Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

# Prioritisation of designated sites for monitoring atmospheric ammonia impacts

## Review and prioritisation of six proposed sites for wider $NH_3$ monitoring

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# 1 Introduction - effects of ammonia

Emission and subsequent elevated concentrations and deposition of atmospheric ammonia gas ($NH_3$) poses a key threat to the integrity of semi-natural ecosystems (e.g., designated sites), particularly where sources are close to sensitive sites. Ammonia emissions largely originate from agricultural sources, i.e., the management and application of livestock manures/slurries and mineral fertilisers. The adverse effects of $NH_3$ and of its secondary reaction products (ammonium-containing particles), together with oxidised nitrogen ($NO_x$, mainly from combustion sources) are eutrophication (N enrichment) and acidification of soils and freshwater.

Semi-natural ecosystems, including nature conservation sites, that are close to $NH_3$ emission sources are particularly at risk, since atmospheric concentrations are largest close to the source, and a significant fraction of the $NH_3$ emitted is deposited within 1 km radius of the source area (e.g., Fowler et al. 1998). Studies have shown that $NH_3$ emissions from intensive livestock farms and deposition to nearby semi-natural vegetation have resulted in changes in species composition and a decline in species richness (e.g., Pitcairn et al. 1998, 2002; Sheppard et al 2011; Levy et al 2019). Particularly sensitive species groups include woodland flowers, peat bog vegetation and lichens (Sutton et al. 2004). Nitrogen deposition from $NH_3$ emissions can therefore potentially lead to loss of conservation value for designated conservation sites.

# 2 Objectives

- The aim of this task was to investigate the following six selected sites (Figure 1) for threats from atmospheric nitrogen inputs, in particular ammonia ($NH_3$). These sites are part of the Collaborative Action for Nature Network (CANN) project. This is a joint initiative between DAERA NIEA and Ulster Wildlife.
  Curran Bog SAC
- Garry Bog SAC
- Moneygal Bog SAC
- Peatlands Park SAC
- Slieve Beagh SAC
- Turmennan SAC


*Figure 1: Map of Northern Ireland showing locations of the 6 proposed sites.*

For the six selected sites, the following activities have been carried out:

- An investigation of all available atmospheric modelling data (emissions, concentrations, deposition)
- Monitoring strategies were proposed to utilise available datasets at CEH and local information provided by NIEA and Ulster Wildlife
- Required resources were identified and a plan was drafted in the form of a short report.
- Prioritisation of the sites for monitoring assessment, based on the steps above.

# 3 Review and assessment of sites

## 3.1. Curran Bog

| | |
|---|---|
| **Latitude** | 54.800 |
| **Longitude** | -6.643 |
| **Area (ha)** | 183.5 |
| **Designated for** | Active raised bogs, Degraded raised bogs still capable of natural regeneration |
| **Site character** | Bogs, Marshes, Water fringed vegetation, Fens (82.6%)<br>Humid grassland, Mesophile grassland (0.5%)<br>Broad-leaved deciduous woodland (16.9%) |
| **Notes** | Several large farms and/or visible slurry stores/lagoons within 2km<br>3 Industrial Emissions Directive (IED) farms within 5km |
| **Links to previous/current monitoring** | Ballynahone Bog (8 ALPHA sites since September 2014) is located close (1.5km) to Curran Bog, to the north/northeast. There is further landscape scale monitoring with 9 ALPHA sites within a 5 km radius of Ballynahone Bog and one DELTA site on the bog itself, since early 2019, which gives a wider understanding of concentrations in the wider area including Curran Bog. |

Curran Bog SAC is situated in an intensive agricultural area, dominated by cattle farming (dairy and beef), with estimated average annual ammonia concentrations of 1.3 – 2.2 µg $m^{-3}$ (2017), therefore exceeding the critical level for its designated features, of 1 µg $m^{-3}$ (Figures 2-4).

The $NH_3$ concentration map (Figure 4) suggests that there is a concentration gradient across the site, with the highest concentrations in the south.

Suggested monitoring locations (5 sites) should help to quantify more spatially and temporally resolved concentrations along a gradient SW-NE from the western edge of the site where the closest farms with livestock houses and manure/slurry storage are located. It is also recommended that a further sampler is placed at a more central/easterly location.

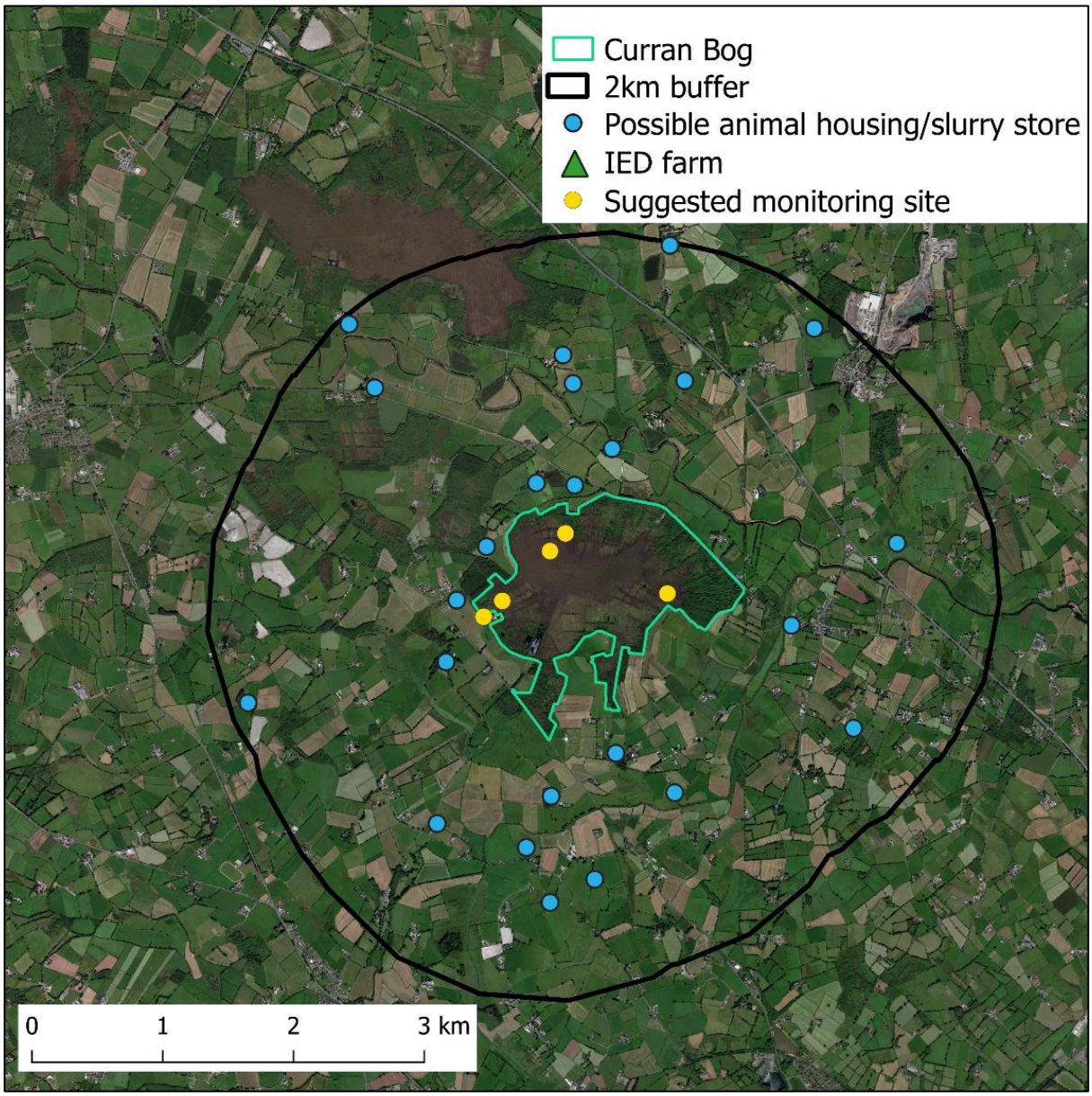


*Figure 2: Map of Curran Bog SAC using ESRI Satellite imagery, showing the locations of possible ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring.*

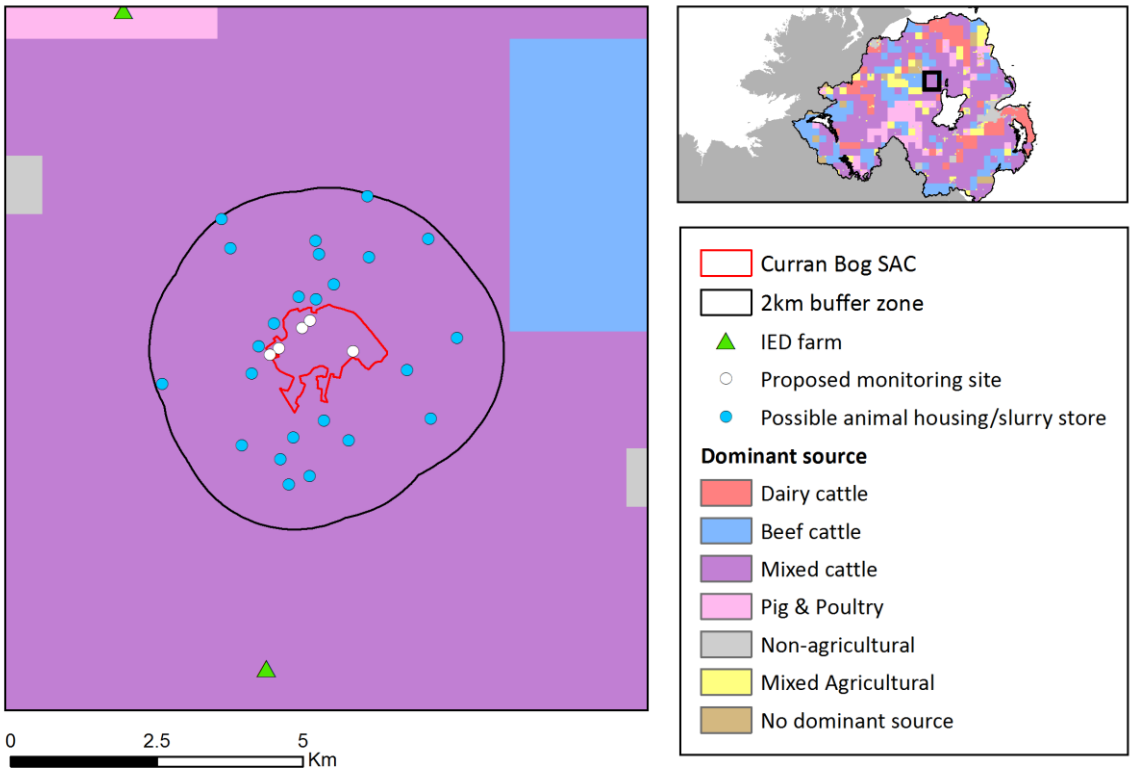


*Figure 3: Modelled dominant ammonia emission sources for Curran Bog SAC (outlined in red) and the wider surrounding landscape at 1 km x 1km grid resolution (*2017 emission data).

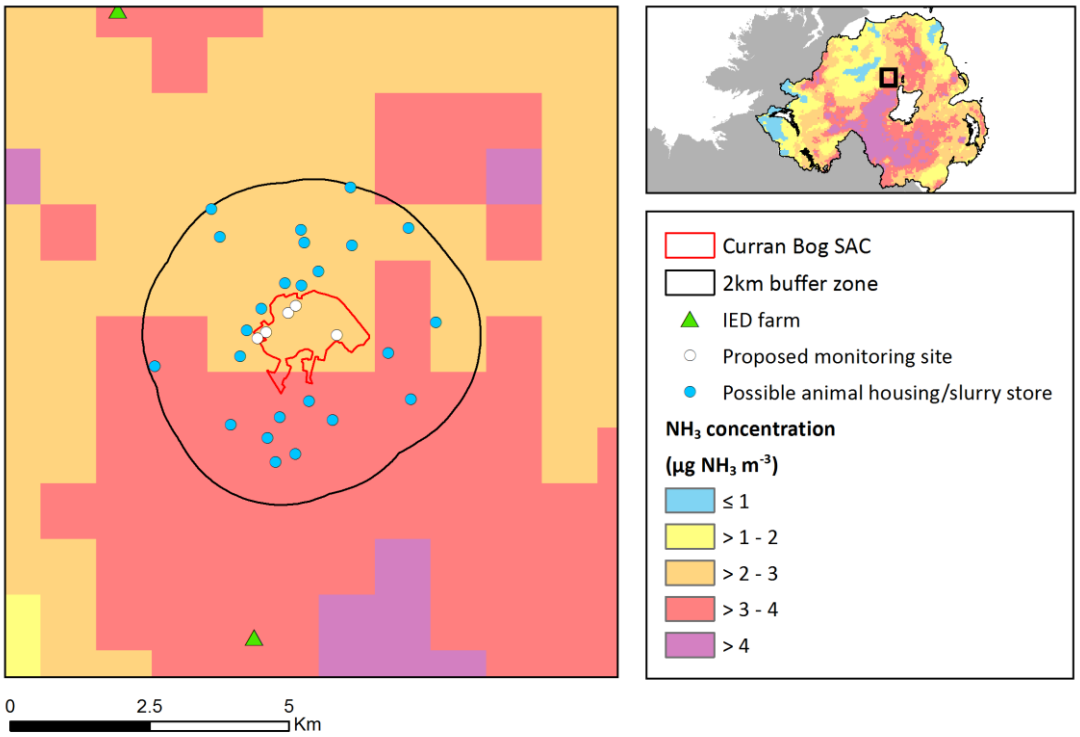


*Figure 4: Modelled ammonia concentrations at Curran Bog SAC (outlined in red) and the wider landscape at 1 km x 1km grid resolution (FRAME* model *output).*

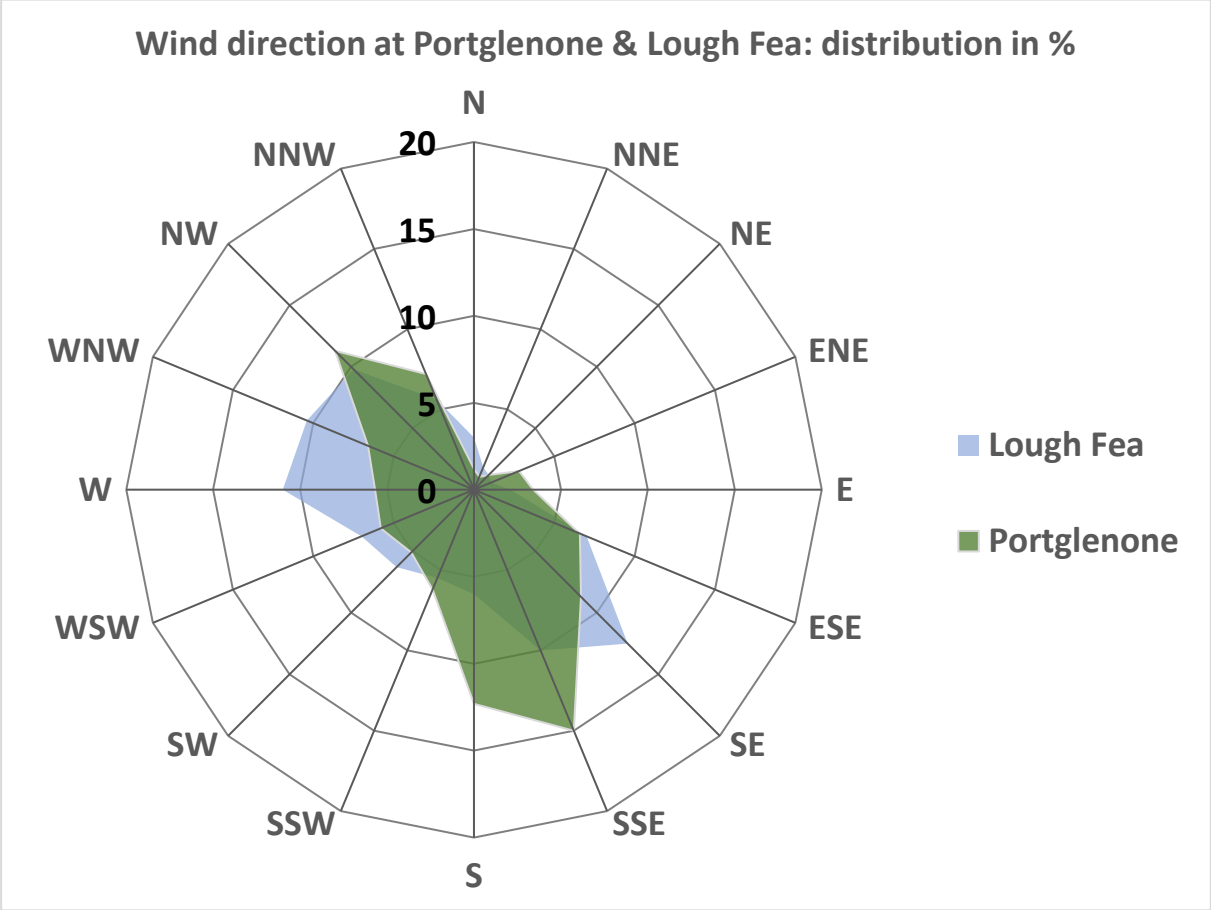


*Figure 5: Wind rose at Portglenone met station (green, 14.4km ENE of the centre of Curran Bog) and Lough Fea met station (blue, 14.9km SW of the centre of Curran Bog)*

## 3.2. Garry Bog

| | |
|---|---|
| **Latitude** | 55.108 |
| **Longitude** | -6.530 |
| **Area (ha)** | 154.9 |
| **Designated for** | Active raised bogs (142.7 ha) |
| **Site character** | Bogs, Marshes, Water fringed vegetation, Fens (100%) |
| **Notes** | Several large farms or visible slurry stores/lagoons within 2km<br>1 IED farm within 2km, 1 within 5km |
| **Links to previous/current monitoring** | Within 10km: AFBI27-D (new NI-wide network of $NH_3$ concentration samplers, set up Mar 2019, by AFBI & CEH); UKA00401 Coleraine (UK National Ammonia Monitoring Network site, https://uk-air.defra.gov.uk/networks/site-info?uka_id=UKA00401) |

Garry Bog SAC is situated in a busy agricultural landscape with predominantly cattle farming (specifically dairy farming, but also beef farming), with the SAC in close proximity to many livestock houses and slurry/manure stores, especially to the west and south. The northern and eastern boundaries of the SAC are bordered by forested areas which provide a buffer zone from agricultural emission sources.

Modelled ammonia concentrations of >1.9 – 2.4 µg $m^{-3}$ (2017) are estimated for the site, with the highest concentrations to the south and west, substantially exceeding the critical level for its designated features of 1 µg $m^{-3}$ (Figures 6 - 8). The 6 suggested monitoring locations are located to cover the W/SW to NE gradient across the site.

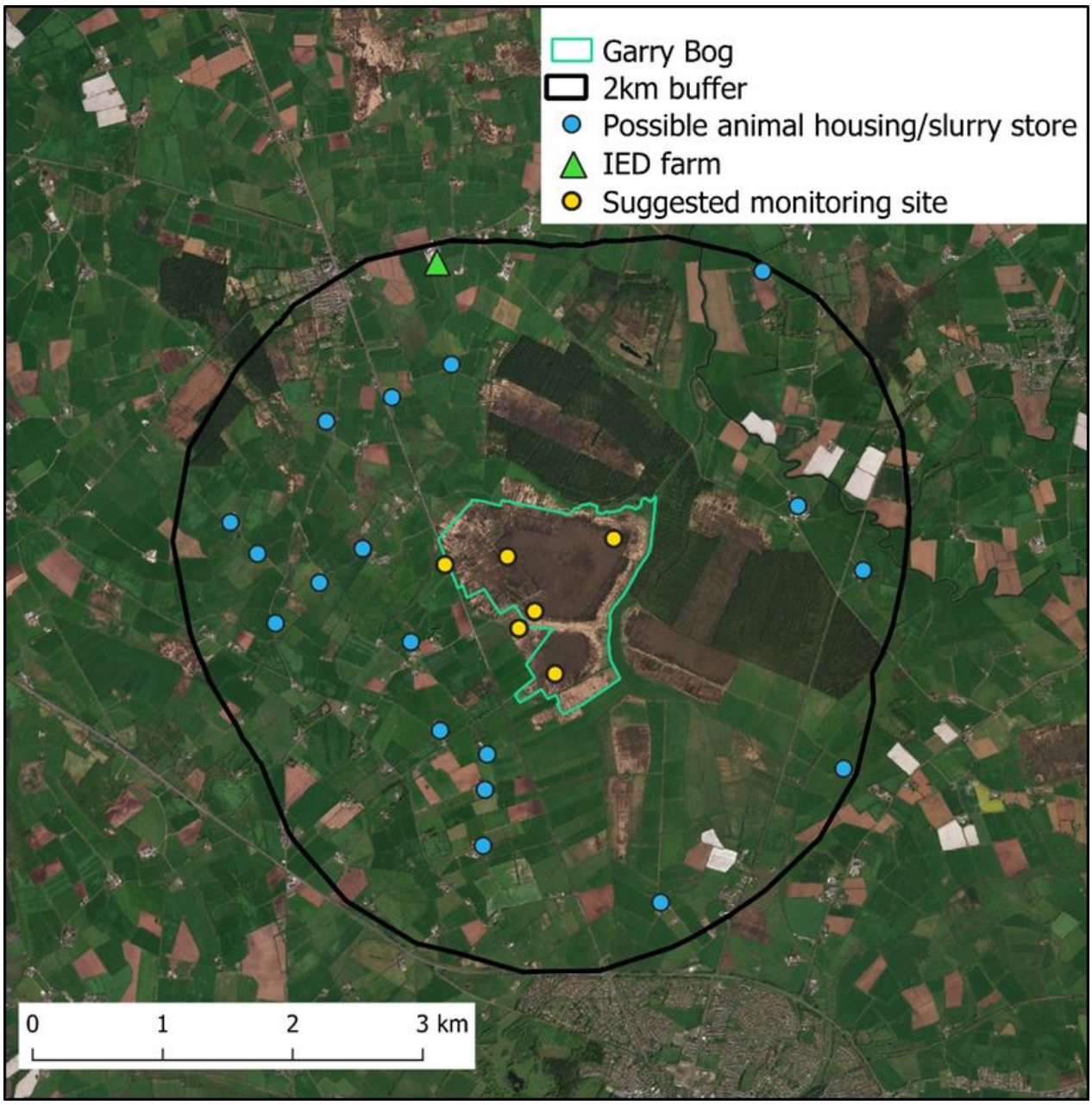


*Figure 6: Map of Garry Bog using ESRI Satellite imagery, showing the locations of likely ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring.*

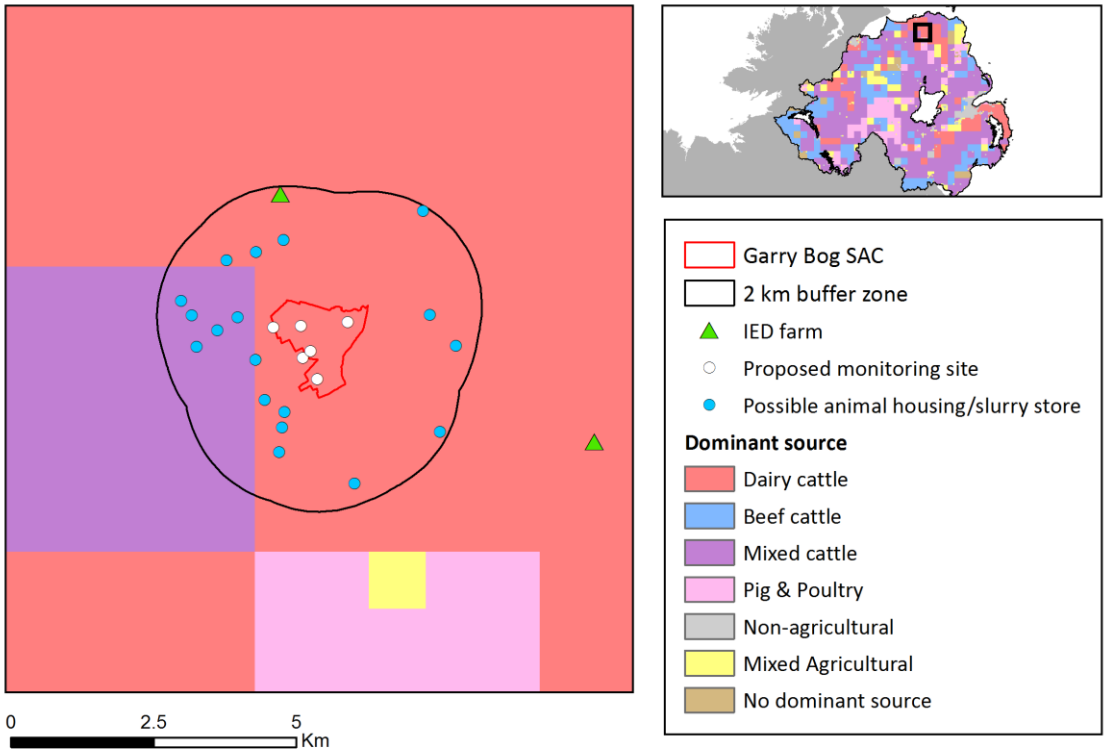


*Figure 7: Modelled dominant ammonia emission source classification for Garry Bog (outlined in red) and the wider landscape at a 1 km x 1km grid resolution (*2017 emission data).

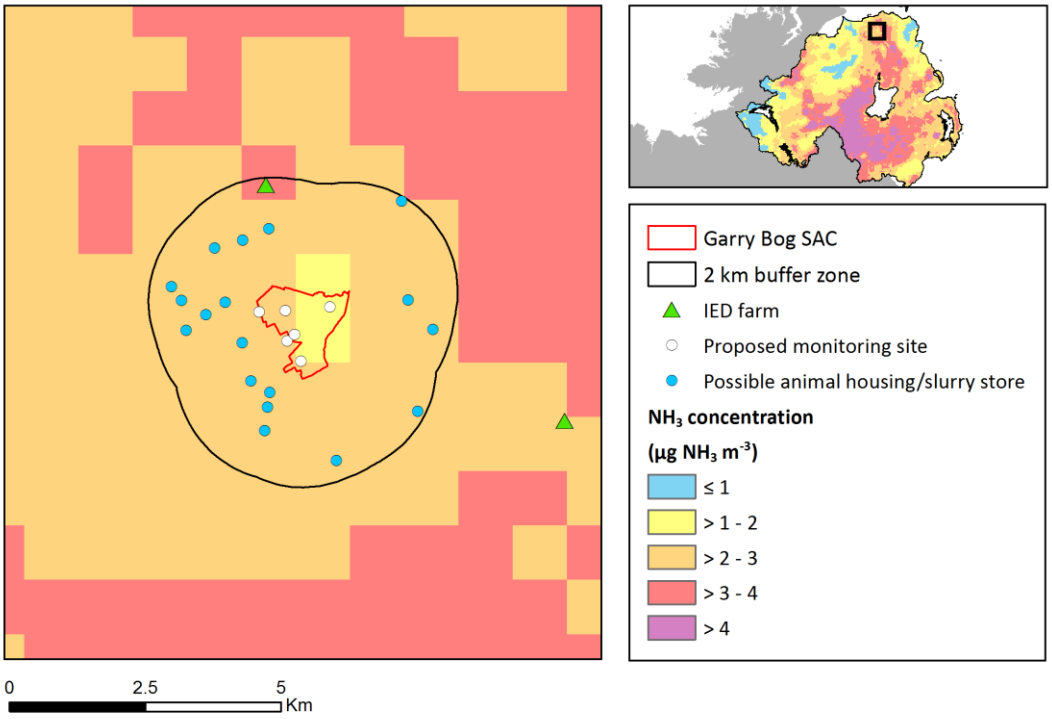


*Figure 8: Modelled ammonia concentrations for Garry Bog SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (FRAME model output).*

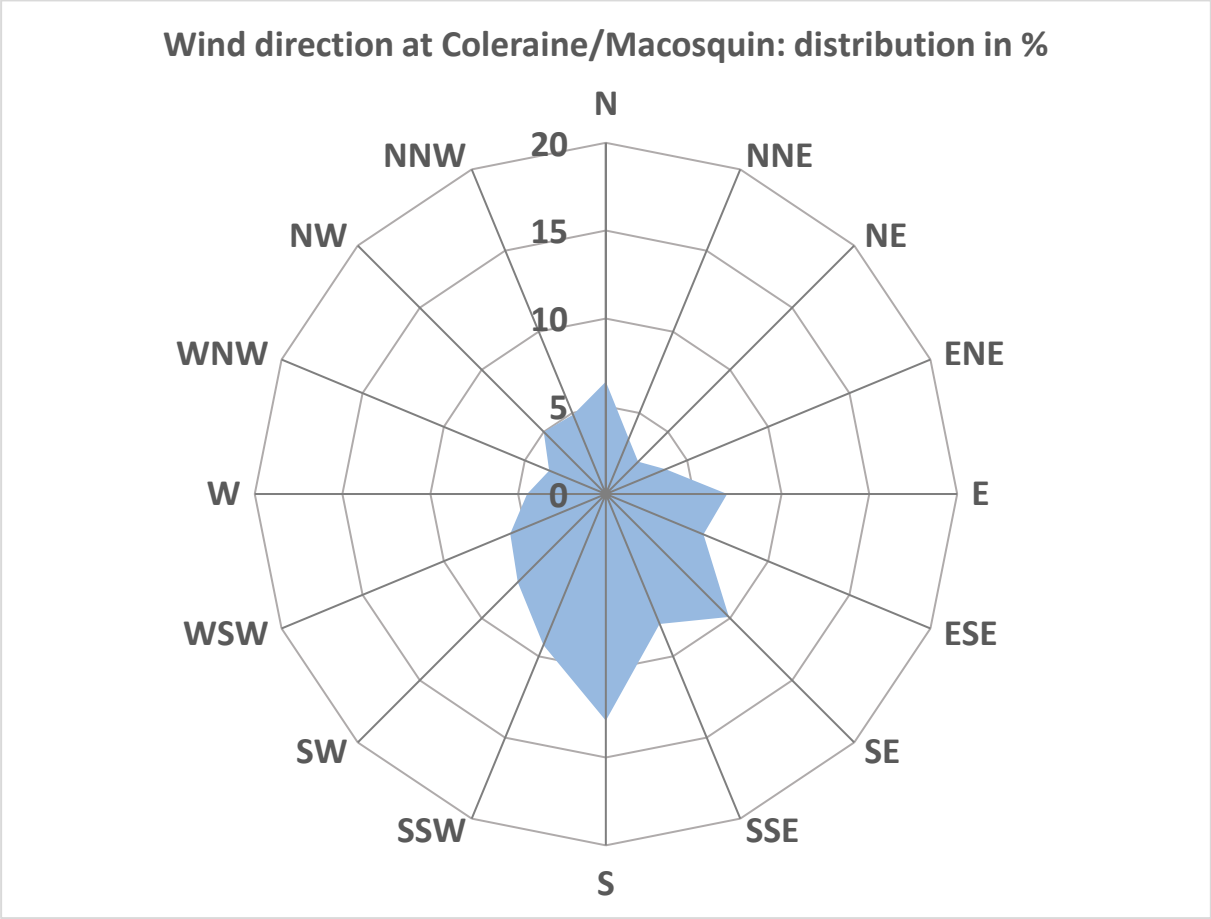


*Figure 9: Wind rose at Coleraine/Macosquin met station (11.8km W of Garry Bog SAC)*

## 3.3. Moneygal Bog

| | |
|---|---|
| **Latitude** | 54.742 |
| **Longitude** | -7. 630 |
| **Area (ha)** | 156.2 |
| **Designated for** | Active raised bogs (142.7 ha) |
| **Site character** | Bogs, Marshes, Water fringed vegetation, Fens (89%)<br>Humid grassland, Mesophile grassland (2%)<br>Coniferous woodland (9%) |
| **Notes** | No IED farms within 5km<br>Small farms within 2km |
| **Links to previous/current monitoring** | AFBI06-A within 10 km (new NI-wide network of $NH_3$ concentration samplers, set up Mar 2019, by AFBI & CEH) |

Moneygal Bog SAC is situated in an agricultural landscape with predominantly mixed dairy and beef cattle farming, with the north-eastern boundary forming the border with the Republic of Ireland. There are several livestock farms in the vicinity of the site, with the closest farms being located to the south/southwest. The north-western boundary and smaller areas to the NE and SE are bordered by forested areas which provide buffer zones from agricultural emission sources.

Modelled ammonia concentrations of 1.7- 2.5 µg $m^{-3}$ (2017) are estimated for the site, with the highest concentrations to the east, substantially exceeding the critical level for its designated features of 1 µg $m^{-3}$ (Figures 10 - 12). The 4 suggested monitoring locations are located to cover the predicted W/SW to W/NE gradient across the site. N.B. The modelled concentrations are less certain for this site, due to its close proximity to the Irish border, as the emission input data for the Republic of Ireland are not as recent and do not contain the same categorical resolution as the UK emission data.

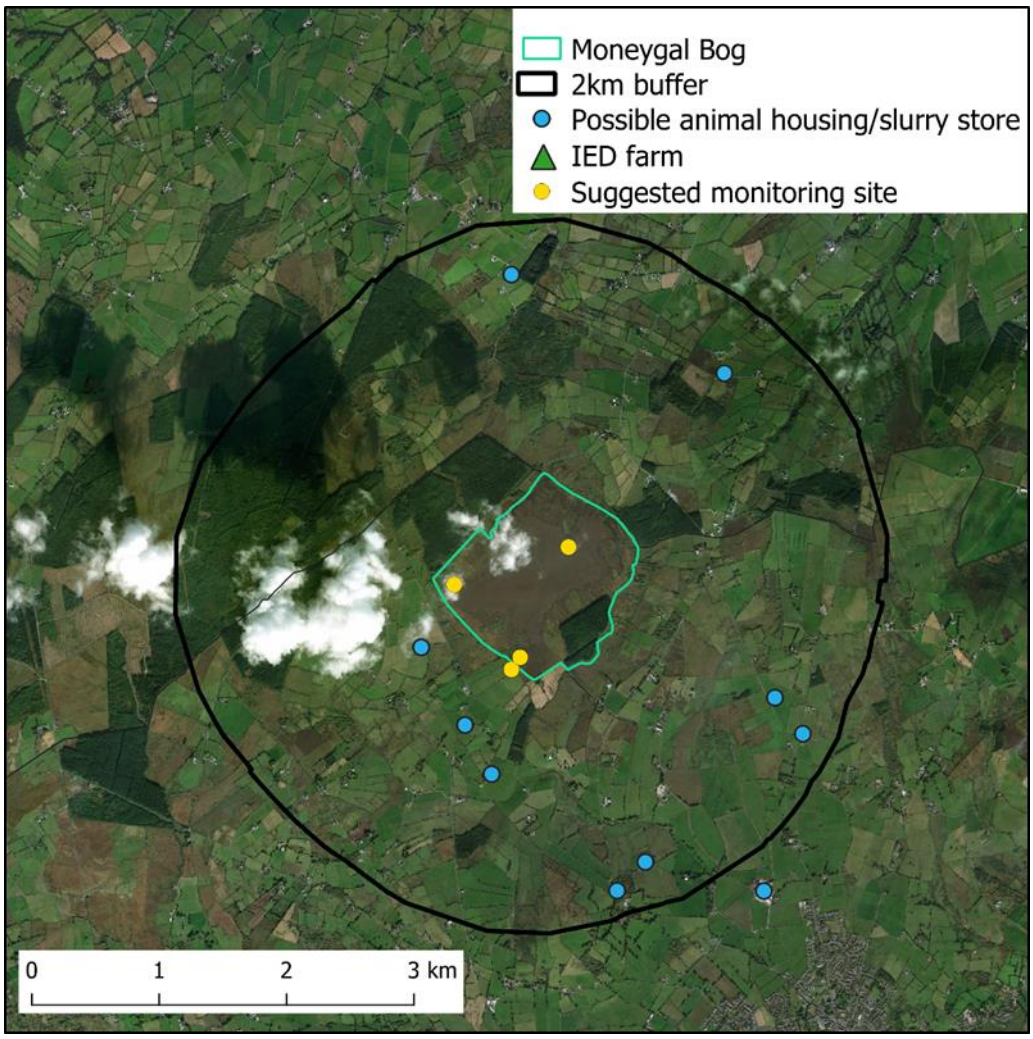


*Figure 10: Map of Moneygal Bog SAC using ESRI Satellite imagery, showing the locations of possible ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring.*

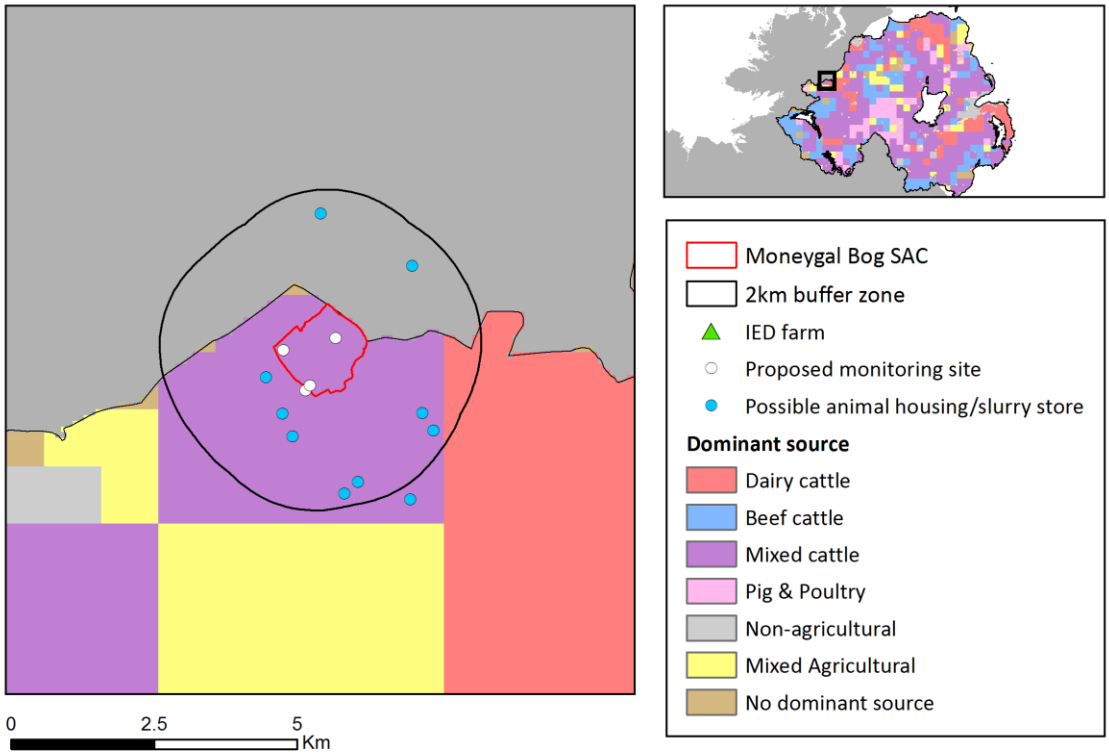


*Figure 11: Modelled dominant ammonia emission source classification showing Moneygal Bog SAC (outlined in red) and the wider landscape at a 1 km x 1 km grid resolution (2017 emission data).*

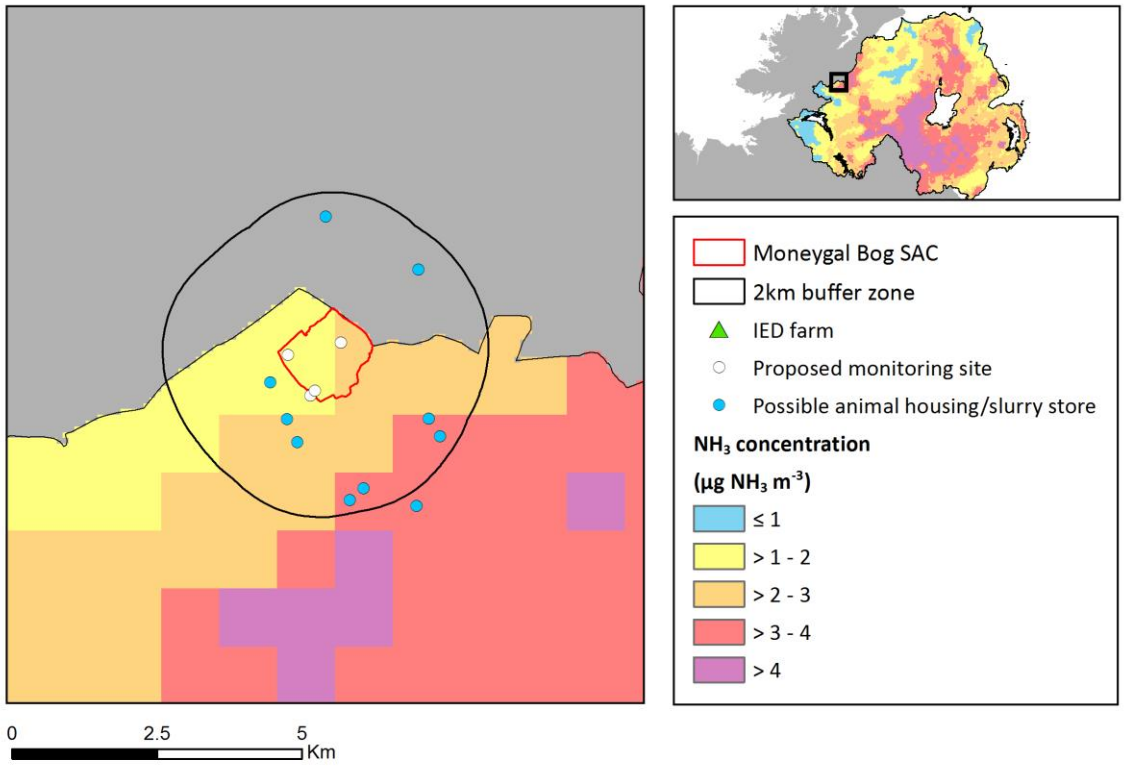


*Figure 12: Modelled ammonia concentrations for Moneygal Bog SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (FRAME model output).*

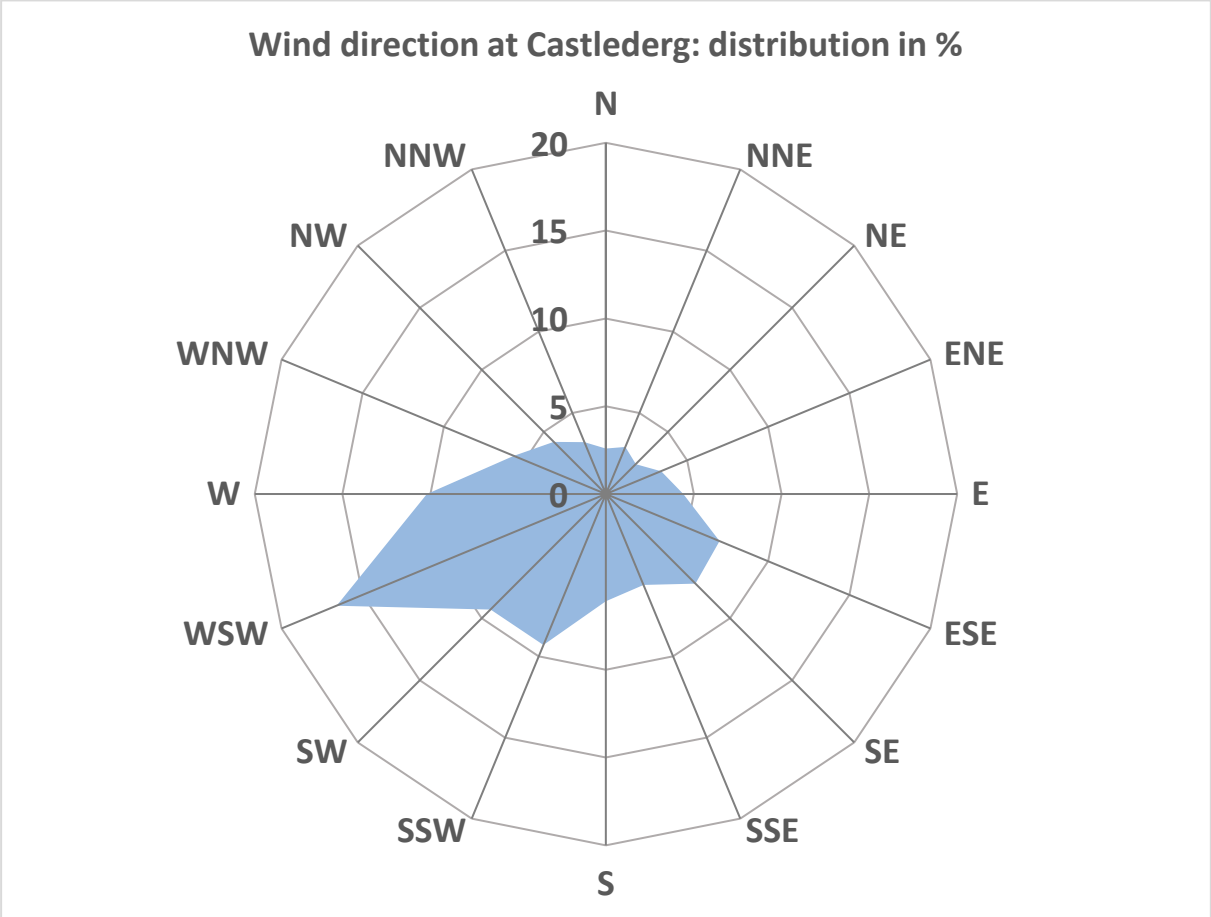


*Figure 13: Wind rose for Castlederg met station (5.4km NW of centre of Moneygal Bog SAC)*

## 3.4. Peatlands Park

| | |
|---|---|
| **Latitude** | 54.488 |
| **Longitude** | -6.599 |
| **Area (ha)** | 207.5 |
| **Designated for** | Active raised bogs (21.8 ha), Degraded raised bog (117.2 ha), Bog woodland (6.1 ha), Old sessile oak woods with Ilex and Blechnum in the British Isles (42.5 ha) |
| **Site character** | Inland water bodies (Standing water, Running water) (4%)<br>Bogs, Marshes, Water fringed vegetation, Fens (72%)<br>Broad-leaved deciduous woodland (24%) |
| **Notes** | 1 IED farm within 2km, 2 within 5km |
| **Links to previous/current monitoring** | Within 10km: AFBI11-A (new NI-wide network of $NH_3$ concentration samplers, set up Mar 2019, by AFBI & CEH).<br>Peatlands Park ex-Sniffer site '03-'04<br>Model assessment undertaken under the EMIND project |

Peatlands Park SAC is located in an intensive farming landscape (predominantly beef & dairy cattle, with at least one IED farm within 2 km of the western boundary). There are parts of the site that border farmland directly, while other areas of the site are more protected with woodland and bog features buffering emission sources.

Modelled ammonia concentrations of 2.7- 3.2 µg $m^{-3}$ (2017) are estimated for the site, with the highest concentrations to the west, north and east, substantially exceeding the critical level for its designated features of 1 µg $m^{-3}$ (Figures 14 - 16). Further to the west (1 - 4 km distance from the western border), there are indications of widespread annual average $NH_3$ concentrations > 4 µg $m^{-3}$. Due to the complexity of the site and the potential for buffering of ammonia impacts by surrounding semi-natural areas, a larger number of monitoring locations is suggested, to cover a number of gradients from potential sources very close to the site boundary towards more central locations with expected lower concentrations.

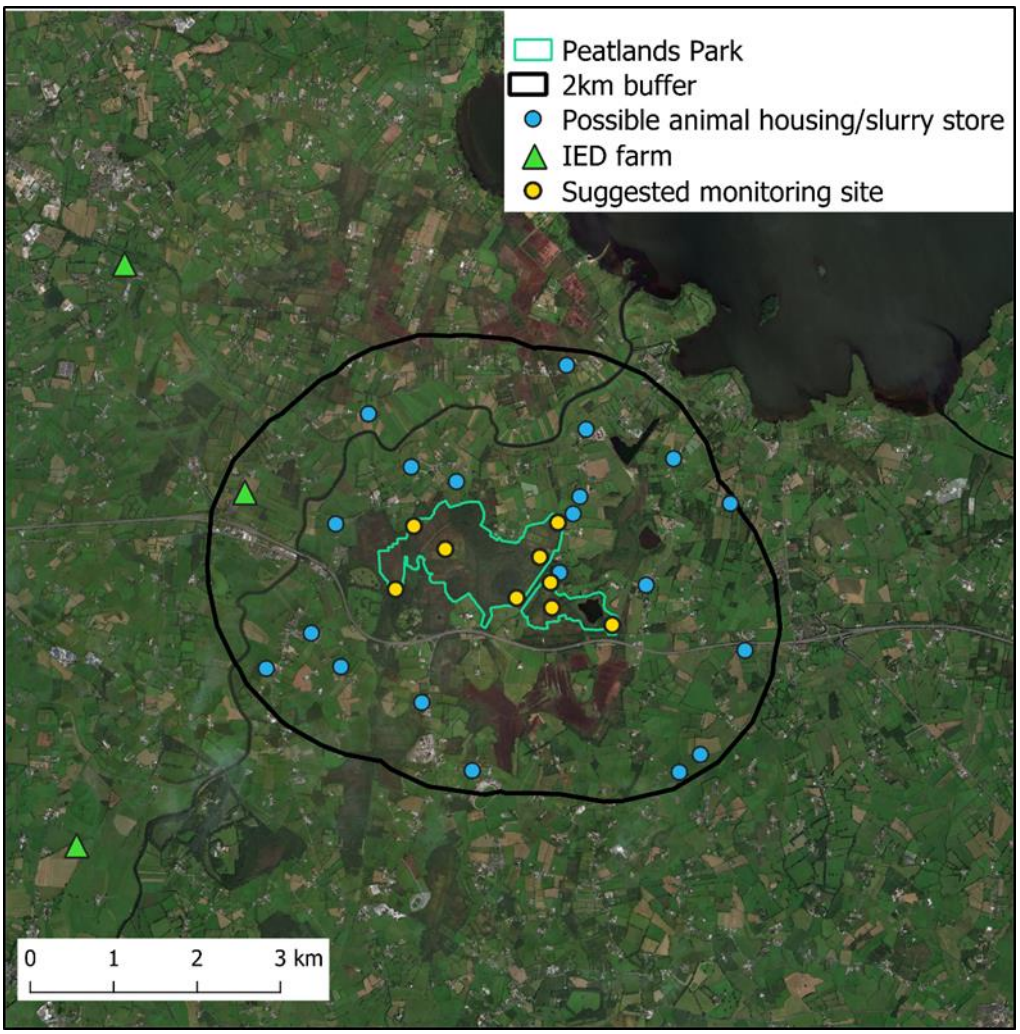


*Figure 14: Map of Peatlands Park using ESRI Satellite imagery, showing the locations of possible ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring.*

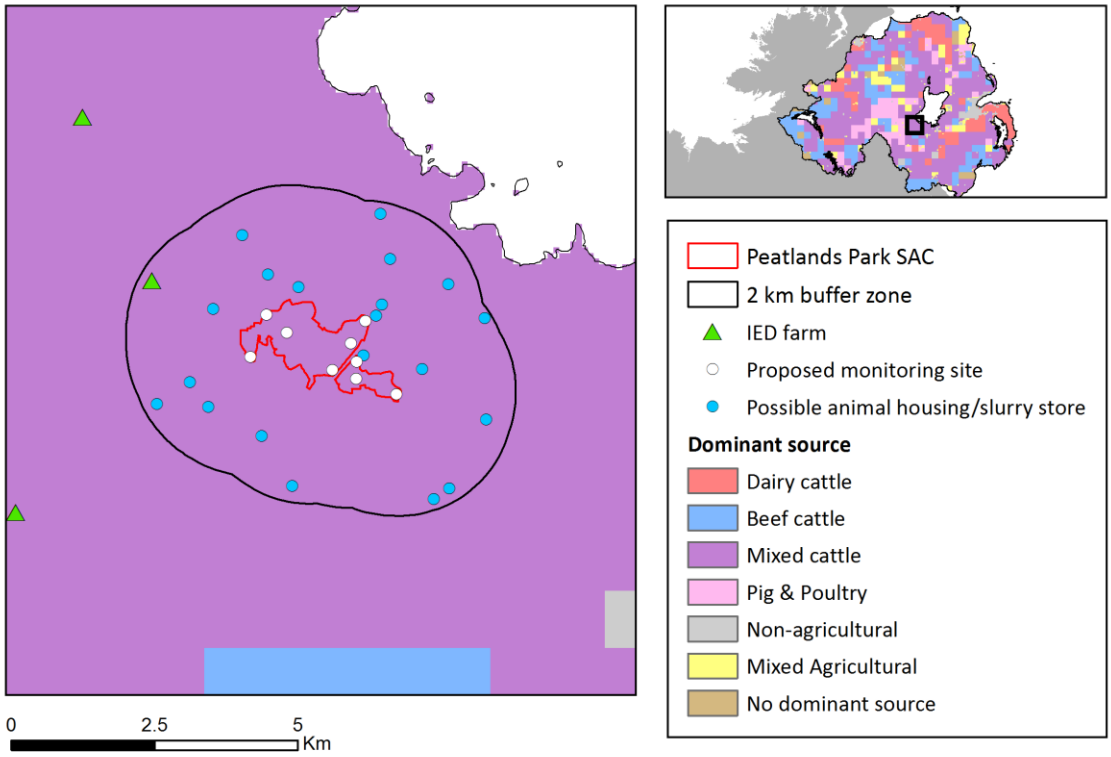


*Figure 15: Modelled dominant ammonia emission source classification showing Peatlands Park SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (2017 emission data).*

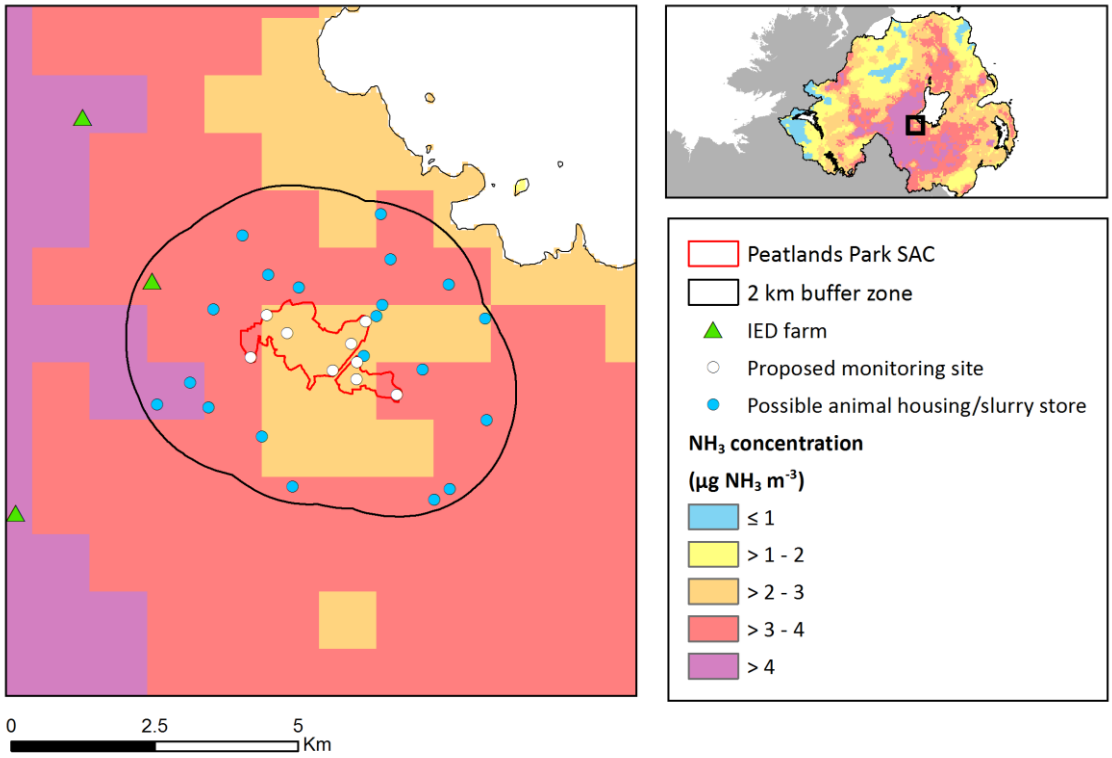


*Figure 16: Modelled ground level ammonia concentrations for Peatlands Park (outlined in red) and the wider landscape at 1 km x 1vkm grid resolution (FRAME model output).*

## 3.5. Slieve Beagh

| | |
|---|---|
| **Latitude** | 54.348 |
| **Longitude** | -7.194 |
| **Area (ha)** | 1,888.2 |
| **Designated for** | Active blanket bog (1112 ha), Natural dystrophic lakes and ponds (est. 15.3 ha), European dry heaths (80 ha) |
| **Site character** | Inland water bodies (Standing water, Running water) (1%)<br>Bogs, Marshes, Water fringed vegetation, Fens (85%)<br>Heath, Scrub, Maquis and Garrigue, Phygrana (14%) |
| **Notes** | 1 IED farm within 5km, several IED farms north-east (within 10km)<br>3 small animal housing within 2km |
| **Links to previous/current monitoring** | AFBI04-A within 10 km (new NI-wide network of $NH_3$ concentration samplers, set up Mar 2019, by AFBI & CEH) |

In contrast to the mainly lowland bog/fen type sites reviewed in this study, Slieve Beagh SAC is a large upland site situated in an agricultural landscape dominated by mixed dairy and beef cattle farming nearby and with a cluster of IED farms to the north (4 - 6 km distance). There are few farms close to the site boundary and most of the site is bordered by less intensively used land (including woodland), providing a buffer zone from agricultural emission sources. The south-western corner of the site forms the border with the Republic of Ireland, with much less detailed data availability for the purposes of this study, with increased uncertainty in the model output data for this site.

Modelled ammonia concentrations of 1.4 – 2.2 µg $m^{-3}$ (2017) are estimated for the site, with the highest concentrations to the north, but all areas exceeding the critical level for its designated features, of 1 µg $m^{-3}$ (Figures 17 - 19). The five suggested monitoring locations are located to cover the boundaries of the site. They have been provisionally located near potential access points (as far as these could have been ascertained via aerial photography – local knowledge will be particularly helpful here).

Due to the uplands character of this site (in contrast to the lowland sites), with few local sources and lower concentrations, but longer-range wet deposition expected to be a significant influence here, it is recommended that vegetation samples are collected for this site and analysed for N content, in addition to the atmospheric $NH_3$ concentration measurements.

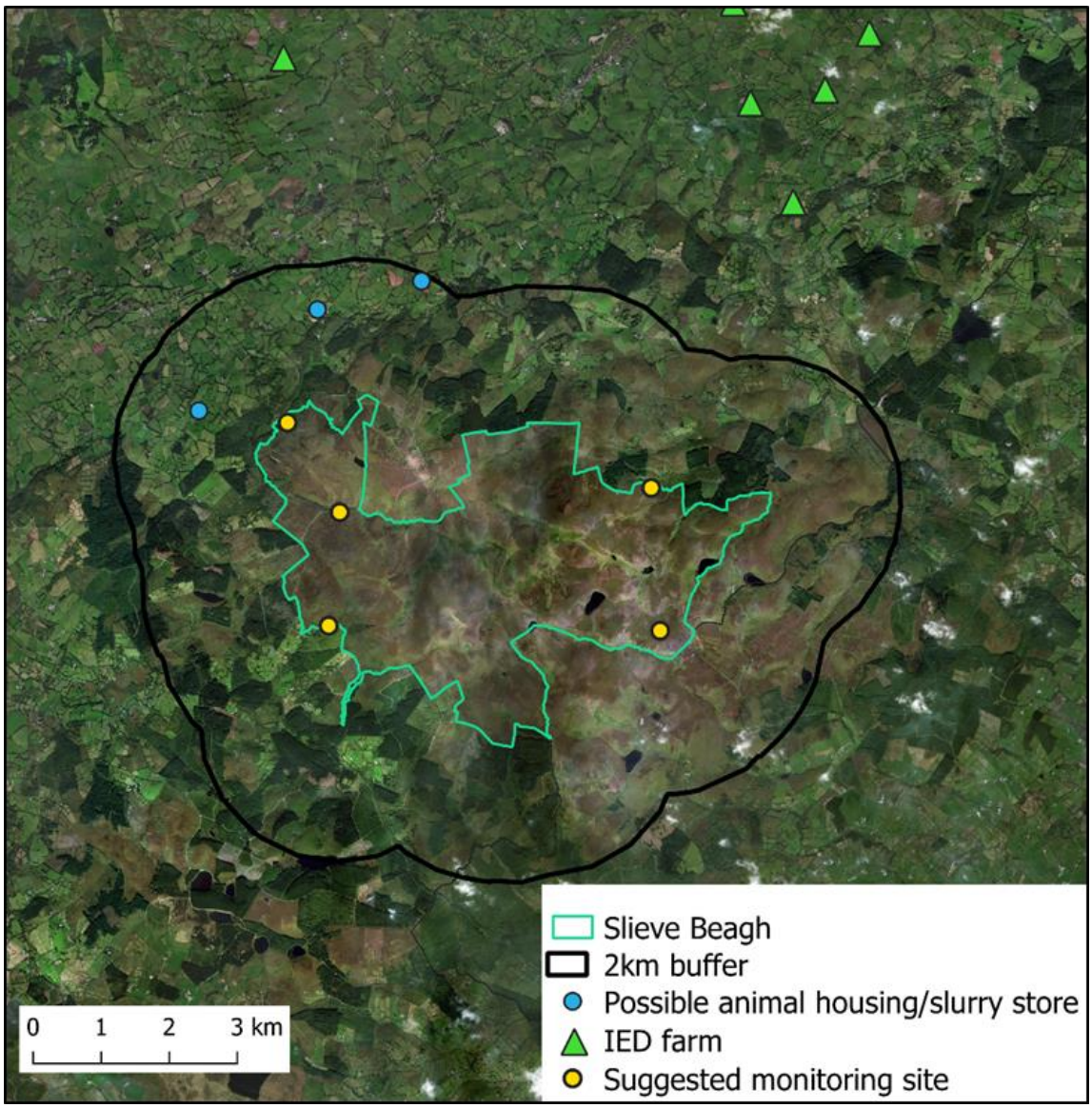


*Figure 17: Map of Slieve Beagh SAC using ESRI Satellite imagery, showing the locations of possible ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring.*

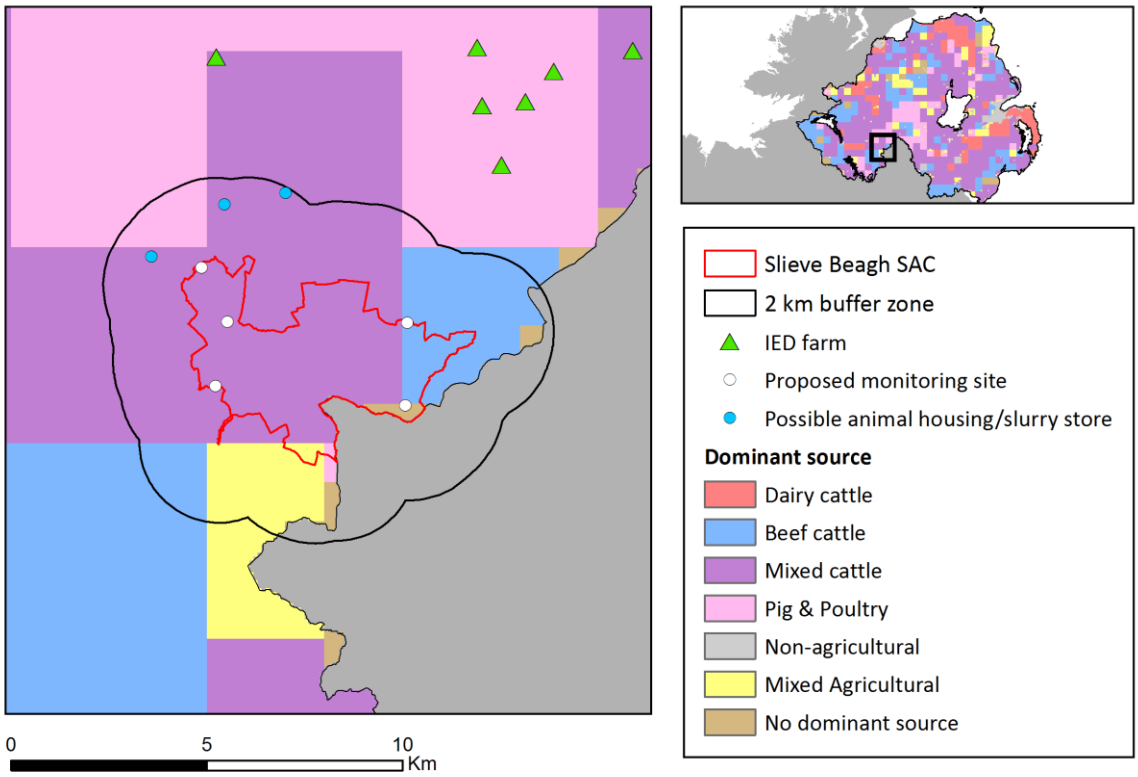


*Figure 18: Modelled dominant ammonia emission source classification showing grid squares containing Slieve Beagh SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (2017 emission data).*

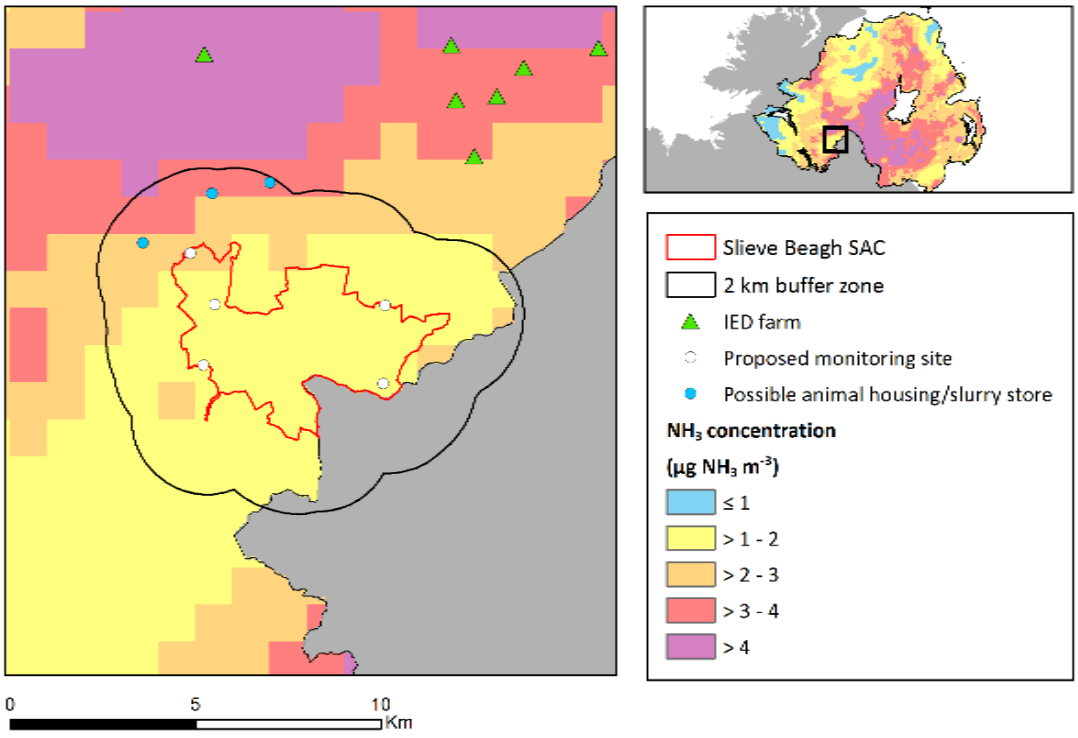


*Figure 19: Modelled ammonia concentrations for Slieve Beagh SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (FRAME model output for 2017).*

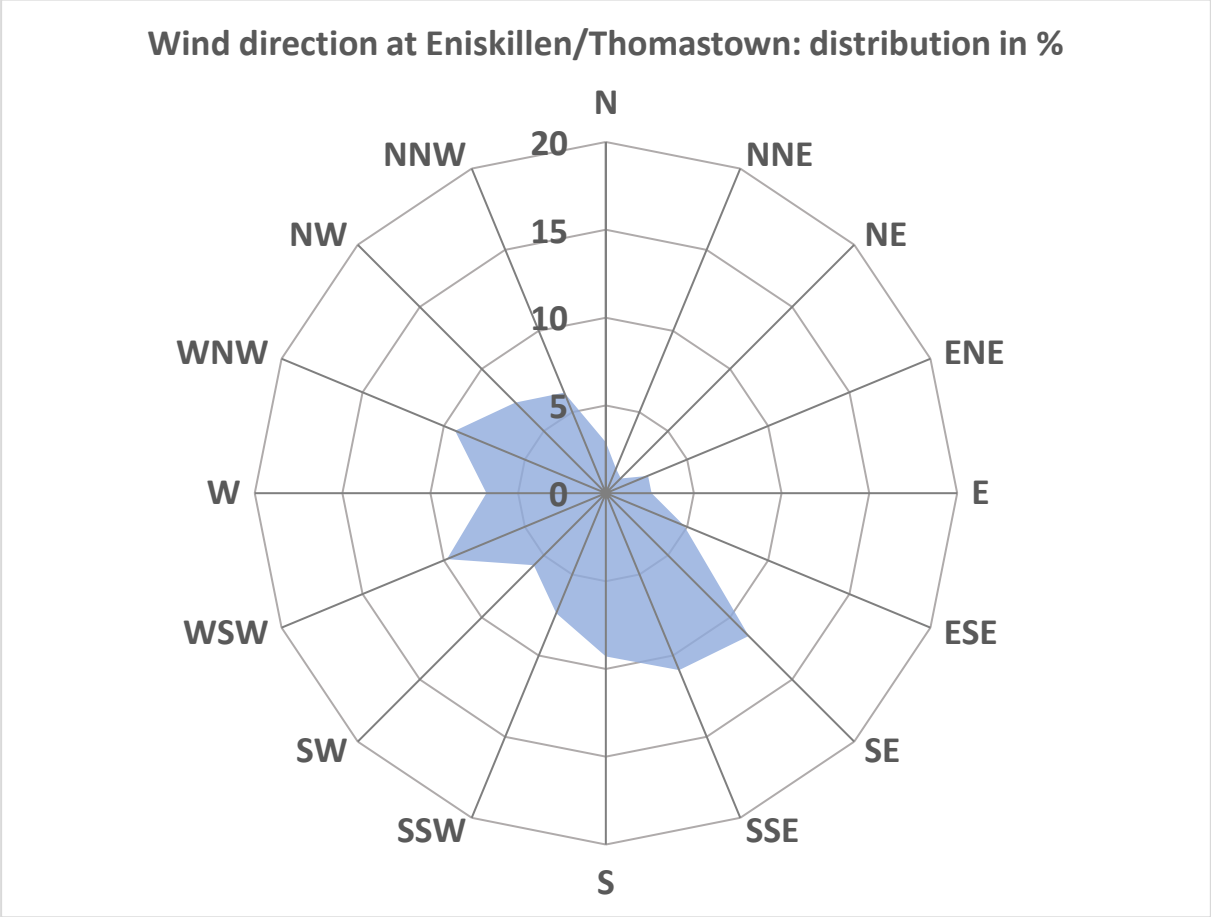


*Figure 20: Wind rose at Enniskillen/Thomastown met station: 26km SW of centre of Slieve Beagh SAC*

## 3.6. Turmennan

| | |
|---|---|
| **Latitude** | 54.379 |
| **Longitude** | -5.714 |
| **Area (ha)** | 14.8 |
| **Designated for** | Transition mires and quaking bogs (4.6 ha) |
| **Site character** | Inland water bodies (Standing water, Running water) (0.4%)<br>Bogs, Marshes, Water fringed vegetation, Fens (50.1%)<br>Dry grassland, Steppes (18.5%)<br>Broad-leaved deciduous woodland (31%) |
| **Notes** | Few small farms evenly spread in 2km buffer.<br>1 IED Farm within 2km, 2 within 5km |
| **Links to previous/current monitoring** | Within 2km: AFBI21-A; within 10km: AFBI13-A (new NI-wide network of $NH_3$ concentration samplers, set up Mar 2019, by AFBI & CEH).<br>Selected site for EMIND project |

Turmennan SAC is located in a very intensive mixed farming landscape (with at least 1 IED farm less than 2 km to the NE). Parts of the site border farmland directly, especially to the east, whereas others (south-western side) are buffered by woodland and other semi-natural features.

Modelled ammonia concentrations of 3.5 - 4.3 µg $m^{-3}$ (2017) are estimated for the site, with the highest concentrations to the east, substantially exceeding the critical level for its designated features of 1 µg $m^{-3}$ (Figures 21 - 23). To the north and west (1 - 4 km distance), there are indications of widespread annual average $NH_3$ concentrations > 4 µg $m^{-3}$. Due to the high concentrations, which are likely linked to local sources, and the expected concentration gradients across the site, 6 monitoring locations are suggested.

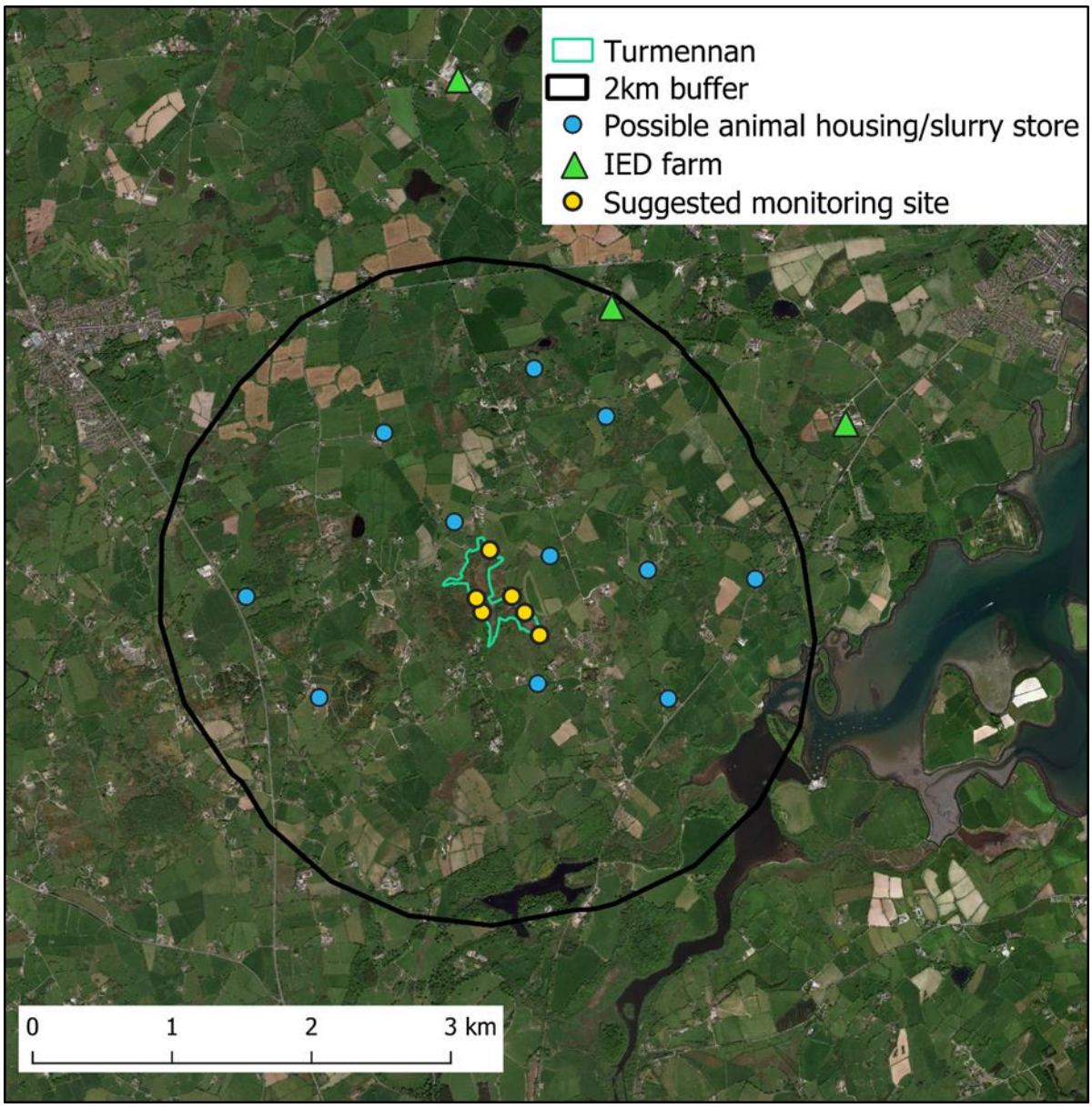


*Figure 21: Map of Turmennan SAC using ESRI Satellite imagery, showing the locations of possible ammonia emission sources within a 2 km radius of the bog and suggested sites for ammonia monitoring*

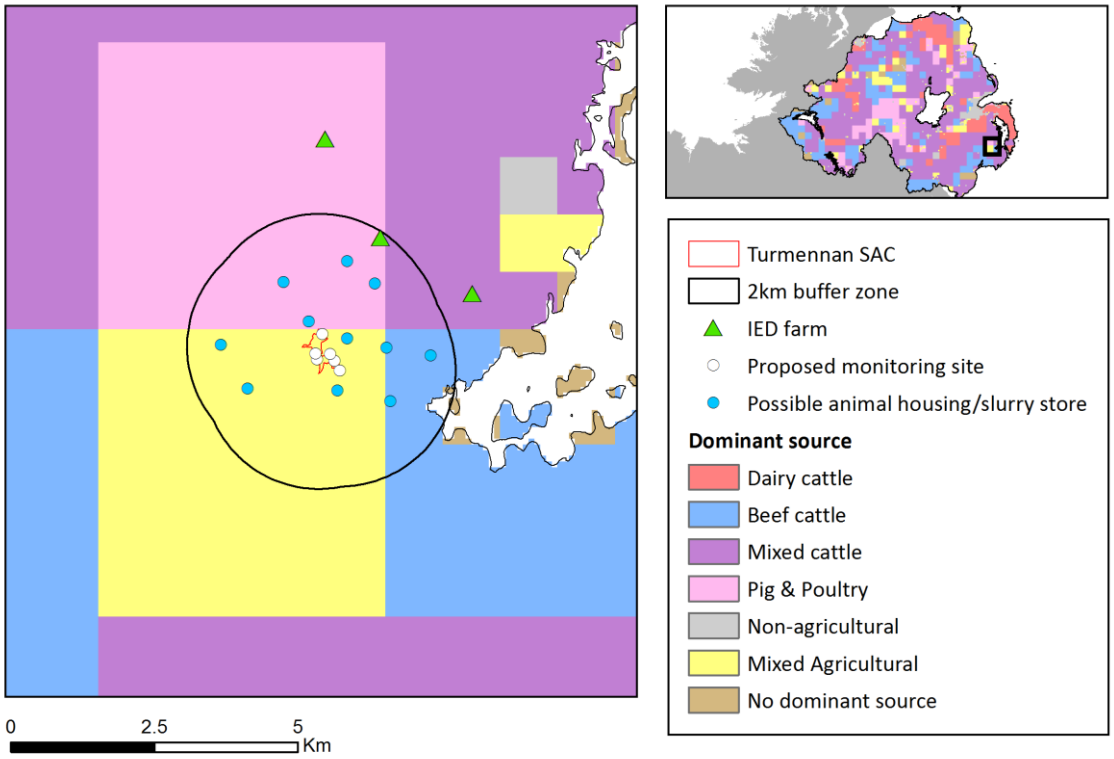


*Figure 22: Modelled dominant ammonia emission source classification showing Turmennan SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (2017 emission data).*

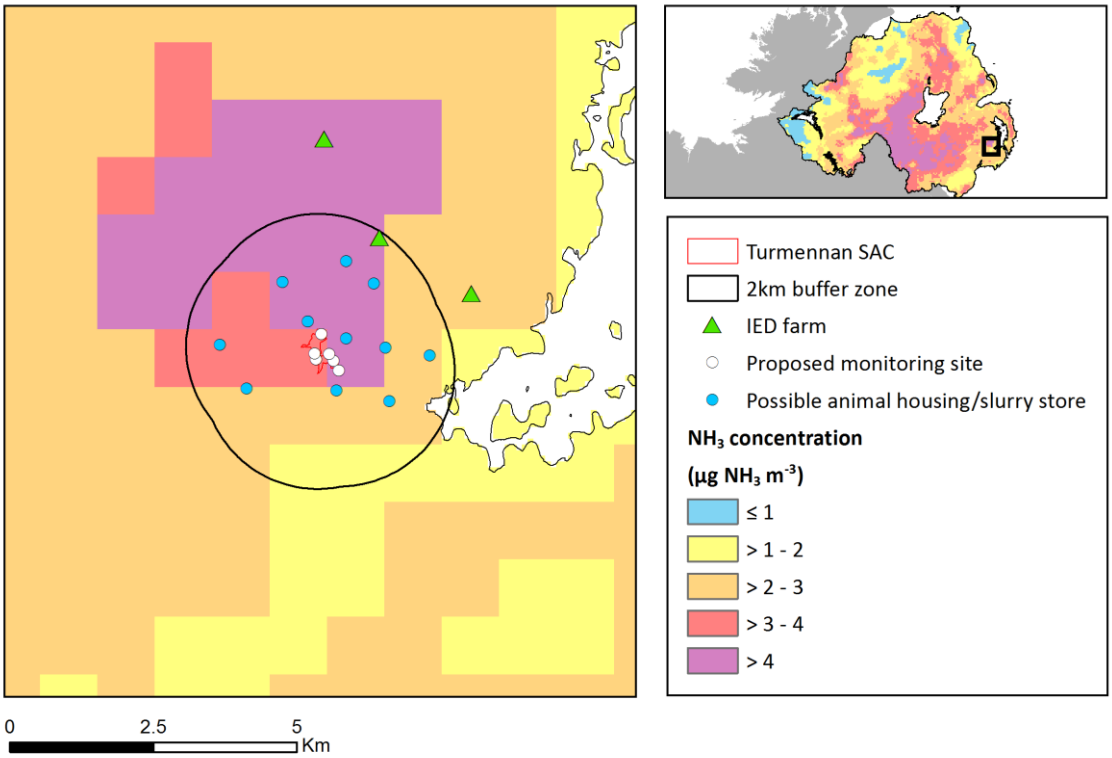


*Figure 23: Modelled ammonia concentrations for Turmennan SAC (outlined in red) and the wider landscape at 1 km x 1 km grid resolution (FRAME model output).*

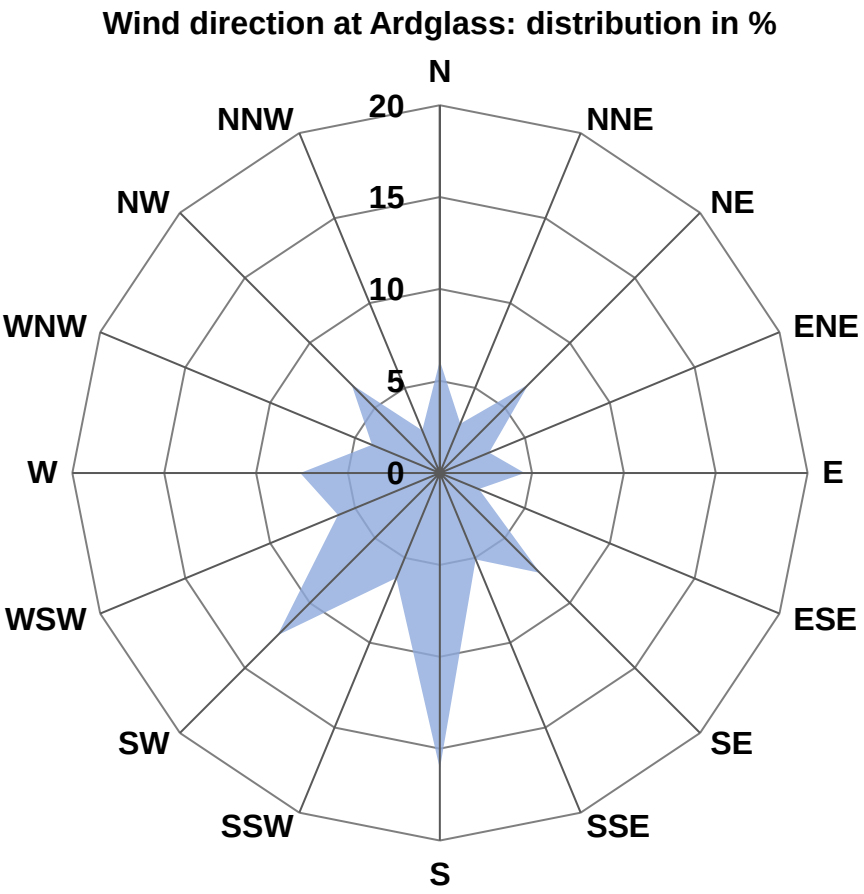


*Figure 24: Wind rose for Ardglass met station (11.7km SE of centre of Turmennan SAC)*

# 4 Proposed Monitoring Strategies

## 4.1 General Strategy

Site monitoring strategies attempt to capture the high spatial variability of ammonia and associated strong atmospheric concentration gradients away from sources. A sufficient number of samplers are needed to capture the concentration profile of a site (including minimum and maximum concentrations) and be able to develop a mitigation strategy, if necessary and appropriate.

Low-cost passive samplers that do not require electricity can easily be deployed without impacting on the site, and will capture average monthly $NH_3$ concentrations, thereby enabling the construction of a seasonal/temporal profile across the site.

The suggested monitoring locations are approximate and have been suggested based on the most recent national modelling data (2017) available at a 1 km by 1 km grid resolution, as well as aerial photography/maps. As a next step, these potential sites need to be reviewed with local knowledge, both in terms of potential $NH_3$ hotspots not evident from the national-scale modelling, and in terms of practicalities of site access, security etc.

## 4.2 Recommendation for prioritisation of sites

Modelled $NH_3$ concentration data for the six sites under review are presented in Table 1, with N deposition and critical load exceedance estimates presented in Table 2.

If sites are prioritised by the level of potential threat to the designated features from atmospheric ammonia, Turmennan is the most urgent site for establishing monitoring (concentration gradient of 3.5 - 4.3 µg $NH_3$ $m^{-3}$). Curran Bog and Peatlands Park follow, with Garry Bog, Moneygal Bog and Slieve Beagh showing the lowest modelled concentrations.

Suggested prioritisation of sites

1. Turmennan (most under threat)
2. Curran Bog and Peatlands Park (equal)
3. Garry Bog and Moneygal Bog (equal)
4. Slieve Beagh (lowest modelled concentrations).

In terms of complexity, Peatlands Park SAC would make an interesting study, with large areas potentially benefitting from shelter by surrounding areas of semi-natural vegetation, contrasted by other areas with emission sources very close to the boundary. Monitoring would be especially useful to resolve this complexity which is difficult to capture with the national scale modelling that averages out pockets of high and low concentrations on and around the bog.

In terms of uncertainty due to lack of detailed modelling data, both Moneygal Bog SAC and Slieve Beagh SAC are located on the border with the Republic of Ireland. The underlying emission maps and other spatial data sets for the Republic of Ireland that feed into the UK scale air pollution modelling have a higher level of uncertainty than those available for Northern Ireland, which are updated annually as part of the UK emission inventory.

Slieve Beagh SAC also differs from the other five sites due to its upland and expansive nature. There may be a larger influence from long-range transported wet deposition of nitrogen at the site, in contrast to the smaller lowland bogs which are in close proximity to local sources. At this site, it would be interesting to collect vegetation samples (rain-fed bog vegetation) over an altitude and concentration gradient, for analysis of total foliar nitrogen. A study at a site in a similar situation, at Cuilcagh Mountain SAC, is about to start, with passive ALPHA® samplers being established across the site and the neighbouring Cuilcagh - Aneurin Uplands SAC (in the Republic of Ireland), and vegetation sampling planned for early spring 2020 (the best time of year given plant growth cycles).

*Table 1: Summary of modelled atmospheric $NH_3$ concentrations and N deposition estimates for the sites under review*

| Priority | Sites | Weighted mean $NH_3$ concentrations ($\mu g\ NH_3\ m^{-3}$) | Range in $NH_3$ concentrations ($\mu g\ NH_3\ m^{-3}$) |
|---|---|---|---|
| 1 | Turmennan | 3.6 | 3.5 - 4.3 |
| 2 | Curran Bog | 2.5 | 2.3 - 3.2 |
| 2 | Peatlands Park | 2.8 | 2.7 - 3.2 |
| 4 | Garry Bog | 2.1 | 1.9 - 2.4 |
| 4 | Moneygal Bog | 2.1 | 1.7 - 2.5 |
| 5 | Slieve Beagh | 1.7 | 1.4 - 2.2 |

Modelled N deposition estimates to low-growing semi-natural vegetation are presented in Table 2. N deposition rates to semi-natural vegetation (woodlands, bogs, heaths, fens, montane habitats etc.), fertilised grassland, arable land etc. vary depending on the type of vegetation and nitrogen saturation. For example, fertilised grassland that has a much higher N content in its tissues, has a much slower uptake rate of dry deposition to leaf surfaces, compared with low-N vegetation such as bogs. For semi-natural vegetation types, dry deposition rates (also referred to as deposition velocities) can be roughly categorised into low-growing habitats versus woodland habitats, with the latter being characterised by much larger leaf surface area and therefore higher deposition velocities. Here we present the estimated N deposition to low-growing semi-natural vegetation (i.e. non-woodland habitats) as it is applicable to the bog features at most of the potential sites. Peatland Park SAC contains some bog woodland features in addition to bog features, therefore the N deposition estimate to woodland features for that site (35.1 kg N $ha^{-1}$ $yr^{-1}$) is applicable to assess the exceedance of the bog woodland (minimum critical load of 5 kg N $ha^{-1}$ $yr^{-1}$). For all other sites, the low-growing semi-natural N deposition estimate is applicable.

The Average Annual Exceedance (AAE) indicator has been estimated at all designated sites using the method below:

$$AAE\ (kg\ N\ ha^{-1}\ yr^{-1}) = \frac{exceedance\ (kg\ N\ ha^{-1}\ yr^{-1}) * exceeded\ area\ (ha)}{total\ habitat\ area\ (ha)}$$

Estimating AAE provides an exceedance value averaged across the whole habitat area and provides a more intuitive value for comparing the exceedance at each site, rather than the binary exceedance/non-exceedance indicator of whether critical loads have been exceeded. For example, the transition mires and quaking bog features of

Turmennan SAC have a (minimum) critical load of 10 kg N $ha^{-1}$ $yr^{-1}$, which is exceeded on average by 13.5 kg N $ha^{-1}$ $yr^{-1}$.

*Table 2: Summary of modelled atmospheric N deposition estimates and exceedance for the sites under review*

| Priority | Sites | Maximum total area of exceedance of critical loads (ha) | Mean N deposition to low-growing semi-natural vegetation (kg N $ha^{-1}$ $yr^{-1}$) | Annual Average Exceedance (AAE) of critical loads (kg N $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|---|
| 1 | Turmennan | 14.8 | 23.5 | 13.5 |
| 2 | Curran Bog | 183.5 | 18.7 | 13.7 |
| 2 | Peatlands Park | 207.6 | 21.2 | 31.1* |
| 4 | Garry Bog | 154.9 | 16.4 | 11.4 |
| 4 | Moneygal Bog | 156.1 | 16.8 | 11.8 |
| 5 | Slieve Beagh | 1,887.8 | 18.0 | 13.0 |

** The N deposition rate for woodland features is applicable at Peatland Park SAC (35.1 kg N $ha^{-1}$ $yr^{-1}$)*

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