

Report of site visit 16 January 2007 to Moninea Bog, Special Area of Conservation, Northern Ireland, including results from foliar bioassay determinations and subsequent ammonia monitoring.

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AUTHORITY AND NATURE OF THIS REPORT

1. I am a research scientist employed by the UK Natural Environment Research Council at the Centre for Ecology and Hydrology (CEH), Edinburgh Research Station, where I am head of the section on Atmospheric Sciences.
2. I completed my PhD on the land-atmosphere exchange of ammonia in 1990, and since then have continued to specialize in the behaviour of atmospheric ammonia in the environment. My work encompasses: measurement and modelling of ammonia emission and deposition, monitoring of atmospheric ammonia concentrations (I lead the UK National Ammonia Monitoring Network), atmospheric dispersion modelling of ammonia at UK and local scales, assessment of environmental effects of ammonia, and policy analysis of ammonia mitigation measures. I have coordinated two EU funded projects on ammonia (EXAMINE, GRAMINAE) and am currently coordinating a 5-year EU Integrated Project, "NitroEurope IP", which includes over 60 institutions from 20 countries.
3. With the support of my section at CEH (staff 30), I provide regular impartial scientific advice on atmospheric ammonia to the Department for Environment Food and Rural Affairs (DEFRA), the Environment Agency, Scottish Environment Protection Agency (SEPA), Natural England, and the Joint Nature Conservation Committee (JNCC). I have also provided similar advice to the European Commission and the European Parliament, as required. I contribute to several of the working groups of the United Nations Economic Commission for Europe (UN-ECE) Geneva Convention on Long-Range Transboundary Air Pollution (CLRTAP), especially the Ammonia Expert Group, for which I coordinate the links with the UNECE Task Force on Measurement and Modelling. As part of this activity, I organized the UNECE Expert Workshop (Edinburgh, December 2006), which recently reviewed and revised the international critical level for ammonia.
4. In the last five years I have provided advice and research contract work to the Environment and Heritage Service (EHS) Northern Ireland, including monitoring of ammonia concentrations and estimation of nitrogen deposition at 10 sites across Northern Ireland, and measurement of ammonia concentrations downwind of poultry houses in relation to housing ventilation system.
5. I was called by the Environment and Heritage Service Northern Ireland to provide expert advice on the health/condition of Moninea Bog in relation to a local source of atmospheric ammonia pollution from Garvary Lodge. Together with my team, I have already provided input on the probable effects of the ammonia, in the form of estimated atmospheric

deposition and critical loads exceedance (e.g. Report of Theobald *et al.*, August 2005). In the present report, I summarize my field observations having visited the site. I then relate these observations to the results of nitrogen bioassay determinations (Appendix 1) from samples collected during my visit to the site and to the results of ammonia monitoring, made subsequent to my visit (Appendix 2).

BACKGROUND

6. Moninea Bog in Fermanagh is designated as a Special Area of Conservation (SAC), under the implementation of the Habitats Directive. The Joint Nature Conservation Committee account of active raised bogs lists Moninea as being one of fourteen SACs in Northern Ireland, where this feature is the primary reason for the designation. (See www.jncc.gov.uk/protectedsites/SACselection/habitat.asp?FeatureIntCode=H7110)
7. The citation notes: “*Moninea Bog is one of the best remaining examples of an active raised bog within the drumlin landscape that occurs across the southern counties of Northern Ireland. The peatland flora typically supports a high cover of bog-mosses, including the hummock-forming species Sphagnum imbricatum and S. fuscum and the nationally rare S. pulchrum. All three native British sundew species, Drosera rotundifolia, D. anglica and D. intermedia, are also present.*”
8. Moninea Bog is located immediately to the east/south east of a poultry farm at Garvary Lodge, which emits significant quantities of ammonia. Broadly, the main ammonia emissions sources from the farm consist of (approximate numbers):
 - 20000 laying hens in a deep pit system operating since the early 1990s
 - 40000 laying hens in a system with removal of manure on belts understood to be operating since 2001
 - 65000 laying hens on a system with manure drying and removal on belts operating since 2005
 - an open lagoon storing liquid poultry manure
9. The exact magnitude of ammonia emissions from Garvary Lodge is not discussed in this report, which focuses on assessing the impacts on Moninea Bog. However, for this purpose it can be considered as established that Garvary Lodge represents a major source of ammonia emission immediately beside the north west edge of Moninea Bog. With winds from the south west through to the north west, emitted ammonia will be advected over Moninea Bog and potentially impact upon it.
10. Bog ecosystem are extremely sensitive to nitrogen inputs, and conservation objectives for Special Areas of Conservation make it plain that agricultural activities on the site should be avoided (DOE-NI,1990). However, it is not possible to avoid all nitrogen inputs, since a significant amount arrives from the ammonia, nitrogen oxides and precipitation, forming “dry deposition” and “wet deposition” nitrogen inputs. The nationally mapped estimate of background grid nitrogen deposition for Moninea Bog (estimated for the 5 km grid-square) is 12 kg N deposition per hectare per year (www.apis.ac.uk). Since this figure is an average over the 5 km grid-square, and as there is significant sub-grid variability in N deposition, this figure should be regarded as indicative; the actual background deposition might vary within the range 10-15 kg N ha⁻¹ year⁻¹. In addition, the background modelled ammonia concentration for the 5 km grid-square surrounding Moninea Bog is 1.5 µg m⁻³.
11. The value of nitrogen deposition below which significant effects on the integrity of the ecosystem are not expected, according to present knowledge, is termed the “critical load”.

Similarly, a “critical level” exists for ammonia, which is the ammonia air concentration above which effects are expected, according to present knowledge. The critical load relevant for bog ecosystems is 5 – 10 kg N ha⁻¹ yr⁻¹, which was agreed by the UN-ECE Expert Workshop at Bern in 2002 (UNECE, 2003). Until recently, the annual critical level for ammonia was that set in at the UNECE Egham Expert Workshop in 1992 (Ashmore and Wilson, 1994) at 8 µg m⁻³. However, there was general agreement in the science community that this value was not sufficiently precautionary for long-term protection of most ecosystems. In December 2006, the UNECE Edinburgh Expert workshop agreed two new critical level values for ammonia (UNECE, 2007), which have since been endorsed by the UNECE International Cooperative Programme on Air Pollution effects on vegetation.

12. The revised ammonia critical levels agreed by the UNECE Edinburgh Workshop, were set for long-term protection of habitats and species based on mean atmospheric ammonia concentrations. It was noted that these values cannot be assumed to protect ecosystems for a period of exposure longer than 20-30 years. For lichens, bryophytes and ecosystems where lichens and bryophytes are essential to the integrity of the ecosystem, a new long term ammonia critical level was set at 1 µg m⁻³. For other semi-natural vegetation and woodland, including higher plants woodland ground flora, the long term critical level was set at 3 µg m⁻³, with an explicit uncertainty range of 2-4 µg m⁻³ reflecting the larger scientific uncertainty on this value. The choice of value in the range 2-4 µg m⁻³ should depend on the legal context of each case and the precaution level to be applied. These new lower values now make the critical levels and critical loads values much more comparable (i.e., the new critical level values broadly provide a similar degree of protection to the empirical critical loads for nitrogen).
13. For Moninea Bog, the appropriate critical load is that for bog ecosystems (5-10 kg N ha⁻¹ year⁻¹). The appropriate critical level for the raised bog itself (where lichens and bryophytes are essential to the integrity) is 1 µg m⁻³. The critical level for the woodland on Moninea Bog, immediately to the east of Garvary Lodge, should be considered as 2 µg m⁻³ (since a precautionary approach is relevant for Special Areas of Conservation), or 1 µg m⁻³ if lichens and bryophytes are argued to be essential to the integrity of this woodland.
14. Atmospheric modelling reported elsewhere shows the poultry farm at Garvary Lodge to be contributing additional nitrogen deposition and ammonia concentrations (above background) over the area of Moninea Bog that are substantially in excess of the critical loads and levels. (Theobald et al., 2005). Nitrogen deposition over the woodland immediately to the east of Garvary Lodge was estimated to reach ~300 kg N ha⁻¹ year⁻¹ (in addition to 12 kg N ha⁻¹ year⁻¹ from background) with NH₃ air concentrations of 33 µg m⁻³ (in addition to 1.5 µg m⁻³ from background). Over the bog itself, the deposition at the edge closest to the farm was estimated to be 45-70 kg N ha⁻¹ yr⁻¹, with NH₃ concentrations of c. 9-14 µg m⁻³, in both cases in addition to background. While it is recognized that there is some degree of uncertainty in such modelled estimates (and it is not the purpose of this report to debate the exact values), they illustrate the potential threat of ammonia deposition to Moninea Bog. Modelled background levels are already slightly above the thresholds. This means that the Bog is already at a general risk from ammonia and nitrogen deposition. Hence, the local contribution from Garvary Lodge will put the bog at significantly additional risk of more extreme damage, particularly in the parts immediately downwind of Garvary Lodge.

15. On the basis of these estimates it is relevant to see whether the expected threat of ammonia from Garvary Lodge appears in practice already to be affecting the health and integrity of Moninea Bog. It was in this context that I visited Moninea Bog on 16 January 2006 in the company of staff from the DOE Environment and Heritage Service to observe the condition of the bog.
16. In making my observations, I was particularly informed by the results of the Whim Bog experiment and controlled, “Open Top Chamber” studies conducted by my Section at CEH Edinburgh. In the Whim Experiment we have been conducting a controlled release of ammonia at 120 kg NH₃ year⁻¹ (in a 35 ° wind sector; equivalent to c. 12000 broilers or c. 4000 layers on a wet manure system) above a blanket peat bog in southern Scotland. We have observed a wide range of effects, with the responses gradually extending larger distances from the source over 5 years of exposure. This has given me a detailed experience of the symptoms which are specific to different plant groups in response to excess atmospheric ammonia.
17. In the light of concerns raised by the modelled ammonia concentrations and my observations of the site, I collected plant material for chemical analysis by my team (described in Appendix 1), and directed the establishment of ammonia monitoring across the site during Spring 2007 (described in Appendix 2).

MY OBSERVATIONS OF THE SITE

18. My observations are restricted to the area of Moninea Bog which I visited, of which an indicative path is shown in **Figure 1a**. In addition, **Figure 1b** shows a map of the site. I entered the site from the south and taking a path broadly northwards to the woodland east of Garvary Lodge. I then returned on a more easterly route south to the same entry point.

Grazing Damage

19. My first observation on entering Moninea Bog was that there is a problem with over grazing by cattle. Adjacent farmer(s) have been allowing access from the west and south (which is unfenced), with this grazing being inappropriate for the optimal management of the bog. This problem is known to the local EHS conservation staff, and is being attended to (i.e., in agreement to fence the bog). The adverse effects of this grazing include trampling (physical damage) and eutrophication, where the cattle had either excreted urine or egested faeces.
20. The trampling of the site creates a physical disturbance which is locally significant in places (in main passage ways), but is mostly an aesthetic problem (i.e., cattle foot holes) rather than a critical problem for biological integrity of the site. This is because the level of physical disturbance is not so significant as to prevent growth of the key higher plant, lichen and moss species. However, the actual removal of biomass by grazing will affect the long term competition and species composition of the canopy.
21. The more serious effect of the over grazing is the excretion/egestion of nitrogen and readily decomposable organic matter onto the bog. Where excretion had taken place, causing extreme local eutrophication over patches of ~0.3 m diameter, there were observed a) extreme damage to moss and lichen species and b) agricultural grass species (e.g. *Lolium perenne*) growing out of decomposing “cow pats” (see **Figure 2**). This is an

extreme adverse effect on the bog, but in a highly patchy and localized form. In terms of the localized damage to the canopy (e.g., due to urine excretion and the associated nitrogen inputs), this included loss of structure of lichens, such as *Cladonia portentosa* and *Cladonia uncialis*, as well as substantial algal growth over *Sphagnum spp.* suffocating the plants.

22. By contrast, a key feature of the overgrazing (as became clear having walked across the bog in both directions) was that the sensitive lichen and moss species remain in the best condition in the most southerly part of the bog, where grazing was significant. This is to say that, where a urine patch or a cow pat occurs, there is an extremely localized problem. However, between these areas, much larger patches of bog vegetation in relatively good condition are seen to survive. This phenomenon and its implications are discussed further below.
23. The walk over the bog showed that only parts of it were affected by this grazing damage. In particular the problem appears to be linked to the southern parts of the bog. The northern parts appear to be little grazed, to the extent that grazing effects are not a major concern in those areas.

Burning of Moninea Bog

24. The aerial photograph of Moninea Bog (Figure 1a) shows an area of recent burning along the north western edge of the bog itself, near Garvary Lodge. This area of burn extends to a strip, up to ~50 m wide, but does not extend into the adjacent woodland.
25. While controlled burning can be an important part of heathland management, I understand this burning was conducted without the consent of DOE-NI. In addition, I am informed that two burns have taken place in the last 2-3 years over broadly the same area of ground, which is unusual, given that nowhere else on the bog is burned. However, it remains unclear whether or not these burns were accidental.
26. Several points may be noted in relation to these burned areas:
 - a) It is not possible at present to determine whether nitrogen deposition is having an effect on the area of the bog which was recently burned. The recent burning thus masks any damage due to ammonia deposition.
 - b) There is evidence that, subsequent to burning, the effects of ammonia deposition on bog/heathland vegetation may actually occur even more strongly as the canopy re-grows. However, these features will take several years to become clear at this site.
 - c) One possibility is that extra ammonia deposition would have given rise to increased occurrence of grasses and dead organic material, which would make the bog more liable to fire. This option involves the conclusion that the ammonia and nitrogen deposition pre-disposed the bog to increased risk of fire.
 - d) The burned areas were of rather limited extent, with minor lasting impacts (through scorching effects) only up to 1-2 m beyond the area of burn. Therefore, the effects of the burning do not hide the effects of atmospheric ammonia deposition to the unburned areas (i.e., the surrounding woodland and the unburned areas of bog).
27. As a result of the last point, it is still possible to assess reliably the effects of atmospheric ammonia deposition from the farm without significant interference from the effects of the recent burning of part of the peat bog.

Effects of ammonia on Moninea Bog

28. Overall, I was struck by the extreme magnitude of the effects of atmospheric ammonia, both on the woodland vegetation and on the bog vegetation itself.
29. My observations relate to:
- the health of plant species known to be sensitive to ammonia, including lichens, bryophytes, other ground flora, shrubs and trees, paying particular attention to integrity of the plant and signs of visible injury,
 - the presence or absence of plant species known to be sensitive to ammonia,
 - the presence or absence of plant species known to favour high nitrogen inputs or high ammonia concentrations – so called “nitrophyte” plants,
 - the overall visual structure of both the woodland canopy and the bog canopy and the surface flora, including characteristic colour of certain specimens.
30. In addition, I collected specimens for the analysis of plant nitrogen bioassays, as bioindicators for atmospheric nitrogen deposition. This included the collection of specimens from a clean reference location approximately 40 km to the north west of Moninea Bog, in an area of low ammonia deposition. The results of these measurements are described in Appendix 1, and these results are also interpreted in relation to the visual observations.
31. Following my visit to the site, CEH Edinburgh in partnership with the EHSNI made measurements of atmospheric ammonia concentrations across Moninea Bog at a subset of the sites noted on Figure 1a, and near a clean reference site (c. 41 km north west of Moninea Bog). The measurements were made for three 4-week periods during February, March and April 2007. The results of these measurements are described in Appendix 2. In the sections below, I clearly separate my visual observations and conclusions (made prior to the results of the biomonitoring and air monitoring), from the subsequent synthesis, which includes the results of these additional measurements.

Visual assessment of atmospheric ammonia effects on the woodland at Moninea Bog

32. It is helpful to consider first the effects on the woodland vegetation that is immediately downwind of the poultry operation at Garvary Lodge.
33. Epiphytic lichens growing on tree trunks and twigs are among the most sensitive species groups to atmospheric ammonia. However, there were very few epiphytic lichens occurring in this wood, possibly because the ammonia levels were so high that conditions were unfavourable even for the nitrophyte species. Of the lichens I did observe, these included small patches of the nitrophytes *Xanthoria parietina* and *Physcia tenella* growing on birch and pine twigs. Both these species are characteristic of high ammonia levels, especially when occurring on these host trees (which have naturally acidic bark). In addition, I noted visible injury on the *Xanthoria parietina* – a bleaching of the lichen thallus (see **Figure 3**), which is suggestive of extremely high levels of ammonia.
34. Only in one area of the woodland I visited (near Site 13 on Figure 1a) were significant epiphytes present including survival of some species which are not nitrophytes. These included *Parmelia* spp and *Ramalina* spp. However, in both cases these specimens showed poor vitality, with the *Ramalina* ssp being colonized by surface living algae – an indication of extreme recent eutrophication. (The fact that the damage is recent is

indicated by the fact that the specimens are still present, while with this level of damage and at current exposure levels, they would be expected to be eradicated over the next few years.) Similarly, none of the most sensitive lichens to ammonia were present, such as *Usea* or *Pseudevernia*, which could have reasonably been expected at this site.

35. The effects on lichens were consistent with observations of woodland bryophytes (mosses and liverworts) at Moninea (Sites 8-13). An abundance of the nitrogen loving moss *Eurynchium praelongum* was noted, as was the occurrence of the moss *Fissidens* spp. which has been observed previously as flourishing under high nitrogen levels. The moss *Rhytidiadelphus squarrosus* was also abundant, which is known to survive high nitrogen levels.
36. By contrast, the moss *Rhytidiadelphus triquetrus* was still present. This moss is characteristic of deciduous woodlands in upland and western Ireland and Britain, and would therefore be expected to occur in such a wood under clean conditions. However, the form of this ground living moss was unexpected. It occurred in a few remaining scattered weak patches on bare soil (suggesting that it was just surviving under unfavourable conditions) (in the vicinity of sites 10-13), while the colour was a deep green (unusual for this species) suggesting a high level of nitrogen enrichment. (see Appendix 1 for the subsequent chemical results).
37. The moss *Polytrichum* spp is known to be sensitive to high ammonia levels, with characteristic damage symptoms being a deep brown/purple colouring of open leaves. Some examples of this symptom were seen (**Figure 4**). However, in this case, since the worst examples occurred near to the burnt bog, it cannot be excluded that the fire had also contributed to the effect. (This is the only instance where fires clearly confused the determination of nitrogen effects.)
38. The woodland ground-flora and canopy under-story was characteristic of a highly eutrophicated environment. Higher plant species characteristic of clean conditions were not present. Instead there was a large amount of *Rubus* spp (Blackberry), a known nitrophyte, which is also characteristic of disturbed ground. In addition, there was a very high occurrence of both *Hedera helix* (Ivy) and *Ilex aquilifolium* (Holly) understory, and a rather poor overstory cover from the trees (linked to the heavy ivy growth) (**Figure 5**). While Holly and Ivy are not known to be specific nitrophytes, they have been observed previously as benefiting and growing luxuriantly adjacent to an other poultry farm. The suggestion is that a) Holly and Ivy are both rather insensitive to high ammonia levels and probably benefit from it, b) possible damage of ammonia to the over story tree canopy would let more light in, allowing increased growth of both the holly and the ivy. These are research questions which require further investigation, but together with the other indicators, they build the picture of a site highly influenced by excess nitrogen deposition.
39. Finally, in regard of the woodland, one of the most extreme features observed was the occurrence of excessive algal growth on tree trunks. **Figure 6** shows two examples of birch trunks approximately 100 m down wind (east) of the poultry houses (Sites 11-15). This shows an unusually thick growth of algae which indicates very high atmospheric ammonia deposition.
40. Overall, from the visual evidence of the lichens, bryophytes, higher plants and algae it can be concluded that this woodland is subject to extremely high levels of ammonia deposition. (This conclusion is tested against the ammonia measurements of Appendix 2,

see Section 59). The loss of sensitive species (including even visible injury on lichens which prefer a high ammonia level!), indicates that the woodland is being very substantially adversely affected by atmospheric ammonia deposition from the farm. These observations are entirely consistent with effects of ammonia observed at other woodlands, although the effects at Garvary Lodge are particularly extreme.

Visual assessment of atmospheric ammonia effects on the bog vegetation at Moninea Bog

41. The effects of ammonia deposition on the bog vegetation of Moninea Bog are the worst that I have ever observed (excepting experimental treatments). These can be clearly attributed to ammonia as they exactly match the features of damage that are observed under field experimental conditions of increasing atmospheric ammonia concentrations (e.g., at the Whim Bog experimental site). In a subsequent section, I explain how it is possible to separate these effects from those of inappropriate grazing by cattle on other parts of the bog.
42. The two most dramatic effects of the ammonia deposition at this site are the loss of the bog mosses (*Sphagnum* species) and the lichens *Cladonia portentosa* and *Cladonia uncialis*. There is substantial widespread damage to these species across the bog. As an approximate indication, I would say that at ~200 m downwind of the farm (near site 17) these species were more than 90% eradicated or injured. At ~400 m downwind (near site 19) I estimate that these species were approximately 50% eradicated or injured. The least injury (attributable to ammonia) was in the far south of Moninea Bog, in the area affected by cattle grazing. Here, for patches where no defecation/urination had occurred, there was probably <10-20% injury, and many apparently healthy *Cladonia* and *Sphagnum* specimens were found. However, I would be unwilling to state that even in this area (furthest from Garvary Lodge) there was no adverse effect of ammonia deposition. It is simply that the plants in this area were much less damaged than closer to the Garvary Lodge Farm.
43. It should be noted that agricultural activities on other fields adjacent to Moninea Bog will contribute to the background ammonia levels, and some adverse effects, recalling that even the background levels slightly exceed the N critical loads and revised NH₃ critical levels. However, the massive deterioration of the bog as one approaches the Garvary Lodge farm, together with the known effects of such large amounts of ammonia deposition, points directly at the ammonia emission and deposition from Garvary Lodge as the reason for damage observed.
44. The specific nature of the damage of ammonia to a *Sphagnum* hummock can be characterised thus (**Figure 7**): First the *Sphagnum* becomes covered with a light covering of green algae, noticeable as a slight slime. As the algal cover increases, this presumably reduces light levels to the sphagnum and also appears to reduce porosity, implying a reduction in gas exchange through the sphagnum. Under this condition, the tops of the *Sphagnum* (the capitula) become easily disconnected from the rest of the plant, which may be because of the poor air exchange leading to death of the plant further into a sphagnum hummock. Finally, under extreme algal growth the whole sphagnum hummock falls apart and decomposes, appearing as a green “mush” on the surface of the peat bog. This process is similar for *Sphagnum* species which are characteristic of both pools and wet lawns. In these cases, the pools and lawns become filled with green slime (see **Figure 8**).

45. The exact mechanisms of why the ammonia increases the algal growth require further investigation, but may be two-fold: a) the extra nitrogen simply favours the algal growth, b) the gaseous ammonia, being alkaline, raises the pH of the normally acidic *Sphagnum* surface, making it suitable for algal growth on the damp sphagnum surface.
46. The characteristic damage of ammonia to clumps of *Cladonia portentosa* or *Cladonia uncialis* (**Figures 9 and 10**) occurs through slightly different but related process to that occurring in *Sphagnum*. Initially, high ammonia exposure may be followed by a pinking of the lichen thallus, as the ammonia reacts with the lichen acids. Subsequently, the thallus may appear bleached and mottled, followed by a loss of integrity of the algal-lichen symbiosis. In some cases the thallus simply dies, and the clump falls apart, leaving the decomposing remains lying on the peat surface. In other cases this death is associated with colonization of the lichens surface by algae. Both these forms of damage were observed at Moninea Bog.
47. The extreme visible damage to *Sphagnum* and *Cladonia* spp within ~200 m may be described in lay terms as a dead *Sphagnum* “mush” and *Cladonia* fragments looking like “a few bleached bones”.
48. In addition to the effects on lichens and mosses, the observations were consistent with effects on higher plants. The site had abundant *Molinia caerulea* (purple moor grass) and *Eriophorum angustifolium* which are known to benefit from enhanced ammonia. Similarly, there was an abundance of *Erica tetralix* (cross leaved heath) which is known to be rather resistant to ammonia. By contrast, although *Calluna vulgaris* (heather) is known to be sensitive to ammonia, the scoring of such effects is harder with a simple site visit, and its health was therefore not assessed. Overall, the effects on the higher plants are harder to detect from a simple winter time visit (as compared with lower plants), and therefore I do not place so much emphasis on it. However, the observations were consistent with responses to excess ammonia.

Results of the chemical bioassays

49. Samples of the plants growing on the bog were submitted for chemical analysis of total nitrogen content and foliar ammonium content. The methods and results are reported in detail in Appendix 1. Two collections of material were made. The main collection was made by myself on 16 January 2007, and the analysis of this material is described first (“main analysis”). Subsequently, my colleague Mr Ivan Simmons collected supplementary plant material on 7 February 2007, which is described second (“supplementary analysis”). The main collection included foliar analysis of both total foliar nitrogen and foliar ammonium, while the supplementary collection included on only analysis of foliar ammonium.
50. The main plant chemical analysis showed extremely high values for samples immediately downwind of Garvary Lodge. For samples of the mosses *Eurynchium praelongum* and *Rhytidiadelphus triquetrus* tissue nitrogen was c. 4 % dry weight near Site 10, which is a factor of 10 higher than values for background conditions. For *E. praelongum* foliar ammonium was c. 50 µg NH₄⁺-N /g fresh weight, which is a factor of 100 higher than the values for background conditions. These are extremely high values, as illustrated by the fact that the agricultural grass, *Lolium perenne*, recorded growing on a decomposing cow pat (Site 5, Figure 2), had a similar nitrogen content to *E. praelongum* and *R. triquetrus* at Site 10.

51. The foliar nitrogen and ammonium values from the main analysis for mosses and lichen at other sites were smaller and decreased with distance away from Garvary Lodge across Moninea Bog:
- | | |
|-----------------------------------|------------------------------------------------------------------------------|
| <i>Cladonia uncialis</i> : | N & NH ₄ ⁺ values at 630 m > clean reference (Site 23) |
| <i>Hypnum jutlandicum</i> : | N & NH ₄ ⁺ values at 66 m > 630 m |
| <i>Sphagnum capillifolium</i> : | NH ₄ ⁺ values at 290 m > 630 m |
| <i>S. papillosum/imbricatum</i> : | NH ₄ ⁺ values at 290 m > clean reference (Site 23). |
52. These comparisons show that foliar nitrogen enrichment is extreme at 4 m, higher at 66 and 290 m than at 630 m (*H. jutlandicum*, *S. capillifolium*) and higher at 290 and 630 m than the clean reference site (*C. uncialis*, *S. papillosum/S. imbricatum*). These distances derive from the locations where there were clear differences in bioassay values, according to Figure 1a, and with the data supported by further measurements of total foliar N at other locations on Moninea Bog.
53. The supplementary analysis (see Appendix 1) focused on foliar ammonium in two species, *Thuidium tamariscinum* and *Hypnum jutlandicum*. In this case all the values were much lower than the main analysis (including at the cleanest sites) and it was difficult to detect spatial trends. The lower values may have been due to the onset of growth and dilution of the ammonium signal, while the lack of spatial signal may indicate that this supplementary collection did not have a sufficiently large sample size.
54. While the results of the supplementary analysis were not clear, overall, it can be concluded, on the basis of the main analysis, that the bioindicator measurements strongly support the conclusions of the visual site observations, i.e. they support the conclusion that atmospheric ammonia from Garvary Lodge is having a significant adverse effect on the site integrity.

Results of the atmospheric ammonia monitoring

55. Atmospheric ammonia monitoring was made for this assessment from 7 February to 30 April 2007. The methods, description of the sampling sites and the results are reported in Appendix 2.
56. Extremely high ammonia concentrations were reported in the woodland on Moninea Bog, immediately to the east of Garvary Lodge. Mean 4-weekly concentrations for the three months tested were in the range 16-34 µg m⁻³ (site Air 1, immediately SW of Site 10 on Figure 1a). Concentrations decreased exponentially with distance from Garvary Lodge, consistent with the normal pattern of dilution away from a significant point source. At the edge of the bog vegetation (site Air 3, SW of Site 13 on Figure 1a), ammonia concentrations were in the range 6.3-11.1 µg m⁻³, for the three test periods. The smallest ammonia concentrations on Moninea Bog were recorded at the site most distant from Garvary Lodge, site Air 6, during February and March with values of 1.1 µg m⁻³ and 1.6 µg m⁻³ respectively. The April value at this site was higher at 3.9 µg m⁻³ (A map of the Air monitoring sites is given in Appendix 2.)
57. The national modelling estimate of NH₃ concentrations at Moninea is supported by comparison with measurements at the reference site Glensheaver (Air 7) 41 km north west of Moninea Bog. During February, the NH₃ concentration at Air 7 was 0.2 µg m⁻³, which was as expected.

58. Long-term NH₃ measurements are also made at the National Ammonia Monitoring Network site near Lough Navar (IH 065545), which provides supporting data on background values for Northern Ireland for this assessment. For the months of March and April 2007, the NH₃ concentration was 0.43 and 1.04 µg m⁻³, respectively. The long term mean Lough Navar is 0.47 µg m⁻³ (www.cara.ceh.ac.uk/nh3network/index.html), which supports the conclusion that the local-background values are higher at Moninea Bog.
59. It should be noted that the NH₃ concentrations at Site 22 (Air 6) on Moninea Bog may still include a significant contribution from Garvary Lodge. However, a conservative estimate of the contribution of Garvary Lodge to atmospheric ammonia on Moninea Bog can be made by subtracting the value of the cleanest site (Air 5 or Air 6) from other measured values. The lower limits of the process contribution of Garvary Lodge to NH₃ concentrations across Moninea Bog (Air 1 - Air 5) are thus: 0.65-15 µg m⁻³ (February 2007) and 0.38-31.5 µg m⁻³ (March 2007). For April, Air 5 is used as background (since Air 6 is subject to other sources), giving minimum process contributions (Air 1 to Air 3) of 7.5 – 30.4 µg m⁻³.
60. The characteristic log-linear decrease of NH₃ concentrations away from Garvary Lodge shows that this farm is the source of the locally enhanced NH₃ concentrations.
61. The ammonia concentration measurements reported here suggest that long term background NH₃ concentrations at Moninea Bog will be above the critical level of 1 µg m⁻³ relevant for the bog community. In addition, the very high NH₃ concentrations measured over Moninea Bog indicate that the critical level will be substantially exceeded, directly as a result of the poultry farming operations at Garvary Lodge.
62. Overall, the NH₃ measurements are very similar to the prior modelling estimates (paragraph 14). Similarly, the measured NH₃ concentrations confirm the prior inference of large NH₃ concentrations derived from the visual observations (paragraph 40).

Separating the effects of grazing vs atmospheric ammonia

63. It may be noted that the effects of cattle grazing and atmospheric ammonia can appear superficially similar. This is not surprising since both represent effects of additional nitrogen input to the peat bog. However, Moninea Bog presents an excellent example of how these different effects can be clearly distinguished.
64. As noted above, the affects of faecal deposits (cow pats) and excretion (urine patches) are extremely localized. Hence the vegetation exposed to either is substantially affected. Where cowpats occurred this led to either green patches of agricultural grass (*Lolium perenne*) or algal growth in wet areas. Similarly, urine patches can explain the occurrence of localized death and algal growth on lichens and *Sphagnum*. By contrast, the physical effect of limited trampling does not adversely affect these species significantly. Hence, between urine and dung patches, the bog vegetation may survive in good (or at least better) condition.
65. By contrast, atmospheric ammonia deposition is diffuse and affects wide areas of the bog surface. Some patchiness can be attributed to local microclimate differences (e.g., direction of exposure) and variation in sensitivity (even within species), but the effect is a widespread level of damage across a site.

66. Moninea Bog is interesting, since the area I visited with significant cattle grazing damage was the furthest from the Garvary Lodge ammonia source. Thus the best surviving specimens were found in the grazed area, while the worse area of damage (near the Garvary Lodge Farm) was little affected by cattle grazing. This demonstrates that, although cattle-grazing is a problem for the ongoing management of Moninea Bog, it can be clearly separated from the major effects of atmospheric ammonia deposition to the site. The ammonia effects on the peatland vegetation are most severe near to Garvary Lodge, and these are matched by characteristic ammonia effects in the woodland adjacent to Garvary Lodge, as well as increased nitrogen bioindicator values. On the basis of these different strands of evidence, together with the biomonitoring and air monitoring data, I conclude that the ammonia emissions from poultry operations at Garvary Lodge are responsible for an extreme level of damage to Moninea Bog.

Possible confounding influences

67. It may be noted that there are cement factories at two locations, about 1.7 km to the west, and 2.2 km to the southwest and a glass factory about 3km to the northwest of the bog. It might be argued by someone that these activities were responsible for the damage seen at Moninea Bog.

68. Some damaging effects of industrial sources in general are feasible, since such processes can include the emission of nitrogen oxides and sulphur dioxide. However, these would not explain the effects of ammonia observed at Moninea (e.g. sulphur deposition would not significantly affect foliar nitrogen, while the lichen effects are highly characteristic of ammonia). Ammonia emissions from cement plants are typically 1% of the emitted nitrogen oxides. Modelling undertaken by EHS shows that the impact on Moninea Bog from these sources would be small, particularly since the elevated nature of the releases leads to much better dispersion from these more distant sources.

69. As a result, no significant adverse effects from local cement works are predicted on Moninea Bog. By contrast, the evidence for the damage observed over the SAC being due to ammonia emissions from Garvary Lodge can be summarized as:

- a) The effects on Moninea Bog and the woodland are highly characteristic of ammonia damage. These include the damage to *Cladonia* and *Sphagnum*, but also features such as the greening of mosses such as *Rhytidiadelphus triquetrus* by the farm and bleaching of *Xanthoria*, supported by plant chemical bioindicator measurements.
- b) Ammonia is known to be emitted from the adjacent poultry farm and the more distant cement and glass factories do not make a significant contribution to nitrogen deposition, nor can they explain the ammonia-specific effects.
- c) The effects of ammonia on Moninea get much worse closer to Garvary Lodge farm. Such a strong gradient across the site would not be expected to occur if the source of pollution was from the more distant cement and glass factories (which would contribute to a more even deposition widely across the site).
- d) The visual observations are supported by chemical bioindicator measurements for a range of plant species, which all point to the most extreme effects immediately adjacent to Garvary Lodge.
- e) Measured ammonia concentrations decrease in an approximate log-linear pattern away from maximum values adjacent to Garvary Lodge, which is exactly as expected downwind of such a poultry farm.

70. Combining these multiple strands of evidence, it can therefore be concluded that significant damage observed to the Moninea Bog SAC is without doubt the result of ammonia emissions from the Garvary Lodge farm. Damage on the site has also occurred through inappropriate grazing and burning of parts of the SAC, but these effects can to a large extent be distinguished from those of the ammonia.
71. Of the three main threats to Moninea Bog (*viz.* Cattle grazing, inappropriate burning, ammonia deposition), I consider the ammonia deposition to be by far the most significant adverse effect. The reasons are:
- a) the burning is only over a small area and (so long as atmospheric nitrogen inputs are low) the moorland is expected to recover relatively quickly. The challenge here is for appropriate management, rather than e.g. two burns over the same land in three years.
 - b) The grazing leads only to patchy damage – between the affected areas (trampling, faecal deposits, urination) the species richness and integrity of the bog appears to be little affected. This matter can also be dealt with easily by appropriate fencing
 - c) The ammonia deposition leads to widespread effects with major losses of species. The diffuse nature of the eutrophication effects means that recovery of the ecosystem integrity may take many years, and may need active restoration management. For example, in the Netherlands, some heathlands have even been managed including removal of surface turfs to remove the eutrophicated material. Maintaining and restoring the integrity of Moninea Bog, is likely to require that the poultry ammonia source largely ceases, coupled with agreement on an active restoration plan for the bog. At the same time, attention needs to be given to address the wider background levels of ammonia reaching the site.

Moninea Bog condition and observation of rare species

72. It was noted in paragraph 7 that Moninea Bog is one of the best remaining examples of an active raised bog in the southern counties of Northern Ireland, including the uncommon hummock-forming species *Sphagnum imbricatum* and *S. fuscum* and the nationally rare *S. pulchrum*, plus all three British sundew species, *Drosera rotundifolia*, *D. anglica* and *D. intermedia*.
73. I would consider Moninea bog as being in unfavourable condition, with substantial deterioration currently occurring. The massive damage to at the site, clearly makes its condition “unfavourable”. In addition, the evidence of the *Cladonia* is relevant to show that damage is currently occurring and getting worse. My estimate is that once a *Cladonia* plant is killed by excess ammonia, its remains only last ~2 years under UK conditions before they are lost or covered by other species, such as re-growing pleurocarpous mosses. Therefore, the stumps of former *Cladonia* plants, plus currently dying *Cladonia* clumps, indicates that the site is deteriorating due to the current ammonia levels. (If the site had been subject to former high ammonia levels and was recovering, then these species would either already be absent or recolonization would be seen, which is not the case). The observation of deteriorating conditions is consistent with increase of the Garvary Lodge ammonia emission in the last 1-2 years (recently erected building) and the last 5-6 years (the second building on the site). In order to protect Moninea Bog from further damage, it therefore becomes an urgent issue to deal with the local ammonia emissions from Garvary Lodge Farm.

74. It may be briefly noted why the damage at this site is so severe (being the worst ammonia damage to a peat bog that I have seen). It is simply that this is a substantial ammonia emission located extremely close to the Moninea Site. Had the farm been located, e.g., 5-10 km from the site, it would have contributed to increased background levels, but would not have been the central threat to the integrity of the SAC.
75. Finally, I should note that among the *Sphagnum* species, I observed the more typical species, *S. capillifolium*, *S. papillosum*, *S. palustre* and *S. magellanicum*. I also observed the occurrence of the cited rare species *S. fuscum* and *S. imbricatum*, both of which showed adverse effects. I only observed *S. pulchrum* in one small clump (provisional identification). On a specimen of *S. imbricatum* I also observed a sample of *Drosera rotundifolia*, but this was only the dead leaves from last year's growth (Figure 7). The presence of the *Drosera* species can be best assessed during summer months when they are actively growing.

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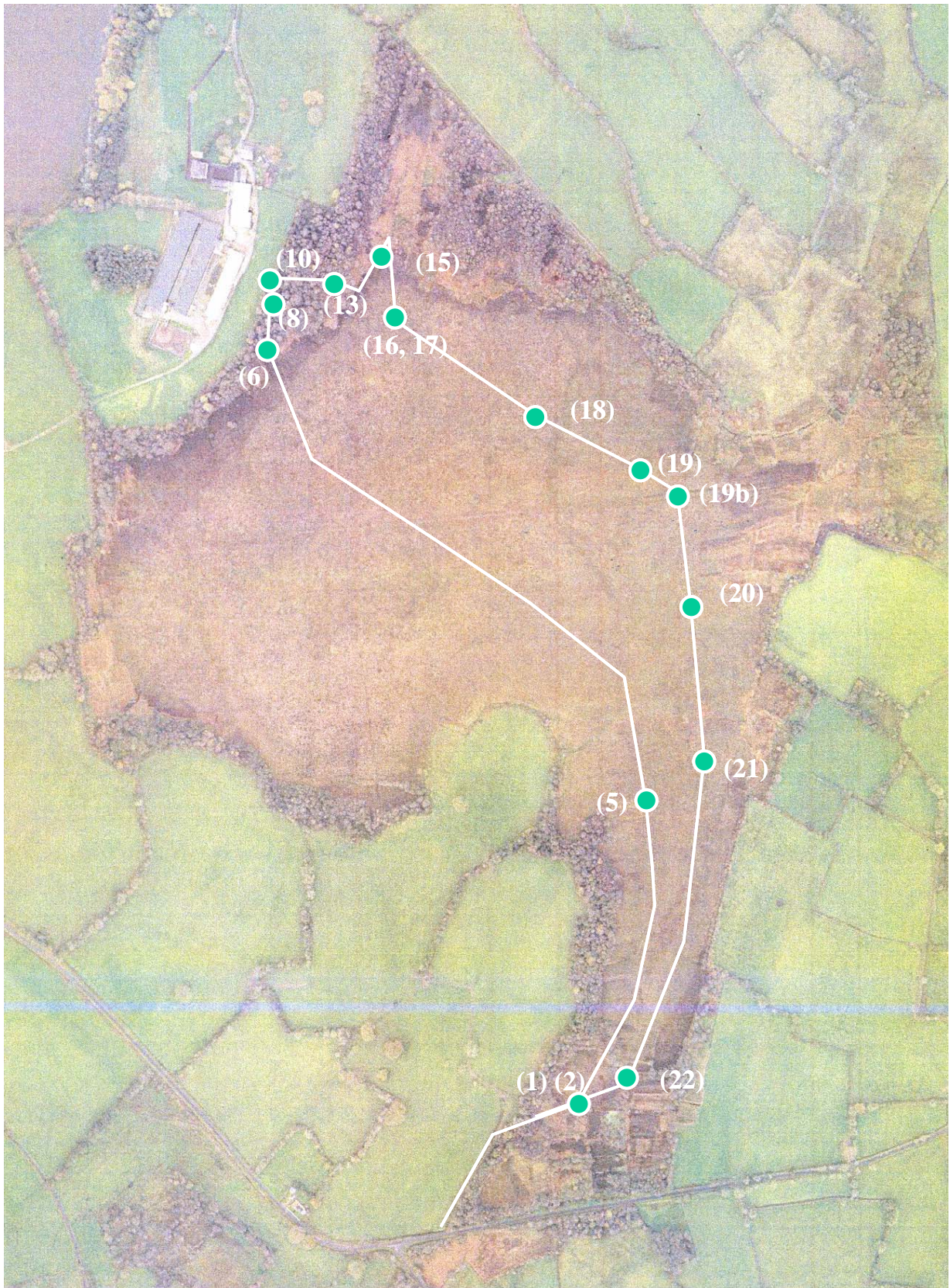


Figure 1a: Aerial photograph of Moninea Bog SAC. The white line indicates my approximate route over the site, starting from the southern corner and proceeding clockwise. The key points on the route were recorded by a GPS, with the numbers referring to observations or points of sample collection. The poultry houses and lagoon can be seen on the north west (top left) corner of the photograph. The burned area is visible as a darker brown on the northern edge of the bog adjacent to the woodland by Garvary Lodge. Additional sites (Sites 23 and 24), approximately 41 km North-West, were used to illustrate reference conditions in an area of low ammonia emissions.

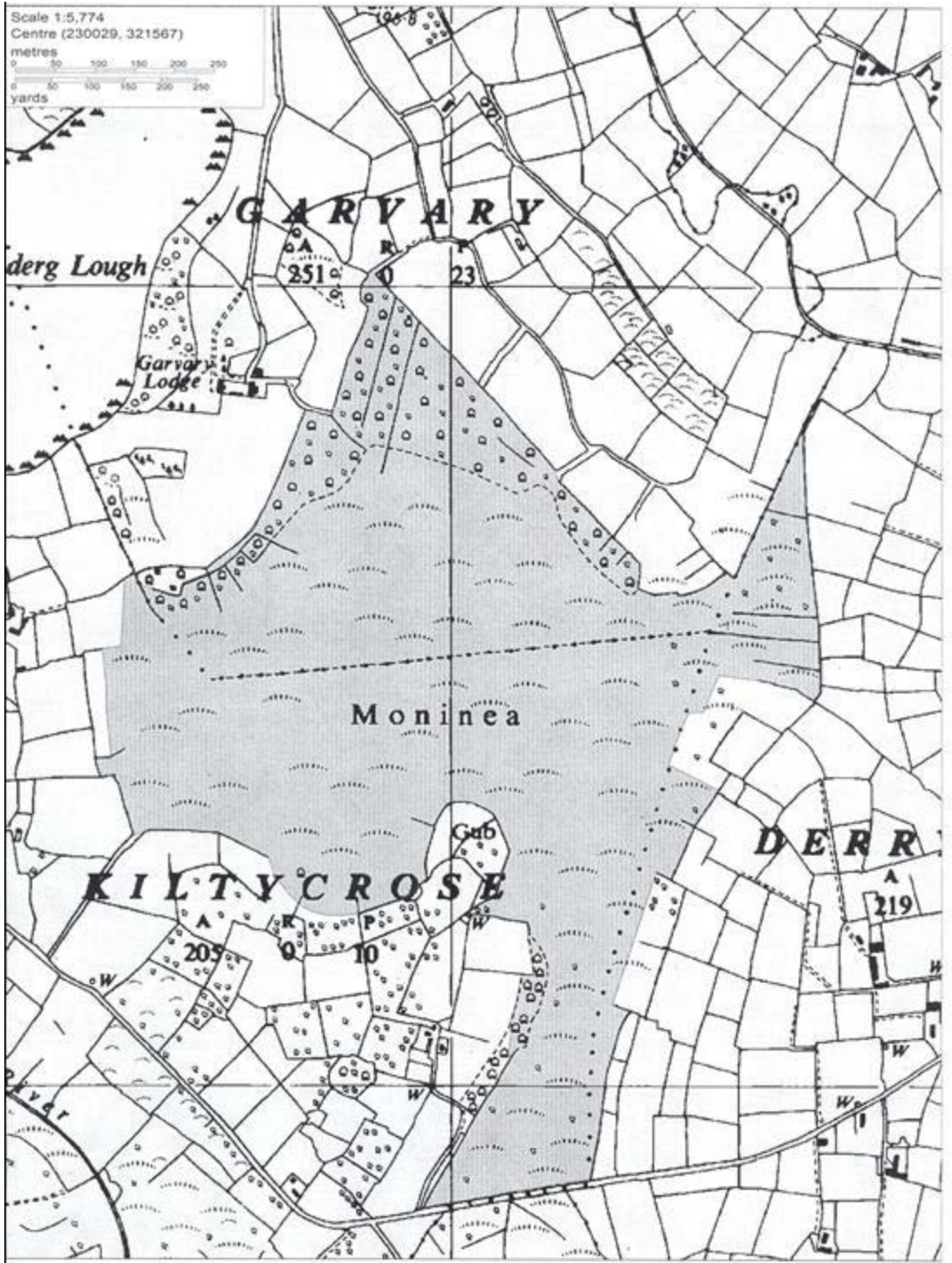


Figure 1b. Map of Moninea Bog.



Figure 2: *Lolium perenne* growing on a former cowpat in near Site 5 on Moninea Bog.



Figure 3: Photograph of damage to the nitrophytic lichen *Xanthoria parietina* observed (on a birch twig) in the wood at Moninea Bog, downwind of Garvary Lodge. (Sites 13-15). The area of lichen thallus on the far left is the usual yellow green colour, while further to the right the thallus has been bleached white, indicative of extremely high ammonia concentrations.



Figure 4: Damage to *Polytrichum* moss consistent with effects of excess ammonia. (Note the blackened leaves). It is possible that some examples of this effect were influenced by fire.



Figure 5: View of the wood on Moninea Bog SAC adjacent to Garvary Lodge Farm (near Site 10). This part of the wood, closest to the farm is dominated by a large amount of Blackberry, Ivy and Holly, and significant gaps in the overstory canopy, consistent with high ammonia deposition.



Figure 6: Examples of heavy algal colonization on birch trunks on Moninea Bog SAC, downwind of Garvary Lodge Farm (Sites 11-15).

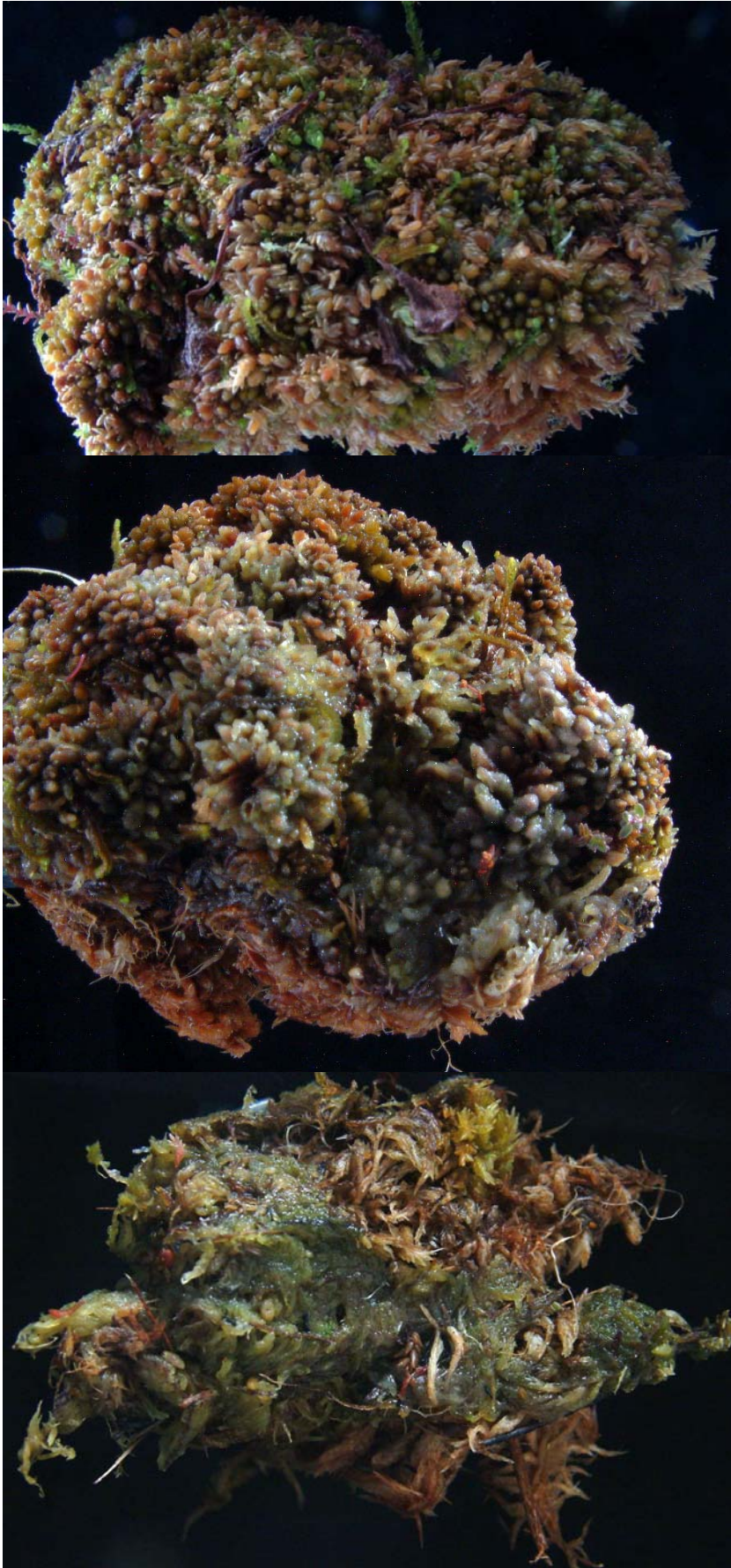


Figure 7: Stages of deterioration of samples of *Sphagnum imbricatum* (samples from Site 18). Top: apparently healthy specimen (with sundew leaves from previous year's growth); Middle: specimen with first stages of overlaying algal growth; Bottom: major algal growth and falling apart of hummock structure.



Figure 8: Illustration of *Sphagnum* pool affected by ammonia deposition on Moninea Bog (site 18).



Figure 9: A damaged clump of *Cladonia portentosa* showing various stages of deterioration, highly characteristic of ammonia damage.



Figure 10: Example of a *Cladonia uncialis* lichen on Moninea Bog. This illustrates recent damage to the plant: Most of the plant is a bleached white (typical of ammonia damage), but the fact that the physical structure of the plant remains indicates that this damage is recent (e.g. probably within the last year). In time specimen will decompose in a similar way to that illustrated in Figure 9. Remaining areas of live lichen thallus are seen in light blue areas to the top and left of the picture.

APPENDIX 1: RESULTS OF CHEMICAL ANALYSIS OF FOLIAR CHEMISTRY ON MONINEA BOG

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Methods

1. Plant samples collected by Mark Sutton on Moninea Bog (15 January 2007) were submitted for chemical analysis of both total nitrogen content (% dry weight) and ammonium nitrogen content ($\mu\text{g NH}_4^+\text{-N/g}$ fresh weight). These analyses were selected since they have been shown to provide useful indicators of atmospheric nitrogen deposition, especially including the effects of elevated ammonia concentrations (Sutton et al. 2004; Leith et al. 2005). The use of both parameters increases the robustness of the analysis, particularly since the response of foliar ammonium to enhanced ammonia deposition is much larger than the response of total foliar nitrogen. Box A1 summarizes the sample collection and analysis procedures. This group of samples is referred to as the main analysis.
2. Following the establishment of ammonia monitoring (See Appendix 2) further moss samples were collected and analyzed for foliar ammonium only (Box A2). The objective was to relate the bioassays directly to the measured ammonia concentrations. This group of samples is referred to as the supplementary analysis.
3. The purpose of the plant chemical analyses was to provide a biochemical indication of the effects of ammonia deposition from the poultry farm at Garvary Lodge. Therefore samples were taken at different distances from the farm, allowing comparison of different distances. By contrast, the measurements represent a small-scale indicative assessment rather than a full scientific study, which would have required many more resources.
4. The locations of the sample collection are shown in Figure 1a, as recorded by a hand-held global positioning system. In order to present the results in a simple graphical form, the sampling points were expressed as the distance from the NW edge of the SAC. A reference point (29802, 21769) which was 4 m to the north of Site 10 was used for calculation of all the other distances for the main analysis. For the supplementary analysis, the same reference point was used as for the ammonia monitoring (Appendix 2).
5. As most of the samples were taken to the E and SE of the Garvary Lodge farm, the calculated distance provides a simple metric of exposure to atmospheric ammonia from Garvary Lodge. A possible exception is Site 6, which was directly to the south of Site 10, so that it would be significantly closer to the edge of SAC than indicated by the calculated distance (66 m). However, this effect may be considered as being offset by the fact that under W and SW prevailing winds, ammonia concentrations would be lower at Site 10 than an equivalent distance E and SE. Therefore, the calculated distance from SAC edge may still be considered a useful general metric of the impact of ammonia from Garvary Lodge.

Box A1: Summary of foliar nitrogen collection and analysis from Moninea Bog.

16 January 2007

Samples collected by Mark Sutton.

On collection the lichen and bryophyte samples placed in paper bags.

17 January 2007

All samples were initially examined in the conference room at CEH Edinburgh. All samples were placed in paper bags and catalogued by Site number and an initial identification carried out. All samples were placed in a cold room set at 4 °C. Sub-samples of vegetation were taken for soluble ammonium analysis. These samples were placed in polythene bags, labelled and placed in a -20 °C freezer until they were cleaned and sampled for soluble ammonium determination.

18 January 2007

Calluna vulgaris samples from all sites were sorted. Disposable powder-free nitrile gloves were always used during the sorting and cleaning process. Current year shoots (2-3 cm in length) were trimmed from the collected shoots. The samples were given a light spray with de-ionised water (to clean surfaces) then put in paper bags and dried in a 70 °C oven for 48 hours.

Some of the bryophyte and lichen samples were photographed using a Canon EOS 350D SLR Digital camera using a 50 mm macro lens under natural light conditions. The auto-levels of all photographs were adjusted using Photoshop CS.

21 January 2007

Additional photographs were taken using the same camera and lens and the photos adjusted using auto-levels in Photoshop CS. Fifteen bryophyte/lichen samples were sorted, cleaned and dried in a 70 °C oven for 48 hours. Only the *Sphagnum capitulum* (mass of crowded branches at the apex to the stem) was used for tissue N determination. The pleurocarpous mosses were trimmed to 2-3 cm depending on species. Only the thalli tips (1-2 cm) were used for *Cladonia uncialis* and *Cladonia portentosa*.

22 January 2007

The last of the photographs were taken. All bryophyte/ lichen samples were sorted, cleaned and dried in a 70 °C oven for 48 hours.

24 January 2007

All samples were ground to a fine powder using a Retsch MM200 Ball mill and placed in 3ml glass vials. The samples were ground for 1.30 minutes at a frequency of 30 I/S. The thirty-nine samples were sent by recorded delivery to the Environmental Analysis Group at CEH Lancaster (See Table A1).

26 January –30 January 2007

Samples were received at Lancaster and stored at room temperature. Analysis for total nitrogen (N) and total Carbon (C) was carried out over the next 4 days and completed by 30 January 2007. The 39 sub samples were dried at 105 °C for 3 hours then 0.008-0.012 g of sample were placed in tin capsules. These were then analysed for total N and C using an Elementar Vario elemental analyser.

23-24 January 2007

The vegetation (bryophytes and lichens) sub-samples for soluble ammonium analysis were cleaned: only the green parts were used and all soil, leaf fragments etc were removed. The vegetation samples were cut in smaller pieces (~ 1 cm), rinsed quickly with de-ionised water, blot-dried with tissue paper and stored in freezer at -20 °C.

26 January 2007

Vegetation samples for soluble NH₄-N analysis were extracted:

1 g (weighed to know the exact amount) of each sample was put in a 20 ml vial. 10 ml of de-ionised water was added. Note: for 2 samples there were only smaller amounts of vegetation available and so there was only 5 ml de-ionised water added to these samples. The vials were closed, shaken and left for 4 hours at room temperature (20 °C). The solution was then filtered (PURADISC™ 25PP disposable filter 0.45 µm Polypropylene) and stored in freezer (-20 °C) until analysis.

29 January 2007

Samples were defrosted and analysed for NH₄⁺ by floRRia (ammonia flow injection analysis). Soluble NH₄-N is expressed as µg N g⁻¹ FW (fresh weight).

The concentration of soluble NH₄ was calculated as:

$$N_{f,NH_4-N} = 14/18 * ([N_{NH_4^+} - N_{bl}] * (M_{extractant} + M_{f,sample}) / M_{f,sample})$$

where N_{f,NH_4} is the nitrogen concentration (µg g⁻¹ fresh weight), from ammonium. $[N_{NH_4^+}]$ is the concentration of ammonium in the extraction solution (µg g⁻¹), $[N_{bl}]$ is the concentration of ammonium in the blanks (= de-ionised water)(µg g⁻¹), $M_{extractant}$ is the mass of extractant used (10 g as standard) and $M_{f,sample}$ is the fresh mass of the leaf sample (g).

Box A2: Summary of the supplementary analysis of foliar ammonium from the same points as ammonia monitoring.

6-7 February 2007

Samples collected by Ivan Simmons (CEH) for sites 1-7.
On collection the bryophyte samples placed in paper bags.

7 March 2007

Samples collected by EHS officer for site 8.
On collection the bryophyte samples placed in paper bags.

15 February 2007 (sites 1-7)

12 March 2007 (site 8)

The vegetation (bryophytes) sub-samples for soluble ammonium analysis were cleaned: only the green parts were used and all soil, leaf fragments etc were removed. The vegetation samples were cut in smaller pieces (~ 1 cm), rinsed quickly with de-ionised water, blot-dried with tissue paper and stored in freezer at -20 °C.

16 April 2007

Vegetation samples for soluble NH₄-N analysis were extracted:
1 g (weighed to know the exact amount) of each sample was put in a 20 ml vial. 10 ml of de-ionised water was added. Note: for 2 samples there were only smaller amounts of vegetation available and so there was only 5 ml de-ionised water added to these samples. The vials were closed, shaken and left for 4 hours at room temperature (20 °C). The solution was then filtered (PURADISC™ 25PP disposable filter 0.45 µm Polypropylene) and stored in freezer (-20 °C) until analysis.

19 April 2007

Samples were defrosted and analysed for NH₄⁺ by floRRia (ammonia flow injection analysis). Soluble NH₄-N is expressed as µg N g⁻¹ FW (fresh weight).

The concentration of soluble NH₄ was calculated as:

$$N_{f,NH4-N} = 14/18 * ([N_{NH4+} - N_{bl}] * (M_{extractant} + M_{f,sample}) / M_{f,sample})$$

where $N_{f,NH4}$ is the nitrogen concentration (µg g⁻¹ fresh weight), from ammonium. $[N_{NH4+}]$ is the concentration of ammonium in the extraction solution (µg g⁻¹), $[N_{bl}]$ is the concentration of ammonium in the blanks (= de-ionised water)(µg g⁻¹), $M_{extractant}$ is the mass of extractant used (10 g as standard) and $M_{f,sample}$ is the fresh mass of the leaf sample (g).

Main Analysis Results: foliar nitrogen compared with foliar ammonium

6. Due to limited amounts of sample material collected, foliar ammonium was only analyzed for a subset of the collected samples (where enough material was available for both ammonium and total nitrogen analysis). **Figure A1.1** presents the results for the paired analysis of total nitrogen and ammonium nitrogen for this subset of sites. Figure A1 shows that both total nitrogen and foliar ammonium are larger closer to Garvary Lodge farm. The highest values were recorded at Site 10, for *Euryhynchium praelongum*, which had a total nitrogen content of 4.2% DW and an ammonium nitrogen content of 43.5 µg /g FW. These represent extremely high values, which are expected for a site so close to a major source of ammonia emission. By contrast, values at the background reference site were 0.3-0.8 N % DW and 0.1-0.55 µg /g NH₄⁺-N FW. Hence, the highest values on the SAC are approximately 10 times higher than background for total N and 100 times higher than background for foliar ammonium.
7. Comparison of the two bioindicator measures in **Figure A1.2** shows that there is a significant correlation between the foliar nitrogen and foliar ammonium values for the samples collected ($R^2 = 0.87$). Such a positive correlation has been shown before by

Sutton et al. (2004) and Leith et al. (2005). As the two measures of nitrogen enrichment are independent, the high correlation demonstrates the robustness of the chemical analysis for each of the parameters.

8. Figures A1.1 and A1.2 are restricted to lichens (*Cladonia* spp) and bryophytes. However, it should be noted that some inter-species differences may occur which can also contribute to the trends shown in Figure A1.1. Nevertheless, where individual species are compared (see also Table A1.1) they typically show larger values at sites closer to Garvary Lodge.
9. For example, at the clean reference location (Site 23) values for the lichen *Cladonia uncialis* were 0.26 N % DW and 0.08 $\mu\text{g NH}_4^+\text{-N / g FW}$, while on Moninea Bog at Site 20 (~630 from the NW edge of the SAC) the corresponding values were 0.31 N % DW and 0.11 $\mu\text{g NH}_4^+\text{-N / g FW}$. The values on the SAC were thus 20% and 37% higher than background, respectively. It should be noted that these values are all small compared with other species, reflecting the nature of *C. uncialis* as a plant of extreme oligotrophic conditions. This may also reflect a particular sensitivity to ammonia, since the plant was not recorded on this visit (in a healthy state) closer to Garvary Lodge.
10. The comparison of *Euryhynchium praelongum* and *Cladonia uncialis* is illustrative of different responses to excess nitrogen. *E. praelongum* is a nitrophytic species and therefore flourishes in high nitrogen situations, storing excess nitrogen in its tissues, as reflected in the bioindicator results. By contrast, *C. uncialis*, as a sensitive nitrophobe, is damaged by excess nitrogen to the extent that it ceases to occur at very high nitrogen inputs. This would explain why *C. uncialis* was not found close to Garvary Lodge, and why the maximum values recorded here are much smaller than for *E. praelongum*.
11. A similar increase in both foliar N and foliar ammonium was found for *Hypnum jutlandicum*. At Site 20 (~630 m from the NW edge of the SAC) values were 0.92 N % DW and 1.78 $\mu\text{g NH}_4^+\text{-N / g FW}$, while at Site 6 (~66 m distance) the values were 1.09 N % DW and 3.72 $\mu\text{g NH}_4^+\text{-N / g FW}$. The values at Site 6 represent an increase of 20% and 110% for total N and foliar ammonium, respectively, as compared with Site 20.
12. By contrast to the above species, in the case of *Sphagnum*, foliar ammonium was found to respond more effectively to ammonia deposition than total foliar nitrogen. For *S. capillifolium* the foliar N values were 0.75, 0.75 and 0.74 N % DW for Sites 18, 21 and 23, respectively (290 m, 630 m and background reference). By contrast, the foliar ammonium values were 1.45, 0.51, 0.53 $\mu\text{g NH}_4^+\text{-N / g FW}$ for the same sites. Similarly, for *S. imbricatum* and *S. papillosum*, the foliar N values were 0.61, 0.68, and 0.61 for Sites 18, 18 (second sample) and 23 (290 m and background reference), while the foliar ammonium values were 1.76, 0.85 and 0.23 $\mu\text{g NH}_4^+\text{-N / g FW}$ for the same sites. These species comparisons indicate that foliar ammonium is a more sensitive parameter to atmospheric ammonia deposition than total foliar nitrogen.
13. While the comparisons of this limited dataset are not suited to detailed statistical analysis, they are nevertheless well suited to inform an expert judgement of the effects of nitrogen on foliar chemistry at this site. The above species-level comparisons be summarized as:
 - Euryhynchium praelongum*: N & NH_4^+ values at 4 m >> all others on site.
 - Cladonia uncialis*: N & NH_4^+ values at 630 m > clean reference (Site 23)
 - Hypnum jutlandicum*: N & NH_4^+ values at 66 m > 630 m
 - Sphagnum capillifolium*: NH_4^+ values at 290 m > 630 m
 - S. papillosum/imbricatum*: NH_4^+ values at 290 m > clean reference (Site 23).

14. Overall, these comparisons show that foliar nitrogen enrichment is extreme at 4 m, higher at 66 and 290 m than at 630 m (*H. jutlandicum*, *S. capillifolium*) and higher at 290 and 630 m than the clean reference site (*C. uncialis*, *S. papillosum*/*S. imbricatum*).

Main Analysis Results: Foliar nitrogen for different plant groups

15. In addition to the paired comparison of total foliar nitrogen and foliar ammonium, additional analyses were conducted for total foliar nitrogen (Table A1.1.). These results are shown in **Figure A1.3**, which compares different plant groups included in the analysis.
16. The clearest response in Figure A3 is for pleurocarpous mosses, with values increasing from 0.4 N % DW for *Racomitrium lanuginosum* at Site 23 to the value of 4.2% for *Eurhynchium praelongum*, already noted. A particularly notable result is a very high value near Site 10 for *Rhytidiadelphus triquetrus* of 3.95 N % DW. This is an extremely high value for this species, and is not surprising given the very green colour of the specimens collected.
17. Foliar nitrogen of *Calluna vulgaris* was found to be larger at 66 and 69 m (Sites 6, 13), than at the other sites. However, in this case, a decrease at the more distant sites was not clearly seen.
18. Foliar nitrogen was found to decrease across the site for the *Cladonia* spp from 124 m (Site 17) to the clean reference (Site 23). The sample at 124 m was of *C. portentosa* and it was seen to be significantly damaged, showing symptoms characteristic of ammonia exposure.
19. For the full dataset of total foliar N for the collected *Sphagnum* samples, there was little observable relationship between total foliar nitrogen and distance. This is not surprising, noting the above comparison between foliar ammonium and total nitrogen. This implies that in future assessments, more emphasis should be given to the measurement of foliar ammonium in *Sphagnum* samples.
20. Figure A3 also shows an outlier point to the overall distribution, for *Lolium perenne*, a species characteristic of intensively managed agricultural grasslands. This extremely high value was from a plant growing on a decomposing cow pat. While this illustrates the problem of overgrazing on the SAC, it is also helpful to put the very high %N values at Site 10 into context.

Main Analysis Results: Effect of specimen health on tissue nitrogen of Sphagnum

21. At Site 18, several different specimens of *Sphagnum imbricatum* were collected (see photograph, Figure 7). This allowed an indicative assessment of the effect of plant health on tissue N content. **Figure A1.4** illustrates the results, and suggests that damaged *Sphagnum* plants have higher nitrogen content. This may reflect an effect that colonization by algae has the damage effect on *Sphagnum imbricatum*. It should be noted that the purpose of Figure A1.4 is *not* to relate damage to distance, since only two distances are included and the samples were preferentially selected in different condition. It should be recalled that overall, the visual assessment showed that adverse effects on Sphagnum were least at greatest distance from the farm.

Supplementary Chemical Analysis Results

22. The results of the supplementary chemical analysis are shown in Table A1.2 and Figure A1.5. Overall, the ammonium values in these samples were much smaller than in the main analysis (even in the cleanest sites). This may be due to the start of spring growth leading to dilution of foliar ammonium. Figure A1.5 shows that there is little clear relationship with atmospheric ammonia concentration. There is a small increase for the moss *Thuidium tamariscinum*, and no clear change for *Hypnum jutlandicum*. Overall, the lack of clear pattern in this supplementary dataset may be due to the small number of samples given the degree of variability between results. The intention had been to identify single species which would occur widely across the site, although this turned out not to be possible.

Conclusions from the chemical bioindicator measurements

23. Overall, on the basis of the main analysis, it can be concluded that the bioindicator measurements strongly support the conclusions of the visual site observations. Immediately adjacent to Garvary Lodge total foliar nitrogen and ammonium nitrogen are extremely high, indicating that the ammonia emissions from Garvary Lodge are having an extreme adverse effect on the site integrity. The values generally decrease across the Bog with increasing distance from Garvary Lodge. In addition, the values on Moninea Bog are higher than the clean reference site. Although the absolute magnitude of the values for some of the most sensitive species appears to be low (e.g. *C. uncialis*, *S. imbricatum*), it should be noted that these species appear to no longer occur closer to Garvary Lodge (probably due to ammonia deposition), so that higher values could not be recorded. The highest bioindicator values occur for nitrophyte species (such as *E. praelongum*), which is able to survive in the immediate vicinity of the farm.
24. Given the clear gradient of foliar chemistry across Moninea Bog from the main analysis, these data support the conclusion that ammonia emissions from Garvary Lodge are having a significant adverse effect on the ecological integrity of the Special Area of Conservation.

References

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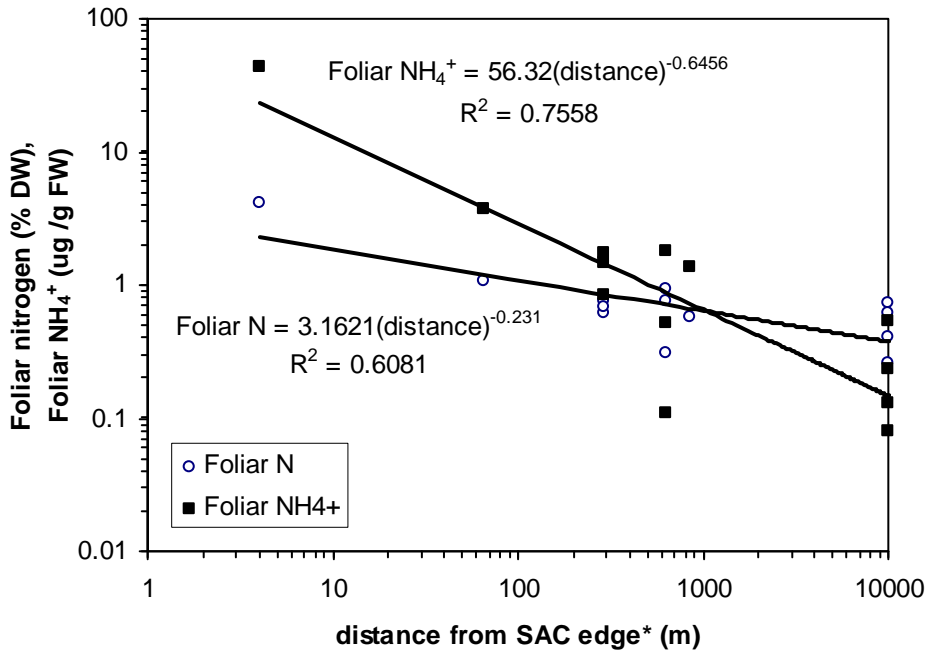


Figure A1.1: Foliar nitrogen content (%N dry weight) and foliar ammonium content ($\mu\text{g NH}_4^+\text{-N/g}$ fresh weight) for moss and lichen species sampled on Moninea Bog (for samples where both foliar N and ammonium analyses are available). * For convenient reference, distances are specified from the edge of the Special Area of Conservation (SAC), 4 m north of Site 10 (See Figure 1a). The results of analyses from the background reference (Site 23) are plotted at an indicative distance of 10000 m.

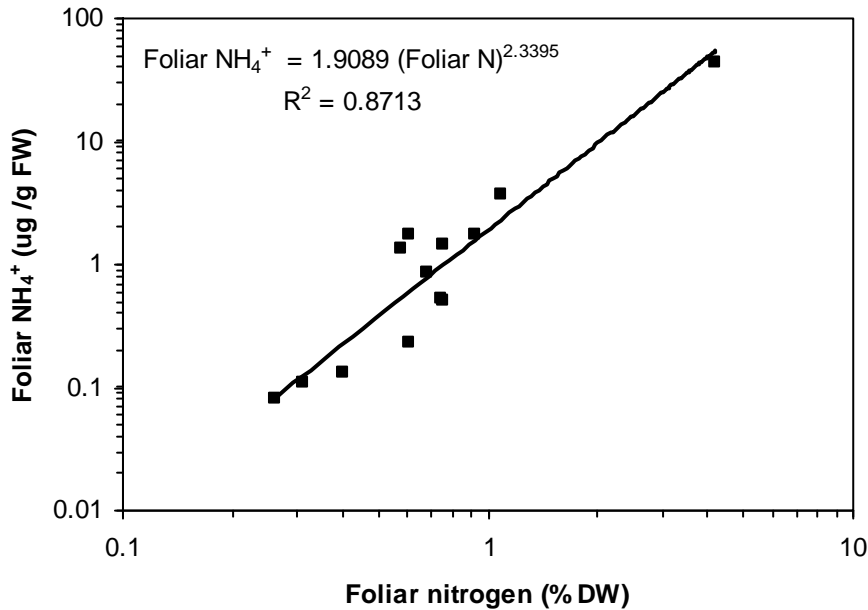


Figure A1.2 Relationship between foliar nitrogen content (%N dry weight) and foliar ammonium content ($\mu\text{g NH}_4^+\text{-N / g}$ fresh weight) for moss and lichen species sampled on Moninea Bog.

Table A1.1: Results of the main plant chemical analysis for total foliar nitrogen and foliar ammonium.

Site number (Moninea Bog)	Site distance from edge of SAC ^a (m)	Chemical ref no. (Lancaster lab.)	Chemical ref no. (Edinburgh lab.)	Species name	Initial visual assessment/ Comments	Total Foliar N (% DM)	Foliar NH ₄ -N (µg /g FW)
10	7	ED58401	1	<i>R. triquetrus</i>	Healthy	3.95	
10	4	ED58403	3	<i>E. praelongum</i>	Healthy	4.2	43.5
6	66	ED58411	11	<i>H. jutlandicum</i>	Healthy	1.09	3.72
6	66	ED58412	12	<i>R. squarrosus</i>	Healthy	1.72	
21	628	ED58404	4	<i>H. jutlandicum</i>	Healthy	0.92	1.78
21	628	ED58410	10	<i>R. lanuginosum</i>	Healthy	0.38	
23	10000	ED58416	16	<i>R. lanuginosum</i>	Healthy	0.4	0.13
21	628	ED58402	2	<i>S. fuscum</i>	Healthy	0.8	
1	872	ED58505	30	<i>S. fuscum</i>	Healthy	0.9	
20	522	ED58504	29	<i>Sphagnum</i> spp.	Brown head fall of when touched	0.8	
23	10000	ED58406	6	<i>S. capillifolium</i>	Healthy	0.74	0.53
18	291	ED58422	22	<i>Sphagnum</i> spp. tbc	Capitulum heads fall off when touched	0.73	
18	291	ED58423	23	<i>S. capillifolium</i>	Healthy	0.75	1.45
19	405	ED58424	24	<i>S. capillifolium</i>	Healthy	0.89	
21	628	ED58502	27	<i>S. capillifolium</i>	Healthy	0.75	0.51
13	69	ED58503	28	<i>S. capillifolium</i>	Healthy	1.02	
19	405	ED58510	35	<i>Sphagnum</i> spp. tbc	pale yellow capitulum	0.47	
23	10000	ED58407	7	<i>S. papillosum</i>	Healthy	0.61	0.23
20	522	ED58509	34	<i>S. papillosum</i>	Healthy	0.77	
18	291	ED58512	37	<i>S. imbricatum</i> (<i>S. austinii</i>)	Compact clump with dead sundew	0.61	1.76
18	291	ED58513	38	<i>S. imbricatum</i> (<i>S. austinii</i>)	middle clump	0.68	0.85
18	291	ED58514	39	<i>S. imbricatum</i> (<i>S. austinii</i>)	Healthy	0.77	
20	522	ED58507	32	<i>S. imbricatum</i> (<i>S. austinii</i>) & slime	Slime & dead sphagnum	1.16	
18	291	ED58511	36	<i>S. imbricatum</i> (<i>S. austinii</i>)	slime, mushy & dead sphagnum	1.03	
18	291	ED58408	8	<i>C. portentosa</i>	Healthy	0.62	
21	628	ED58409	9	<i>C. portentosa</i>	Healthy	0.76	
23	10000	ED58419	19	<i>C. uncialis</i>	Healthy	0.26	0.08
21	628	ED58420	20	<i>C. uncialis</i>	Healthy	0.31	0.11
2	872	ED58425	25	<i>C. portentosa</i>	Healthy	0.51	
22	855	ED58501	26	<i>C. portentosa</i>	Healthy	0.58	1.36
19	405	ED58506	31	<i>C. portentosa</i>	Healthy	0.64	
17	124	ED58508	33	<i>C. portentosa</i>	green algae and damaged	0.81	
22	855	ED58405	5	<i>C. vulgaris</i>	Healthy	1.13	
13	69	ED58413	13	<i>C. vulgaris</i>	Healthy	1.54	
23	10000	ED58414	14	<i>C. vulgaris</i>	Healthy	1.3	
6	66	ED58415	15	<i>C. vulgaris</i>	Healthy	1.59	
19	405	ED58417	17	<i>C. vulgaris</i>	Healthy	1.18	
21	628	ED58418	18	<i>C. vulgaris</i>	Healthy	1.1	
5	630	ED58421	21	<i>L. perenne</i>	Healthy (growing on decomposed cattle faeces)	4.68	

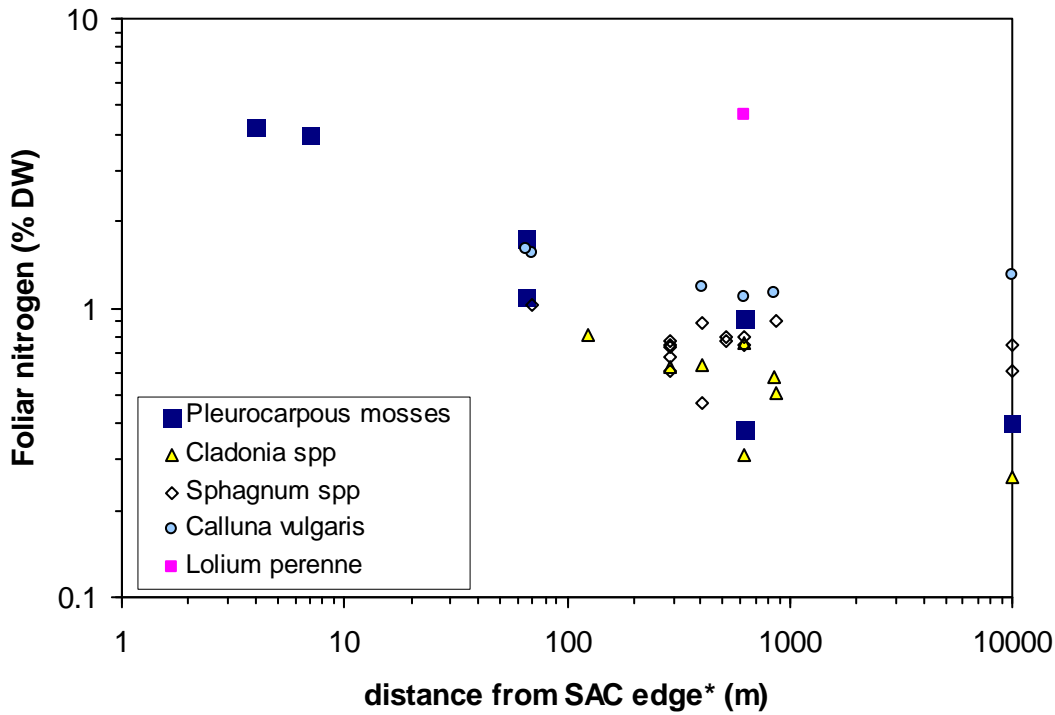


Figure A1.3: Foliar nitrogen content (%N dry weight) plant species sampled on Moninea Bog.
 * For convenient reference, distances are specified from the edge of the Special Area of Conservation (SAC), 4 m north of Site 10 (See Figure 1a). The results of analyses from the background reference (Site 23) are plotted at an indicative distance of 10000 m. The result for *Lolium perenne* is an outlier, recorded from regrowth on cattle faeces (cf. Figure 2).

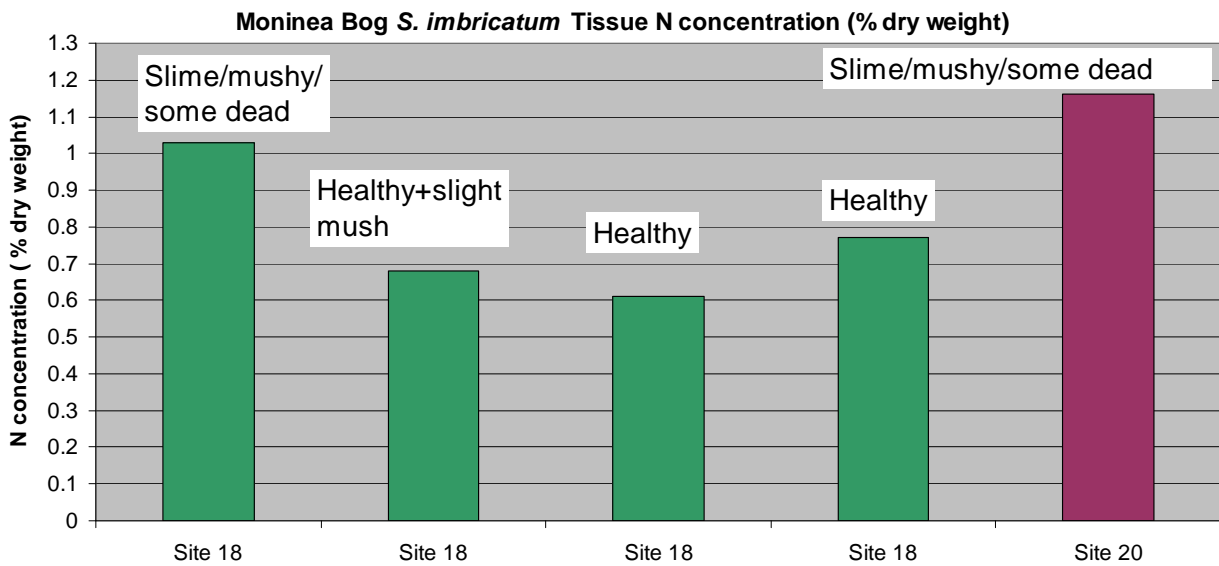


Figure A1.4: Comparison of foliar nitrogen contents (%N) of *Sphagnum imbricatum* specimens in different levels of condition. There is an indication (not statistically tested) that damaged specimens (colonized with algae) have higher tissue N content.

Table A1.2: Results of the supplementary plant chemical analysis for foliar ammonium.

Sample number	Site number (Moninea Bog)	Site distance from edge of SAC ^a (m)	NH ₃ conc. (µg m ⁻³) (see Table A2.1)	Species name	Foliar NH ₄ -N (µg /g FW)
1	Air 1	4 (SE)	27.7	<i>Thuidium tamariscinum</i>	0.82
2	Air 2	23 (SE)	15.4	<i>Thuidium tamariscinum</i>	0.86
3	Air 3	56 (SE)	9.32	<i>Hypnum jutlandicum</i>	0.21
4	Air 4	301 (SE)	(2.09)	<i>Hypnum jutlandicum</i>	0.17
5	Air 5	524 (SE)	2.43	<i>Hypnum jutlandicum</i>	0.28
6	Air 7	842 (SSE)	2.19	<i>Hypnum jutlandicum</i>	0.30
7	Air 7 a/1	40909 (NW)	(0.23)	<i>Hypnum jutlandicum</i>	0.34
8	Air 7 a/2	40909 (NW)	(0.23)	<i>Thuidium tamariscinum</i>	0.24
9	Air 7 a/3	40909 (NW)	(0.23)	<i>Hylocomium splendens</i>	0.64
10	Air 7 a/4	40909 (NW)	(0.23)	<i>Pleurozium schreberi</i>	0.24
11	Air 8	131 (E)	4.74	<i>Hypnum jutlandicum</i>	0.05

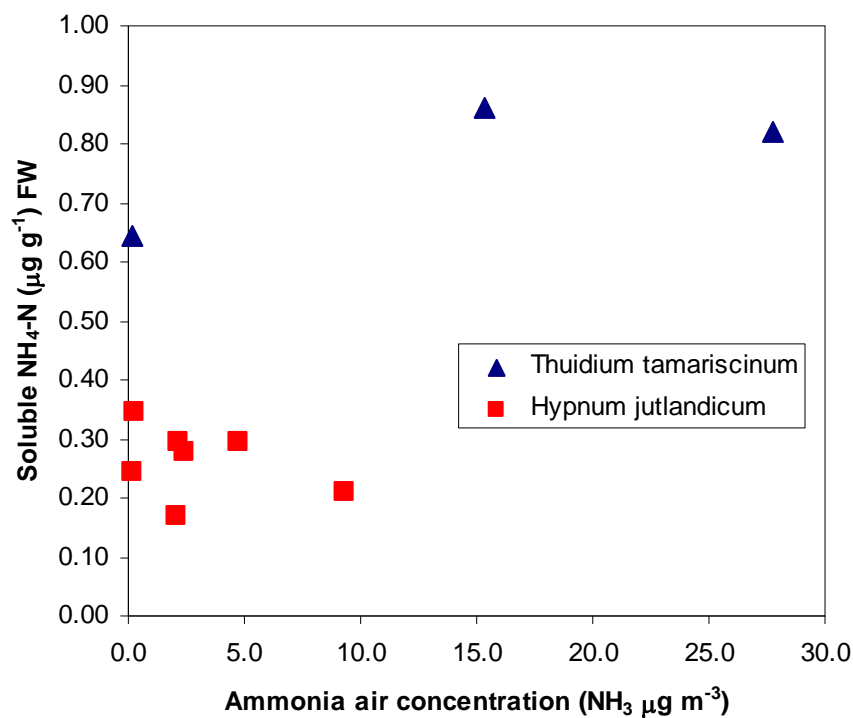


Figure A1.5: Summary of supplementary analysis of foliar ammonium in two moss species.

APPENDIX 2: AMMONIA MONITORING ON MONINEA BOG AND COMPARISON WITH NEARBY REFERENCE SITES

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Methods

1. Ammonia was monitored across Moninea Bog using CEH ALPHA (Adapted Low-cost Passive High Absorption) samplers, following the standard procedures of Tang et al. (2001), as used in the UK National Ammonia Monitoring Network.
2. As part of the quality control of the measurements, triplicate ALPHA samplers were used, allowing calculation of the percentage coefficient of variation of the measured NH₃ concentrations (= standard deviation/mean *100) (Tang and Sutton, 2003) and 95% confidence limits. Both laboratory and field blank samplers were used, with replicate blanks indicating a detection limit in the region of 0.01-0.02 µg m⁻³, values which are much smaller than background NH₃ concentrations in Northern Ireland (Tang et al., 2004).
3. For quality assurance of the aqueous chemical extracts of the ALPHA samplers, CEH take part in the Aqua Check Scheme. CEH also coordinates ammonia measurements across Europe in the NitroEurope project led by CEH.
4. Sampling was made on Moninea Bog for three periods of approximately four-weeks, through February, March and April 2007. The locations of the air sampling sites are shown in Figure A2.1.
5. Box A2.1 provides a summary of the sampling dates on Moninea Bog and the associated dates by which the chemical analysis was completed. It should be noted that collected samples are stable for more than 1-2 months, but rapid turn-over of samples was required for the timescales of this assessment.

Results: atmospheric ammonia concentrations

6. The atmospheric ammonia concentrations measured across Moninea Bog are summarized in Table A2.1 and Figure A2.2, with the first of these also giving the comparison against the other reference sites, Glensheaver and Lough Navar.
7. The background ammonia concentrations in Northern Ireland are well illustrated by Lough Navar, where the long-term mean (from the National Ammonia Monitoring Network (www.cara.ceh.ac.uk)) is 0.47 µg m⁻³. For the months of March to April 2007, the ammonia concentrations at this site were 0.43 and 1.04 µg m⁻³, respectively. (There was no reading for February 2007.) High values frequently occur in Spring since this is the main period for land spreading of cattle manure in the UK, and the higher value at Lough Navar in April 2007 is consistent with this feature.
8. Ammonia concentrations were also measured further west at Glensheaver. The purpose of this was to report NH₃ concentrations at a site where samples for biomonitoring would be taken under clean background conditions. The ammonia concentrations for February

was $0.2 \mu\text{g m}^{-3}$. There are no data for March or April, because the ammonia samples, together with the sample post were stolen. This value is lower than the mean at Lough Navar, suggesting that Glensheaver is more representative of background conditions. However, with only one month of measurement at Glensheaver, this conclusion can only be taken as indicative.

Box A2.1: Summary of ammonia monitoring and analysis from Moninea Bog.

16 January 2007 Mark Sutton visited Moninea Bog and subsequently identified suitable monitoring locations.

7 February 2007 Ivan Simmons visits Moninea Bog to set up sampling posts and ALPHA samplers. Actual locations of posts recorded with GPS.

7 March 2007 ALPHA samplers changed by EHS staff with exposed samplers posted back to CEH.

15 March 2007 Chemical analysis completed at CEH and EHS informed of results for February

2 April 2007 ALPHA samplers changed by EHS staff with exposed samplers posted back to CEH

4 April 2007 Chemical analysis completed at CEH and EHS informed of results for March

30 April 2007 Final ALPHA samplers collected by EHS staff and returned to CEH for analysis.

2 May 2007 Chemical analysis completed at CEH and EHS informed of results for April

9. By contrast to these two background stations, the concentrations of ammonia over Moninea Bog were all much larger. Ammonia concentrations were found to decrease in an approximate exponential (i.e. log-linear) relationship with distance from Garvary Lodge (see Figure A2.2).
10. The largest ammonia concentrations were recorded at site Air 1, which was in the Moninea Bog SAC at the north-west edge, adjacent to Garvary Lodge. At this site, NH_3 concentrations ranged from 16 to $34 \mu\text{g m}^{-3}$.
11. The smallest ammonia concentrations on Moninea Bog were recorded at the site most distant from Garvary Lodge, site Air 6 during February and March with values of $1.1 \mu\text{g m}^{-3}$ and $1.6 \mu\text{g m}^{-3}$ respectively. The April value at this site was higher at $3.9 \mu\text{g m}^{-3}$ (see paragraph 15 below)
12. At the edge of the bog itself, (site Air 3) the ammonia concentrations ranged from 6.3 to $11.1 \mu\text{g m}^{-3}$.

Interpretation of measured ammonia concentrations

13. The different NH_3 concentrations for the different months may be related to a) differences in wind direction and b) differences in local background NH_3 concentration and c) some variation in the NH_3 emissions from Garvary Lodge. Wind direction data and their relationship to the measured NH_3 concentrations at sites Air 1-Air 3 are summarized in Table A2.2.
14. During the February measurement period, winds blew from the relevant wind-sector ($226\text{-}345^\circ$) for 15% of the time, compared with 34% of the time during the March monitoring period and 24% during the April monitoring period. Overall, (7 February – 30 April) winds blew from this wind-sector for 24% of the time, compared with a long term mean of 32%. These values show that the frequency of the affected wind-sector was rather less than the long-term mean, indicating that the NH_3 concentrations monitored would be somewhat lower than those expected from long-term monitoring. Secondly, they show that February had fewer winds from relevant wind-sector than March and April. Expressed as a percentage to February (Table A2.2), 131% more winds from the relevant wind sector

occurred during March, with the figure being 65% for April. This difference explains the higher measured NH₃ concentrations in March than in February (68% to 106% higher for sites Air 1 to Air 3). For April, NH₃ concentrations were 76% to 111% higher than in February (sites Air 1 to Air 3), which is larger than the 65% higher frequency of relevant wind directions. This suggests that the ammonia emissions may have been higher from Garvary Lodge during April than the previous months, although other factors may have played a role (e.g. windspeeds and stability).

15. Table A2.1 shows that the background concentration of NH₃ recorded at Lough Navar was much larger in April 2007 than in March 2007. This is consistent with larger NH₃ concentrations on Moninea Bog at sites Air 5 and Air 6 during April compared with March. Although Garvary Lodge is expected to make some contribution to the measured NH₃ concentration at Air 5 and Air 6, the larger values during April can be considered as due to higher NH₃ emissions from other surrounding sources. As noted above, the most likely reason for the higher background in April is due to the frequent spreading of cattle manures to fields during this month.
16. The clear log-linear decrease in ammonia concentrations adjacent to Garvary Lodge (Figure A2.1) provides conclusive evidence that there is a major source of atmospheric ammonia at that site. This is because the log-linear decrease reflects the dilution of ammonia due to atmospheric dispersion away from Garvary Lodge. The magnitude of the maximum values, are such that the poultry farming activities can be considered as the only reasonable source of this ammonia. This result was fully expected given the known ammonia emissions from poultry farming activities and the small distance between Garvary Lodge and Moninea Bog.
17. The smallest values on Moninea Bog (generally at site Air 6) are much larger than the background reference sites (Glensheaver and Lough Navar). A significant fraction of this difference will be due to mixed agricultural NH₃ sources in the vicinity of Moninea Bog. A further part of this difference will also be due to site Air 6 also being influenced by Garvary Lodge. This is to say that, in the absence of ammonia emissions from Garvary Lodge, the NH₃ concentrations at site Air 6 (~840 m from the edge of the SAC) would be significantly smaller than measured.
18. It is possible to estimate the minimum contribution of the Garvary Lodge poultry farm to NH₃ concentrations across Moninea Bog purely on the basis of the measurements. This minimum is simply calculated as the difference between the NH₃ concentration at site Air 6 and the other sites closer to Garvary Lodge. For April, the high background value and the larger value at site Air 6 compared with site Air 5, suggests a significant effect of other (cattle) farming activities on site Air 6, reducing the reliability of April for this calculation. Therefore, based on the data for February and March, when the background concentrations were smaller, the minimum contribution of Garvary Lodge (the process contribution) is estimated as: 23.3 µg m⁻³ (edge of SAC, Air 1), to 7.1 µg m⁻³ (edge of bog on SAC, Air 3) and 0.55 µg m⁻³ (524 m from the edge of the SAC, Air 5).
19. In actuality, Garvary Lodge will also make a contribution to NH₃ at site Air 6, so that the real process contributions will be larger than those given in the previous paragraph. The only practical way to estimate this is through atmospheric dispersion modelling, as conducted by Theobald et al. (2005) and EHSNI. Based on the most recent modelling by EHSNI using the ADMS model using long term meteorology for the years 1994 and 1995,

the estimated process contributions of Garvary Lodge are: approximately $0.8 \mu\text{g m}^{-3}$ at Air 5 and $0.6 \mu\text{g m}^{-3}$ at Air 6.

20. The above modelled contributions can be adjusted by the wind frequency data and used to refine the estimate of background contributions which should be subtracted from raw measured values to estimate the contribution from the farm. This approach leads to calculated background contributions of $0.82 \mu\text{g m}^{-3}$ and $0.96 \mu\text{g m}^{-3}$ for February and March respectively and revised average values of the contribution from the farm of $23.7 \mu\text{g m}^{-3}$ at Air 1, $7.6 \mu\text{g m}^{-3}$ at Air 3 and $1.01 \mu\text{g m}^{-3}$ at Air 5. Thus the refined estimate of the contribution at Air 5 is substantially higher than the simple minimum estimate in paragraph 18 above. It should be noted that the April results are similar to the March results close to the farm, and the averages derived above are therefore likely to underestimate the contribution from the farm.

Relationship of the measured concentrations to ammonia effects

21. The relevant critical level for ammonia for the bog vegetation of Moninea Bog is $1 \mu\text{g m}^{-3}$. The measurements show that even the cleanest site on Moninea Bog (Air 6) is above this value at $2.2 \mu\text{g m}^{-3}$ for February-April 2007. The contribution of Garvary Lodge to ammonia at Air 5 (524 m from the farm) is at least an additional $0.55 \mu\text{g m}^{-3} \text{NH}_3$ (based on a simple background correction) or $1.01 \mu\text{g m}^{-3}$ (based on a more refined estimate of background). Compared with the critical level, Garvary Lodge thus accounts for a minimum contribution of 55% compared with site Air 6. Based on a more refined background correction, this figure is 101%. In the context of the Habitats Directive, both of these estimates represent a significant additional contribution to NH_3 exposure to site Air 5. As a result, I could not be safe in concluding it would have no adverse effect on the Special Area of Conservation. (In fact the visual observations, suggest that adverse effects are occurring at Site Air 5, see main report).
22. In the case of locations on Moninea Bog closer to Garvary Lodge, the problem is even worse than this. At the leading edge of the bog, closest to Garvary Lodge, the process contribution estimated by the measurements alone is a minimum of $7.1 \mu\text{g m}^{-3}$, or a minimum of 710% of the critical level. At these values, there is no doubt that extreme adverse effects of ammonia will be occurring on the bog.
23. In the woodland adjacent to Garvary Lodge, the levels are even more extreme. At the leading edge (Air 1), the process contribution accounts for a minimum of 1165% compared with the woodland critical level of $2 \mu\text{g m}^{-3}$, while further into the woodland (Air 2), the value is 623%. (These values would be doubled if the critical level for epiphytes were agreed to apply).
24. By contrast to site Air 5, it is more uncertain as to whether Garvary Lodge is making a significant contribution to NH_3 concentrations and adverse effects at site Air 6 (840 m from the farm). This is because in this case the contribution can only be estimated from modelling. However, based on the modelled process contribution of $0.6 \mu\text{g m}^{-3}$, the farm contributes 60% of the critical level, which still represents a significant contribution to adverse effects.
25. The present analysis focuses on ammonia concentrations and the critical level rather than nitrogen deposition and the critical load, for the simple reason that this matches to the

measurements made. However, it should be noted that the measured NH_3 concentrations can also be related to enhancements in total N deposition on the SAC resulting from ammonia emissions at Garvary Lodge. The conclusions of such a critical loads comparison are consistent with those conducted using the critical level. In short, a process contribution of $0.55 \mu\text{g m}^{-3} \text{NH}_3$ would (at a typical deposition velocity of 20 mm s^{-1} for bog vegetation) equate to an additional N deposition of $2.9 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. With a critical load of $5\text{-}10 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, this accounts for a minimum additional deposition of 29-58% at site Air 5. The percentage values are much larger at distances closer to the farm. For example, at the edge of the bog at site Air 3, with a minimum process contribution of $7.1 \mu\text{g m}^{-3} \text{NH}_3$, the additional nitrogen deposition would be c. $37 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, representing a minimum percentage contribution of 370%-740%. These simple calculations are sufficient to illustrate how ammonia from Garvary Lodge will dominate total nitrogen deposition at the NW edge of the bog, as well as in the woodland at the NW edge of the SAC.

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- Tang Y S., van Dijk N., Love L., Dragosits U., Rippey B., and Sutton M.A. (2004) Ammonia Monitoring in Northern Ireland. Final Report to SNIFFER, Project UKPIR04 230/8046. 42 pp (June 2004)

Table A2.1: Results ammonia monitoring across Moninea Bog and nearby reference sites

Site numbering for air measurements	Equivalent site number for visual observations	Distance from edge SAC ^a (m)	Period 1 7/2-7/3/2007 ($\mu\text{g m}^{-3}$ / %c.v)	Period 2 7/3-2/4/2007 ($\mu\text{g m}^{-3}$ / %c.v)	Period 3 2/4-2/5/2007 ($\mu\text{g m}^{-3}$ / %c.v)	Average Periods 1-3 ($\mu\text{g m}^{-3}$)
Moninea Bog						
Air 1	Near Site 10	4 (SE)	16.1 / 2%	33.1 / 4%	34.0 / 2%	27.7
Air 2	Site 8	23 (SE)	10.1 / 2%	17.5 / 4%	18.5 / 4%	15.4
Air 3	SW of Site 13/ SE of Site 8	56 (SE)	6.3 / 3%	10.6 / 1%	11.1 / 4%	9.32
Air 4	Site 18	301 (SE)	2.1 / 2%	Missing data ^b	Missing data ^b	(2.09)
Air 5	Site 20	524 (SE)	1.8 / 4%	2.0 / 2%	3.6 / 2%	2.43
Air 6	Site 22	842 (SSE)	1.1 / 2%	1.6 / 1%	3.9 / 3%	2.19
Glensheaver						
Air 7		40909 (NW)	0.23 / 1%	Missing data ^c	Missing data ^c	(0.23)
Supplementary site on Moninea Bog						
Air 8		131 (E)	n/a	4.1 / 0%	5.4 / 3%	4.74
National NH₃ network (single denuder)						
Lough Navar			n/a	0.43	1.04	(0.74)

Results are reported as the mean of 3 triplicate ALPHA passive samplers for each month. The coefficient of variation (cv%) gives a measure of overall precision from the replicates (= standard deviation/ mean x 100). The National Ammonia Network measurements using DELTA denuders are not replicated. ^a, in relation to a reference point 4 m NW of Air 1 calculated from GPS readings (Direction from reference point given in brackets). ^b, Sampling pole sunk into ground and coated papers of samplers dislodged. ^c, Pole and samples stolen during March 2007.

Table A2.2: Summary of wind direction data for February to April 2007 and the relationships to measured NH₃ concentrations during the period. Meteorological Office wind data from St. Angelo, Northern Ireland, provided by EHSNI.

Wind direction (degrees)	% time wind in sector during month			Average % time in wind sector	
	7 Feb - 7 March	7 March - 2 April	2 April - 30 April	(7 Feb-30 Apr)	Long term mean
346 – 15	0.1	4.2	1.9		
16 – 45	0.3	5.9	7.6		
46 – 75	6	0.9	5.6		
76 – 105	5	0.3	3.2		
106 – 135	12.1	2.2	6		
136 – 165	27.6	9.3	12.9		
166 – 195	12.4	10.6	10.1		
196 – 225	11.4	15.3	10.5		
226 – 255	4.6	7.1	5.2		
256 – 285	6.6	8.2	7.6		
286 – 315	3.4	9.6	9.1		
316 – 345	0.1	9.1	2.4		
Total (not calm)	89.6	82.7	82.1		
Calm	10.4	17.3	17.9		
Monitoring sector (226-345)	14.7	34	24.3	24.3	31.7
Sector wind frequency (month)/ Sector wind frequency (Feb) (dimensionless)					
$(226-345)_{\text{month}}/(226-345)_{\text{Feb}}$	1	2.31	1.65		
Site NH₃ concentration ($\mu\text{g m}^{-3}$)					
Air 1	16.1	33.1	34		
Air 2	10.1	17.5	18.5		
Air 3	6.3	10.6	11.1		
NH₃ (month)/NH₃ (Feb) (dimensionless)					
Air 1 (month) / Air 1 (Feb)	1	2.06	2.11		
Air 2 (month) / Air 2 (Feb)	1	1.73	1.83		
Air 3 (month) / Air 3 (Feb)	1	1.68	1.76		

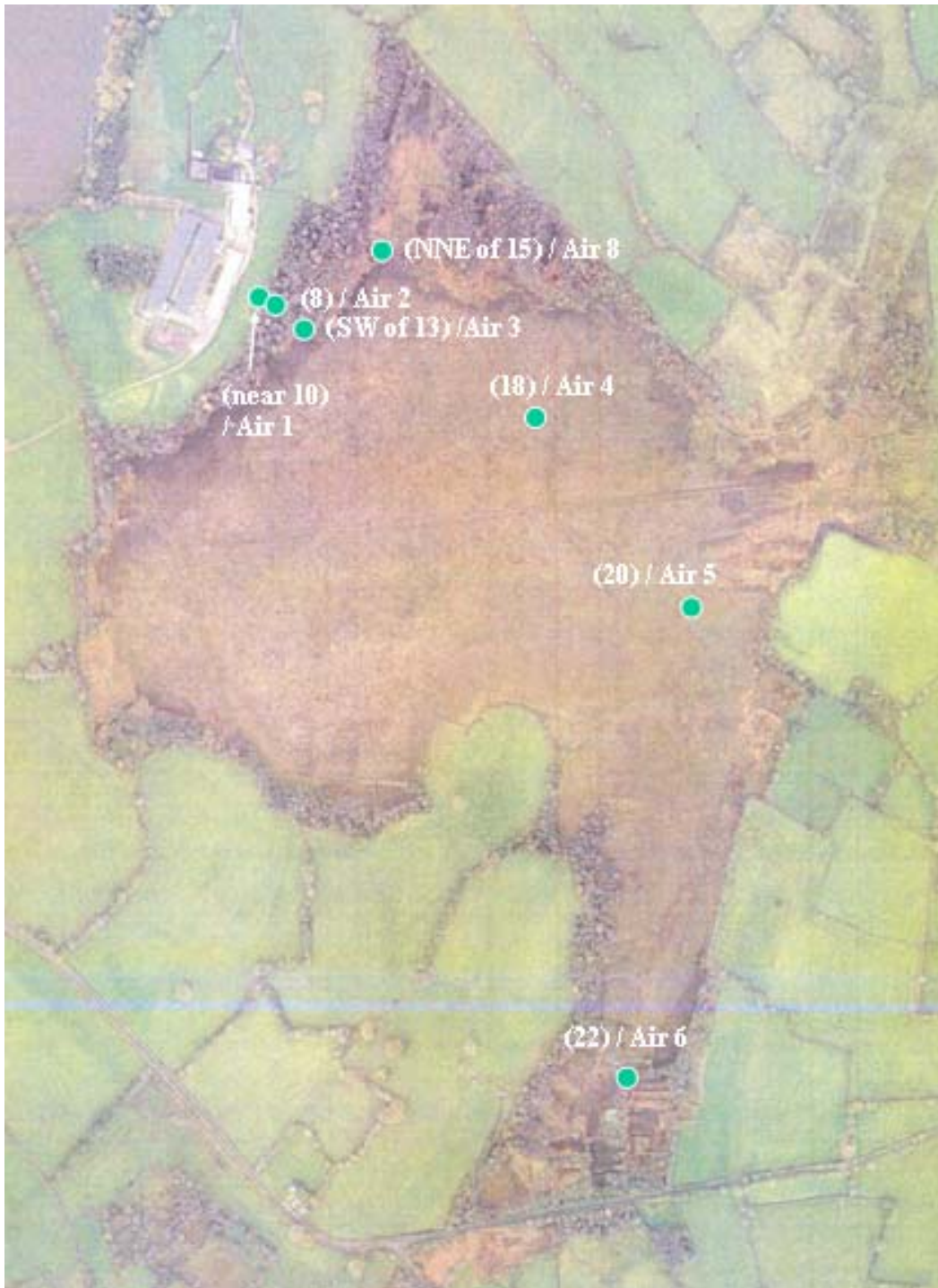


Figure A2.1: Location of the air sampling points on Moninea Bog. The first number in brackets gives the relationship to the visual observation sites (Figure 1a). The second number Air 1 – Air 6 is the numbering used for the ammonia measurements. As far as possible the same or nearby sites were used for both. Air 8, not shown, was a supplementary site, NE of the main transect; Site 7 was at Glensheaver, 41 km NW of Moninea Bog.

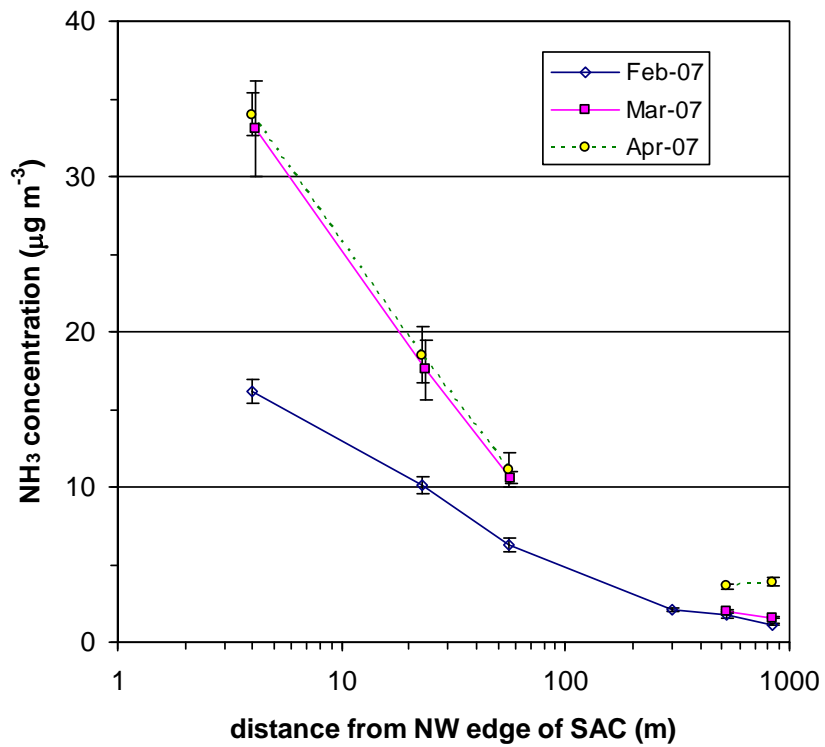


Figure A2.2: Atmospheric ammonia concentration measured 1.5 m above ground across Moninea Bog SAC.
 * For convenient reference, distances are specified from the edge of the Special Area of Conservation (SAC), 4 m north west of Site Air 1 (See Figure A2.1). As standard deviations were so small, error bars are shown here as 95% confidence limits. Additional measurements further to the N of this transect were made at Air 8 (see Table A2.1).