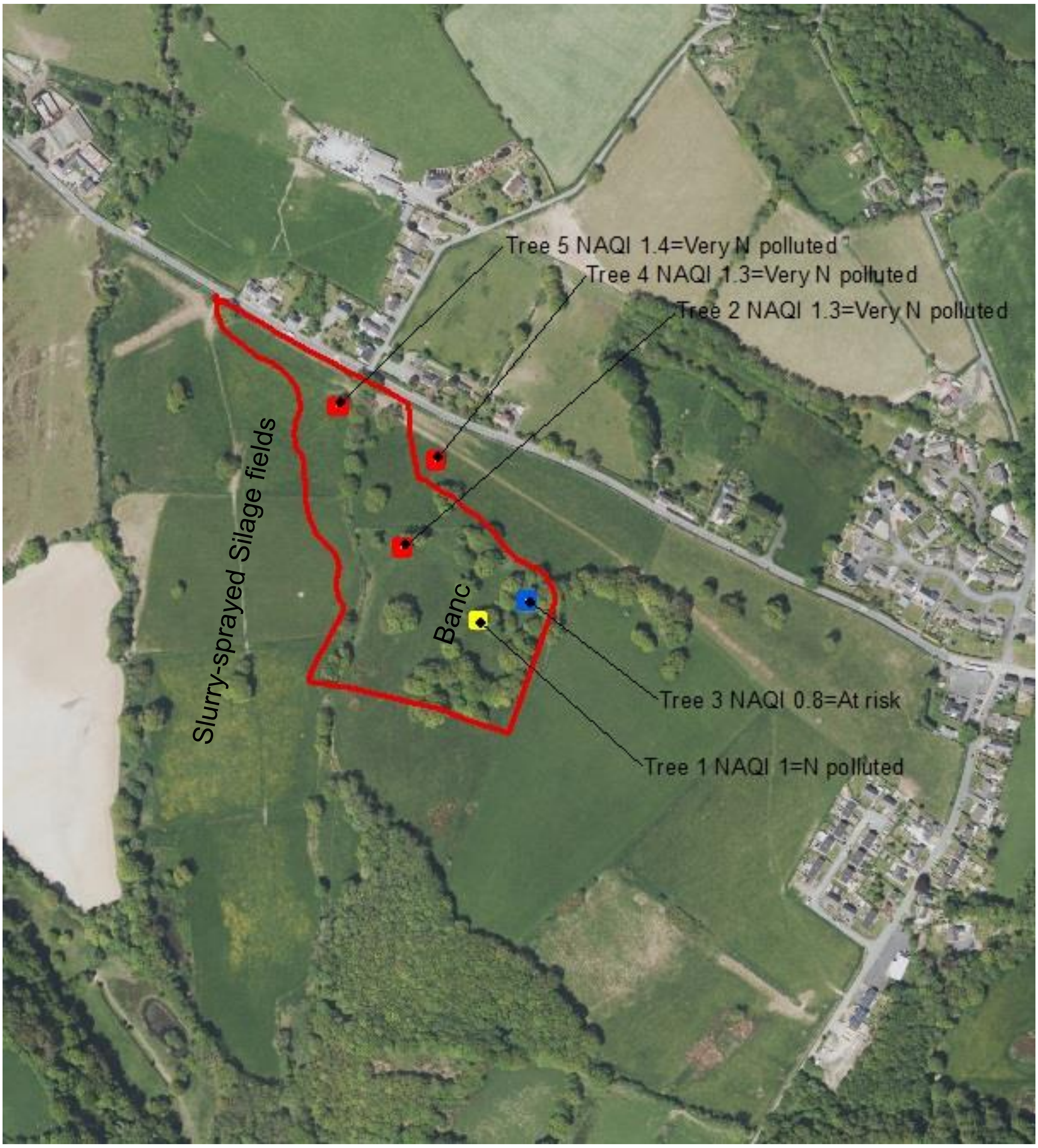

Figure 2.3: NAQI scores for 5 trees in Parc Pontfaen SSSI (red boundary). Tree locations are coloured according to the NAQI score: red = Very N polluted; yellow= N polluted; blue = At risk; green = clean.

2.3 Discussion & conclusions

2.3.1 The condition of twig epiphytes

The twig lichens at Parc Pontfaen include constant ammonia-tolerant species such as *Physcia tenella* and *Xanthoria parietina*, and only sparse representations of ammonia-sensitive species (see Appendix 1 of original report). Ammonia-sensitive species such as *Evernia prunastri*, *Parmelia sulcata* and *Usnea* sp. are almost completely absent from the northern two trees (4 & 5), which have a long history of manure and slurry application close to their canopies; the lower branches and twigs of those trees almost entirely lack macrolichens except on their north-east sides (facing away from the silage fields). Instead of macrolichens, the epiphyte flora on these lower branches is composed of a thin crust of *Arthonia radiata* (Fig. 2.4), in a much more profound example of epiphyte loss than those noted at Dinefwr (Bosanquet, 2017b) or the ammonia-polluted parkland at Gregynog SSSI. This almost total lack of epiphytes will preclude any ecosystem services performed by lichens, such as nutrient cycling, water retention and invertebrate sheltering (thus removing a foodsource for birds).

Figure 2.4 (left): a thin crust of lichens on very polluted branches; Figure 5 (right): macrolichens including *Hypogymnia physodes* and *Parmelia sulcata* on an ‘At risk’ branch.

The epiphyte flora is less degraded in the banc field, which forms the heart of the SSSI. Ammonia-sensitive lichens including the indicator species *Evernia prunastri*, *Hypogymnia physodes* (Fig. 2.5), *Parmelia sulcata* and *Usnea* sp. are present, and occur in reasonable abundance on a few branches, although the growth of *Usnea* in particular is very patchy. However, ammonia-tolerant lichens are abundant on every oak twig on the banc, and the twigs represent the 'Physcion' and 'Xanthorion' assemblages typical of ammonia polluted areas. One remarkable feature of the twigs in the lower part of the banc is an abundance of *Ramalina fastigiata* (Fig. 2.6): a distinctive lichen of base-rich, nutrient-rich bark that would not normally be expected to occur on oak. The transition between an ammonia-sensitive epiphyte assemblage composed of *Usnea*, *Evernia* and *Parmelia* and an ammonia-tolerant mix of *Physcia* spp. and *Xanthoria parietina* might be regarded as esoteric, and solely the concern of lichen specialists, although it does highlight the pollution that is affecting the entire parkland ecosystem. The structural diversity of epiphytic lichens is lower in the ammonia-tolerant assemblages, providing a lower capacity for water retention and less of a niche for invertebrates to exploit. Pescott *et al.* (2015) have showed that there are complex interrelationships between epiphyte abundance and invertebrate diversity and abundance, and invertebrates are (like lichens) a key part of a healthy parkland/woodland ecosystem. Notwithstanding the potential for ecosystem change, the deteriorating twig lichen flora is likely to be a precursor to (further) deterioration of the trunk epiphyte assemblage for which Parc Pontfaen SSSI was notified, as trunk epiphytes decline more slowly under increased ammonia concentrations but do gradually change (Pat Wolseley *in litt.*).

Figure 2.6: orange *Xanthoria parietina* and large tufts of grey *Ramalina fastigiata* on tree 2.

The report by Orange (2017) includes a map of notable lichens (Fig. 2.7), with most species present on the banc but a number on trees in the silage fields. This map requires some interpretation, in part because it does not show trees that were surveyed and have limited lichen interest and in part because some of the notable lichens are not necessarily sensitive to ammonia pollution. Notable lichens in the silage fields are *Anaptychia runcinata*, *Dirinia massiliensis*, *Pertusaria coccodes* and *Pertusaria reddenda*, which are believed to be sensitive to SO_2 but are not listed as either sensitive or tolerant to ammonia in van Dobben & ter Braak (1999). The ammonia-tolerant *Diploicia canescens* is frequent to abundant on the trunks of these trees, as well as in the northern SSSI field and along the west side of the banc field. The lack of notable species in the western half of the banc field on the map of Orange (*loc. cit.*) is only really apparent when one examines an aerial photograph and realises that there are groups of oak trees within this western half. These support abundant *Diploicia* and other ammonia-tolerant species suchas *Arthonia pruniata*, *Phyrrospora quernea* and *Schismatomma decolorans*, with *Opegrapha xerica* on 10/26 the only notable species recorded. The most sensitive species, such as *Cresponea premnea* (tree 10/12), *Lecanactis subabietina* (10/12, 10/13, 10/14, 10/18, 10/21, 10/28 & 10/29), *Parmotrema crinitum* (10/6, 10/18 & 10/19), *Pachyphiale carneola* (10/7), *Schismatomma cretaceum* (10/9, 10/15, 10/17 & 10/24) and *Usnea flammea* (10/30) are restricted to the eastern half of the banc and are concentrated in areas that are screened from westerly winds (and ammonia drift from the slurry fields) by other trees.

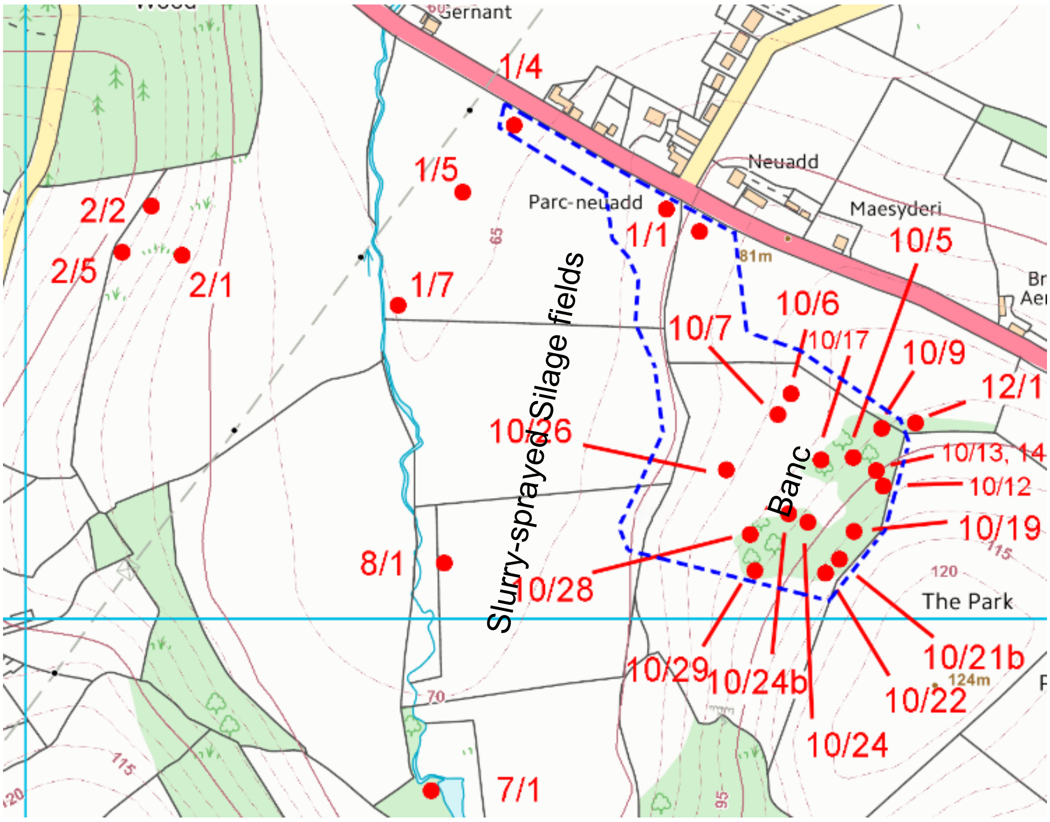

Figure 2.7: map from Orange (2017) showing trees that support notable lichens on their trunks.

2.3.2 Direct and indirect sources of ammonia

Twig lichen observations at Parc Pontfaen are of particular significance because they help to demonstrate how ammonia pollution affects epiphytes even in areas where no direct inputs of slurry or manure take place. The banc has not been fertilised for decades because of the farmers' careful management of the SSSI interest. The northern field – which is only partly within the SSSI – has received some inputs of manure and lime, whilst the north-western field – which has its north-eastern and eastern boundaries in the SSSI – has received annual slurry inputs since 1992. Twig epiphytes are almost absent from the last two fields, but impacts are also visible in the banc, and are particularly severe in its western half adjacent to the silage fields. Tree 2, which is 'very N polluted' but retains some scraps of *Usnea* among abundant *Xanthoria* and *Physcia*, is less than 50 m from a silage field where slurry is regularly applied. Tree 1 is further from the silage field but is not shielded from it by any other trees; it is 'N polluted' but has a lower abundance of ammonia tolerant lichens than Tree 2. Tree 3 is sheltered from the silage field by other oaks, and its 'At risk' twigs and branches retain a reasonable abundance of sensitive epiphytes. Oaks near the eastern edge of the banc are similar to Tree 2, with abundant *Physcia* and *Xanthoria* and very little *Usnea*. Regular slurry applications are a significant source of ammonia, but distance from that slurry and shelter by other oaks combine to protect at least some trees from enrichment.

Figure 2.8 (left): Tree 3 on the zero input banc; Figure 2.9 (right): Tree 4 in the manured northern field.

As well as the adjacent silage fields, Parc Pontfaen has other relatively improved agricultural fields in the surrounding area. The frequency of slurry and/or manure applications on these fields is currently unknown because they lie in different ownerships, but it is likely that they make occasional large contributions to the overall ammonia concentration on the SSSI. An additional point source of ammonia – the Coed Farm Cilcennin chicken unit 1.5 km NNE of the SSSI – was modelled by Edgington (2017) as potentially providing 0.04 µg/m³ of ammonia on average per year: a contribution that is 4% of the Critical Level of 1.0 µg/m³. There are currently 16,000 birds at Coed Farm, and the modelling covers a proposal to double that to 32,000 birds. It is uncertain from Edgington (*loc. cit.*) how much ammonia the current 16,000 birds contribute, but it is considered likely to be small compared with the inputs from adjacent landuse.

Two factories that lie 2.5 km ESE of Parc Pontfaen emit Nitrogen Oxides and Sulphur Dioxide, although these are limited by NRW permits. Both of these pollutants are known to have significant impacts on lichens. The late 20th century loss of *Lobaria* *scrobiculata* and *Nephroma laevigatum* would be consistent with Sulphur Dioxide pollution, but that cannot be linked to the recently licensed factories and occurred at a time when Sulphur Dioxide was abundant in much of southern Wales (albeit relatively less so in Ceredigion). The current condition of the epiphytic lichens at Parc Pontfaen SSSI seems consistent with ammonia pollution rather than NO_x or SO_2 pollution, but Davies *et al.* (2007) state that *Physcia adscendens*, *P. tenella*, *Xanthoria parietina* and *X. polycarpa* are highly tolerant of NO_x, whilst *Evernia prunastri*, *Hypogymnia physodes* and *Usnea cornuta* are sensitive to NO_x. The factories may contribute to the damage that is occurring at Parc Pontfaen SSSI, and more detailed examination of modelling data would be needed to establish the relative levels of each pollutant reaching the site.

Increasing traffic on the A482 is also likely to contribute NO_x to the site, and it may be no coincidence that the twigs that almost completely lack epiphytes are on trees close to the road. However, the most striking correlation remains that between distance from the silage fields and the Nitrogen Air Quality Index of twig lichens, and reducing ammonia pollution from this source is likely to provide the best option for protecting the epiphyte flora that remains. Assessing air pollution impacts on lichens is often highly complicated, with different pollutants playing different roles, but this should not be seen as a reason to ignore the fact that <u>the lichen feature at Parc Pontfaen SSSI is degraded when compared with the 1970s</u>.

2.3.3 Implications for site management

The 2016 lichen survey (Orange, 2016) demonstrated that parkland lichen interest remains at Parc Pontfaen SSSI, although the condition of the SSSI feature has deteriorated significantly since the 1970s when *Lobaria* and *Nephroma* were present. Slurry applications adjacent to the SSSI for 25 years are the likely cause of much of the deterioration, but external sources of ammonia pollution, N compounds from an increasingly busy road and two factories, and long distance Sulphur Dioxide pollution may have contributed as well. The continued survival of ammonia sensitive epiphytes on the banc shows that the zero input management there has protected the lichens to some extent, otherwise they would be as damaged as those in the northern and north-western fields; continuing that management will help to safeguard their survival. Reducing ammonia drift from the silage fields may allow gradual recovery of the epiphytes on the banc, although *Anaptychia ciliaris* is probably beyond saving.

In the medium term, the parkland lichens require additional host trees and shelter from pollution drift. Consideration should be given to careful siting of groups of oak trees, particularly in the western part of the banc field; ash and elm would be better screening trees, but Ash Dieback and Dutch Elm Disease prevent their use. Even fast-growing poplars might provide a suitable screen to block ammonia drift from the silage fields, although that would have landscape implications for the parkland.

In an ideal world there would be systems available to provide zero input buffer zones around important lichen sites such as Parc Pontfaen, and this approach to Sustainable Management of Natural Resources needs careful consideration. Alternatives for slurry disposal and silage production would be needed, however, and a wide zone (2 km radius or more) would be needed to provide genuine protection from ammonia drift. Management of this kind would need a national policy change, significant funding, and acceptance that some parts of the countryside are not suitable for ammonia-producing intensive agriculture; protecting lichens may not be considered a sufficient priority for such radical work however.

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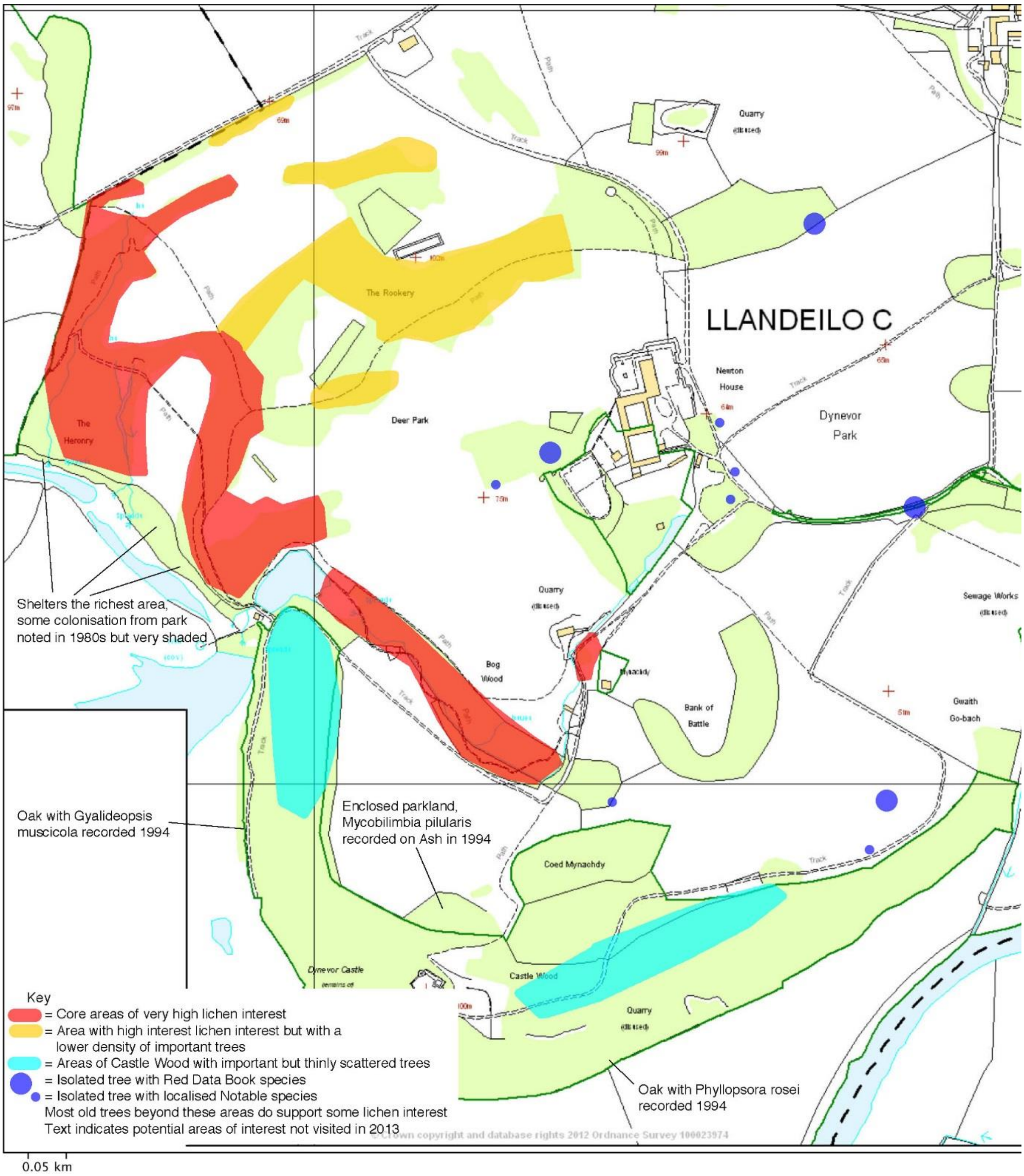
Report 3) Dinefwr Park SSSI - a transect recording twig lichens to investigate current ammonia levels

3.1 Background

Dinefwr Park SSSI in Carmarthenshire supports the richest assemblage of Nationally Rare and Scarce lichens of any parkland in Wales, and a richer assemblage than all but one of England's parklands (Melbury Park; T. Wilkins Natural England *in litt.*). It has a long history of lichen recording, culminating in a survey by Neil Sanderson (2014) commissioned by Plantlife and the National Trust. Many of the rarest lichens within the SSSI are sensitive to air pollution: the high levels of SO_2 in the 20th century are considered to have led to the loss of a number of species, and ammonia pollution in the 21st century poses an ongoing threat.

The Air Pollution Information System (www.apis.ac.uk) uses modelling to give a figure of ammonia deposition at Dinefwr Park. 2013-2015 data give a concentration of 1.34 $\mu g\ m^{-3}$ for the Dinefwr area. However, that figure is based on modelling at 5 km square resolution, and the 5 km square that Dinefwr Park sits in (SN62SW) includes high productivity farmland in the Tywi valley, a number of dairy farms, and the town of Llandeilo (Fig. 3.1). The presence of an outstanding, nationally significant lichen assemblage in Dinefwr Park SSSI suggests that the modelled concentration – which is higher than the 1 $\mu g\ m^{-3}$ critical level for ammonia sensitive lichens according to APIS – may not reflect conditions in the heart of the parkland. Ammonia is a relatively short range pollutant, and it is possible that some areas are sufficiently remote from current ammonia sources to escape significant ammonia pollution.

Figure 3.1: Dinefwr Park (red circle) stands out as paler low nutrient grassland than the rest of the 5km square in which it sits (blue square) [some high productivity riverside leys appear pale because of recent mowing].



Shelters the richest area, some colonisation from park noted in 1980s but very shaded

Oak with Gyalideopsis muscicola recorded 1994

Enclosed parkland, Mycobilimbia pilularis recorded on Ash in 1994

Oak with Phyllopsora rosei recorded 1994

Key

🟥 = Core areas of very high lichen interest

🟨 = Area with high interest lichen interest but with a lower density of important trees

🟦 = Areas of Castle Wood with important but thinly scattered trees

● = Isolated tree with Red Data Book species

• = Isolated tree with localised Notable species

Most old trees beyond these areas do support some lichen interest

Text indicates potential areas of interest not visited in 2013

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Figure 3.2: lichen interest on Dinefwr Park SSSI (from Sanderson, 2014); note that the richest areas are in the western 'Deer Park' area, and there are only isolated trees of interest in the eastern parkland.

The aim of the current survey (13th April 2017) is to investigate whether there are already signs of ammonia enrichment on the edges of the SSSI. Sanderson (2014) has already shown that there is a difference in the abundance and diversity of the lichens of acid lignum between the eastern part of Dinefwr Estate (which was farmed with inputs of NPK until the late 20th century) and the heart of the Dinefwr Deer Park (which has had zero inputs for decades) (Fig. 3.2). Sanderson (*loc. cit.*) explicitly states (p. 37) that "externally reductions in ammonia pollution from adjacent farmland are required" to protect the important lichens of the Deer Park. A paragraph discussing ammonia effects within the SSSI (Sanderson p. 23) is best quoted in full: *"At Dinefwr Oak twigs were examined wherever accessible, the Nutrient Rich Bark Community (Physcietum ascendentis) was only rarely well developed. The strongest development was on twigs on isolated trees in the south of the landscape park, which were used as shelter by large sheep herds. This is a local effect, the parkland trees along the northern edge of Castle Wood have well developed Exposed Acid Bark Communities (Pseudevernietum furfuraceae) and local development of the Sheltered sub-canopy Community (Usneetum articulato-floridae var ceratinae) with Usnea subfloridana and Usnea wasmuthii* Nb (NS) *indicating low ammonia on trees here. They are sheltered by a woodland from the prevailing winds. Across the park similar communities occur in the low lying sheltered areas of the park. In exposed areas moderately nutrient demanding species such as Ramalina farinacea and Ramalina fastigiata are typically frequent with the more demanding Physcia tenella occasional and the nitrogen resistant highly resistant species, Xanthoria parietina and Physcia adscendens rare or absent. The nitrogen avoiding species such as Evernia prunastri, Usnea subfloridana and Parmelia saxatilis were still present but tended to be occasional. The very* *sensitive Usnea florida NT (S42), was recorded by Orange (1985 & 1988) was recorded in the 1980s as present but not frequent, however, it was not refound in 2013 and is either lost of much reduced"* [it was rediscovered by Sam Bosanquet near the Castle Oak in 2017]. *"The twig flora suggests moderately background ammonia deposition from adjacent farmland, which is being attenuated locally within the park in sheltered areas (ammonia is a very short range pollutant). This is supported by the "APIS" website, which gives the background levels of ammonia pollution at 1.65 µg m^3, above the critical level for impact on lichens of 1.0 µg m^3. Serious impacts kick in over 2 – 3 µg m^3, with the complete loss of nitrogen sensitive species."*

3.2 Methods

A transect across Dinefwr Park was identified to cover trees in the heart of the Deer Park and those on the edge of the SSSI. Three nearby farms with more intensive management were then recorded to provide a contrast with the zero input SSSI parkland: National Trust land north-west of the SSSI (historic manure inputs but zero input for several years under a Glastir agreement); a privately owned farm[1] north of Dinefwr (regular applications of chicken manure); and Gelli-aur College Farm (regular slurry application). Four groups of five trees along the Dinefwr transect were recorded for their tree trunk lichens, and one tree within each group was recorded for its twig lichens; five tree trunks and one set of twigs were recorded on each of the non-SSSI farms.

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[1] The privately owned farm is deliberately not identified in this report; it is referred to as 'Farm X'.

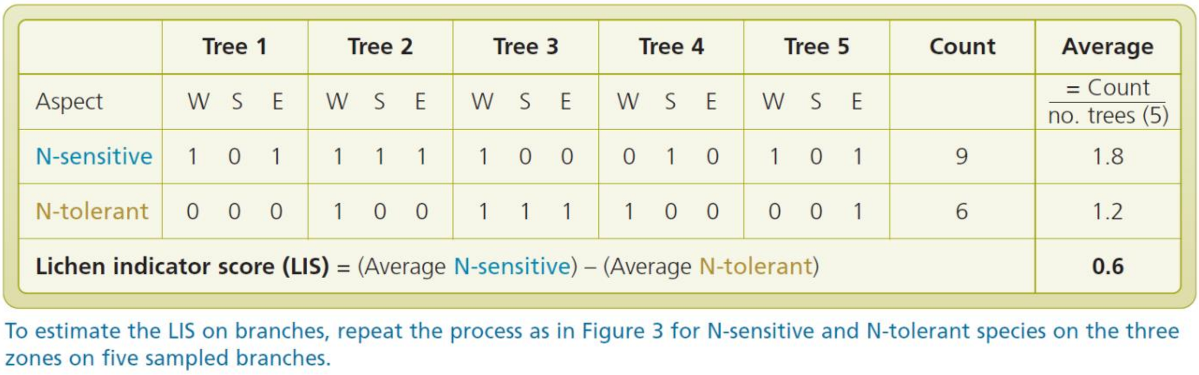
Figure 3.3: transect across Dinefwr Deer Park, with lichens on trunks (five green circles) and twigs (one orange square) recorded at four locations (A–D).

Identifying impacts on the lichens of acid lignum and acid bark which make the SSSI so important is a specialist task, requiring a national-level expert. However, Wolseley *et al.* (2017) have produced a standard method for measuring impacts on a site's lichens from ammonia. This tried and tested method, which is a slightly more complex version of the OPAL survey used by schools (Power *et al.*, 2017) was used here at Dinefwr. The survey method involves recording the presence of nitrogen-tolerant and nitrogen-sensitive lichens on tree trunks or twigs on groups of five oak or birch trees. The lichen species involved are all easy to identify (Table 3.1), without the need for specimen collection or microscope work.

Table 3.1: Nitrogen-sensitive and Nitrogen-tolerant species used by Wolseley *et al.* (2017).

Nitrogen-sensitive	Nitrogen-tolerant
Bryoria spp.	*Amandinea punctata*
Evernia prunastri	*Arthonia radiata*
Graphis spp.	*Candelariella reflexa*
Hypogymnia spp.	*Lecidella elaeochroma*
Ochrolechia androgyna	*Physcia adscendens/tenella*
Parmelia spp.	*Punctelia subrudecta*
Pseudevernia furfuracea	*Xanthoria parietina*
Sphaerophorus globosus	*Xanthoria polycarpa/ucrainica*
Usnea spp.	

Trees were recorded with a GPS, and lichen identifications were restricted to those listed in Table 3.1 and were made in the field – the methodology is potentially repeatable to allow monitoring of changes. A Lichen Indicator Score (LIS) was calculated using the system shown in Wolseley *et al.* (2017) (Fig. 3.3). At the same time as the LIS scoring species were being recorded, a detailed search of oak trunks outside Dinefwr Estate SSSI was undertaken to search for some of the more distinctive rare species known from the SSSI, especially *Cresponea premnea* and species of *Calicium* and *Chaenotheca*.



	Tree 1			Tree 2			Tree 3			Tree 4			Tree 5			Count	Average
Aspect	W	S	E	W	S	E	W	S	E	W	S	E	W	S	E		= Count / no. trees (5)
N-sensitive	1	0	1	1	1	1	1	0	0	0	1	0	1	0	1	9	1.8
N-tolerant	0	0	0	1	0	0	1	1	1	1	0	0	0	0	1	6	1.2
Lichen indicator score (LIS) = (Average N-sensitive) – (Average N-tolerant)																	**0.6**

To estimate the LIS on branches, repeat the process as in Figure 3 for N-sensitive and N-tolerant species on the three zones on five sampled branches.

Figure 3.3: the Lichen Indicator Score methodology from Wolseley *et al.* (2017).

3.3 Results

Recording on the four groups of trees along the transect in Dinefwr Park produced Lichen Indicator Scores (LIS) for twig lichens and trunk lichens for each group (see Appendix 1 of original report for full data); LIS scores were also worked out for the three contrasting farms. The lowest LIS score was -3, for the twigs at Gelli-aur, whilst the highest was 2.2 for twigs in the middle of Dinefwr Deer Park. Wolseley *et al.* (2017) give a system for converting these LIS values to a Nitrogen Air Quality Index (NAQI), based on their UK-wide survey. The highest LIS score, for twigs at Dinefwr, corresponds to a NAQI of 0.3 (‘Clean’), whereas the lowest LIS score, for twigs at Gelli-aur, corresponds to a NAQI of 1.6 (‘Very N Polluted’) (Table 3.2).

Table 3.2: Lichen Indicator Scores (LIS) and Nitrogen Air Quality Indices (NAQI) for trees at Dinefwr Park and nearby farms, using the methodology of Wolseley *et al.* (2017) (see Appendix 1 for full data). NAQI are coloured to match Figure 5: green=Clean; blue=At Risk; yellow=N Polluted; red=Very N Polluted.

Site	N inputs	Trunk LIS	Trunk NAQI	Twig LIS	Twig NAQI
Dinefwr A	Zero	0.6	0.9	0.8	0.6
Dinefwr B	Zero	1.4	0.7	2.2	0.3
Dinefwr C	Zero	1.4	0.7	1.8	0.4
Dinefwr D	Zero	0.4	1.0	0.2	0.8
Dinefwr farm	Past	-0.2	1.2	-0.6	1.0
Farm X	Manure	-0.2	1.2	-1.6	1.2
Gelli-aur	Slurry	-1.0	1.4	-3.0	1.6

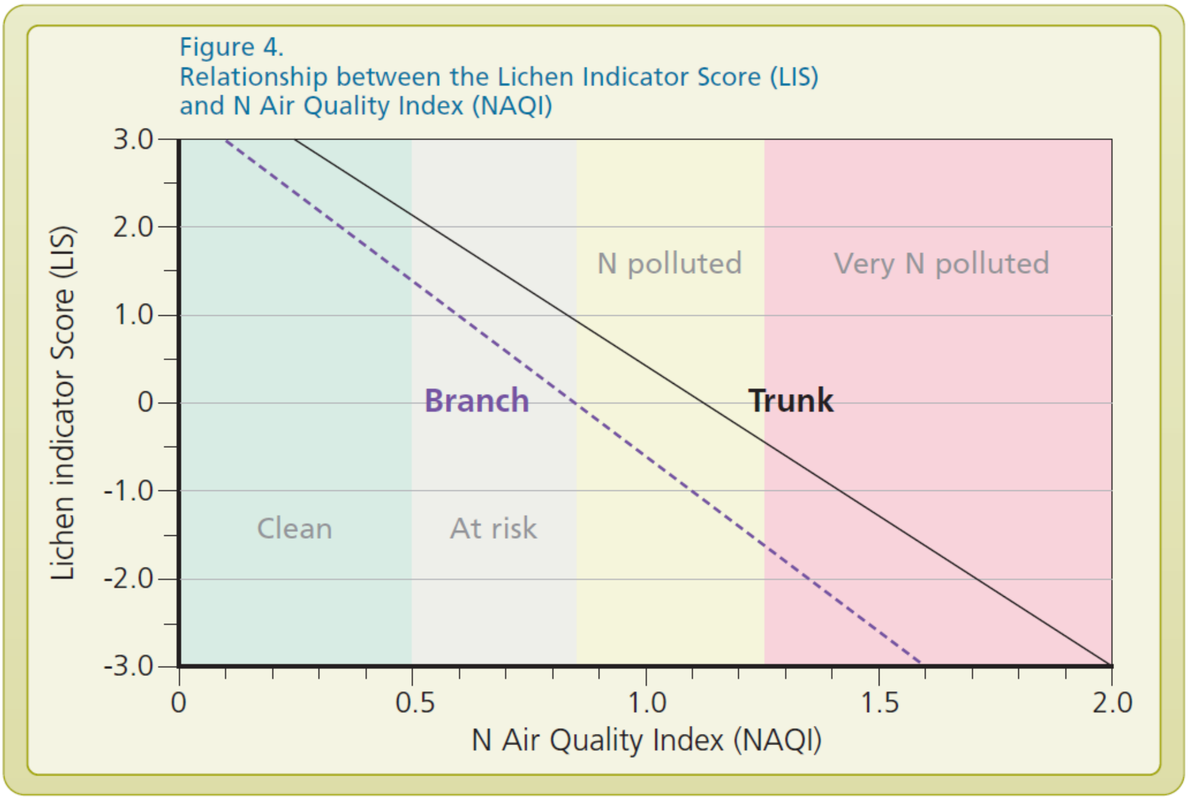


Figure 3.5: the Nitrogen Air Quality Index derived from the LIS score according to Wolseley *et al.* (2017).

A number of other records were made during the survey: a 40 cm tangle of *Usnea articulata* was found at head height in an oak at SN6101522802, the second Dinefwr record of this SO_2-sensitive lichen. The dry bark lichen *Cresponea premnea* was seen on two trees at Gelli-aur (SN59012096 & SN59212108), three at Dinefwr farm (SN60632309, SN60642309 & SN60692307), and on three on Farm X. A relatively full list was recorded for the trunk of Tree 1 on Farm X, comprising: *Cresponea premnea*, *Diploicia canescens*, *Flavoparmelia caperata*, *Hypotrachyna afrorevoluta*, *Lecania naegelii*, *Melanelixia elegantula*, *Melanohalea subaurifera*, *Ochrolechia androgyna*, *Opegrapha atra*, *Parmelia saxatilis*, *Parmelia sulcata*, *Parmotrema perlata*, *Phaeophyscia nigricans*, *Pertusaria amara*, *Phlyctis argena*, *Physcia adscendens*, *Physconia distorta*, *Punctelia borreri*, *Pyrrhospora quernea*, *Ramalina farinacea*, *Ramalina fastigiata*, *Rinodina roboris*, *Schismatomma decolorans* and *Xanthoria parietina*.

3.4 Conclusions & recommendations

The Nitrogen Air Quality Index (NAQI) scores calculated for Dinefwr Park and three comparison farms show the same pattern for twig lichens and trunk lichens (Table 3.2). The pattern is clearest for twig lichens, with the slurry-enriched Gelli-aur College Farm being ‘Very Polluted’, the manure-treated Farm X and the previously manured Dinefwr Farm being ‘N Polluted’, trees on the south-western and north-western margins of Dinefwr Park being ‘At Risk’ and trees in the middle of the Deer Park being ‘Clean’. These NAQI scores correspond to a change from an unpolluted twig flora in which *Usnea* species are abundant (Fig. 3.6) to a twig flora dominated by the ammonia-tolerant *Xanthoria* and *Physcia* species (Fig. 3.7). This is a wholesale ecological change, and the exact effects on the ecosystem services provided by the epiphytic lichens remains unknown. Massive epiphyte loss because of industrial pollution has been demonstrated by Ellis *et al.* (2011), and this has been linked to reduction in woodland soil fertility as epiphytes falling to the woodland floor have been lost. The structural complexity of an *Usnea*-dominated epiphyte flora is much greater than that of a *Xanthoria*-dominated epiphyte flora, and invertebrate niches might be expected to decline as a result. There are, in addition, complex effects as epiphytes increase because of reduced SO_2 pollution – areas of the UK that almost entirely lacked epiphytes in the mid-20th century now support a range of epiphytic lichens and the insects that feed on them (Pescott *et al.*, 2015) – but also decline/change because of ammonia pollution. Overall, it is important to realise that the effects of ammonia pollution on the epiphytic lichens at Dinefwr Park are likely to be broader than declines in the lichens *per se*.

Figure 3.6 (left): the twig epiphyte flora in the 'Clean' heart of Dinefwr Deer Park, dominated by bushy grey *Usnea* and *Evernia*; Figure 3.7 (right): the twig epiphyte flora at the 'Very N Polluted' Gelli-aur, dominated by flat orange *Xanthoria*.

The pattern of Nitrogen Air Quality Index scores for oak trunks is less clear than that for twigs, although Gelli-aur remains ‘Very N Polluted’ and Farm X and Dinefwr Farm are still ‘N Polluted’. The high pollution levels are very obvious as well, with *Xanthoria parietina* and *Candelariella reflexa* (Fig. 3.8) on the trunks at Gelli-aur and Farm X: profound change in bark pH and nutrient availability is needed for these species to become established on an oak trunk. Other species recorded on the trunk of Tree 1 on Farm X, alongside these observed ammonia tolerant lichens, include *Diploicia canescens*, *Phaeophyscia nigricans* (Fig. 3.9), *Phlyctis argena* and *Ramalina fastigiata*, all of which are typical of enriched bark and are more characteristic of ash trees in farmland than oak trees. There are, however, interesting juxtapositions on Tree 1, where ammonia-sensitive lichens such as *Cresponea premnea* (Fig. 3.10), *Parmelia saxatilis* and *P. sulcata* grow alongside the ammonia-tolerant species. This is probably indicative of an assemblage in transition, from an ammonia-sensitive assemblage to an ammonia-tolerant one, particularly as the most tolerant species are associated with a deep groove where manure would collect after spreading. The abundance of *Diploicia canescens* is particularly obvious at the ‘Very N Polluted’ Gelli-aur, and is characteristic of parkland oaks that receive regular manure inputs (S. Bosanquet pers. obs. in Monmouthshire).

Figure 3.8 (left): orange *Candelariella reflexa* on an oak trunk at Farm X; Figure 3.9 (right): dark grey *Phaeophyscia nigricans* on an oak trunk at Farm X.

Figure 3.10: the acid dry bark lichen *Cresponea premnea* (black spots) in a bark crevice on an oak trunk at Farm X.

The oak trunk lichens at Dinefwr do not give quite such a strong impression of clean air as do the twig lichens: the middle of the Deer Park is classed as ‘At Risk’, whilst groups of trees near the south-western and north-western margins are identified as ‘N Polluted’. Examination of the data for these trees (Appendix 1 of original report) shows differences from those at Farm X and Gelli-aur however: there are no ammonia-tolerant lichens on the trunks, in contrast to the presence of *Candelariella*, *Physcia* and *Xanthoria* (Fig. 3.11) on the polluted trunks, but there is also a general paucity of ammonia-sensitive indicators. Tree trunk bark preserves ecological conditions for longer than twig bark – the latter is newly produced each year and reflects local conditions more readily – this is why there are separate lines for branches and trunks when the LIS is being converted to a NAQI (Fig. 3.5). The ancient oaks at Dinefwr have experienced decades of air pollution, particularly from SO_2, and their trunks still remain influenced by that pollution as the outer layer of bark remains outermost as a trunk expands. The ancient oaks are very clearly of national significance for their lichens (Sanderson, 2014), and the paucity of the indicators on them is probably a sign that the methodology of Wolseley *et al.* (2017) is not suitable for such ancient trunks. The results of the twig analyses, and the presence of ammonia-tolerant lichens on oak trunks on the polluted farms show the method works well in the area otherwise.

Figure 3.11: *Xanthoria parietina* (orange) is appearing among grey *Parmelia*, *Punctelia* and *Flavoparmelia* lichens on an oak trunk on Farm X.

The UK trend is one of a gradual reduction in ammonia concentrations between the 1990s and 2014, although levels rose between 2014 and 2015 nationally (DEFRA, 2016). This gradual reduction is much smaller than those experienced by other forms of air pollution, such as Nitrogen Oxides and SO_2 (DEFRA, *loc. cit.*). Agriculture is the source of the vast majority of ammonia pollution, and DEFRA (*loc. cit.* p. 9) ascribe the increase between 2014 and 2015 to larger dairy herds and “organic and urea-based fertilisers”. This is, of course, a national picture, and this national reduction masks local increases around sites of intensive agriculture, particularly where there are clusters of intensive livestock units (Aazem & Bareham, 2015). Ammonia pollution operates at much shorter ranges than SO_2 pollution, but clusters of farms can increase ammonia levels across a landscape (Fig. 3.12), with potential landscape-scale impacts on epiphytic lichens and the ecosystems in which they occur.

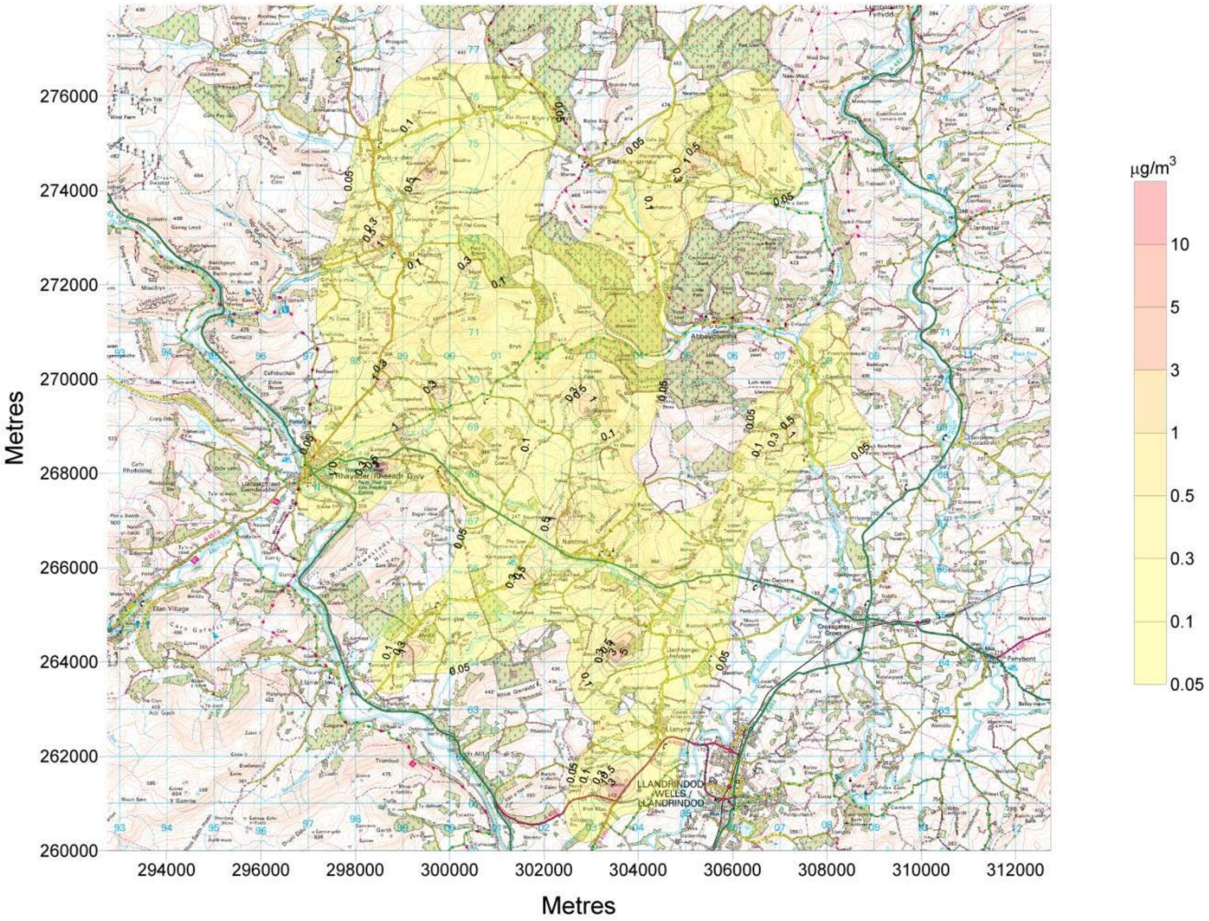


Figure 3.12 (from Aazem & Bareham, 2015): detailed ADMS modelled ammonia concentrations from poultry farm units [in the St Harmon area of Radnorshire].

Lichen survey in Dinefwr Park SSSI and its surroundings demonstrates clearly that ammonia levels are very low in the middle of the Deer Park, but are higher on the edges of the SSSI. These edges have experienced the same zero input management as the middle of the park, differing in their proximity to external sources of ammonia rather than in past management. The presence of ammonia-tolerant lichens and a lower abundance of *Usnea* on twigs is indicative of ongoing impacts from outside the SSSI on the notified, nationally significant lichen feature. Observations on nearby farms show how even greater ammonia pollution affects epiphytic lichens on oak trees, with a wholesale change to a *Xanthoria*-dominated twig assemblage at Gelli-aur and on the younger twigs of Farm X. Modelling on APIS indicates that the 5km square that contains Dinefwr Park already exceeds the critical level for ammonia concentration with respect to lichens, but the findings of the current survey suggest that this broad-scale model reveals only part of the picture: ammonia levels within the Deer Park are lower than those on the edges of the SSSI, and are highly likely to be below the critical level, and lower again than those on nearby farms. Action is needed to ensure that this situation does not deteriorate, and consideration should be given to funding local farmers to expand the zero input zone around Dinefwr Park SSSI that has been started by the National Trust with support from Glastir. Increased ammonia pollution through the introduction of additional slurry or manure within the surroundings of Dinefwr is likely to have profound effects on the lichen flora, particularly in the heart of the Deer Park where ammonia-sensitive, ‘Clean’ air lichens have survived.

3.5 References

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Report 4) Gregynog SSSI – three transects recording twig lichens to investigate current ammonia levels

4.1 **Background**

Gregynog SSSI is the richest known epiphytic lichen site in Montgomeryshire, the most important parkland for lichens in Powys, and the second richest parkland lichen site in Wales; only Dinefwr Park SSSI in Carmarthenshire has a richer lichen assemblage. The two SSSI units at Gregynog – Gregynog Great Wood (Fig. 4.1) and The Warren – have both been visited by lichenologists on several occasions, with the latest set of records dating from a 2011 visit by the Lichen Apprentice Scheme Wales (LASW) led by national experts Neil Sanderson, Steve Chambers and Ray Woods. The lichen assemblage is one of the notified features of the SSSI, whilst a number of individual lichen species are also notified features. Many of the individually notified species and those that make up the SSSI assemblage are sensitive to air pollution: the high levels SO_2 in the 20th century are considered to have led to the loss of a number of species, and ammonia pollution in the 21st century poses an ongoing threat. Ammonia is a particular threat because it increases bark/lignum pH, and many of the rare lichens at Gregynog grow on naturally base-poor, nutrient-poor bark or lignum (Fig. 4.2).

Figure 4.1: a parkland oak in Gregynog Great Wood; Figure 4.2: a black *Chaenotheca* pinhead lichen on base-poor lignum in Gregynog Great Wood.

The Air Pollution Information System (www.apis.ac.uk) uses modelling to give a figure of ammonia deposition at Gregynog. 2013-2015 data give a concentration of 1.09 µg m^{-3} for Gregynog SSSI. That figure is based on modelling at 5 km square resolution despite ammonia typically operating at much shorter distances. The 5 km square that Gregynog SSSI sits in (SO09NE) includes at least three chicken farms and much improved pasture, but the SSSI is largely surrounded by semi-improved habitat designated as National Nature Reserve. The presence of a nationally significant lichen assemblage in Gregynog SSSI suggests that the modelled concentration – which is higher than the 1 µg m^{-3} critical level for ammonia sensitive lichens according to APIS – may not reflect conditions in the heart of the SSSI. Ammonia is a relatively short range pollutant, and it was hoped that some areas would be sufficiently remote from current ammonia sources to escape significant ammonia pollution. That is the case at Dinefwr Park SSSI, where the richest areas for lichens are buffered from surrounding intensive agriculture by nearly 1km of zero-input pasture managed by the National Trust, although the margins of Dinefwr Park SSSI were recently found to be showing signs of ammonia pollution (Bosanquet, 2017).

The aim of the current survey was to establish whether there are already signs of ammonia pollution in Gregynog SSSI, to inform NRW decision making about Sustainable Management of Natural Resources in the area.

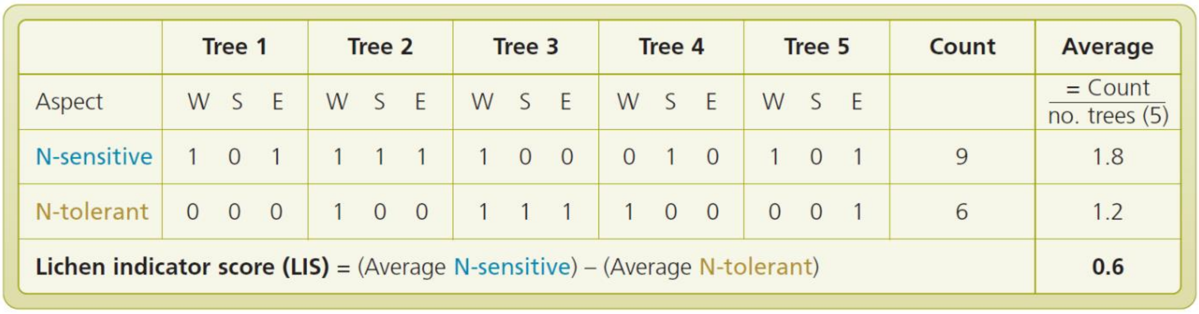
4.2 Methods

Three areas of Gregynog National Nature Reserve (NNR) were sampled using transects: Gregynog Great Wood (SSSI), The Warren (SSSI) and the east end of the NNR. In contrast to the study at Dinefwr Park SSSI (Bosanquet, 2017), no nearby farms were included in the Gregynog study, not least because some of the non-SSSI land within the NNR is sufficiently nutrient-rich to provide good examples of enriched twig epiphytes. Identifying impacts on the lichens of acid lignum and acid bark which make the SSSI so important is a specialist task, requiring a national-level expert. However, Wolseley *et al.* (2017) have produced a standard method for measuring impacts on a site’s lichens from ammonia. This tried and tested method, which is a slightly more complex version of the OPAL survey used by schools (Power *et al.*, 2017) was used here at Gregynog. The survey method involves recording the presence of nitrogen-tolerant and nitrogen-sensitive lichens on tree trunks or twigs on groups of five oak or birch trees. The lichen species involved are all easy to identify (Table 4.1), without the need for specimen collection or microscope work. During the Dinefwr survey (Bosanquet, *loc. cit.*), twig lichens appeared to give a more sensitive reflection of ammonia impacts than trunk lichens, not least because some ammonia-sensitive trunk lichens were found to be surviving in bark crevices even when the adjacent bark showed signs of enrichment. Only twig lichens were surveyed at Gregynog.

Table 4.1: Nitrogen-sensitive and Nitrogen-tolerant species used by Wolseley *et al.* (2017).

Nitrogen-sensitive	Nitrogen-tolerant
Bryoria spp.	*Amandinea punctata*
Evernia prunastri	*Arthonia radiata*
Graphis spp.	*Candelariella reflexa*
Hypogymnia spp.	*Lecidella elaeochroma*
Ochrolechia androgyna	*Physcia adscendens/tenella*
Parmelia spp.	*Punctelia subrudecta*
Pseudevernia furfuracea	*Xanthoria parietina*
Sphaerophorus globosus	*Xanthoria polycarpa/ucrainica*
Usnea spp.	

Trees were recorded with a GPS, and lichen identifications were restricted to those listed in Table 4.1 and were made in the field – the methodology is potentially repeatable to allow monitoring of changes, and is easily replicable across Wales. A Lichen Indicator Score (LIS) was calculated using the system shown in Wolseley *et al.* (2017) (Fig. 4.3).



	Tree 1			Tree 2			Tree 3			Tree 4			Tree 5			Count	Average
Aspect	W	S	E	W	S	E	W	S	E	W	S	E	W	S	E		= Count / no. trees (5)
N-sensitive	1	0	1	1	1	1	1	0	0	0	1	0	1	0	1	9	1.8
N-tolerant	0	0	0	1	0	0	1	1	1	1	0	0	0	0	1	6	1.2
Lichen indicator score (LIS) = (Average N-sensitive) – (Average N-tolerant)																	**0.6**

To estimate the LIS on branches, repeat the process as in Figure 3 for N-sensitive and N-tolerant species on the three zones on five sampled branches.

Figure 4.3: the Lichen Indicator Score methodology from Wolseley *et al.* (2017).

4.3 Results

Recording of twig lichens at 15 localities on three transects at Gregynog allowed calculation of Lichen Indicator Scores for these trees (see Appendix 1 for full data). The lowest LIS score was -1.8, for the twigs at the east end of the NNR, whilst the highest was 1.6 for twigs in The Warren. Wolseley *et al.* (2017) give a system for converting these LIS values to a Nitrogen Air Quality Index (NAQI), based on their UK-wide survey (Fig. 4.5). The NAQI for the 15 trees show a range from 'Clean' to 'Very N polluted' (Table 4.2; Fig. 4.6).

Table 4.2: Lichen Indicator Scores (LIS) and Nitrogen Air Quality Indices (NAQI) for trees at Gregynog, using the methodology of Wolseley *et al.* (2017). NAQI are coloured to match Figure 5: green=Clean; blue=At Risk; yellow=N Polluted; red=Very N Polluted.

Tree	Transect	Notes	LIS	NAQI	Pollution level
Gregynog 1	NNR east	Edge of parkland, semi-improved	0.8	0.6	At risk
Gregynog 2	NNR east	Parkland with marshy flora	1.4	0.5	Clean
Gregynog 3	NNR east	Edge of improved pasture	0.6	0.7	At risk
Gregynog 4	NNR east	Edge of improved pasture	-0.6	1.0	N polluted
Gregynog 5	NNR east	Middle of very improved pasture	-1.8	1.3	Very N polluted
Gregynog 6	Warren	Edge of NNR near silage field	-1.6	2.3	N polluted
Gregynog 7	Warren	Edge of parkland, zero inputs	-0.6	1.0	N polluted
Gregynog 8	Warren	Middle of parkland, zero inputs	1.6	0.4	Clean
Gregynog 9	Warren	Edge of parkland, zero inputs	0.2	0.8	At risk
Gregynog 10	Warren	Middle of parkland, zero inputs	0.6	0.7	At risk
Gregynog 11	Great Wood	Middle of parkland, zero inputs	-1.2	1.1	N polluted
Gregynog 12	Great Wood	Edge of parkland, zero inputs	0.2	0.8	At risk
Gregynog 13	Great Wood	Middle of parkland, zero inputs	-1.0	1.1	N polluted
Gregynog 14	Great Wood	Middle of parkland, zero inputs	1.4	0.5	Clean
Gregynog 15	Great Wood	Edge of parkland, zero inputs	-0.6	1.0	N polluted

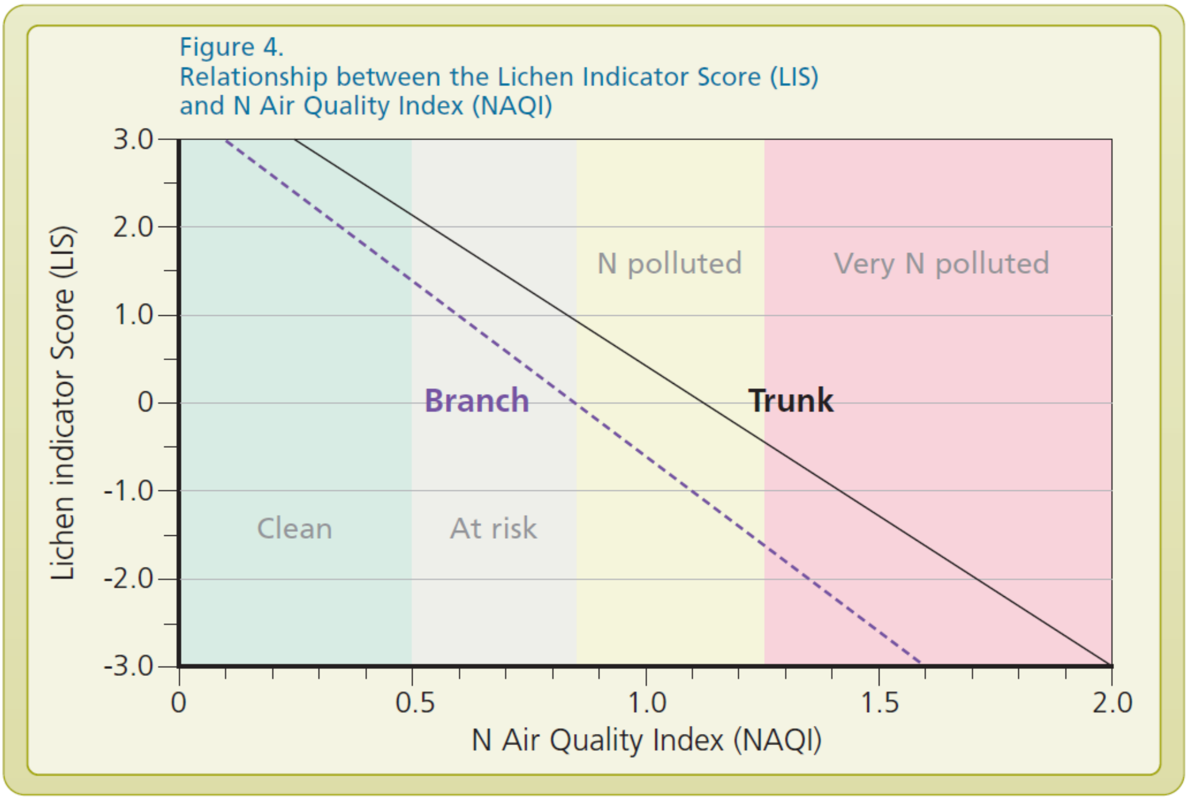


Figure 4.5: the Nitrogen Air Quality Index derived from the LIS score according to Wolseley *et al.* (2017).

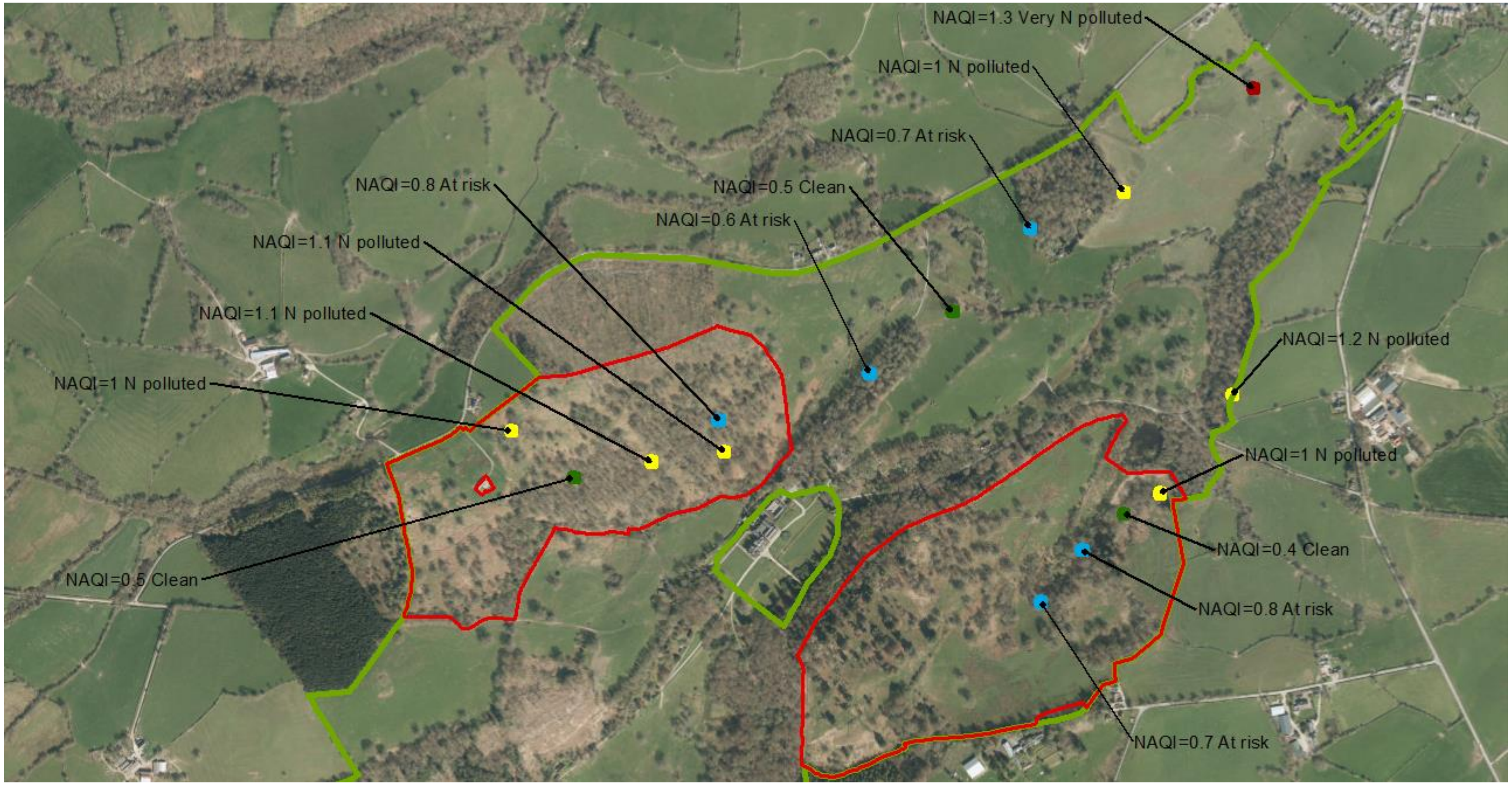


Figure 4.6: NAQI scores for 15 trees in Gregynog NNR (green boundary), including two transects around Gregynog SSSI (red boundary) and one along the eastern part of the NNR. Tree locations are coloured according to the NAQI score: red = Very N polluted; yellow = N polluted; blue= At risk; green = clean.

4.4 Conclusions & recommendations

The results at Gregynog are not quite as clear-cut as those at Dinefwr Park SSSI (Bosanquet, 2017), as the latter had a single transect covering ‘clean’ twigs in the centre of the SSSI to ‘Very N polluted’ twigs on a slurry-drenched dairy a few kilometres away. The twig lichens at Gregynog all show signs of ammonia pollution, and it is this which is believed to cause the slightly less clear picture. There are some ‘clean’ trees within both SSSI units, but even they support constant *Physcia* and near-constant *Xanthoria* (Fig. 4.7), and the majority of trees within the SSSI are either ‘at risk’ or ‘N polluted’. It appears as though the ‘clean’ trees are just slightly less far down the transition from N-sensitive *Usnea*-dominated twigs (Fig. 4.8) to N-tolerant *Xanthoria*-dominated twigs, and there is a degree of chance as to whether there are slightly fewer sensitive species on any particular tree. Much of the *Usnea* appeared moribund and coated with algae (Fig. 4.9), and further deterioration is likely in the very near future as these tufts of *Usnea* die. The extreme end of the trend towards ammonia tolerant epiphytes is more clear-cut, as *Usnea* are completely absent from the ‘Very N polluted’ easternmost tree, which supports a classic orange *Xanthorion* community (Fig. 4.10): a suite of ammonia-tolerant lichens that would not naturally occur on oak twigs in Powys.

Figure 4.7 (left): *Usnea*, *Parmelia* and *Evernia* on a typical ‘clean’ branch (although note incoming orange *Xanthoria*); Figure 4.8 (right): orange *Xanthoria* and grey *Physcia* on a young oak twig.

Figure 4.9 (left): *Usnea* encrusted with algae; Figure 4.10 (right): twig dominated by orange *Xanthoria*.

This is a wholesale ecological change, and the exact effects on the ecosystem services provided by the epiphytic lichens remains unknown. Massive epiphyte loss because of industrial pollution has been demonstrated by Ellis *et al.* (2011), and this has been linked to reduction in woodland soil fertility as epiphytes falling to the woodland floor have been lost. The structural complexity of an *Usnea*-dominated epiphyte flora is much greater than that of a *Xanthoria*-dominated epiphyte flora, and invertebrate niches might be expected to decline as a result. There are, in addition, complex effects as epiphytes increase because of reduced SO_2 pollution – areas of the UK that almost entirely lacked epiphytes in the mid-20th century now support a range of epiphytic lichens and the insects that feed on them (Pescott *et al.*, 2015) – but also decline/change because of ammonia pollution. Overall, it is important to realise that the effects of ammonia pollution on the epiphytic lichens at Gregynog are likely to be broader than declines in the lichens *per se*.

The UK trend is one of a gradual reduction in ammonia concentrations between the 1990s and 2014, although levels rose between 2014 and 2015 nationally (DEFRA, 2016). This gradual reduction is much smaller than those experienced by other forms of air pollution, such as Nitrogen Oxides and SO_2 (DEFRA, *loc. cit.*). Agriculture is the source of the vast majority of ammonia pollution, and DEFRA (*loc. cit.* p. 9) ascribe the increase between 2014 and 2015 to larger dairy herds and “organic and urea-based fertilisers”. This is, of course, a national picture, and this national reduction masks local increases around sites of intensive agriculture, particularly where there are clusters of intensive livestock units (Aazem & Bareham, 2015). Ammonia pollution operates at much shorter ranges than SO_2 pollution, but clusters of farms can increase ammonia levels across a landscape, with potential landscape-scale impacts on epiphytic lichens and the ecosystems in which they occur.

Figure 4.11 (left): unimproved ‘zero input’ grassland and bracken in The Warren section of Gregynog SSSI, with tree ‘Gregynog 10’; Figure 4.12 (right): improved pasture by tree ‘Gregynog 3’.

Gregynog is in an area of relatively high ammonia – APIS gives a concentration of 1.09 µg m^{-3} for the area, although that is based on modelling at a 5x5km resolution so the actual concentration in different parts of the SSSI is unknown. That concentration is a long-term annual average, for comparison with a Critical Level of 1 µg m^{-3} for lichen-rich communities proposed by Cape *et al.* (2009). Even the Critical Level is a best-fit, because different ammonia sensitive lichens are damaged by a wide range of different ammonia concentrations (Pat Wolseley pers. comm.). Detailed modelling is needed to establish how ammonia concentrations vary across the site, especially given the variation in NAQI values in different areas of Gregynog. Ideally, measurement of actual ammonia levels experienced by the SSSI should be instigated as well, because of potentially large-scale variations in ammonia concentrations through the year. Ammonia is a relatively short-range pollutant, with highest concentrations within a few hundred metres of sources, but certain atmospheric conditions can spread plumes of ammonia-laded air and cause impacts more than

1km distant. Gregynog SSSI has no direct inputs of manure or slurry, as evidenced by the semi-natural habitat (Fig. 4.11), so direct applications within the SSSI are clearly not the cause of the ammonia pollution that the site is experiencing. Some parts of the non-SSSI NNR are, or have been until recently, subject to significant applications of manure and/or slurry and support improved pasture (Fig. 4.12); inputs within the NNR may well be affecting the lichens in the adjacent SSSI. However, any such localised inputs are small compared with the site's environs: there are three intensive chicken farms within 3 km of Gregynog, as well as dairy farms that spread slurry on silage fields – existing sources are already causing sufficient drift of ammonia on to the SSSI to cause visible deleterious effects on the epiphytic lichens for which the SSSI is notified.

NRW have a duty under the Environment (Wales) Act 2016 to "prevent significant damage to our ecosystems" and to "maintain and enhance biodiversity". Significant damage to the ecosystem at Gregynog SSSI – one of the two most important parklands for lichens in Wales – has been identified, such that it is no longer being 'maintained'. This damage is not the fault of a single farm but is the combined result of many farms, as documented also in Radnorshire by Aazem & Bareham (2015). Damage might be reduced by requiring current ammonia-producing farms in the area to use improved technology to reduce their emissions. Without significant reductions in current ammonia concentrations there is no possibility that the ecosystem at Gregynog SSSI could survive additional inputs from any more intensive farms. The lichens that make the site special **will be lost** unless ammonia enrichment is reduced.

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Report 5) Coedydd Llawr-y-glyn SAC/SSSI – a visit to assess lichen diversity

5.1 Introduction

5.1.1 Background

Coedydd Llawr-y-glyn SAC is in western Montgomeryshire, 8 km NNW of Llanidloes. It is "one of several sites [SAC] representing old sessile oak woodland in the core of its Welsh range" and it "comprises a group of woodland blocks set around a series of connected valleys" (www.jncc.gov.uk, accessed 13th March 2017). The citation for Coedydd Llawr-y-glyn SSSI, which underpins the SAC, states that the site is "part of a remarkable group of acid sessile oak woodlands situated on hill slopes around the headwaters of the river Trannon. The individual woods are complementary to each other in their botanical interest and display well the range of ecological variation which occurs within these acid woodland types. Rare bryophytes and lichens occur." Only one lichen is specifically mentioned in the SSSI citation, however – "the larger trees in Coed Pen-y-banc commonly support the lichen, *Thelotrema lepadinum*" – and this species is also mentioned in the SAC description.

Despite the SSSI citation mentioning that rare lichens occur on the site, there seems to be remarkably little information on the site's lichens in the SSSI files. The Threatened Lichen Database (TLDB), maintained by the British Lichen Society, includes 1976 records of *Bryoria fuscescens* (Wales Redlist Vulnerable), *Thelotrema lepadinum* (Wales Redlist Near Threatened) and *Usnea florida* (GB Redlist Near

Threatened) from the western part of the SAC, along with a 1987 record of *Lecanactis subabietina* from the eastern part of the site. Ray Woods (pers. comm.) did not consider the woodland particularly remarkable for lichens, at least compared with the woods of the Elan Valley, but has spent very little time there. The TLDB records appear to come from two visits, and it is clear that the woodland complex has never been subject to a full lichen survey. The presence of *Thelotrema*, at least previously, was sufficient to suggest that further epiphytic species of interest might be present.

Two proposals for chicken farms within 4 km of the SAC were submitted to NRW in 2016/2017. These highlighted the fact that knowledge of the lichen flora of the SSSI/SAC is so patchy that a full assessment of potential impacts from the proposed chicken farms is not possible. The current visit was intended to provide a preliminary assessment of the lichen interest of the SSSI/SAC, so that NRW could decide whether a full lichen survey and impact assessment was required.

5.1.2 Methods

Sam Bosanquet visited two woodlands within the SSSI/SAC on 1st March 2017. 3½ hours was spent in Coed Gwernafon (Woodland Trust) making a detailed assessment of the typical lichen flora of the woods, whilst a ½ hour visit to Coed Glanyrafon (privately owned) was intended to check whether the lichens were broadly similar. Lichens growing on tree trunks, snags, branches and twigs were checked along a meandering walk up the stream valley at the south-west end of Coed Gwernafon, including the wooded slopes of The Hill (Fig. 5.1). Most identifications were made in the field, but small specimens of some species (e.g. *Calicium* & *Chaenotheca*) were collected for microscope checking of spores. Photographs document species of interest and the overall habitat. A handheld Garmin GPS was used to record 8-figure Grid References for all records, with 10-figure readings for certain notable species. Some species were only recorded when first encountered, or only on a subset of the trees on which they grow – for example the canopy lichens *Platismatia glauca* and *Hypogymnia physodes* – but the old woodland indicator *Thelotrema lepadinum* was recorded at every locality where it was seen so as to demonstrate the widespread distribution of lichen interest within the site. Because *Thelotrema* is specifically mentioned in the SAC description and SSSI citation, its detailed distribution is particularly informative for decision making.

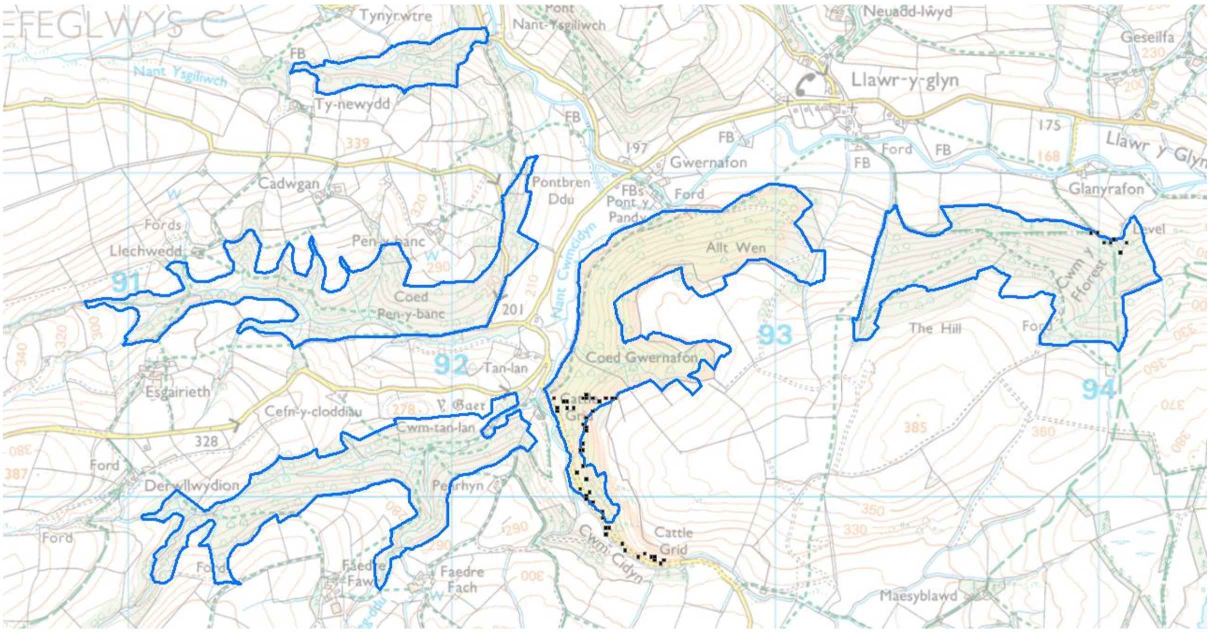


Figure 5.1: Coedydd Llawr-y-glyn SAC (blue outline), and the extent of the lichen survey in 2017 (black squares).

Only epiphytic lichens were recorded; no attempt was made to examine lichens on rocks or earth banks. It is important to note that SB is an apprentice lichenologist rather than an expert, so only a subset of the species present on the site were identified and recorded; identifications were careful and are considered to be accurate, but a genuine expert would doubtless record more (potentially rarer) species. Ray Woods checked the dataset recorded by SB and said that it “looked fine to me” (Ray Woods *in litt.*), suggesting that there are no obvious ‘howlers’ among the records.

5.2 **Results**

5.2.1 Observations in 2017

40 species of lichen were seen during the survey of Coed Gwernafon, 17 of which were also noted during the brief visit to Coed Glanyrafon along with one additional *Arthonia*. A full set of data is presented in Appendix 1 of the original report. Most species were recorded on the trunks, twigs and fallen branches of oak (*Quercus petraea*), but some records were made from sycamore (*Acer pseudoplatanus*), hazel (*Corylus avellana*), grey willow (*Salix cinerea*) and rowan (*Sorbus aucuparia*). Oak ‘snags’ – standing dead trunks – were also found to hold pinhead lichens, such as *Chaenotheca chrysocephala*.

The old woodland indicator *Thelotrema lepadinum* (Figs. 5.2 & 5.3) – a large-spored lichen that is a poor colonist of newly planted habitats – is remarkably widespread in Coed Gwernafon (Fig. 5.4), and also occurs in Coed Glanyrafon. The majority of colonies are on oak trunks, but it also occurs on sycamore, hazel and rowan. This species is listed as Near Threatened in Wales by Woods (2010). Both the SSSI citation and the SAC description mention this species by name.

Figures 5.2 & 5.3: *Thelotrema lepadinum* on oak at Coed Gwernafon.

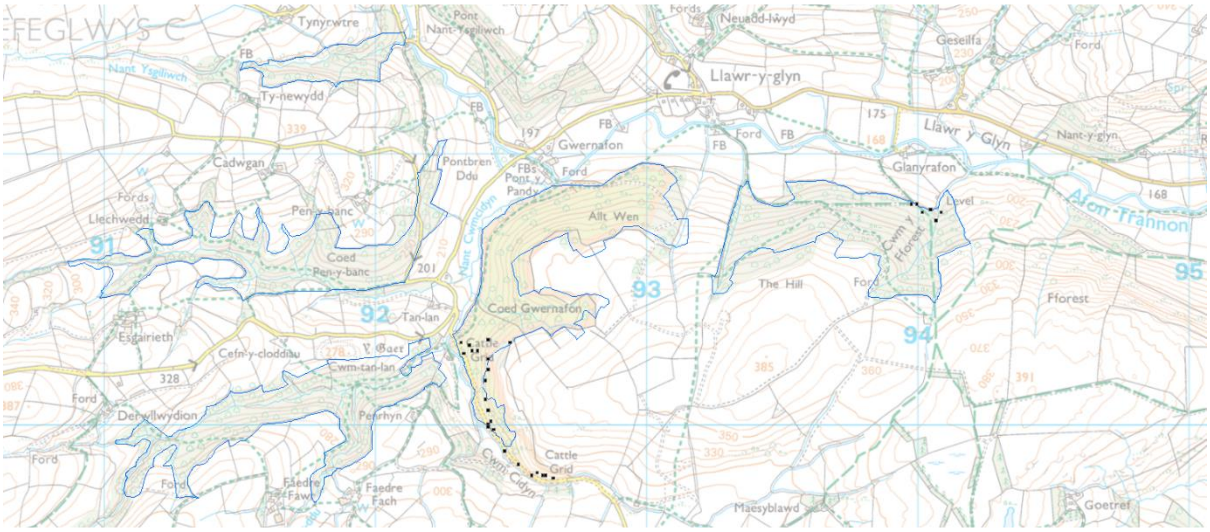


Figure 5.4: the distribution of *Thelotrema lepadinum* (black squares) in the survey area.

The pinhead lichens *Calicium glaucellum*, *Chaenotheca brunneola* (Figs. 5.5 & 5.6) and *C. chrysocephala* (Figs. 5.7 & 5.8) were all identified microscopically from small specimens taken from dry bark crevices of oak trees, with the two *Chaenotheca* also occurring widely on snags. Although these species are considered to be Least Concern in Britain, they are uncommon in Wales and *C. chrysocephala* had not previously been recorded in SN99. They are indicative of relatively sheltered, dry bark conditions and their presence in an Atlantic woodland is of interest because the woodland's bryophyte flora is suggestive of relatively high rainfall. In many ways these lichens emphasise the unusual position of Coedydd Llawr-y-glyn SAC on the less rain-drenched eastern side of the Cambrian Mountains, allowing the woodland to hold both western and eastern biofloristic elements. The draft revised *Guidelines for Selection of Biological SSSIs* for lichens (Sanderson *et al.*, 2018) include a 'pinhead index', where 10 species of *Calicium*, *Chaenotheca* and related genera is the threshold for selection as a SSSI feature. The current score is well below that threshold, but pinhead lichens often occur together and further survey is likely to increase the tally.

Figures 5.5 & 5.6: *Chaenotheca brunneola* at Coed Gwernafon.

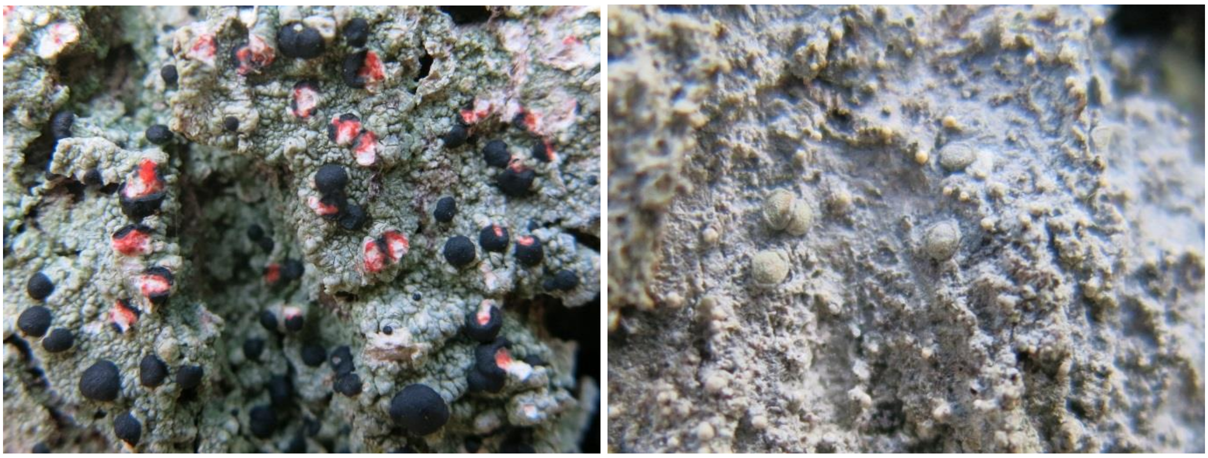
Figures 5.7 & 5.8: *Chaenotheca chrysocephala* at Coed Gwernafon.

Usnea florida (Figs. 5.9 & 10) was found in four localities on fallen oak branches in Coed Gwernafon, as well as on canopy twigs near the upper edge of the wood adjacent to The Hill. These records suggest that *U. florida* is relatively frequent in the woodland canopy in the northern half of the area surveyed on 1st March 2017; it was not found in the southern spur of woodland. *Usnea florida* is listed on Section 7 of the Environment Act (formerly Section 42 of the NERC Act), and is listed as Near Threatened on the GB Red List because of declines in south-west England that have been blamed on eutrophication through ammonia deposition. Its presence in the north-western part of Coed Gwernafon indicates that atmospheric pollution is minimal there, but its apparent absence from the southern spur of woodland is of concern.

Figures 5.9 & 5.10: *Usnea florida* at Coed Gwernafon.

The New Index of Ecological Continuity (NIEC) is a method for identifying high quality lichen habitat in oceanic southern Britain (Sanderson, 2018). Six species listed on the NIEC were recorded in Coed Gwernafon in 2017: *Catinaria atropurpurea*, *Chaenotheca* sp. (both *C. brunneola* and *C. chrysocephala*), *Lecanora jamesii*, *Punctelia reddenda*, *Thelotrema lepadinum* and *Usnea florida*; there is also a previous record of *Lecanactis subabietina* from the SAC. The threshold for selection as a SSSI feature is 20 species, but the current survey is highly unlikely to have identified all of the NIEC species that are present within the five woods that make up the SAC.

A few other species of interest were found during the survey. *Mycoblastus sanguinarius* (Fig. 5.11) has a north-western distribution in Britain and was newly recorded for SN99 during the current survey. It was seen on single oak bases in both Coed Gwernafon and Coed Glanyrafon. *Arthonia elegans* has a south-western distribution and was also new for SN99; it was collected for microscope identification from a streamside hazel. *Hypotrachyna laevigata* is restricted to high rainfall areas of western Britain, and its presence on a willow at Coed Gwernafon is indicative of affinities to the classic Atlantic woodlands of north-west Wales. Finally, *Lecanactis abietina* (Fig. 5.12) is widespread in Britain but is present in remarkable abundance at Coed Gwernafon and Coed Glanyrafon, dominating extensive areas of dry bark.



Figures 5.11 & 5.12: *Mycoblastus sanguinarius* and *Lecanactis abietina* at Coed Gwernafon.

5.3 Discussion & conclusions

5.3.1 Lichen diversity at Coedydd Llawr-y-glyn

The richness of the lichen assemblage at Coedydd Llawr-y-glyn is indicated by the fact that a relatively inexperienced lichenologist found 40 species during a survey lasting only a few hours. Several notable species were discovered, including at least six (*Arthonia elegans*, *Catinaria atropurpurea*, *Chaenotheca chrysocephala*, *Megalaria pulverea*, *Mycoblastus sanguinarius* and *Ochrolechia tartarea*) which were new for the SN99 hectad. Large 'Lobarion' lichens were not encountered, but *Usnea florida* is locally frequent alongside foliose species such as *Platismatia glauca*: parts of the wood have a very lichen-rich feel (Figs. 5.13 & 5.14), with lichens covering oak trunks, branches and twigs. This abundance of lichens is characteristic of the old sessile oakwood Annex 1 habitat, even though some of the species present at Coedydd Llawr-y-glyn are absent from the very high rainfall areas of westernmost Britain.

Figure 5.13: lichen-covered oak trunks at Coed Gwernafon.

The lichen assemblage of oak trunks in the wood shows both eastern and western elements. Abundant to dominant *Lecanactis abietina* and locally frequent *Chaenotheca* species are characteristic of relatively eastern parts of Britain and are uncommon in the far west and Ireland, whereas *Ochrolechia androgyna* and *Thelotrema lepadinum* are more typical of suboceanic parts of Britain and are relatively widespread in Ireland. The common theme is that these oak trunk lichens require a relatively low bark pH and are therefore likely to be sensitive to ammonia pollution, though observations suggest that the trunk lichen flora is less rapidly affected by ammonia deposition than the twig flora (Wolseley *et al.*, 2003).

Figure 5.14: abundant foliose lichens on oak branches at Coed Gwernafon.

The twig flora of the north-western part of Coed Gwernafon and the north-eastern part of Coed Glanyrafon is typical of acid woodland – with species such as *Platismatia glauca*, *Hypogymnia physodes*, *Evernia prunastri* and *Usnea florida* – and "acid sessile oak woodland" is specifically mentioned in the SSSI citation as the principal feature for which the SSSI was notified. Wolseley & Pryor (1999) discuss the twig flora of a similar Atlantic oakwood – Coed Tycanol in Pembrokeshire – and mention differences in species succession on twigs between different parts of the wood. The north-western and northern parts of the area of Coed Gwernafon surveyed hold a twig and branch flora rich in large foliose lichens of the *Parmelietum* and *Usneetum*, and similar associations at Coed Tycanol hold a number of notable lichen species. Further detailed analysis of the twig flora of Coed Gwernafon and Coed Glanyrafon may reveal additional species of interest in addition to the *Punctelia reddenda* noted on 1st March. Van Herk (1999) and Wolseley *et al* (2003) describe how acid twig lichens are replaced by nitrophilous lichens close to sources of enrichment with Nitrogen compounds, and monitoring of N enrichment with lichens is now a widely used tool: http://www.apis.ac.uk/nitrogen-lichen-field-manual (accessed 13th March 2017). The southern parts of the area of Coed Gwernafon that was surveyed in March 2017 held very limited foliose lichens, suggesting different ecological conditions. Wolseley & Pryor (*loc. cit.*) mention N enrichment altering the twig communities at Coed Tycanol, and further investigation at Coed Gwernafon may show that similar changes have already taken place there.

Figures 5.15 & 5.16: the north-western and north-eastern parts of the survey area, where twigs and branches support abundant foliose lichens and frequent to abundant *Usnea*.

The pinhead lichens (*Calicium* and *Chaenotheca*) mentioned above (p. 6) grow on lignum and base-poor bark: very low nutrient substrates that are vulnerable to ammonia pollution. No pinhead lichens were found in the southern spur of Coed

Gwernafon, although two species of *Chaenotheca* were seen on snags in an area where algae are locally abundant on oak trunks (see below).

5.3.2 Signs of enrichment

During the lichen survey, 10 trees supporting abundant algae (commonly described by lichenologists as algal 'gunk') were noted (Figs. 5.17–20). Some of these still retained diverse lichens, including *Thelotrema lepadinum* in one case, but the algae grew over otherwise bare bark. Bryologists and lichenologists have noted an increasing abundance of algal 'gunk' on trees in recent years, and links to ammonia enrichment are reported by Plantlife (2017); indeed the algal 'gunk' at Coed Gwernafon appears identical to that illustrated in Figure 10 of Plantlife (*loc. cit.* p. 11). The distribution of the trees on which algal 'gunk' is abundant is notable (Fig. 5.23): they are in the south-western spur of the SAC and alongside the road in Cwm Cidyn (just outside the SAC). It is possible that the roadside trees suffer from N emissions from traffic, but the road is very minor and the northern cluster of trees is not really very close to the road; equally possible is that the distribution of algal 'gunk' signifies occasional ammonia deposition on easterly winds, because the valley to the east holds considerably more productive farmland than other nearby areas. Algal 'gunk' was not noted in Coed Glanyrafon, but a green algal film over *Lecanactis abietina* on one tree there (Figs. 5.21 & 5.22) is suggestive of enrichment there. Further investigation would be needed to establish the true distribution of signs of atmospheric N enrichment in the SAC/SSSI.

Figures 5.17 & 5.18: algal ‘gunk’ on an oak trunk in the central SW part of Coed Gwernafon (SN92409022).

Figures 5.19 & 5.20: algal ‘gunk’ on an oak trunk in the southern spur of Coed Gwernafon (SN92528985).

Figures 5.21 & 5.22: an algal film over *Lecanactis abietina* in Coed Glanyrafon (SN94039078).

Algal growth on oak trunks and algal films over lichens are highly visible signs of ecological problems, and evidence from elsewhere suggests that they are likely to result from atmospheric Nitrogen deposition (Plantlife 2017). A more insidious effect is the loss of large foliose and fruticose lichens, such as the acidophilous *Platismatia glauca* and *Usnea florida*, on oak twigs because of ammonia enrichment, even though nitrophilous species such as *Xanthoria parietina* and *Physcia adscendens* are also absent. The southern part of the survey area has almost no lichens in the canopy – in stark contrast to the lichen-rich canopy of the northern part – and this lack of canopy lichens (Fig. 5.24) corresponds with the area where algal 'gunk' was noted. More detailed mapping of areas of the woodland where the canopy is lichen-rich, compared with areas where the canopy lacks lichens, could help to inform whether the SAC is currently suffering from atmospheric N deposition, particularly when combined with mapping algal 'gunk'.

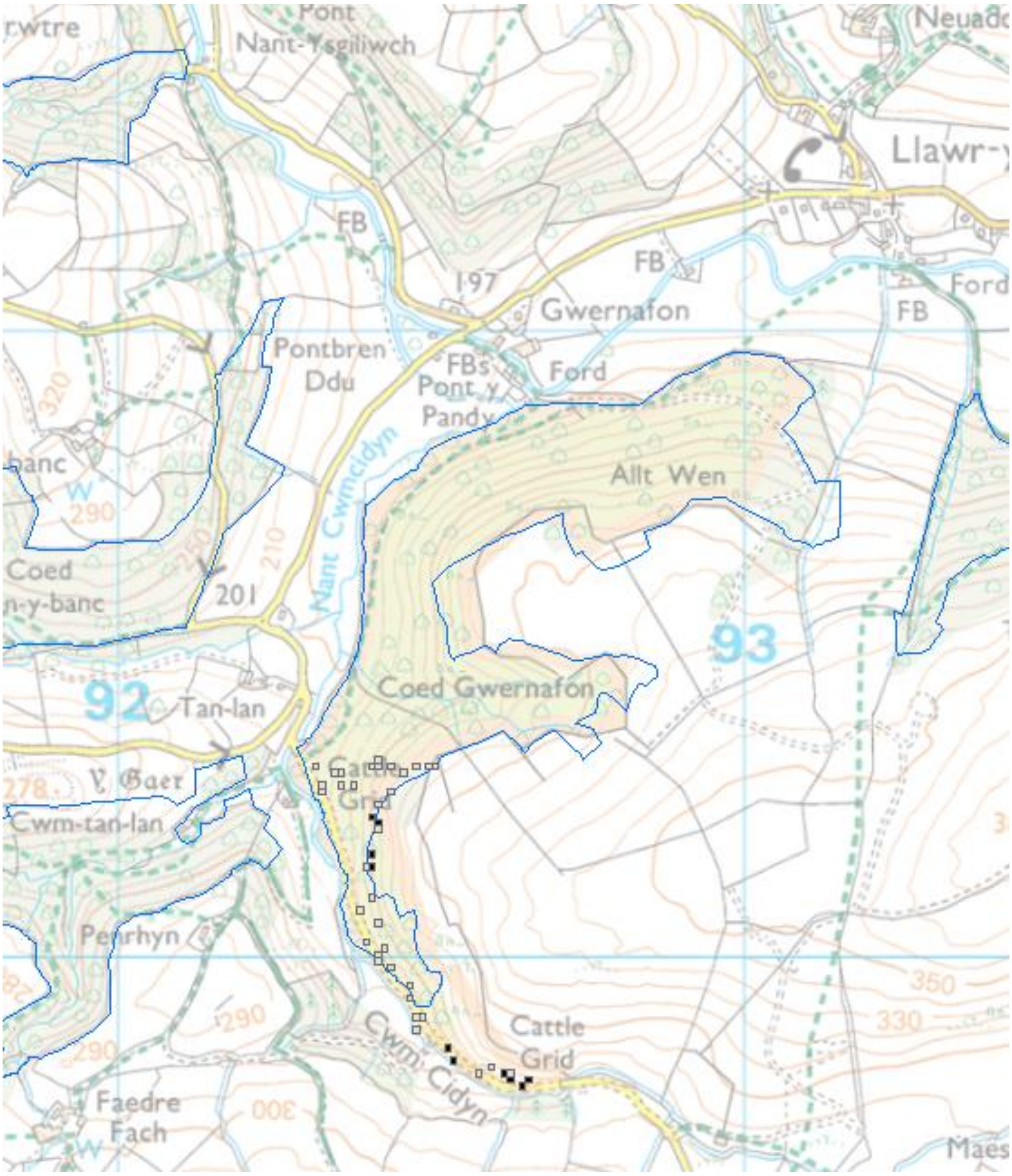


Figure 5.23: the distribution of algal 'gunk' in Coed Gwernafon on 1st March 2017: black squares show algal 'gunk' on oak trunks; white squares show oak trunks surveyed and no algal 'gunk' seen.

Figure 5.24: woodland canopy devoid of lichens in south-western Coed Gwernafon (SN92409010).

5.3.3 Recommendations

This initial survey of the lichens of Coedydd Llawr-y-glyn SAC revealed a number of notable lichens, including the ammonia-sensitive Section 7 species *Usnea florida*, an assemblage of acidophile twig lichens that is characteristic of the Annex 1 old sessile oakwoods habitat, and nutrient-poor trunk and snag species including some that had not previously been recorded from this hectad. These findings are enough to indicate that the SAC woodlands are of lichenological interest and hold a number of elements that characterise the woodland habitat and which are vulnerable to ammonia deposition. Because of this potential for damage to the Annex 1 habitat and the Coedydd Llawr-y-glyn SAC, impact assessments involving the SAC and potentially increased atmospheric N deposition need to be cast-iron. The SAC woodland already shows signs of atmospheric N enrichment in its southern spur: algal 'gunk' on a number of trees and a strikingly reduced canopy lichen flora. Any additional ammonia inputs could see these effects spreading deeper into the SAC, into areas that are currently very lichen-rich.

The full lichen interest of the SAC can only be ascertained by a targeted survey by an expert lichenologist. A commissioned survey of this kind should be seen as a high priority, so that site management and protection can be properly evidence-based.

5.4 References

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Report 6) Gathering twig lichen data for Powys SSSIs to investigate ammonia levels [by Dr Joe Hope]

6.1 Background

The role of anthropogenically generated reactive nitrogen pollution is now being considered one of the most immediate threats to the global ecosytem, along with biodiversity loss and even ahead of climate change (Campbell *et al.*, 2017). The effects of atmospheric nitrogen pollution on terrestrial ecosystems in the UK are also increasingly being recognised as problematic (Plantlife, 2017). According to one analysis, 63% of all nitrogen-sensitive habitats across the UK receive higher nitrogen deposition rates than they are able to tolerate (Hall *et al.*, 2016). Negative effects of nitrogen pollution may include reduction of species diversity and replacement of distinctive niche-adapted species with more common and widespread ‘weedy’ ones. Biological groups differ widely in their sensitivity to nitrogen pollution and its effects; groups such as lichens and bryophytes that access significant amounts of their water and nutrient requirements directly from the atmosphere or rainfall run-off tend to be particularly susceptible, though sensitivity varies markedly across species (Wolseley *et al.,* 2003). This differential sensitivity results in clear shifts in community make-up with variability in deposition rates; a survey protocol (APIS) has thus been devised to estimate levels of nitrogen loading from frequency of epiphytic indicator species (Wolseley *et al.,* 2017). The APIS survey includes methods for recording lichens on both tree stems and twigs. The twig survey is considered particularly valuable in making estimates of very recent (1 to 2 years) deposition, since these are the timescales in which the such epiphytes will have colonised new substrate.

Atmospheric nitrogen pollution occurs in two mains forms: nitrogen oxides (NO and NO_2 – collectively NO_x) and ammonia (NH_3). The former are mainly generated by industrial processes and transport emissions whereas ammonia pollution is predominantly associated with agriculture, particularly intensive livestock production. Thus, NO_x tend to be the more important pollutants in industrial and heavily populated areas, while ammonia is the larger problem in rural areas – which is also where the majority of semi-natural habitats and protected sites are located. So although the effects of these two forms of nitrogen pollution are not readily distinguishable on the ground, it is ammonia pollution that is recognised as the major threat to protected sites and priority habitats in Wales. Also, away from point sources, NO_x deposition rates are much less spatially variable than those of ammonia; modelled concentrations can be obtained from the APIS 'Search by location' tool found at http://www.apis.ac.uk/search-by-location. Biological indicator protocols such as APIS are useful in resolving the finer resolution pattern of N deposition, which will be largely be accounted for by ammonia pollution.

Recent surveys of epiphytic lichen communities in SSSIs in Wales (at Gregynog and Dinefwr) have shown evidence of variable but significant levels of recent nitrogen deposition (reports 3 & 4, above). The present study has been commissioned in order to provide current baseline data for a more widespread range of sites across the county of Powys.

6.2 Methods

The survey methodology used here is that of APIS (Air Pollution Information System, (Wolseley *et al*., 2017) with some minor variations. The present survey examined only twigs, to give the best estimate of current conditions, rather than looking at trunks as well. The indicator species list had also been amended slightly to reflect the most up-to-date understanding of local conditions, after discussions between NRW and the APIS developers. The original and amended lists are presented in below in Table 6.1.

Table 6.1: APIS indicator species from the original list and the amended 2017 list

2017 Powys survey list	**Original APIS protocol list**
Nitrogen Sensitive Species	
Bryoria fuscescens	*Bryoria fuscescens*
Evernia prunastri	*Evernia prunastri*
Graphis elegans/scripta	*Graphis* species
Hypogymnia physodes/tubulosa	*Hypogymnia* species
[*Ochrolechia androgyna*] excluded as only on trunks	*Ochrolechia androgyna*
Parmelia saxatilis	*Parmelia* species
Parmelia sulcata	
Pseudevernia furfuracea	*Pseudevernia furfuracea*
[*Sphaerophorus globosus*] excluded as only on trunks	*Sphaerophorus globosus*
Usnea species	*Usnea* species
Nitrogen Tolerant Species	
Amandinea punctata	*Amandinea punctata*

Arthonia radiata	*Arthonia radiata*
Candelariella reflexa	*Candelariella reflexa*
Lecidella elaeochroma	*Lecidella elaeochroma*
Physcia adscendens/tenella	*Physcia adscendens/tenella*
Punctelia subrudecta	*Punctelia subrudecta*
Xanthoria parietina	*Xanthoria parietina*
Xanthoria polycarpa/ucrainica	*Xanthoria polycarpa/ucrainica*

Identification of sites was completed by NRW staff prior to the commencement of the contract for the current work. 12 sites were selected, as shown in Table 6.2.

Table 6.2: Sites for 2017 lichen survey of Powys SSSIs

Site Code	Site	SSSI	Grid ref.	Region	Feature
A	Coed Copi'r Graig	Coed Copi'r Graig SSSI	SJ0315	E Powys	ESIEC
B	Coed Gwernafon	Coedydd Llawr-y-glyn SSSI	SN9290	NW Powys	Old Sessile Oakwood
C	Coed Ty-mawr	Coed Ty-mawr SSSI	SJ1209	E Powys	-
D	Pen-dugwm Woods	Pen-dugwm Woods SSSI	SJ1014	E Powys	-
E	Coed Malgwyn	Coedydd Beili, Malgwyn a Cribin SSSI	SN8983	NW Powys	Old Sessile Oakwood
F	Allt Goch	Marcheini Uplands	SN9772	W Powys	Assemblage
G	Coed yr Allt Goch	Coed yr Allt Goch SSSI	SN9067	W Powys	Old Sessile Oakwood
H	Saw Mill Wood	Caban Lakeside Woodlands SSSI	SN9162	W Powys	ESIEC
I	Glannau east	Coedydd Glanau a Cwm Coel SSSI	SN9165	W Powys	NIEC
J	Henfron	Coedydd Glanau a Cwm Coel SSSI	SN9064	W Powys	NIEC
K	Allt Ddu	Carn Gafallt SSSI	SN9364	W Powys	ESIEC
L	Coed Blaen-y-cwm	Carn Gafallt SSSI	SN9563	W Powys	ESIEC

Within each site, five trees were selected for sampling. The methodology specified the following conditions that should ideally be met.

1. Site – calcareous soils to be avoided
2. Species – only oak (*Quercus* spp.) or birch (*Betula* spp.) trees to be sampled
3. Situation – open and unshaded
4. Form – single stemmed and straight stemmed, with stem dbh > 40 cm
5. Ivy – trees substantially covered in ivy to be avoided
6. Branching – a minimum of five* branches in an open aspect must be accessible for examination along a length of 1.5 m back from a terminal bud

(* The APIS methodology requires 3 to 5 branches per tree, but the brief for this work specified 5 branches per tree.)

Selecting suitable trees for sampling was probably the most challenging part of the work, along with completing the fieldwork in the time allocated. Ideally, the surveyor would look over the whole site, and then subsequently select the most typical trees, but this approach was found to be too time consuming to be realistic. Instead, a route was chosen that seemed to give the best prospects of finding suitable trees, and trees that satisfied the sampling conditions were surveyed as encountered. Trees that were suboptimal in some way (e.g. partially shaded) but could provide 5 accessible branches were mentally noted and ‘banked’, to be returned to if 5 optimal trees could not be located. Because of the scarcity of suitable trees in many sites, condition 4 (form) was relaxed since it was considered to be more relevant to surveys that included trunk sampling. The route was usually planned on arrival at site, with reference to maps, aerial photographs and whatever views of the site could be made on approach. A typical method would be to look for open grown trees either from the approach, or on the aerial photographs or, failing both, to look along the broadly south facing boundaries of the site.

A photograph was taken of each tree (three examples are given in Figure 6.1), its girth at breast height was measured with a tape and its grid reference was recorded using a handheld GPS. From each tree, five twigs were chosen for recording. Little guidance is given in the APIS methodology, other than that the twigs should be “in an open aspect and within easy reach”, so in the current survey the least shaded of all the accessible twigs were selected. Each twig was followed to 1.5 m up its supporting branch and divided into 3 zones of 50 cm each. (Initially a tape measure was used for this purpose, but a more time-efficient system was adopted when it was discovered that the distance from the surveyor’s elbow to tip of middle finger was almost exactly 50cm!). Zones were recorded as 1, 2 and 3 with 1 being closest to the tree stem and 3 closest to the terminal bud. Lichens on the indicator list were recorded by running the eye with an illuminating x10 hand lens along the branch/twig from thick end to terminal bud.

The APIS protocol uses a custom recording sheet, but for this work it was found more expedient to use a waterproof notebook and use two letter codes for indicator species rather than the tick-box grid system of the form. The notebook is easier to handle when wrapped up in twigs and branches and does not need to be covered during rainfall. Species pairs such as *Parmelia sulcata* and *P. saxatilis* were recorded separately and individually to allow for retrospective differentiation in data analysis. Additionally, *Platismatia glauca* was recorded as a potential N sensitive species and where a thick coating of green algae was encountered, this was also recorded as a possible indicator of N enrichment.

Figure 6.1: sampled trees – Allt Ddu 1 (top L), Allt Goch 2 (top R) and Coed Gwernafon 3 (bottom).

Most sites were surveyed with help from a field assistant, whose most important practical role was in writing the codes in the notebook, as per dictation from the surveyor. Typically, the upper sections of the branches that may be easily accessible at the terminal bud might lie naturally of a height of around 2 to 2.5 metres, requiring a strong pull to bring them to eye height. Thus, if recording is being attempted by one person, a significant amount of time can be taken up with releasing the branch to write results in the notebook, and then hauling the branch back to eye level and refinding the position on the branch that was previously being examined.

6.3 Results

Data were collected from each of the twelve sites, with data collected from five twigs on five trees on all sites except Pendwgwm Woods, a dense woodland with few edges onto open ground, where lichens were recorded only from a single rather shaded tree (non-systematic observations of canopy twigs and fallen branches suggested a poor twig flora, with very few foliose or fruticose lichens). All of the trees from which data were recorded were oak (*Quercus petraea*, *Q. robur* and intermediates) except for at Blaen-y-Cwm where four of the trees were downy birch trees (*Betula pubescens*) on account of a scarcity of suitable oak trees. Birch twigs are more slender and smoother than oak twigs, so they tend to naturally support a lighter abundance and diversity of lichen epiphytes; also birch trunk bark is known to be more acidic on average than that of oak, so it is likely that twigs follow a similar pattern. Results from birch trees are not therefore really *exactly* comparable with those from oak, however we would expect them both to show a broadly similar picture in terms of abundance balance of nitrogen sensitive and tolerant species.

The full dataset is provided as in the form of a spreadsheet in Microsoft Excel format, and some summary results are presented here. The mean values and standard deviation of the Nitrogen Air Quality Index (NAQI) of all sites sampled is shown in Table 6.3. A box plot of the data values for each site is shown in Figure 6.2.

Table 6.3: NAQI means and standard deviations for each site, with pollution levels determined from the NAQI means as per the APIS protocol

Site Code	Site name	Mean NAQI	S.D. NAQI	Pollution Level
A	Coed Copi'r Graig	1.21	0.30	N Polluted
B	Coed Gwernafon	0.54	0.31	At risk
C	Coed Ty-mawr	1.12	0.16	N Polluted
D	Pen-dugwm Woods	0.85	0.00	At risk
E	Coed Malgwyn	0.52	0.15	At risk
F	Allt Goch	0.63	0.18	At risk
G	Coed yr Allt Goch	0.26	0.04	Clean
H	Saw Mill Wood	0.30	0.12	Clean
I	Glannau east	0.46	0.27	Clean
J	"Henfron" (Cwm Coel)	0.25	0.08	Clean
K	Allt Ddu	0.26	0.10	Clean
K	Coed Blaen-y-cwm	0.28	0.14	Clean

Table 6.4: Statistical significance matrix of NAQI sample means from sites. Figures below 0.5 are in bold with yellow background.

	A	B	C	E	F	G	H	I	J	K	L
A	1.0000	**0.0070**	0.5753	**0.0016**	**0.0054**	**0.0001**	**0.0002**	**0.0032**	**0.0001**	**0.0001**	**0.0002**
B	**0.0070**	1.0000	**0.0055**	0.8955	0.5733	0.0684	0.1289	0.6687	0.0662	0.0780	0.1105
C	0.5753	**0.0055**	1.0000	**0.0004**	**0.0024**	**0.0000**	**0.0000**	**0.0020**	**0.0000**	**0.0000**	**0.0000**
E	**0.0016**	0.8955	**0.0004**	1.0000	0.3154	**0.0054**	**0.0315**	0.6788	**0.0071**	**0.0110**	**0.0281**
F	**0.0054**	0.5733	**0.0024**	0.3154	1.0000	**0.0018**	**0.0081**	0.2771	**0.0022**	**0.0033**	**0.0077**
G	**0.0001**	0.0684	**0.0000**	**0.0054**	**0.0018**	1.0000	0.4929	0.1463	0.8089	1.0000	0.7599
H	**0.0002**	0.1289	**0.0000**	**0.0315**	**0.0081**	0.4929	1.0000	0.2654	0.4520	0.5716	0.8089
I	**0.0032**	0.6687	**0.0020**	0.6788	0.2771	0.1463	0.2654	1.0000	0.1391	0.1630	0.2251
J	**0.0001**	0.0662	**0.0000**	**0.0071**	**0.0022**	0.8089	0.4520	0.1391	1.0000	0.8619	0.6795
K	**0.0001**	0.0780	**0.0000**	**0.0110**	**0.0033**	1.0000	0.5716	0.1630	0.8619	1.0000	0.7942
L	**0.0002**	0.1105	**0.0000**	**0.0281**	**0.0077**	0.7599	0.8089	0.2251	0.6795	0.7942	1.0000

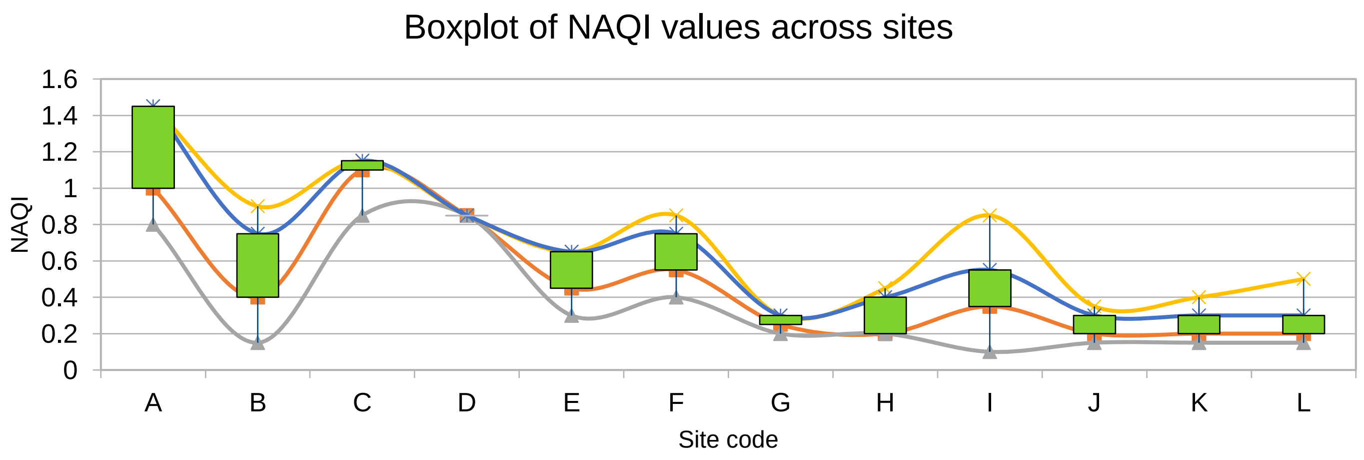

Figure 6.2: Boxplot of NAQI values across sites. Lower and upper limits of boxes show 1st and 3rd quartiles respectively; lower and upper limits of whiskers show lower and upper limits of data range.

There is a wide range of values from the upper range of the “N polluted” level down to “clean”. The boxplot shows the clear separation of data ranges between sites. Student’s t-test was used to confirm that differences between means of NAQI of sites were statistically significant. A matrix of significance values is shown in Table 6.4 (Pendwgwm was omitted because only one tree was sampled). In brief, four groups can be identified within which site means were not statistically different from each other: (1) A (Coed Copi’r Graig) and C (Coed Ty-mawr) form a group with the highest values [**N polluted**], (2) E (Coed Malgwyn) and F (Allt Goch) form a mid-range group [**At risk**], (3) G to L (Coed yr Allt Goch, Saw Mill Wood, Cwm Coel, Allt Ddu and Coed Blaen-y-cwm) form a low group [**Clean**], and (4) Sites B (Coed Gwenafon) and I (Glannau east) have very high variance, so are not separate from any sites other than group 1. Mean values of NAQI from any of the sites in Groups 1 to 3 are statistically different from mean values from sites in any of the Groups 1 to 3.

Broadly speaking, the more polluted sites tend to be in the north of the area covered, and the cleaner sites in the south (Fig. 6.4). Data were provided from NRW on the distance from the nearest poultry farm (D_f). While this is a very crude measure of the potential inputs from agricultural activities in the vicinity, there is a fairly clear relationship between the mean NAQI value and D_f. A plot of these variables is shown in Figure 6.3. Pearson’s *r* is given as 0.7, thus r^2 of 0.49 (explanatory influence of D_f on NAQI). The correlation is significant with a p-value of 0.011 though of course one must be cautious of inferring causative relationships from correlations. Site A (Coed Copi'r Graig) presents as a notable outlier to the trend, and thus might motivate us to seek to understand if the influence of agriculture on this site is being underestimated in some way (for example, is there another farm which is closer than the figure given, or is the local agricultural practice of an unusually intensive nature?) If the outlying data point is disregarded, there is a suggestion of a ‘reverse J’ form to the data spread, which might suggest a power law type relationship (and indeed, a power law regression does give a slightly higher Pearson’s coefficient than the linear model), but it seems prudent to consider that these data are probably too coarse to justify such a refinement of the model, as tempting as that may be.

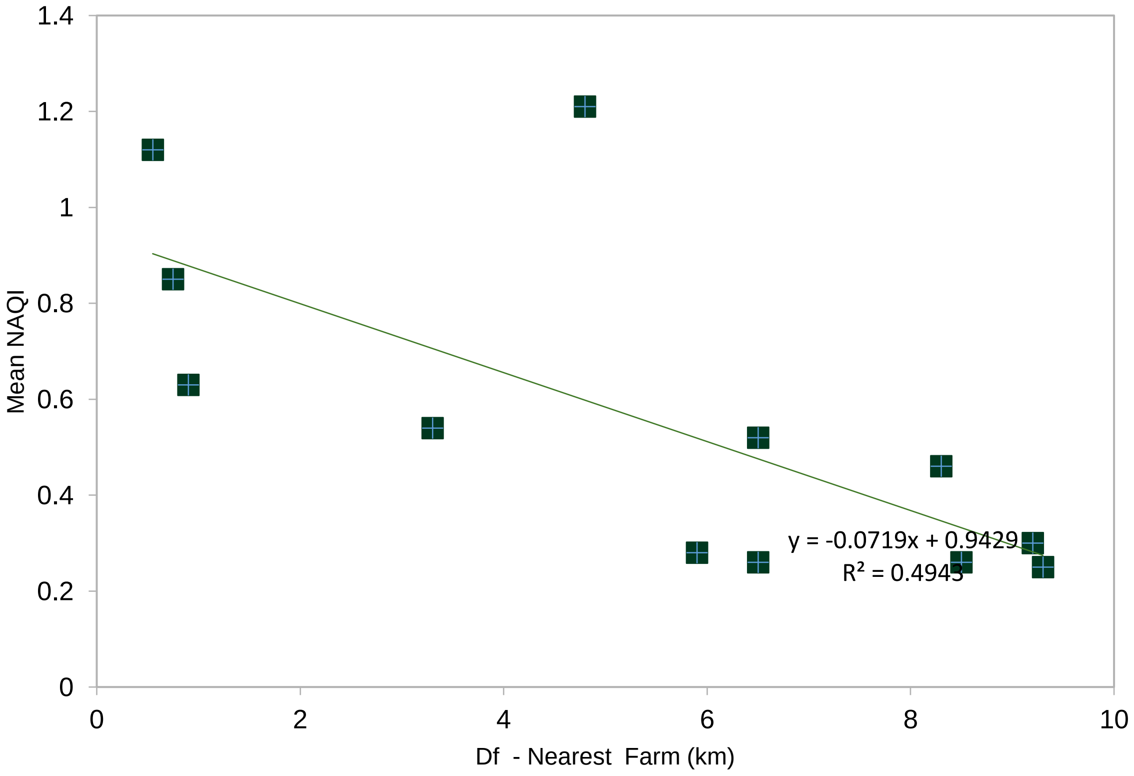

Figure 6.3: Scatter plot of NAQI vs. distance to nearest farm

Plots of NAQI from this study versus modelled values of NH_3 or NO_X deposition from APIS showed no correlation. It is likely that the modelled data will be better placed to estimate geographical variation in deposition levels at a much coarser scale than can be achieved by on the ground sampling.

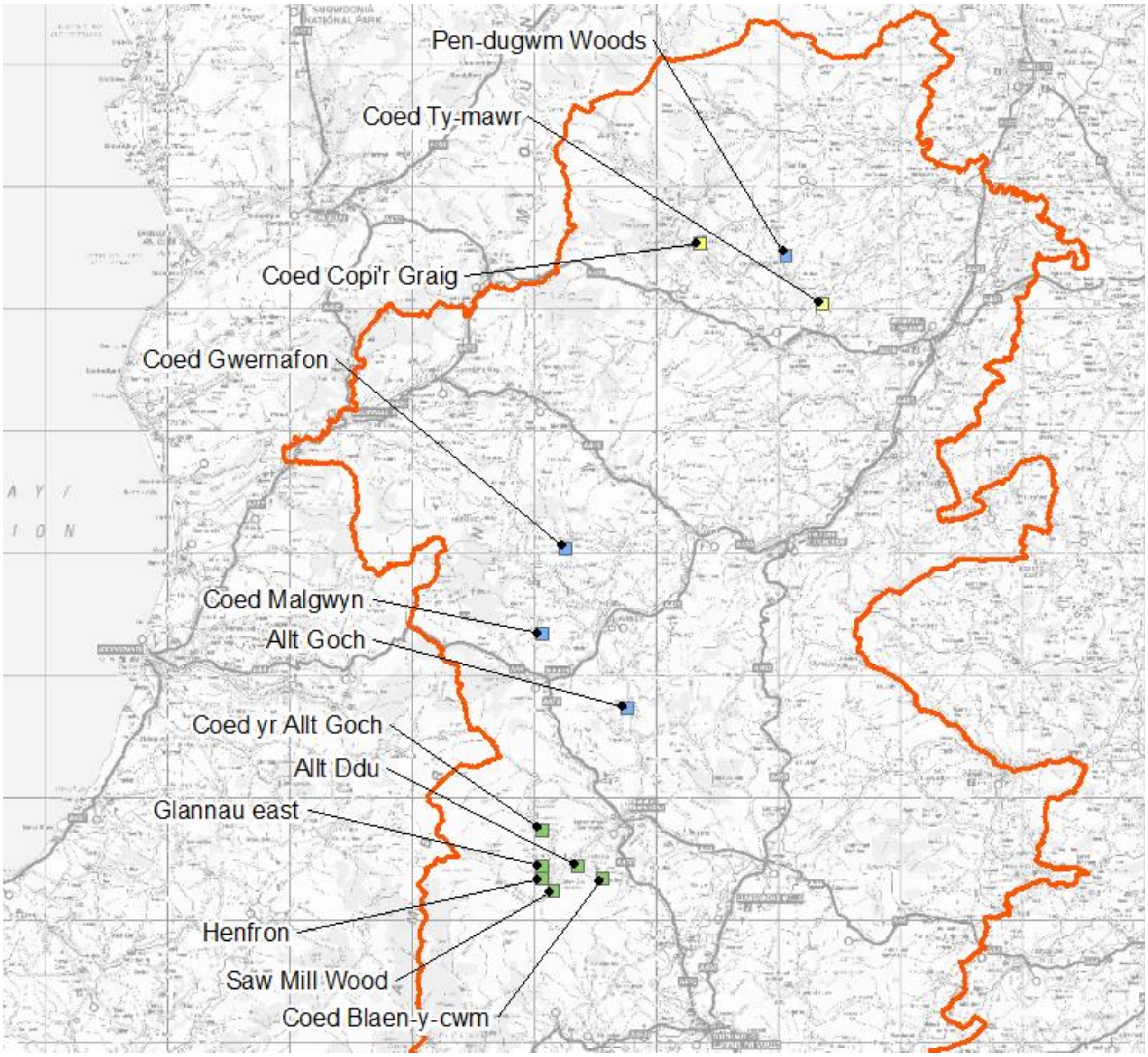

Figure 6.4: the 12 sites covered in the Powys SSSI twig lichen survey, and the pollution level inferred from their mean NAQI: green=clean, blue=at risk, yellow=N polluted.

6.4 Conclusions & recommendations

The results indicate that heightened nitrogen levels were present in at least half of the sites that were sampled. For reasons that have been outlined in the introduction it can be considered highly likely that the source of this eutrophication will have been air pollution from agricultural activities in the areas around the affected sites, and the relationship between indicated N deposition rates and distance to farms fits with this assumption. However, because the survey was not expressly designed to examine the relationship between distance from sources of ammonia and nitrogen deposition, caution must be taken in interpreting the results here. If a quantitative relationship were to be sought, a survey might be designed that placed transects running radially from well-defined point sources of ammonia pollution.

If more work were to be done using the APIS methodology it would be worth considering gradual improvement of the data collection method, in a way that could allow new datasets to be restrospectively compared with old datasets in a like-with-like manner. For instance, the list of N-sensitive and N-tolerant lichens contains some elements that appear a little at odds with the personal observations of the author (as well as some other lichenologists in informal consultations). Furthermore, not all the lichens on the lists seem equally strong indicators. It might be possible to apply weightings, as is done with Ellenberg values (Hill *et al.*, 1999). Even if weightings are not applied to species, it may be possible to better utilise the current data in the way they are currently collected. At present each twig segment can only score -1, 0 or 1 depending on whether N-sensitive species, N-tolerant species, or both are present. There is no account taken for the abundance or diversity of species, so at present a branch covered with N-sensitive species plus a tiny bit of a tolerant species will score the same as a branch in which that situation is reversed. A scoring method that weighted according to diversity could be simply devised to operate on data that had already been collected, but if abundance were to be considered this would involve modification of the data collection method.

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Report 7) The decline of the ammonia-sensitive lichen *Bryoria fuscescens* in Wales in the early 21st century

7.1 **Background**

Air pollution from intensive agriculture is becoming an increasingly important topic in Wales and the rest of the UK, both because of its effects on human health and the environment (Plantlife, 2017). Species composition in lichen- and bryophyte-rich ecosystems has been shown to change significantly depending on air pollution (Wolseley *et al.* 2003), with consequent implications for invertebrates (Pescott *et al.* 2015) and the rest of the ecosystem that is underpinned by the lichens and bryophytes. Ammonia is particularly linked to intensive agriculture, and although the UK trend in ammonia concentrations was one of a gradual reduction between the 1990s and 2014, levels rose between 2014 and 2015 nationally (DEFRA, 2016). Trends in Wales follow the national picture, but the increase here has been greater (Simon Bareham, pers. comm.), whilst there have been significant local increases around sites of intensive agriculture, particularly where there are clusters of intensive livestock units (Aazem & Bareham, 2015).

Surveys of epiphytic lichens at SSSI in Wales in 2017 showed local changes in species composition consistent with ammonia enrichment (Reports 1 to 5, above). However, the majority of the ammonia-sensitive lichens recorded during those surveys remain widespread in Wales: there is evidence of local changes in epiphytic lichens, and by inference a high probability of widespread ecosystem change, but no headline-grabbing declines in any particular species. It sometimes takes a decline in a distinctive species – be it Lapwing, Curlew, Tree Sparrow or the Elm tree – to galvanise decision-makers into changing policy.

Figure 7.1: long, grey-brown strands of *Bryoria fuscescens* on an oak in Allt-y-gest SSSI, Powys.

The Horsehair-lichen *Bryoria fuscescens* (Fig. 7.1) is distinctive and widespread, and observations suggest that it has declined substantially in Wales. The related *B. bicolor* also appears to have declined, but was never widespread in Wales, whilst *B. smithii* seems to have been lost from Wales. This report examines whether the apparent decline in *Bryoria fuscescens* in Wales is genuine, and whether there are links between *Bryoria* population trends and ammonia pollution.

7.2 Methods

The lichen *Bryoria fuscescens* was selected for detailed investigation because of its apparent decline in Wales. This decline has already led to it being listed as Vulnerable in *A Lichen Red Data List for Wales* (Woods, 2010). Wolseley *et al.* (2017) list *Bryoria* as being sensitive to ammonia increases, and it is known to have declined at Gregynog SSSI, the subject of Report 4 (Ray Woods pers. comm.). This species has several features that make it especially suitable for study:

1. *Bryoria* is a genus of distinctive, large lichens that can be recognised (at least at genus level) from a distance and is therefore less likely to be overlooked than many small lichens;
2. *Bryoria* are sufficiently uncommon in Wales, at least now, to warrant specific recording by lichenologists;
3. *Bryoria* were recorded across most of Wales in the 20th century, rather than being restricted to a small area, and trends are likely to reflect large-scale changes rather than stochastic events;
4. *Bryoria* occur/occurred in parts of Powys that are now subject to high concentrations of ammonia, as well as in areas that remain relatively unpolluted;
5. *Bryoria* is ecologically important in the epiphyte layer of forests in parts of North America and Scandinavia, so a decline cannot be dismissed as esoteric.

Maps of *Bryoria fuscescens* on the NBN Atlas (www.nbnatlas.org.uk) appear to show a substantial decline in Britain, especially in Wales (Fig. 7.2). This corresponded to its very real scarcity now in much of Wales: the author has only encountered *B.*

fuscescens five times in Wales during 19 years of fieldwork for NRW and one of its predecessor bodies (Bosanquet, pers. obs.), and all those encounters were incidental to other work. Five incidental *ad hoc* sightings by an observant (then) non-specialist contrast with more than 50 *ad hoc* records made by SB of the similarly distinctive Environment (Wales) Act Section 7 lichen *Usnea articulata*. Two additional ammonia-sensitive lichens that show substantial declines on the NBN Atlas were also considered for investigation, but *Cetraria sepincola* was considered too geographically restricted in Wales to allow detailed analysis (Fig. 7.3), whilst *Tuckermanopsis chlorophylla* (Fig. 7.4) is relatively easy to overlook and would only be recorded by specialists, making the dataset for the latter species less robust than that for *Bryoria fuscescens*.

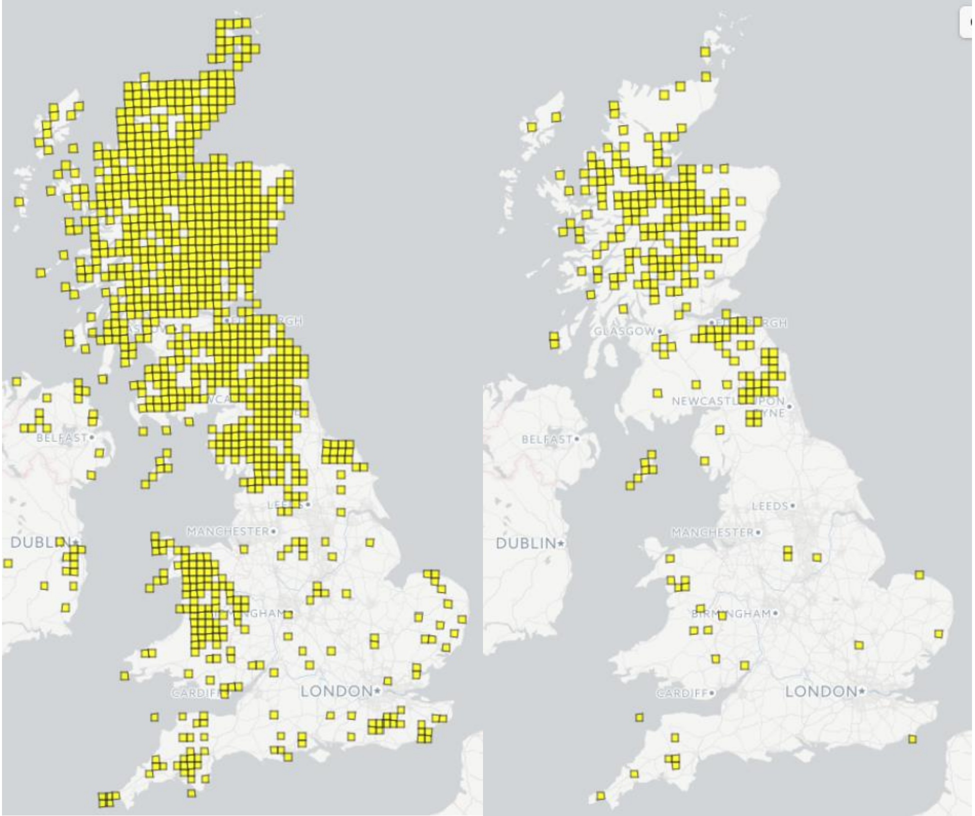

Figure 7.2: *Bryoria fuscescens* distribution in Britain and eastern Ireland – all records (left) and post-2000 records (right). From www.nbnatlas.org.uk (accessed 1st November 2017).

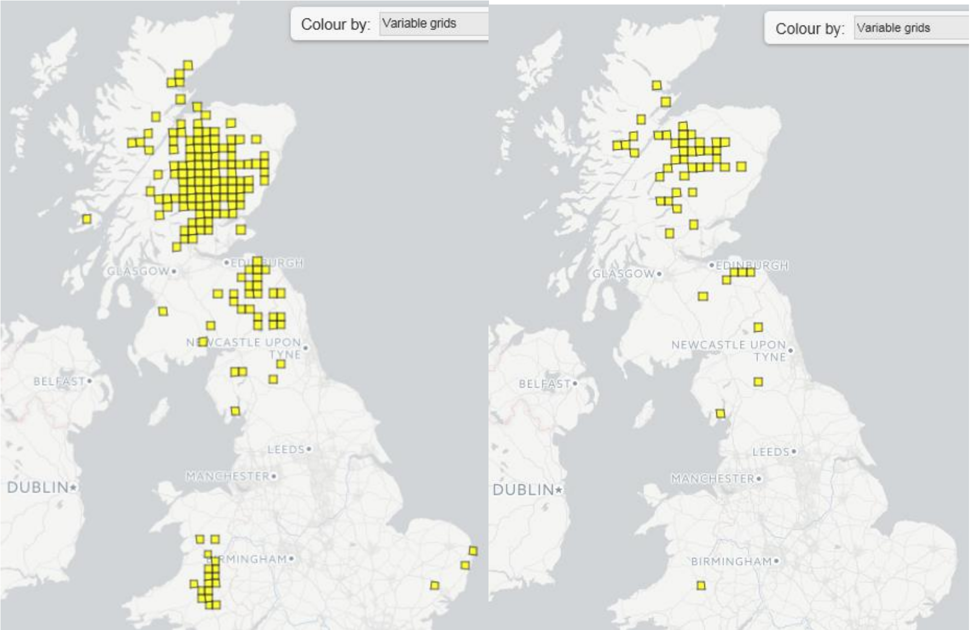

Figure 7.3: ***Cetraria sepincola*** **distribution in Britain and Ireland – all records (left) and post-2000 records (right). From www.nbnatlas.org.uk (accessed 1st November 2017).**

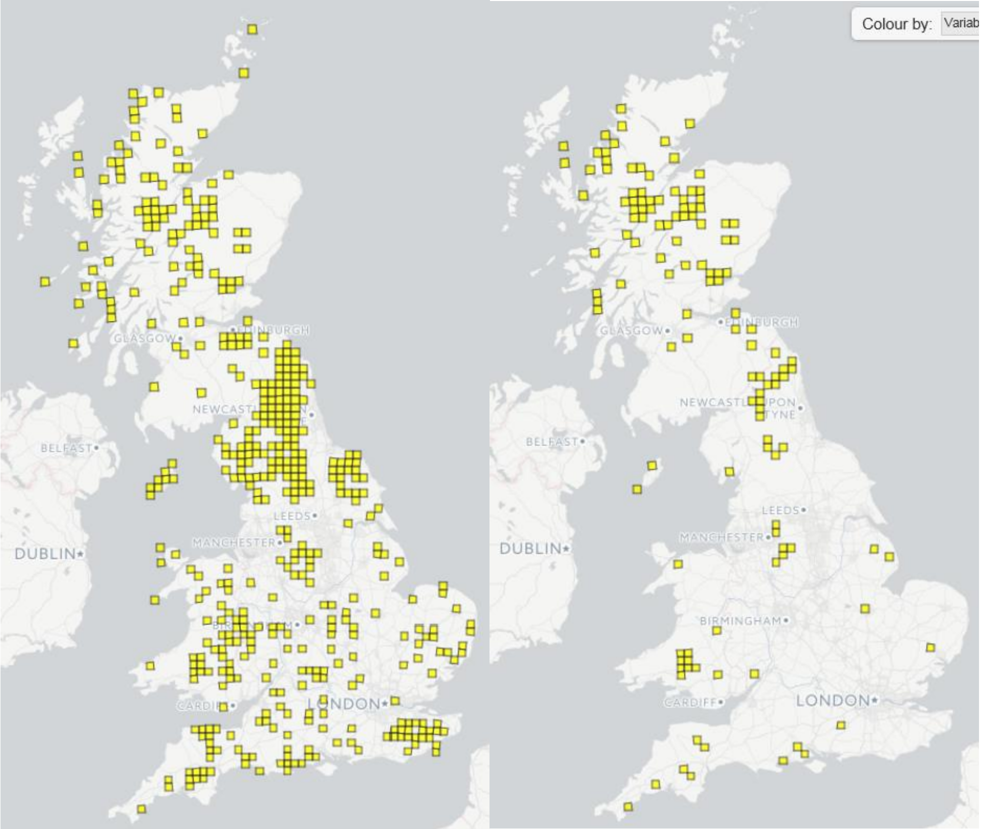

Figure 7.4: ***Tuckermanopsis chlorophylla*** **distribution in Britain and Ireland – all records (left) and post-2000 records (right). From www.nbnatlas.org.uk (accessed 1st November 2017).**

Records of *Bryoria fuscescens* and the closely related (and questionably distinct) *B. subcana* in Wales were downloaded from the NBN Atlas in November 2017; the majority come from the British Lichen Society database, but some are from the network of Local Environmental Records Centres. All active lichen recorders in Wales were contacted by email, along with a small number of GB experts who have recorded recently in Wales; they were asked to provide any records of *Bryoria fuscescens* that they considered would be absent from the NBN dataset. Alan Orange examined herbarium specimens in the National Museum of Wales and mobilised data for those specimens. All new data were combined with the NBN records to produce a detailed record of the species' distribution in Wales. Records were then assigned to a 20-year date category: pre-1940; 1940-59; 1960-79; 1980-99; and 2000-19. Records were then assigned to 1km squares of the Ordnance Survey grid, and the occupancy of each grid square by *Bryoria* in each 20-year date category was assessed. Finally, each grid square in which *Bryoria* occurs/occurred was assigned a modelled ammonia concentration from the AQ Emissions 2010 layer in NRW's ArcGIS.

7.3 **Results**

The NBN dataset for *Bryoria fuscescens* (including *B. subcana*) includes 94 records from Wales, whilst 51 records resulted from the data request to Welsh lichenologists. These 145 records come from 106 different 1km squares of the Ordnance Survey grid. All records were assigned to a 20-year date class (Table 7.1).

Table 7.1: records of *Bryoria fuscescens* and *B. subcana* from 1km squares of the OS Grid in Wales, in each 20 year period from 1940 to 2019, change in presence within each square, and ammonia levels from the AQ Emissions 2010 ArcGIS layer.

	pre-1940	1940-59	1960-79	1980-99	2000-19	Change	NH3	NH3 Band
Count:	**8**	**4**	**22**	**46**	**32**		**μg/m^3**	**μg/m^3**
SH1121			1			V. old	0.113706	0.0-0.2
SH1221		1	1			V. old	0.113706	0.0-0.2
SH1325			1			V. old	0.059156	0.0-0.2
SH2677					1	Recent	0.733148	0.6-0.8
SH2774			1			V. old	0.672795	0.6-0.8
SH2992			1			V. old	0.168068	0.0-0.2
SH3343			1			V. old	0.848259	0.8-1.0
SH3665	1					V. old	0.67269	0.6-0.8
SH5373			1			V. old	2.864284	1.5-3.0
SH5958					1	Recent	0.388329	0.2-0.4
SH6063					1	Recent	0.577771	0.4-0.6
SH6149					1	Recent	0.2114	0.2-0.4
SH6331		1				V. old	0.33067	0.2-0.4
SH6344	1					V. old	0.297646	0.2-0.4
SH6423	1					V. old	0.324834	0.2-0.4
SH6431	1					V. old	0.331479	0.2-0.4
SH6469	1					V. old	0.633344	0.6-0.8
SH6836			1			V. old	0.265653	0.2-0.4
SH6938					1	Recent	0.430361	0.4-0.6
SH7268	1					V. old	0.215659	0.2-0.4
SH7316				1		Older	1.046063	1.0-1.5
SH7561		1				V. old	0.206561	0.2-0.4
SH7569	1					V. old	0.278174	0.2-0.4
SH8023					1	Recent	0.412329	0.4-0.6
SH8132					1	Recent	0.187486	0.0-0.2
SH8132					1	Recent	0.187486	0.0-0.2
SH8241					1	Recent	0.197121	0.0-0.2
SH8337	1					V. old	0.226401	0.2-0.4
SH8431			1			V. old	0.187531	0.0-0.2
SH8432					1	Recent	0.187094	0.0-0.2
SJ0114			1			V. old	0.61642	0.6-0.8
SJ0151				1		Older	0.176512	0.0-0.2
SJ0544				1		Older	1.023849	1.0-1.5
SJ0729				1		Older	0.333976	0.2-0.4
SJ1836				1		Older	0.311252	0.2-0.4
SJ2106				1		Older	2.165854	1.5-3.0
SN0833		1				V. old	1.21755	1.0-1.5
SN6598					1	Recent	0.585974	0.4-0.6
SN6753					1	Recent	0.415109	0.4-0.6
SN6994			1	1		Older	0.565378	0.4-0.6
SN7193					1	Recent	0.220802	0.2-0.4

SN7197			1			V. old	0.447489	0.4-0.6
SN7293					1	Recent	0.211237	0.2-0.4
SN7294					1	Recent	0.409952	0.4-0.6
SN7297				1		Older	0.420157	0.4-0.6
SN7385					1	Recent	0.259005	0.2-0.4
SN7397			1			V. old	0.410503	0.4-0.6
SN7658					1	Recent	0.191138	0.0-0.2
SN7775				1		Older	0.268826	0.2-0.4
SN7784					1	Recent	0.34243	0.2-0.4
SN7867					1	Recent	0.274708	0.2-0.4
SN7937				1		Older	0.883123	0.8-1.0
SN8044					1	Recent	0.307065	0.2-0.4
SN8453				1		Older	0.099411	0.0-0.2
SN8553				1		Older	0.100894	0.0-0.2
SN8575					1	Recent	0.156967	0.0-0.2
SN8793					1	Recent	0.357061	0.2-0.4
SN8795			1			V. old	0.776174	0.6-0.8
SN8952				1		Older	0.22201	0.2-0.4
SN8961				1		Older	0.223599	0.2-0.4
SN8964				1		Older	0.220174	0.2-0.4
SN8968				1		Older	0.224488	0.2-0.4
SN8983			1			V. old	0.309132	0.2-0.4
SN9064			1	1		Older	0.220174	0.2-0.4
SN9162				1		Older	0.140217	0.0-0.2
SN9163				1	1	Both	0.140268	0.0-0.2
SN9190			1			V. old	0.419944	0.4-0.6
SN9192				1		Older	0.417848	0.4-0.6
SN9264					1	Recent	0.331515	0.2-0.4
SN9363				1		Older	0.141599	0.0-0.2
SN9364				1	1	Both	0.330221	0.2-0.4
SN9365				1		Older	0.330221	0.2-0.4
SN9366				1		Older	0.330221	0.2-0.4
SN9376					1	Recent	0.76485	0.6-0.8
SN9392					1	Recent	0.418514	0.4-0.6
SN9421				1		Older	0.57572	0.4-0.6
SN9422				1		Older	0.536807	0.4-0.6
SN9463				1	1	Both	0.146651	0.0-0.2
SN9468				1		Older	0.331547	0.2-0.4
SN9469			1	1		Older	0.449178	0.4-0.6
SN9522				1		Older	0.534728	0.4-0.6
SN9570			1			V. old	0.458973	0.4-0.6
SN9659				1		Older	0.433896	0.4-0.6
SN9665				1		Older	1.05072	1.0-1.5
SN9671				1	1	Both	0.862456	0.8-1.0
SN9676			1			V. old	0.45108	0.4-0.6
SN9757				1		Older	0.641413	0.6-0.8
SN9765				1		Older	1.047443	1.0-1.5
SN9997				1		Older	0.844548	0.8-1.0
SO0062				1		Older	0.437362	0.4-0.6

SO0247				1		Older	0.682704	0.6-0.8
SO0571			1			V. old	0.473516	0.4-0.6
SO0671				1		Older	1.346698	1.0-1.5
SO0771			1	1		Older	1.346697	1.0-1.5
SO0861			1			V. old	1.608595	1.5-3.0
SO0897			1	1	1	Both	0.953634	0.8-1.0
SO0963				1		Older	1.7455	1.5-3.0
SO1069				1		Older	1.349653	1.0-1.5
SO1164				1		Older	1.540451	1.5-3.0
SO1362					1	Recent	1.490978	1.0-1.5
SO1585			1			V. old	1.082837	1.0-1.5
SO1588			1			V. old	1.472463	1.0-1.5
SO2020				1		Older	0.674111	0.6-0.8
SO2220					1	Recent	0.483932	0.4-0.6
ST1077				1		Older	1.549807	1.5-3.0
ST1985	1					V. old	0.679857	0.6-0.8

The most basic analysis of the data on distribution of *Bryoria fuscescens* (including *B. subcana*) in Wales is to compare the number of occupied 1km squares in the past with the number occupied now. If the 20 year period 1980-1999 is compared with the 18 year period 2000 to 2017 then there appears to have been a **31% decline** in the species' distribution in Wales. However, it is considered likely that all post-2000 sites were occupied in the past – there is no ecological reason to consider *B. fuscescens* to be particularly mobile at the landscape scale (although *Bryoria* are somewhat mobile within individual sites), and it was a late colonist following substantial SO_2 reductions in a Finnish city (Ranta, 2001) rather than being a rapid coloniser as conditions improve. If the assumption that post-2000 sites represent persistent colonies then the 32 squares that are now known to support *B. fuscescens* could be compared with a total of 73 occupied squares since 1980. These figures would indicate that a decline from 73 to 32 occupied squares (**a 57% decline** or 43% survival) has occurred between these two comparable periods. If older records are included then the decline is even more dramatic – a 66% decline since the 20th century, from 93 occipied 1km squares since 1960. Whichever figure is taken, the evidence points towards a substantial decline in the number of sites at which *B. fuscescens* occurs. Examination of the NBN records of other lichen species indicates that there has not been a large-scale reduction in lichen recording in Wales, such as might produce an artificial declining trend, although there have been changes in recording patterns so some areas that held *Bryoria* in the 1980s/90s have not been revisited recently. The overall pattern of recording between the two periods is considered to be broadly similar, and general under-recording in some regions (as shown on NBN) has been counteracted by the inclusion of non-NBN data requested from lichen recorders.

Two other forms of decline need to be considered – a decline in abundance and a decline in range. The data are relatively uninformative on whether there has been a decline in abundance of *Bryoria fuscescens* on the sites where it occurs, but a small number have notes on abundance. Francis Rose recorded *B. fuscescens* as being ‘Frequent’ at Gregynog SSSI in his 1987 diary, whilst Ray Woods (*in litt.*, 2017) described some trees at Gregynog as supporting such an abundance of *Bryoria* in the 1980s that they looked ‘bearded’; this site supports only scraps of *Bryoria* now. *Bryoria fuscescens* was described as being “common” in the Trawscoed area of Meirionnydd in the early 2000s, but has now virtually gone (Andrew Graham *in litt.*, 2018). All five of the colonies seen by Sam Bosanquet in the last 20 years were small, but there are no older records from these sites to compare this to. Direct monitoring or photographic evidence would be needed to provide more evidence of declines in abundance, but the situation at Gregynog suggests that declines in abundance will have occurred on at least some other Welsh sites.

GIS mapping suggests that there has been a decline in range, at least over the long term (Fig. 7.5). A relatively conservative boundary box around the Area of Occupancy of *Bryoria* in Wales from 1800 to 1999 has an area of 11900 km^2, whereas the Area of Occupancy based on records from 2000 to 2017 is 4925 km^2. Loss from the Cardiff area of south Wales since it was last noted in 1995 is undoubtedly genuine, as are losses from the eastern edge of the species' range. However, it is possible that *B. fuscescens* remains on Mynydd Preseli in south-west Wales (Ross Grisbrook pers. comm.) despite an unsuccessful search in 2017. Continued presence on coastal rocks in north-west Wales is also possible, as there is a 2013 record from western Anglesey. The decline in Area of Occupancy may not, therefore, be quite as dramatic as Fig. 7.5 suggests, but there has certainly be a decline in the range of *B. fuscescens* in Wales in recent years.

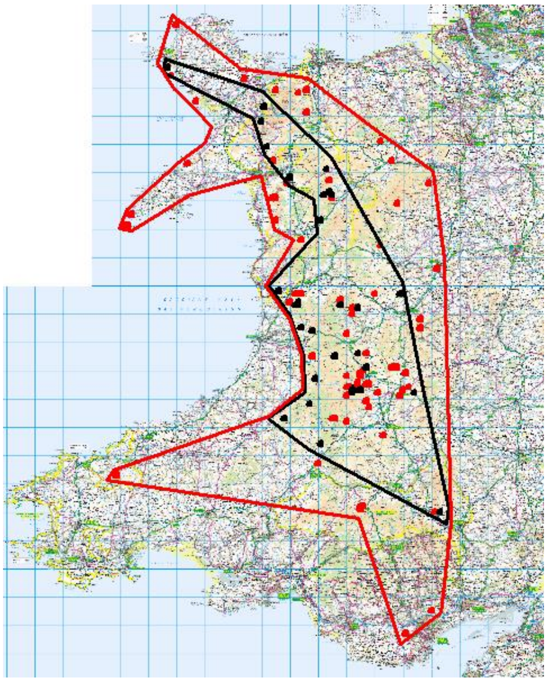

Figure 7.5: distribution of *Bryoria fuscescens* (including *B. subcana*) in 1km squares of the OS Grid in Wales, and area of occupancy, with records from 2000 to 2017 in black and records from 1800 to 1999 in red.

Comparing the distribution of *Bryoria fuscescens* in Wales with 2010 ammonia concentrations (Fig. 7.6) shows the same overall decline in number of occupied squares and Area of Occupancy mentioned above, but it also provides a potential explanation for these declines. The majority of recent (post-2000) records of *B. fuscescens* are from areas of Wales with modelled ammonia concentrations of <0.5 µg/m^3, whilst most colonies in areas with higher modelled concentrations have not been recorded recently. Some colonies have survived in areas with higher modelled ammonia concentrations: *Bryoria* was present in 2006 on Llandegley Rocks (2010 ammonia concentration of 1.49 µg/m^3), and persists in 2017 at Gregynog (0.95 µg/m^3), Gilfach Farm (0.86 µg/m^3) and Neuadd-fach (0.76µg/m^3). This persistence does not indicate tolerance of even those reported ammonia levels, however, because microtopography may protected colonies from exposure to ammonia, and the modelling is generally at 5x5km resolution so actual levels at the *Bryoria* colony may be considerably lower than the modelled concentration for the larger square.

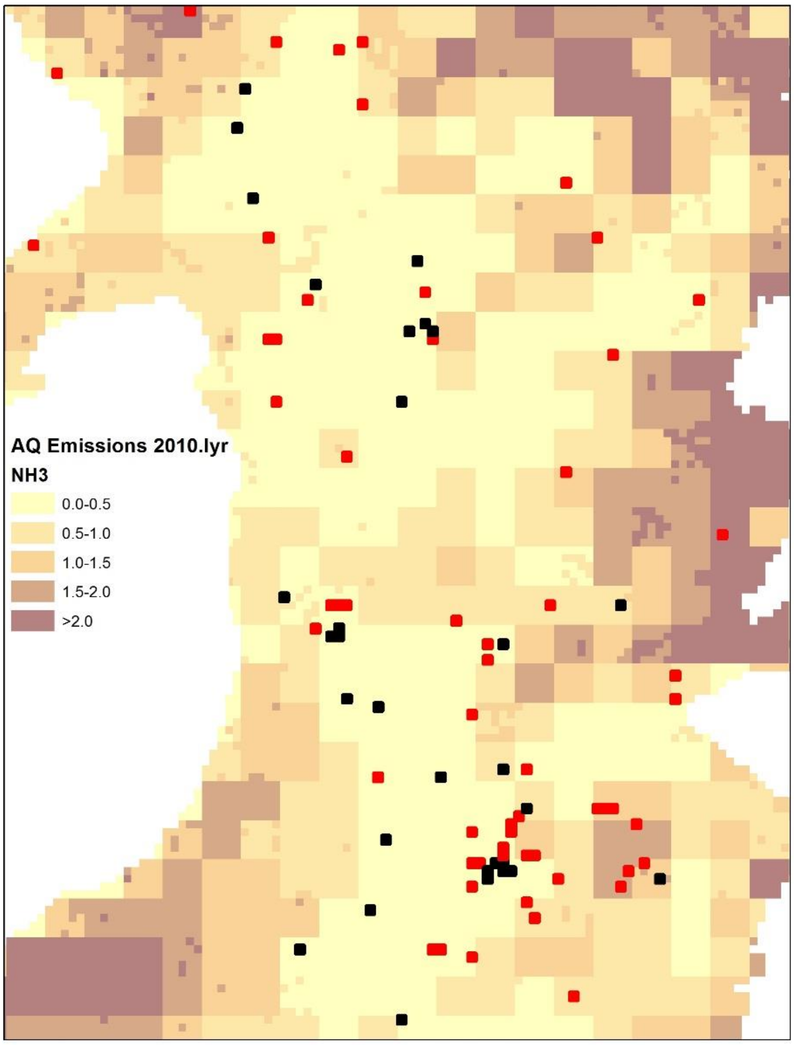

Figure 7.6: distribution of *Bryoria fuscescens* (including *B. subcana*) in 1km squares of the OS Grid in mid/north Wales, with records from 2000 to 2017 in red and records from 1800 to 1999 in red, over 2010 ammonia concentrations from the AQ Emissions 2010 ArcGIS layer.

The survival of *Bryoria fuscescens* at different modelled concentrations of ammonia was investigated by comparing the observed number of occupied 1km squares at each of seven ammonia concentration bands, with the expected number of occupied squares in that band if the 43% survival across Wales was uniform within each ammonia band (Table 7.2). Analysis indicates that survival is greater than the Welsh average at ammonia concentrations of ≤0.6 μg/m^3 and much lower than the national at concentrations of ≥1.0 μg/m^3. The results are relatively close to the average at concentrations of 0.6-1.0 μg/m^3 although the majority of surviving colonies in that range are likely to be protected by microtopography and the concentrations they experience are likely to be lower than the modelled concentration for the 5x5km square where they occur. A Chi-squared p value of 0.56 (5 degrees of freedom) indicates the null hypothesis that *Bryoria* survival and ammonia concentration are unconnected can be rejected with 99.5% confidence.

Table 7.2: the number of 1km squares in Wales supporting *Bryoria fuscescens* in 1980-2017, the expected number of occupied squares (given 43% survival across Wales), the observed number of occupied squares, and the observed percentage survival, given for each of sevem ammonia concentration bands. Survival at greater than the national figure is highlighted in green, whilst lower survival is highlighted in red.

Ammonia Concentration Band (μg/m^3)	Occupied 1km squares (1980-2017)	Expected remaining (2000-17)	Observed remaining (2000-17)	Observed percentage survival
1.5-3.0	4	1.72	0	0.0%
1.0-1.5	8	3.44	1	13%
0.8-1.0	4	1.72	2	50%
0.6-0.8	5	2.15	2	40%
0.4-0.6	17	7.31	8	47%
0.2-0.4	22	9.46	11	50%
0.0-0.2	13	5.59	8	62%

Results for *Cetraria sepincola* and *Tuckermanopsis chlorophylla* are less clear-cut than those for *Bryoria fuscescens*. *Cetraria sepincola* appears to have vanished almost entirely from Wales (Fig. 7.3), and it could not be relocated during targeted surveys at either Cors Llyn Coethlyn SSSI or Abercamlo Bog SSSI in 2017 (Alastair Hotchkiss and Ray Woods *in litt*, 2017). *Tuckermanopsis* was still present near the River Wye at Builth Wells in 2017, but a decline was suspected by Ray Woods (*in litt.*): “it appeared to have decreased in stature – I spotted it originally when walking past and yesterday had to very carefully search the trunk to find the dozen or so small colonies". It is likely that both of these ammonia-sensitive lichens have declined in Wales, but further survey is needed.

7.4 Conclusions & recommendations

7.4.1 Conclusions

Data from the NBN Atlas and expert lichenologists show a significant decline in the epiphytic lichen *Bryoria fuscescens* in Wales. It has declined in three metrics: number of occupied sites (high confidence), Area of Occupancy (high confidence), and abundance on occupied sites (moderate confidence). Declines have been (statistically) significantly greater in areas with higher ammonia concentrations than in areas where ammonia concentrations remain low. *Bryoria fuscescens* (Horsehair Lichen) is a large, distinctive lichen that is a major component of epiphyte communities in parts of Europe and north America. Experiments have shown that N-enrichment causes declines in *Bryoria* spp., and overall changes in epiphyte composition, and that *Bryoria* declines more under high concentration of N than low concentrations (Johansson *et al.*, 2012). The decline in *Bryoria* in Wales parallels the loss of larger epiphytic lichens such as *Usnea* species in 'N-polluted' and 'very N-polluted' epiphyte communities described around Dinefwr Park SSSI (Report 3) and in Gregynog SSSI (Report 4), and has similar implications in terms of ecosystem function, but has occurred to some extent even in parts of Wales that experience little ammonia enrichment. Long-range N deposition probably contributes to these declines, as has been reported in central/northern Europe (van Herk *et al.*, 2003), whilst observations in upland Ceredigion implicate local ammonia enrichment from sheep gathering (Steve

Chambers pers. comm.). Regardless of the causes of declines in low ammonia areas, the significantly greater declines in areas of higher ammonia implicate short-range causes, especially intensive agriculture.

Consideration should be given to the robustness of the data. Analysing species records made by a wide range of people over several decades may produce false trends, for example if recording effort is greater in one period than another, or if there are identification difficulties. *Bryoria fuscescens* is a highly distinctive species in a Welsh context, at least if *B. subcana* is included within a wide definition of *B. fuscescens* (the two species may be genetically identical and there are suggestions that *B. subcana* is a shade form of *B. fuscescens*), whilst the 26 people who made the records are all intermediate or expert lichenologists who would not mistake other species for *Bryoria*. Recording effort is not thought to have changed dramatically in those parts of Wales where *Bryoria* grows between 1980-99 and 2000-17: commissioned site surveys have continued, and although Ray Woods has done somewhat less *de novo* recording in recent years that is balanced by increased recording by Steve Chambers, Sam Bosanquet and the Welsh Government Lichen Apprentice Scheme. The most significant change is that lichenologists now consider *Bryoria* sufficiently unusual that they record every colony they encounter, whereas in the past they did not always note it because it was unremarkable: "Unfortunately *B. fuscescens* was so common I failed to collect detailed records so its difficult to be certain it has completely gone but I can state with certainty it is much diminished" (Ray Woods *in litt.*, 2017). Any changes in data collection would thus make recent records relatively more frequent in relation to true abundance than older records, downplaying the decline.

DEFRA data show that ammonia concentrations have increased in GB and Wales since 2014 (DEFRA 2016), and are higher now in Wales than they were in 2010 (Jones *et al.*, 2017). Use of modelled AQ data from 2010 in the analysis presented in Table 7.2 is not ideal because it is seven years out of date, but the overall pattern of enrichment – and therefore the assessment against broad zones of ammonia concentrations – should still be accurate.

At the same time as ammonia and nitrogen oxide levels have increased, sulphur dioxide pollution has been declining. The combined effect of these pollutants needs to be considered. Effects of ammonia on *Bryoria fuscescens* may have been slowed because of continued impacts from sulphur dioxide and acid rain, although there is no evidence to indicate that *Bryoria* requires SO_2 *per se*: its most robust British populations are in north-east Scotland where sulphur dioixide levels were never particularly high, and Ranta (2001) showed that *Bryoria* spp. increased in the city of Tampere after SO_2 levels reduced significantly. SO_2 pollution has declined to such an extent in Wales that it is generally considered not to be of ecological significance to lichens any more, but in the 1980s and 1990s it was still an ecologically significant pollutant in much of Wales. The combined effect of ammonia and sulphur dioxide on *Bryoria fuscescens* and other ammonia-sensitive lichens requires experimental investigation, but the fact that it is a complex subject should not be seen as indicating that ammonia pollution is not a significant cause of the *Bryoria* decline.

Another potential contributory factor in the decline of *Bryoria* is Climate Change. Research indicates that *Bryoria fuscescens* and *B. capillaris* have huge external water storage capacities (Esseen *et al.*, 2017), holding up to 8.6 tonnes of water per hectare in some boreal forests in north America. This ability to store water externally makes

Bryoria susceptible to rotting, and *B. fuscescens* could have declined in Wales because of increasingly wet conditions. However, the continued abundance of *B. fuscescens* in the Trawscoed area of Meirionnydd – which is not only a very wet, high rainfall of Wales, but has also experienced similar changes in climate to parts of the Cambrian Mountains where *Bryoria* has declined – suggests that Climate Change is probably a relatively minor contributor to the population change compared with pollution. Local changes in woodland structure, especially increased canopy closure, may have caused more humid conditions at some *Bryoria* colonies, potentially explaining why *B. fuscescens* has declined in parts of the Elan Valley of mid Wales where ammonia concentrations remain low. Widespread clearance of *Larix* plantations in Wales in recent years because of *Phytophtora* disease is not considered a significant factor in the *Bryoria* decline despite some strong populations of *Bryoria* being on larch trees for example in north Wales, because the overall number of Welsh records of *Bryoria* on larch is very small (2 of the 54 records that have substrate notes) compared with the number from oak (21 records) and rock (26 records).

7.4.2 Recommendations

The statistically significant link between ammonia concentrations and the decline in *Bryoria fuscescens* in Wales indicates that this distinctive lichen can be used to indicate areas where ammonia levels are currently very low. Such areas are now rare in Wales, and require protection from the ongoing national increase in ammonia. **It is suggested that NRW and other bodies should use the presence of *Bryoria* lichens as a key indicator of sites that are highly vulnerable to ecological damage from intensive agriculture**. Areas with historic records of *Bryoria* should be resurveyed if there are proposals for agricultural intensification nearby, and *Bryoria* should be highlighted if it is located during Twig Lichen Surveys.

A decline of between 31% and 57% in *Bryoria fuscescens* over the last 40 years combines with a significant and increasing threat to suggest that this is one of the most threatened lichens in Wales. It is also a species where action could be taken to reverse the decline, by reducing ammonia pollution around remaining colonies. **This species should be considered for addition to Section 7 of the Environment (Wales) Act**, not only because of its decline and the potential for action, but also because it is a highly distinctive lichen that has the potential to provide significant ecosystem services in clean air woodland ecosystems. The closely related *B. subcana* should also be added to the Section 7 list.

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