National Ecosystem Monitoring Network (NEMN)-Design

Monitoring Air Pollution Impacts across Sensitive Ecosystems

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Monitoring Air Pollution Impacts across Sensitive Ecosystems

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Prepared for the Environmental Protection Agency
by
University College Dublin and the UK Centre for Ecology & Hydrology

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DISCLAIMER

This report is based on research carried out/data from June – October 2020. More recent data may have become available since the research was completed.

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Executive Summary

Under the EC National Emissions Ceiling Directive (NECD 2016/2284), EU member states are required to monitor (Article 9) and report (Article 10.4) air pollution pressure and impacts on ecosystems that are representative of each country's freshwater, forest, natural and semi-natural habitats. Ireland developed the National Ecosystem Monitoring Network (NEMN) in 2018, with the first data submission on 1st July 2019. In response to recommendations from the EC, Ireland is seeking to improve its NEMN. In this document, we propose methods for monitoring air quality and ecosystem parameters, and for selecting sites to be included in NEMN to improve representative coverage across sensitive habitat types and major pollution gradients. The air pollution impacts of interest are in the first instance those relating to the substances for which reduction commitments are set in Annex II to the NECD (i.e. SO_2, NO_X, NMVOC and NH_3), that is those contributing to acidification and eutrophication of ecosystems, and as precursors of ozone damage to vegetation growth and biodiversity changes. The development of the NEMN is intended to be an iterative process, with incremental improvements over time. The existing network is composed of International Co-operative Programme (ICP) Forests and Waters sites operated under the Air Convention (UN-ECE CLRTAP) and Water Framework Directive (2000/60/EC), respectively. The existing network structure is based on that of ICP Forests, which is composed of two networks with different monitoring intensity, Level II and Level I.

Level II: sites are used to install permanent or semi-permanent equipment to continuously monitor atmospheric concentrations and deposition of pollutants. The current NEMN contains eight identified Level II sites: four ICP Waters sites, two ICP Forests sites and two semi-natural habitat sites. The four ICP Waters sites are monitored by the EPA, and results were submitted to the European Commission under the NECD in 2019 (NECD 2016/2284). The two ICP Forests sites, one in Wicklow and a second in Mayo, were intensively monitored in the period 1991–2017. Monitoring on these two sites was suspended in 2017 due to lack of funding, and are reliant on inclusion within the NEMN to continue, including satisfying Ireland's (non-binding) commitments under the Air Convention (UN-ECE CLRTAP). Two sites intended to represent semi-natural habitats were proposed for inclusion within this network in 2018. However, as no relevant data has yet been collected on these sites, this report will review their suitability for retention based on both the risk posed to the sites and their suitability for long term monitoring.

Level I: sites are used to monitor long-term pollutant impacts on soil and vegetation, so can be visited comparatively infrequently, for periodic surveys, and do not require monitoring equipment installed on site. Cost-effectiveness is an important consideration for the design of the network, and some estimated costs are presented in Appendix 1 of this report. Not all costs for options could be prepared, due to uncertainty around public procurement, and these costs must be seen as tentative. The current network includes 35 Level I sites, on ICP Forests Level I sites, with locations selected as a subset of the systematic National Forest Inventory grid.

Feedback from the EC on the first round of NECD reporting showed that the submitted data from Ireland do not sufficiently capture ecosystem types particularly sensitive to impacts of air pollution, such as heathlands, bogs and acid-sensitive grasslands and strongly recommended expanding the network to include these non-forest habitats. This requires some changes to methodology, which in turn provides an opportunity to focus on monitoring methods that are cost-effective and can provide robust scientific evidence of air pollution impacts and recovery. Changes in the floristic composition of the vegetation are particularly useful for detecting air pollution effects on ecosystems, as are some relatively cheap biogeochemical measurements such as soil pH and nitrogen content of bryophytes. Effects of pollution on these ecosystem parameters are mainly gradual, so monitoring once every four years is adequate. This report makes recommendations for site selection and monitoring methods for the next phase of NECD data submission, notably: a)

including only a limited number of habitats in this phase, to ensure an adequate number of sites per habitat; and b) establishing permanent plot locations, to be more certain of detecting real change in future surveys.

The terrestrial ecosystem habitats were selected based on their sensitivity to air pollution, in particular N deposition and gaseous ammonia (of conservation importance in Ireland). The NEMN-design team recommend expanding the network to including five semi-natural terrestrial habitats, 15 sites per habitat, surveyed every 4 years: Raised Bog, Blanket Bog, Wet Heath, Calcareous Grassland and *Molinia* Meadow. Other existing networks will provide sites and data for Level I Forests and Level II Freshwaters. This phase of network design focuses primarily on expanding terrestrial ecosystem monitoring, where Level II sites are split into Level II and Level II core. Level II will receive less intensive monitoring but cover a greater number of sites, and Level II core will focus on intensive monitoring on very few sites. This report recommends using 15 Level II terrestrial ecosystem sites across the country, to include 7 Level II core sites. The primary focus of this approach is to represent the range in pressure from pollutant nitrogen (N), in particular the range in ammonia concentration, which is highly spatially variable. Nitrogen pollution is of particular concern for ecosystems in Ireland and globally. Sites should be representative of N risk and take account of co-correlated or modifying factors such as rainfall, S, O_3, management and size. A stratified selection process ensures the 15 sites per habitat are balanced across the N deposition gradient and rainfall. Practicalities and links to other networks were also considered, in addition to a proposed Level I Freshwater network.

Deposition of both reduced (ammonia and ammonium) and oxidised nitrogen causes eutrophication, leading to dominance by tall and fast-growing species, and acidification, both of which result in species loss. Ammonia has direct toxic effects, especially on sensitive bryophytes and lichens. Monitoring ammonia concentration allows this pressure to be characterised, and also provides evidence useful for estimating total N deposition. Ireland currently lacks a long-term continuous ammonia monitoring network. The proposed network has the potential to greatly improve the accuracy of concentration and deposition modelling carried out for Ireland. Additionally, this report recommends seeking partnership with other atmospheric monitoring schemes such as those carried out by the Integrated Carbon Observation System (ICOS), Teagasc, the Northern Irish Environment Agency (NIEA), Ulster Wildlife, the CANN project, etc. The monitoring carried out under these schemes is relevant to the required NECD data submission, e.g. for monitoring carbon flux, ammonia concentrations and additional meteorological parameters. Potential synergies in terms of site access are limited, since many of these networks do not typically focus on habitats of interest to the NEMN (with the exception of surveys carried out by the CANN project). However, their integration as additional sites would improve the resolution of atmospheric monitoring used to validate national models.

This phase of the NEMN highlights the importance of linking with National Parks and Wildlife Service (NPWS) biomonitoring for Level I Terrestrial Ecosystem sites. Where previous monitoring can be used to identify suitable sites for inclusion, they are also indicative of sites where biodiversity data has been collected in the form of relevés[*]. These can be linked with impacts from atmospheric pollution, as has been carried out in existing literature. In addition to providing historic data, a long-term link with future surveys would be invaluable to the NEMN. As the NPWS will carry out repeat surveys on nationally important habitats, identifying sites to which return visits should be carried out to benefit the NEMN will maximise the synergy with existing monitoring schemes. The inclusion of at least 5 relevés per habitat type of interest to the NEMN, may already be carried out in such surveys, though highlighting it now as a bare minimum for the NEMN is

[*] A small plot within which vegetative species are recorded.

important and the importance of fixed relevés highlighted. While this phase of the network focused on including sites recommended to the EC for Ireland, namely bogs, heaths and grasslands, other habitats were also reviewed for potential inclusion in future phases. These are upland lakes, limestone pavements, sand dunes, and oak woodlands, which should be considered for future inclusion. NPWS biomonitoring also occurs on limestone pavement, sand dunes and oak woodlands. Aligning the Habitats Directive reporting cycle of 6 years to the four-year NEMN reporting and monitoring cycle will require an increase in monitoring frequency on the selected sites.

Once sites from past NPWS monitoring schemes were identified, the relevant habitats were extracted, and the pressure from atmospheric pollutants was estimated for each site based on the most recently modelled EMEP data, and also recently published Irish literature. Nitrogen deposition is the most important driver of biodiversity impacts from atmospheric pollution in Ireland, and as such was used as the predominant driver of the required risk-based approach. Sites were categorised based on the modelled amount of total nitrogen deposited. This phase of the NEMN focused on identifying sites representative of five relevant habitat types, namely, raised bogs, calcareous grassland, wet heaths, blanket bogs, and *Molinia* meadows. It is recommended that each habitat has at least 15 Level I sites. If the number of sites is cost limited, the number of habitats should be reduced, not the number of sites within a habitat. For each habitat type, 15 Level 1 sites were selected from the prepared list, to represent the gradient of atmospheric pollution for each of these 5 habitats. The total number of terrestrial ecosystem Level I sites in the proposed network is 60, since some sites have more than one habitat, in particular blanket bog and wet heath. The number of Terrestrial Ecosystem Level II sites for each habitat type was based on sensitivity of the habitat and likelihood of impacts, where 6 sites are recommended for raised bogs, 4 for calcareous grassland, 3 for wet heath/blanket bog and 2 for *Molinia* meadows. The Level II core sites were selected to represent the high and low ends of the gradient for each habitat type (though a third site is recommended for raised bogs), and are included within the Level II sites i.e. 15 Level II sites and 7 Level II core. There are no additional sites proposed for the previously submitted Forest and Freshwater Level II sites, though additional monitoring required for these sites are detailed.

Site visits were carried out to review the suitability of identified Level II terrestrial sites. This required interviewing and meeting individuals familiar with the sites, typically NPWS conservation rangers. This ruled out some previously selected sites (namely Split Hills and Long Hill Esker SAC), but also identified new more suitable sites such as Moanour SAC. While not all proposed Level II sites were visited, their inclusion in previous NPWS monitoring networks indicates they may be suitable. However, it is still recommended that the remaining sites be visited in the near future.

The current proposed NEMN features **37 ICP Forest Sites** (2 Level II and 35 Level I), **25 Freshwater Sites** (4 Level II and 21 Level I), and **60 Terrestrial Ecosystem Sites** (nested design, 15 Level II, 7 Level II core). Monitoring across these sites will be carried out by a variety of stakeholders alongside the EPA. Additionally, the NEMN-design team have made a number of recommendations for improving this network as it progresses in the future, including;

- Inclusion of other sensitive habitats (dry heaths, limestone pavement, sand dunes and oak woodlands)
- A review of the potential for additional surveys on Level I forests within NEMN network.
- Ensuring at least 15 Level I sites with 5 relevés per habitat of interest
- Using an expanded Level II network with reduced equipment to function as a required continuous long term national NH_3 monitoring network
- Expanding the Level II network further by including synergies with other atmospheric monitoring in Ireland (i.e. NIEA/Ulster Wildlife, ICOS, Teagasc).
- Utilising an expanded Level II network to validate national concentration and deposition modelling (i.e. EMEP, EMEP4IE, MARSH).

1. Introduction

1.1 National Ecosystem Monitoring Network (NEMN) – legislative background

Under the EC National Emissions Ceiling Directive (NECD 2016/2284), EU Member States are required to develop national networks to monitor (Article 9) and report (Article 10.4) air pollution pressures and impacts on sensitive freshwater and terrestrial ecosystems (see Box 1).

Article 9(1) of the NEC-Directive requires that Member States conduct monitoring on the basis of:

ecosystem types

'a network of monitoring sites that is representative of their freshwater, natural and semi-natural habitats and forest ecosystem types, taking a cost-effective and risk-based approach'.

and

the impacts of interest

'The air pollution impacts of interest for the ecosystem monitoring are in the first instance those relating to the substances for which reduction commitments are set in Annex II to the Directive (i.e. SO_2, NO_X, NMVOC, NH_3 and $PM_{2,5}$), that is: acidification, eutrophication, and ozone damage to vegetation growth and biodiversity. While the impacts of other pollutants (e.g. heavy metals) are also of concern, a stepwise approach is appropriate and it is proposed that the first phase of monitoring focus on these three impacts.'

Ireland's response is the development of the National Ecosystems Monitoring Network (NEMN) which will carry out required monitoring on Ireland's freshwaters, forests, and other semi-natural habitats. A first submission of NEMN monitoring sites and indicators was made to the European Commission in June 2018, followed by the first submission of NEMN data in the Article 9 reporting template in June 2019.

Box 1. Requirements for monitoring negative impacts of air pollution on sensitive ecosystems, under the NEC Directive (2016/2284).

Article 9 of the NECD requires Member States to develop and implement a monitoring system which:

- Can identify negative impacts of air pollution on ecosystems (acidification, eutrophication and ozone damage),
- Covers a network representative of the Member State's habitats.

Annex V of the Directive sets out a list of optional parameters the Member States may use in implementing the obligation. The Directive states that 'Member States shall report the following information referred to in Article 9 to the European Commission and the European Environment Agency (https://rod.eionet.europa.eu/obligations/767):

- To report by 1 July 2018 and every four years thereafter, to the Commission and the European Environment Agency, the location of the monitoring sites and the associated indicators used for monitoring air pollution impacts (Article 10(4)(a));
- To report by 1 July 2019 and every four years thereafter, to the Commission and the European Environment Agency, the monitoring data referred to in Article 9.

A review of the first Article 9 submissions commissioned by the EC made a number of recommendations for Member States in their national reporting before the next round in 2022 and

2023 (WER, 2019). In particular, countries are encouraged to identify key habitats of national importance, and to develop a “Level I” network for monitoring air pollution impacts on these habitats. The review made recommendations in three areas (see Box 2).

For Ireland, the report noted the provision of extensive datasets for forests and surface waters, but identified evidence gaps for assessing impacts of air pollution on the biodiversity of other terrestrial habitats such as grasslands, heathlands and bogs (WER, 2019). This report proposes changes and extensions to the existing NEMN, with the aim of improving the monitoring and reporting of air pollution pressure and impacts on a representative coverage of relevant ecosystems for Ireland.

Box 2. Recommendations to the EC following the first NECD reporting round (WER, 2019).

Representative coverage across major ecosystem types (MAES Level II):

- Additional monitoring sites representing grassland, heathland and shrub, wetland and cropland sites
- Inclusion of additional terrestrial key parameters should be considered to enhance the breadth of data available.
- Each ecosystem type to contain at least one active monitoring site reporting indicators at recommended frequency (Annex V).
- A triad of similar sites to increase robustness of monitoring data.
- Level I monitoring at all sites.
- Level II monitoring at sensitive ecosystems and areas of higher pollution pressure

Representative coverage across major pollution gradient:

- Sites in areas of high S and N deposition, and high O_3.
- Sensitive ecosystem sites (e.g. nutrient-limited grasslands and heathlands, wetlands (receiving high rainfall)).
- Sites with unfavourable conservation status (HD) or below ‘good’ ecological quality (WFD).
- Background sites for comparison

Representative coverage across conservation status

The feedback to the EC **(WER, 2019)** made recommendations on collection and reporting of monitoring data, summarised in Box 3.

Box 3. Recommendations from the EC on monitoring data following the first NECD reporting round.

- Air quality data: some modelled data allowed, e.g. flux-based ozone and critical level exceedances.
- Ecosystem parameters should be collected via monitoring.
- Re-use data collected under Habitats Directive, Water Framework Directive and Ambient Air Quality Directive.
- The Commission and member states to facilitate development of manuals on wetlands, grassland, and heathland with standardized methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution.

The review report recommended a step-wise approach in identifying sites for inclusion within each Member States; national networks, outlined in Figure 1-1. In designing the next phase of the NEMN, the seven steps were adopted to ensure that the network would be:

- Cost-effective (e.g. linking and forming synergies with existing networks),
- Representative of nationally important habitat types,
- Representative of national air pollution pressures,
- Representative of level of protection they are afforded and that they are adequately spatially distributed.

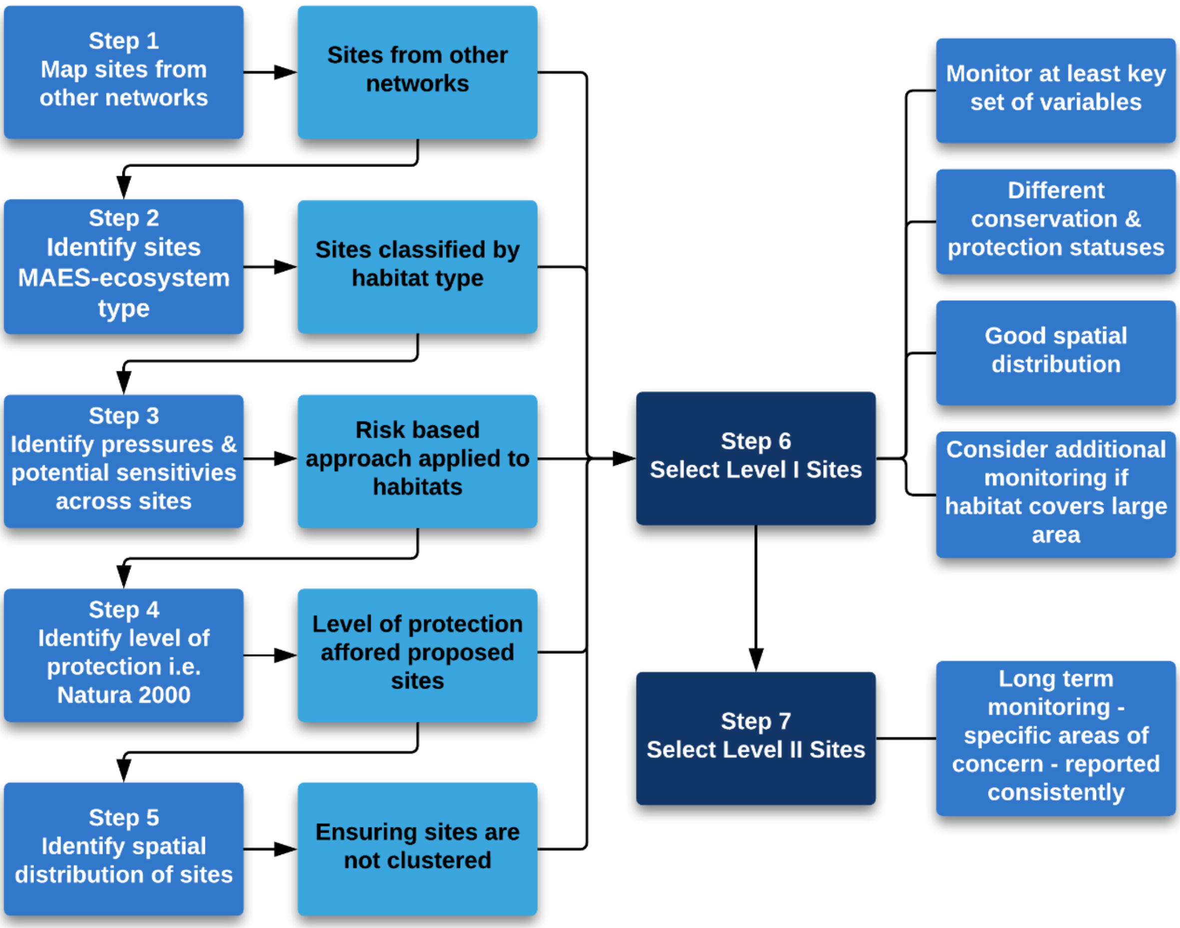


Figure 1-1. Seven steps for identifying additional monitoring sites for inclusion in NEMN, adapted from European Commission feedback (WER, 2019).

1.2 Current NEMN network

The current NEMN for Ireland (2019 reporting) comprises 43 sites, 37 of which are sites drawn from ICP Forests level I and II sites (Table 1 – 1, Figure 1-2). As identified in the EC review (WER, 2019), grasslands, heathland and shrubs, and inland wetlands (Bogs) are poorly, or not represented at all in the NEMN. The current levels of active monitoring and data collection on these sites vary substantially. While freshwater sites are monitored (quarterly) by the EPA under ICP Waters and the Water Framework Directive (2000/60/EC) (European Communities, 2000), monitoring on ICP Forests Level II had ceased prior to inclusion in the NEMN. There is also a need to increase the number of terrestrial indicators for monitoring and reporting.

In this document, we propose methods for selecting sites and for monitoring to reinforce and improve the Irish NEMN. This will provide the evidence needed to determine the state of, and predict changes in, terrestrial and freshwaters ecosystems due to the impacts of air pollution, in particular by nitrogen (especially ammonia), ozone and sulphur. These changes include eutrophication, acidification, ozone damage and biodiversity loss.

Table 1-1. National Ecosystems Monitoring Network (NEMN) sites for which data were first reported in 2019 to the EC.

Level 1	MAES Ecosystem Type (Level 2)	EUNIS Habitat classes (Level 1)	No. of NEMN sites
Terrestrial	Urban ecosystems		Not relevant
	Cropland	I: Regularly or recently cultivated agricultural, horticultural and domestic habitats	none
	Grassland	E: Grasslands and land dominated by forbs, mosses or lichens.	1: Ballymachugh (new site – no data reported)
	Woodland and Forest	G: Woodland, forest and other wooded land	35: ICP Forests Level I 2: ICP Forests Level II
	Heathland and Shrub	F: Heath, scrub and tundra	none
	Sparsely or un-vegetated land		Not relevant
Freshwater	Inland wetlands	D: Mires, bogs and fens	1: Clara Bog Level II (new site – no data reported)
	Rivers and lakes	C: Inland surface waters	1: ICP Waters 3: Acid Lakes
TOTAL			43

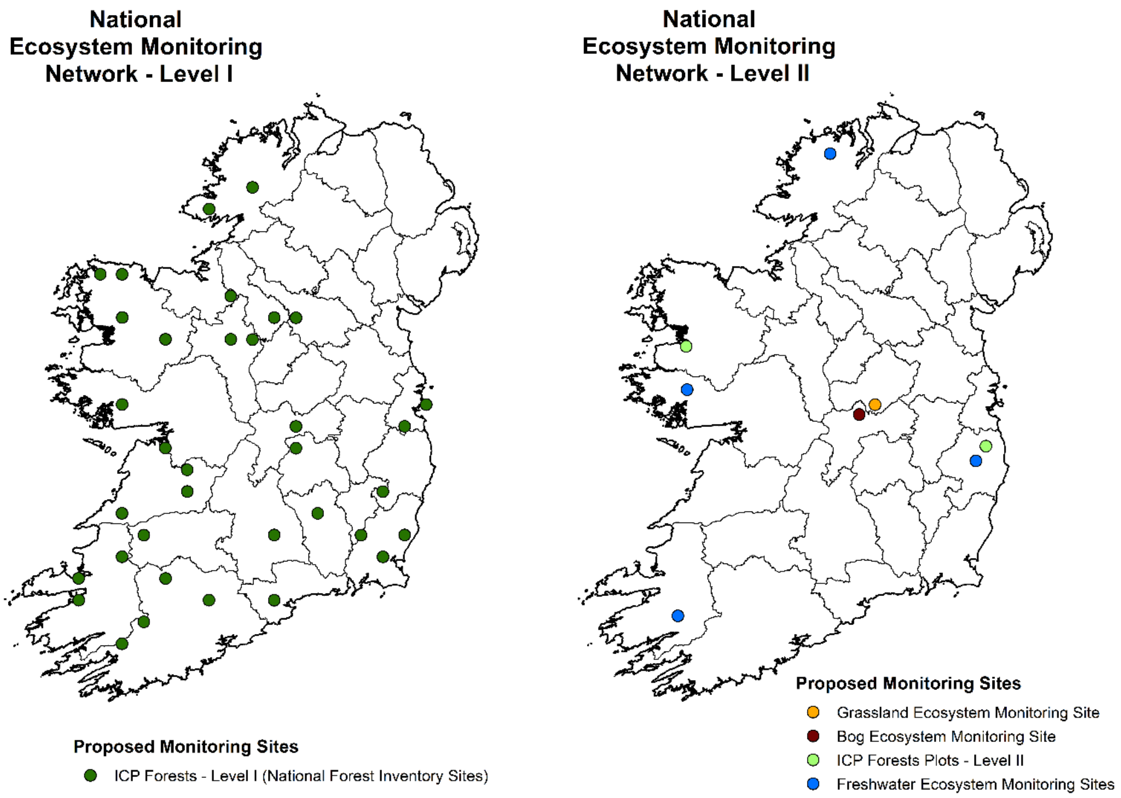


Figure 1-2. Monitoring sites in the National Ecosystem Monitoring Network (NEMN) for Ireland reported in 2018 and 2019 to European Commission in compliance with the National Emission Ceilings Directive. Left: Level I sites. Right: Level II sites.

The ICP Forest Level II sites have collected data on acidification and eutrophication of habitats since 1987, which ceased after 2017. Since 2017, one survey has been carried out on ICP Forests Level I, which was assessment of crown condition (Figure 1-2 - Left). While crown condition is not a requirement of the NECD data submission, the inclusion of these sites will rely on the monitoring of relevant parameters in Annex V. To maintain continuity of the long-term dataset, It is recommended that monitoring that has ceased on these sites are restarted, Additional parameters to be measured at the ICP level II sites are also proposed which are covered in the following sections.54

1.3 Critical Loads and Critical Levels

The concepts of critical load (CLo), a rate of pollutant input above which there may be harmful effects on ecosystems, and critical level (CLe), a gaseous concentration above which harmful effects may occur, have been important in air pollution policy. The CLo and Cle values are set according to scientific evidence (Bobbink & van Hettelink 2011; APIS 2020; Centre for Ecology and Hydrology, 2016), and have been subject to periodic review and revisions – for example, the ICP-M&M Coordination Centre for Effects is currently coordinating a review of empirical critical loads for nutrient-N. Current reporting of ecological impacts of air pollution (acidification, eutrophication and ozone damage) in the Article 9 template relies to a large extent on CLo and CLe exceedances as a proxy for whole ecosystem damage. Future reporting from the NEMN will therefore continue to report these metrics, in line with any agreed revisions in CLo and Cle values. To provide supporting evidence, we propose to include monitoring and reporting of key parameters that can be linked more clearly with indicators of direct air pollution effects and impacts on ecosystems, discussed in this report.

For the purpose of sites selection to cover a gradient of risk, modelled total N deposition rather than CLo or CLe exceedance was used, since the latter are available for designated features only (e.g. with Eunis classifications such as SACs, SPAs). Future modelling of critical loads and levels should be validated by this monitoring network, benefitting national modelling of impacts.

2. NEMN Structure

The aim of the NEMN is to provide evidence for negative impacts of air pollution on representative terrestrial and freshwater ecosystems for Ireland, including evidence for ecosystem recovery time when pollution pressure is reduced. The data collected will constitute the national response under NECD. The design of the network also needs to be statistically robust. A well-designed network is likely to support many scientific studies and thus contribute to reviews of critical loads and levels at country and EU scale.

An assessment of air pollution impacts on ecosystems must be based on reliable evidence and make best use of resources, that will inform policy and management needs:

Evidence needs:

- Detect changes in air quality (AQ) pollutant concentrations, and from the ecosystem measurements identify the relationships to air pollution levels.
- Use of indicators that can be linked to air pollution impacts, distinguishable from climate change impacts.
- Evidence must include receptor-based monitoring to detect, characterise and quantify potential ecological changes in response to any potential improvements in air quality.
- Due to cumulative effects of reactive nitrogen (Nr) inputs and long time lags, rate of ecosystem recovery are expected to be slow.
- Climate change is a key driver of ecological changes. Evidence from receptor-based measurements must be able to distinguish between the effects of climate change and air pollution.
- Both historic and current management practices will also affect ecological changes.

Best use of resources:

- Use of data from existing monitoring networks, national level surveys, modelled and Earth observation data to contribute effectively to the NEMN monitoring and reporting.
- Coordination and synergies with existing national monitoring programmes, in particular those established under the EU air quality legislative framework (EPA ambient air quality network), NPWS, EMEP and Met Eireann networks and the ICP Forest Level I and II network).

Air pollution effects on ecosystems are best assessed by monitoring both *pressure* and *impacts*. Pressure measurements include pollutant concentrations (e.g. $\mu g\ m^{-3}\ NH_3$) and deposition fluxes (e.g. $kg\ N\ ha^{-1}\ yr^{-1}$). In the case of ozone, it is the ozone uptake into leaves, i.e. the accumulative uptake of ozone into leaves over a specified growing period or Phytotoxic Ozone Dose (PODy; $mmol/m^2$). Impact indicators include measurements that show whether the system is under threat, sometimes called *midpoint* indicators, such as soil pH or N concentration in plant tissue (Rowe et al., 2017). Impact indicators may also be *endpoints,* measurements that are directly relevant to people's experience of and concern for the environment (Rowe et al., 2017). Endpoints include biodiversity indicators such as species-richness, and also biogeochemical targets such as the Nitrates Directive limit of 50 mg $NO_3\ L^{-1}$ for drinking water.

2.1 Tiered monitoring strategy

A tiered monitoring strategy is proposed. Air pollution *pressures* on ecosystems will mainly be assessed through a "Level II" network of monitoring stations and modelling of concentrations and deposition; whereas *impacts* will be assessed through infrequent monitoring of a more extensive "Level I" network, which includes the nested Level II network within it, in order to directly align pressures with impacts at key sites. Nesting of Level II sites within the Level I network also allows benchmarking of the national dispersion and deposition models required to estimate the *pressures* (i.e. air pollution concentrations or deposition load) at each of the Level I sites, in order to assess their contribution to observed *impacts* on ecosystems. Changes to semi-natural ecosystems caused by air pollution are in many cases gradual, so Level I sites require monitoring only once every several years. Such changes may be difficult to separate from the effects of other environmental pressures and gradients. To detect air pollution impacts, data on floristic composition and "slow" environmental variables such as soil pH or plant tissue N content are often most useful, since these metrics integrate change over time (Rowe et al. 2017). Monitoring pollution pressure requires more frequent, long-term continuous measurements and greater annual costs, so fewer Level II sites are proposed.

A tiered approach is proposed for cost-efficient monitoring and reporting of air pollutant concentrations and depositions in the NEMN (Figure 2-1.). Long-term data in air pollutant concentrations and depositions are needed as evidence to detect changes in pressure from air pollutants, and from the ecosystem measurements identify the relationships to air pollution levels. A combination of modelling and on-site measurements of the key pollutants will provide the necessary evidence to assess changes and potential recovery in ecosystem responses following reduction in their emissions. The data will also provide the evidence to test how effective abatement measures are in reducing their emissions.

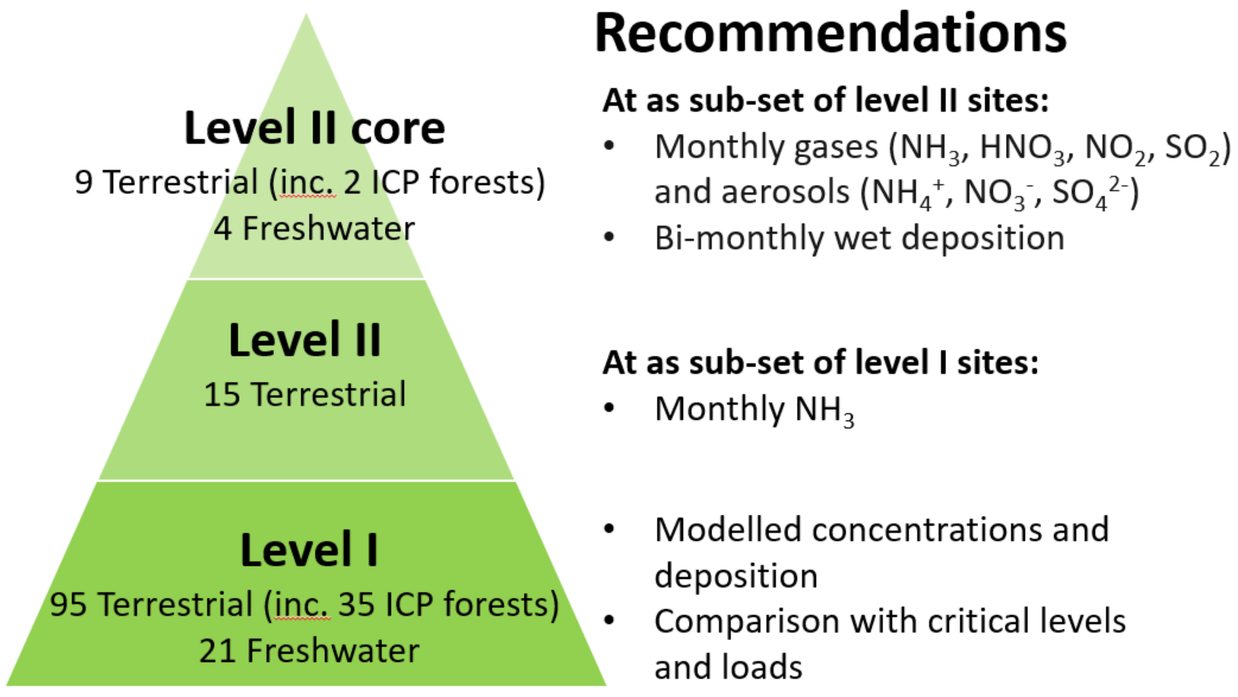


Figure 2-1. Tiered monitoring strategy for air pollution monitoring in NEMN

Level I

Additional clarifications from the EC to Article 9 monitoring states that "*As a general rule and for the sake of improved accuracy of the analysis, **modelling should not replace measurements**. However, modelling can, for some parameters such as atmospheric NO_x concentrations, usefully complement monitoring data, especially when monitoring networks are of lower density and for those sites where there are still gaps on measured parameters. Where applied, the use of modelling to complement measuring should primarily concern atmospheric concentrations and only if unavoidable also deposition of pollutants." (*EC, 2019b*).* Member States are strongly encouraged to gradually extend and develop their monitoring networks to make sure that modelling is only an interim solution, as measurements are the preferred option for all parameters in the template (and measurements are also needed for the validation of models) (EC, 2019b).

Level II

It is recommended to carry out long-term, continuous measurements of NH_3 with passive diffusion samplers (e.g. ALPHA® samplers) at all level II sites, to detect changes in NH_3 concentrations and deposition, NH_3 is a highly reactive, water-soluble gas with substantial spatial variability in concentrations and deposition at a local scale. Studies have shown that reactive N deposition in the vicinity of NH_3 sources are dominated by dry NH_3-N deposition (e.g. Pitcairn et al. 1998, ROTAP 2012). Dry deposition of NH_3 is generally largest in the high emission areas, where NH_3 concentrations are also greatest, and intensively fertilized areas may in fact act as a net source for NH_3 rather than a sink. Therefore, deposition will mainly occur to nearby unfertilised land with a small N content, and the amount of deposited N increases substantially close to the source. Semi-natural ecosystems and conservation areas (which are of low N status) near emission source are therefore particularly at risk. Also, while the centre of a large reserve may be less at risk than the overall national assessments suggests, smaller reserves and the edges of large reserves are much more at risk. For a robust assessment of ecological impacts of atmospheric NH_3 at a sensitive site, it is necessary to quantify the site-specific local NH_3 concentrations and NH_3-N dry deposition. It is therefore proposed that monitoring efforts in the NEMN to focus on quantifying the site-specific contribution by NH_3 concentrations and deposition (NH_3-N dry deposition) to the total N deposition to the sensitive receptor.

Where current Level II sites, namely forests and freshwater will continue as planned (with some modifications proposed in following sections), this distinction applies to terrestrial ecosystem Level II sites. Level II sites for forest and freshwater sites will follow the proposed Terrestrial Ecosystem Level II core monitoring plan.

Terrestrial Ecosystem Level II core

N deposition from other reactive nitrogen species in the atmosphere include dry deposited N from HNO_3, NO_2 and NH_4^+, and wet deposited N from NH_4^+ and NO_3^- (Figure 2-2). Ammonium sulphate and ammonium nitrate aerosol are formed by the atmospheric oxidation and reaction of precursor gases (SO_2, NO_x) with NH_3 and comprise a major component of fine particulate matter (Figure 2-2). In this form, $PM_{2.5}$ makes an important contribution to sulphur and nitrogen deposition. The gases and aerosols are removed from the atmosphere by wet (in precipitation) or dry (direct uptake by vegetation and surfaces) deposition processes. The availability of concentration data will decrease the uncertainty in estimating dry deposition and therefore total deposition of sulphur and nitrogen species.

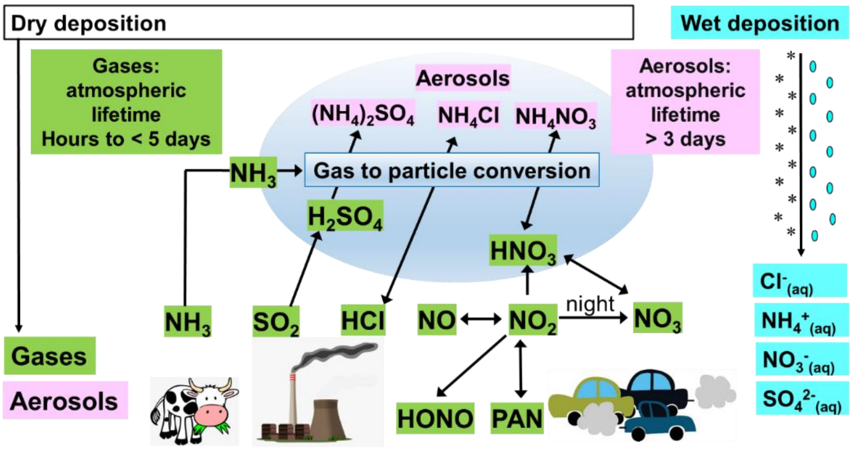


Figure 2-2. Reaction scheme showing the emissions, atmospheric chemistry and fate of NH_3, acid gases and NH_4^+ aerosols. (reproduced from Tang, 2020a).

The low deposition velocity of particulate NH_4^+ to most types of vegetation (the exception would be forest edges) means deposition from particulate NO_3^-, SO_4^{2-} and NH_4^+ is expected to be small. However, while the gases deposit locally close to sources, the aerosols can be transported longer distances and contribute to pollution in places far from sources, including across national boundaries. Ammonium in particle form is therefore a transboundary pollutant, exchanged between Ireland and other countries.

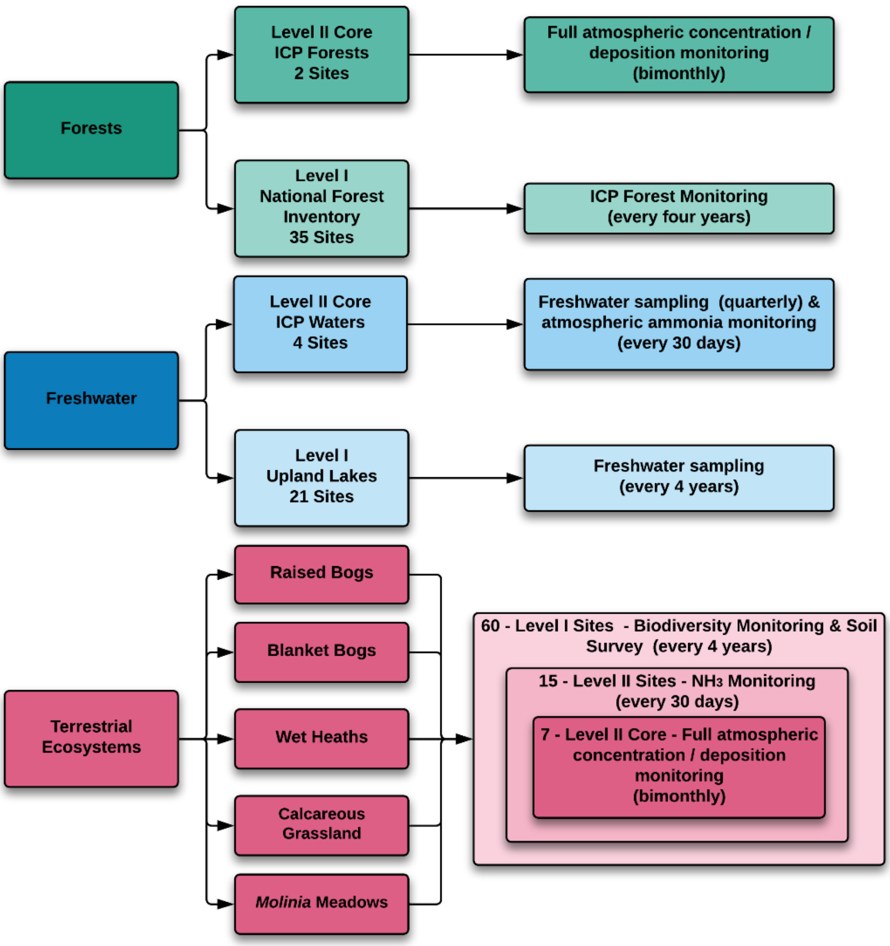


Figure 2-3.Core recommended National Ecosystem Monitoring Network, including existing and proposed sites.

2.2 Selecting sites for representative coverage of key habitats

Six major categories of ecosystems (MAES Level II) are considered relevant for the NEC-Directive: Grasslands, Cropland, Forests and Woodlands, Heathland and Shrub, Wetlands, and Rivers and Lakes. These are also the key habitats listed in Annex I of the Habitats Directive. This phase of network development focused on three priority habitats that are not well represented in the NEMN. This included Grasslands, Heathland and Shrub, and Inland Wetlands (specifically bogs) (Sect. 1.2; Table 1-1). These were selected on the basis that they are sensitive to air pollution, in particular to gaseous ammonia and N deposition, and that they are habitats of particular conservation importance within Ireland. Feedback on Ireland's 2018 submission of monitoring sites required under Article 10 (4) b of the NECD 2016/2284 (European Union, 2016), stated "Preferentially more (natural) grassland sites. Given the importance of the Irish mores and peat bogs, more sites in these ecosystem types would also be welcomed" (WER, 2018). We therefore recommend that this phase of the network focuses on these five specific Annex I habitats, representing three of the MAES Level 2 ecosystems: 1) Grassland, 2) Heathland and Shrub and 3) Inland wetlands (Table 2-1.).

Table 2-1. Proposed inclusion of new sites from five key Annex 1 habitats in NEMN that are nationally important sensitive habitats for Ireland.

MAES Ecosystem Type (Level 2) /	Annex I habitats	NEMN Category	No. NEMN sites reported 2019	New sites to be reported 2023
Grassland	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) important orchid sites (6210)	Terrestrial Ecosystem	1: Ballymachugh (new site – no data reported in 2019)	**15**
	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (6410)		none	**15**
Heathland and Shrub	Northern Atlantic wet heaths with *Erica tetralix* (4010)		none	**15**
Inland wetlands	Blanket bogs (7130)		none	**15**
	Active raised bogs (7110)/Degraded raised bogs still capable of natural regeneration (7120)		1: Clara Bog Level II (new site – no data reported in 2019)	**15**
Woodland and Forest		Forest	35: ICP Forests Level I 2: ICP Forests Level II	No change
Rivers and lakes		Freshwater	1: ICP Waters 3: Acid Lakes	20 Upland Lakes 1 Marine Institute Lake
Urban ecosystems		-	none	Not considered relevant
Cropland		-	none	Not considered relevant
Sparsely or un-vegetated land		-	none	Not considered relevant
TOTAL number of sites			43	81 new sites + 41 existing sites = 122 sites in total

*Wet heath is commonly associated with blanket bog and we recommend only surveying this habitat on sites that have blanket bog

In Table 2-2, habitats are ranked in order of priority for inclusion in the Terrestrial Ecosystem Level I network. This is mainly based on sensitivity to N deposition, according to their threshold for Critical Load for nutrient-N. However, we considered it important to represent grasslands, in particular two classes that can be very species-rich in Ireland, calcareous grasslands and *Molinia* meadows. If there is insufficient resource to include sites from all five Annex 1 habitats, we recommend prioritising the inclusion of the most sensitive habitats in the first phase (e.g. habitats with higher ranking in Table 2-2), and considering the excluded habitats in the second phase instead. This would be preferable to reducing replication (15 sites per habitat) or reducing the suite of monitoring to be implemented at each site (see later).

Table 2-2. Priority ranking of habitats considered for inclusion within this phase of the NEMN. Critical Load values shown are the ranges given in Bobbink & van Hettelink (2011).

Rank	Habitat	Critical Load (kg N ha^{-1} yr^{-1})	Likelihood of impact
1	Raised Bog	5-10	High
2	Blanket Bog	5-10	High
3	Wet Heath	10-20	High
4	Calcareous Grassland	15-25	High
5	Molinia Meadow	15-25	Low – Medium

Bogs are particularly sensitive to N pollution, as indicated by their low Critical Load thresholds. Raised and blanket bogs are distinct habitats and are typically monitored under separate programmes by the NPWS, hence it was deemed appropriate to monitor both habitat types separately within the NEMN. Of Ireland's raised bogs, 44 were monitored as part of the 2013 raised bog monitoring project (Fernandez et al., 2014). These sites are prioritised for inclusion within the NEMN (see also Sect. 3.6).

Some of the sites identified for possible inclusion have multiple habitats present within the ecosystem area. We recommend that the current phase focuses on the five habitats above (Table 2-2.), but that the potential for extending the survey to other habitats at the same sites is also considered during site visits. We recommend that later phases of the network focus on other pollution-sensitive habitats that are important in Ireland. These include:

- Dry heaths (4030)
- Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) (6510)
- Arable
- Improved grassland
- Limestone pavements
- Sand dunes
- Atlantic oak woodlands
- Alpine and Boreal heaths (4060)

Upland lakes are typically mapped to greater detail than MAES Level 2, and are mapped to either Fossitt Level 2, or to Annex I habitat level, providing the required information for step 2 (Figure 1-1). However, limestone pavements, sand dunes, oak woodlands and upland lakes are also nationally important habitats for Ireland and as such should be considered for future inclusion. This network proposes site selection based on Annex I habitat, which will allow for more in-depth comparison of impacts across sites. There are advantages to including sites from the Natura 2000 network, in particular in terms of habitat continuity, since these sites are afforded the strictest level of protection in Ireland.

3. NEMN Site Identification

The NEMN needs to be representative (habitats, pollution gradient), cost-effective and risk-based. Linking the NEMN network with existing ecological monitoring networks and programmes will allow for both the representation of monitored habitats and cost-effectiveness of the network to be addressed. In line with seeking cost-effective approaches to setting up and maintaining the NEMN, a division in approaches to broad habitat categories is recommended, namely for Forests, Freshwaters and Terrestrial Ecosystems. This section details rationale for identifying such sites to ensure they are representative and risk based.

3.1 Forests

Under the Convention on Long Range Transboundary Air Pollution, several International Cooperative Programmes (ICPs) have investigated the effects of air pollution. Ireland has participated in ICP Forests in the period 1987–2017. A two-tier system of plot intensity uses Level I plots for periodic surveys, and Level II plots for continuous intensive monitoring with installed equipment (also split into Level II and Level II core). The tiered sampling proposed for the NEMN arises from the ICP Forests approach.

Three Level II forest plots were monitored in the period 1990–2017, while up to 35 Level I plots have been assessed annually during 1989–2020, with a gap in 2013–2018. Monitoring of Level II plots has since ceased, with one plot (Roundwood) due for clearfell, though relocation is an option. Restart of monitoring contributing to these programmes depends on the inclusion of these sites, and support for relevant monitoring, within NEMN. The recommendation that the NEMN uses ICP methods suggests that this synergy can be achieved, with suitable support. Under ICP Forests, the Biosoil survey coordinated soil-solid sampling for chemical characterisation across a large network of European sites, a periodic assessment that integrated earlier national surveys, and is overdue for replication. This was carried out at Level I and Level II plots, and should be repeated across all NEMN sites every 10 years.

A 5-year cyclical inventory of the forest estate of Ireland, as located using aerial imagery, is in its fourth cycle. Sites are selected on a 2 km systematic grid, and many surveys carried out once in the sampling cycle, with no site infrastructure. The National Forest Inventory (NFI) managed by the Department of Agriculture Food and Marine, was used as a basis for the selection of ICP Forests Level I sites. A randomised systematic grid design was used to provide the required number of sample points necessary, to ensure the integrity and statistical accuracy of the results. A 2 km x 2 km grid was overlaid on the total land base of Ireland, to create initial plot locations at the intersection of the grid lines. This grid density equated to 17,423 points nationally, each representing approximately 400 hectares (ha).

Each plot centre was randomly located within a radius of 100 m from the grid intersection, by adding randomly generated numbers (-100 to +100) to each of grid intersection. As the grid is permanent it allows for the periodic re-assessment of these primary sample points to monitor forest land-use change e.g. afforestation and deforestation. In the most recent NFI 1,923 permanent sample points were established within forests. The ICP Forests Level I network is selected as a strict subset of the NFI network, located on a 16 km grid with arbitrary start point, and using the same grid placement and sites as NFI.

Both ICP Forests Level I and II were part of the 2019 NEMN submission, and the current phase does not propose any additional forest sites. Feedback from Ireland’s first submission of data indicate that the number of sites are sufficient, though additional monitoring parameters should be considered (WUR, 2019). Both current Level I and Level II sites are presented in Figure 3-1.

3.2 Freshwaters

EPA are the regulatory body responsible for freshwater monitoring in Ireland, as both the competent authority responsible for the Water Framework Directive (2000/60/EC) and ICP Waters Lake Monitoring Programme. WFD monitoring includes surveillance, operational and groundwater monitoring. Water categories (or networks) distinguished are rivers, lakes, transitional and coastal waters, and groundwater, each with subnets defined. Surveillance Monitoring Network (SM) and Operational Monitoring Network (OM) both include Lakes Maumwee, Veagh, and Glendalough Upper. SM Subnet 2 Long Term Trend Monitoring is matched with the pre-existing monitoring programme Lakes in Acid Sensitive Areas. OM Subnet 2 Monitoring of the effectiveness of Diffuse Source measures is similarly matched with the Lakes in Acid Sensitive Areas. These alignments are identified in the 2006 establishment of the Water Framework Directive Monitoring Programme (Ireland, 2006).

Three loughs (Veagh, Maumwee, Glendalough upper) and their feeder streams, part of ICP Waters are monitored quarterly by the EPA. These three loughs continue a former Acid Lakes Network (mid-1980s to present). The Lough Maumwee combination of lakes and streams forms the longest continuous observed water chemistry record (since 1984) for acid-sensitive surface waters in Ireland. Geographical representation has been improved by including a lake in the southwest, Upper Lake, Co. Kerry, from the acid lakes network. Data for freshwater monitoring was submitted for all four lakes as part of Irelands 2019 submission under the NECD (2016/2284/EU). It is proposed that these four lakes constitute the core Level II freshwater monitoring network, as they monitor freshwater chemistry and biodiversity, requirements for freshwater sites within the NEMN.

A network of small upland lakes selected by the SUAS project (Aherne et al., 2013) where there was a maximum of 1 lake in each 10 x 10 km square of the Ireland National Grid, the highest altitude lake in the square, with selection of squares random, weighted in favour of acid-sensitivity on the basis of bedrock categories of the Skokloster classification. Thus, any lake could be selected, regions with many lakes were more represented, any altitude could be present but locally upland lakes are always chosen and the network favours uplands. Lakes with marked anthropogenic influence confirmed in the field, including discharges, abstraction, and construction, were individually excluded. These lakes were sampled in much of the network three times, at decadal intervals, approx. 1997, 2007, 2017, with a small number sampled annually through that period. Additional linked surveys of upland soils, sediments were conducted. The lakes presented within this report were monitored as part of all three surveys and form a good baseline for potential site selection. This network satisfies the criteria of being risk-based (sampling weighted by inferred weathering rate), representative (selected from an original subset of >200 sites), and cost effective (existing and ongoing sampling scalable to resource availability). Additionally, a lake within the Burrishoole catchment maintained by the Marine Institute could be integrated into the Level I network. The site is regularly manned, and could be developed into a freshwater Level II site in the future utilising existing staff to maintain the site.

This phase of the NEMN recommends expanding monitoring to include a Level I network of upland lakes previously monitored by the SUAS project. These sites are remote and difficult to access, as such only 20 sites are recommended in this phase. There is potential to expand into additional sites in future phases, pending success of monitoring intended for 20 proposed sites. These were selected from the 31 most recently surveyed lakes (historic data for 1997, 2007 and 2017) following the approach used for terrestrial habitats (outlined in Section 3.3), to ensure 20 sites selected represented a nitrogen deposition gradient. It is recommended that monitoring on these lakes could be divided across the four-year NEMN reporting cycle, where 5 site visits a year to such sites seem a manageable approach. As sites are clustered, it is recommended that at least one site from each cluster is included in each years monitoring scheme.

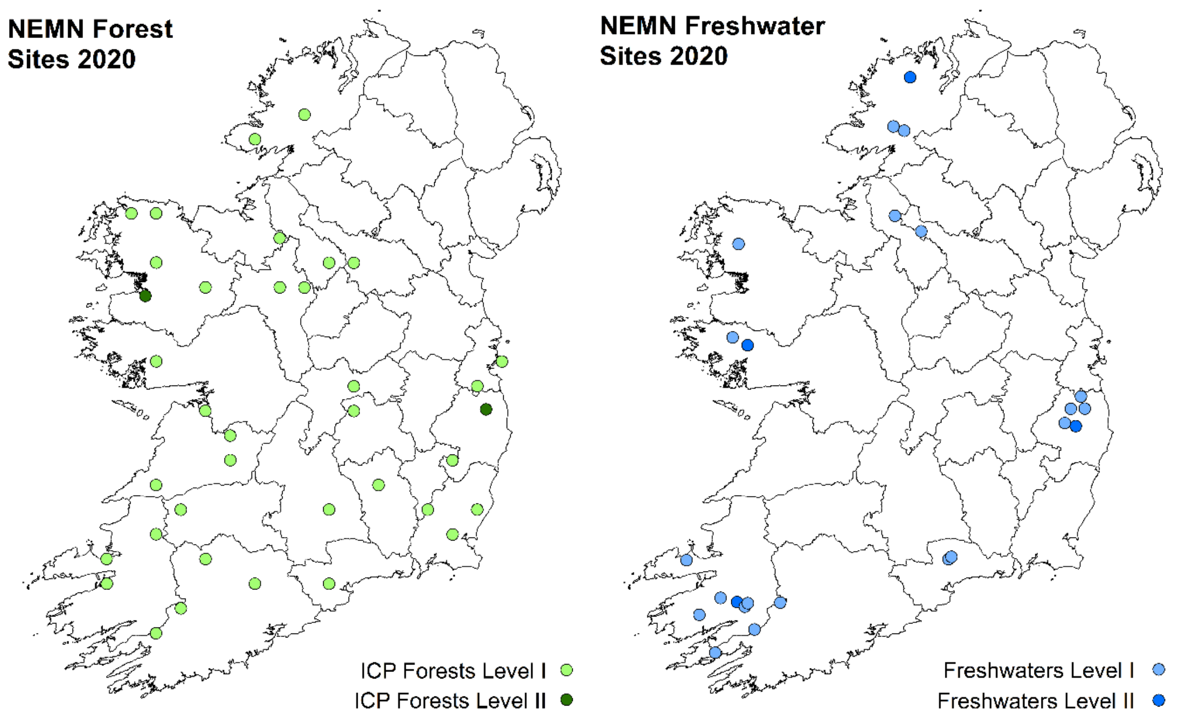


Figure 3-1. NEMN Forest and Freshwater Level I and Level II sites.

3.3 Terrestrial Ecosystems

The status of Irish Natura 2000 sites is reported by National Parks and Wildlife Service (NPWS) under Habitats Directive (92/43/EEC) every 6 years. This reporting requires national monitoring programmes, which typically occurs less frequently than the reporting cycle. Linking with biomonitoring conducted by the NPWS would form an ideal basis for Level I monitoring in the future. When surveys are repeated, the inclusion of identified NEMN sites should be treated as a priority. Inclusion within the NEMN may indicate a need for additional funding, subject to appropriate negotiations and approvals, in order to account for an increased frequency of survey, inclusion of additional sites, increased time in the field (due to use of permanent relevés), and potential maintenance of Level II sites by NPWS staff.

The first step in site identification for terrestrial ecosystems to include within the NEMN made use of previous and proposed monitoring networks for semi-natural habitats developed by the NPWS (Step 1, Figure 1-1), since these identify specific habitats at a given site, and to develop potential synergies with these networks. Reports for a number of relevant surveys are available as Irish Wildlife Manuals (https://www.npws.ie/publications/irish-wildlife-manuals) and these were used to identify sites from habitats on interest. (These habitats are typically mapped to greater detail than MAES Level 2, and are mapped to either Fossitt Level 2, or to Annex I habitat level, thus circumventing step 2 (Figure 1-1). The habitats selected were based primarily on their sensitivity to critical load of eutrophication (N deposition), (

Table 2-2) but also their relative importance and abundance. The initial review included habitats such as bogs, heaths and grasslands surveyed in the Irish Wildlife Manuals, as recommended by the EC. Habitat types as defined by MAES Level II contain further classification of habitats that may respond differently to air pollution. This network proposes site selection based on Annex I habitat, which will allow for more in-depth comparison of impacts across sites. By default, this focuses efforts within Ireland's Natura 2000 network. There are advantages to including sites from the Natura 2000 network, in particular in terms of habitat continuity, due to these sites being afforded the strictest level of protection in Ireland. As these are protected sites, appropriate assessment is required where permanent air quality monitoring is proposed (i.e. Level II and Level II core)).

While feedback from the first submission has prioritised monitoring on **semi-natural grasslands**, **heath** and **bogs;** this report also considers other sensitive habitats which may be considered for future iterations. It is intended that sites selected to represent these habitats will be prioritised from within the Natura 2000 network in order to ensure the retention of specified habitats in the future. These are presented in Appendix 3, ranked using the same risk-based approach.

3.3.1 Habitats

As indicated previously, this phase of the network will focus on semi-natural terrestrial habitats regularly monitored by NPWS. As described in previous chapters, this will benefit the NEMN as these sites are likely to be monitored again at specified intervals by the NPWS going forward. Effective communication with NPWS as a primary stakeholder in this network, will ensure selected sites will be revisited and permanent relevés integrated into their monitoring scheme where appropriate. This is a very clear synergy between existing, ongoing monitoring and the requirements of the NEMN. Habitats identified during this review are summarised in the following sections.

Semi-Natural Grasslands

The most recent national semi-natural grassland survey (Martin et al., 2018) identified 110 core sites, 103 were designated with a unique site code (7 sites had second locations therein). Of the 103 sites, 93 received a full survey while others were excluded for a number of reasons. The NEMN-Design will considered 93 locations for inclusion within its grassland monitoring network. Sites representative of solely lowland hay meadows were excluded from review.

Bogs

Blanket bogs are typically monitored within the same programme that monitors heathlands (to follow), due primarily to typically occurring within the same areas. 6 upland sites were monitored as part of the hen harrier monitoring programme (Moran and Wilson-Parr, 2014), while 16 sites were surveyed as part of the national survey of upland habitats (to be increased to 21 by 2021) (Perrin et al., 2014, 2010). However, due to the cost of upland survey and NPWS survey priorities, these sites are not likely to be revisited for survey by the NPWS within the coming years. A focus for blanket bog sites identified within future NPWS monitoring programmes, namely sites within the Wild Atlantic Nature LIFE Project were prioritised. A total of 24 upland sites will be monitored as part of this programme over the next 9 years. 44 bogs were monitored as part of the 2013 raised bog monitoring project (Fernandez et al., 2015), these sites were selected to be included within the review of potential bog sites within the NEMN. The combination of blanket and active bogs resulted in a total of 66 sites for review.

The GIS datasets for Annex I habitats listed below were reviewed and compiled for potential inclusion within the NEMN.

- Active raised bogs* (7110)/Degraded raised bogs still capable of natural regeneration (7120)
- Blanket bogs (*if active bog) (7130)

Heath

Similar to blanket bogs, 6 upland sites were mapped as part of the Hen Harrier SPA mapping project (Moran and Wilson-Parr, 2014), and 16 were surveyed as part of the national survey of upland habitats (Perrin et al., 2014, 2010). The 24 sites within the Wild Atlantic Nature programme were also prioritised for inclusion, in order to economise on the synergy between networks.

The surveys conducted in the past identified three Annex I habitats below, which when mapped were identified as potential sites. The hen harrier habitat mapping however, did not clarify if any of the identified heath would qualify as an Annex I habitat.

- Northern Atlantic wet heaths with *Erica tetralix* (4010)
- European dry heaths (4030)
- Alpine and subalpine heaths Alpine and Boreal heaths (4060)

Limestone Pavement

The national survey of limestone pavement and associated habitats (Wilson and Fernández, 2013) was carried out in 2013, from which the majority of available limestone habitats data is derived. Surveys on limestone pavements were recorded in two formats, full polygons were drawn for NHAs and small 100 x 100 m polygons. As the digitised 100 x 100 m blocks cannot be used to infer a cover over the entire site, risks were applied to the site boundaries and the area referred to is that based on the overall site, not the annex I habitat Limestone Pavement (Annex I habitat code 8240) therein. This resulted in 45 polygons across 40 unique sites being included in the analysis. These sites were reviewed for potential inclusion in future phases of the NEMN, but will not be directly considered for this current phase. Sites for potential future inclusion are listed in Appendix 4.

Sand Dunes

The National Sand Dune Monitoring Project carried out by the NPWS in 2011 (Delaney et al., 2013) monitored 41 sites. Strandhill is listed twice as habitats monitored occurred in two separate SACs covering different areas. For the purposes of the NEMN these two sites would likely be combined into one. Polygons were not available for Lough Yganavan in Co. Kerry, and hence was excluded from analysis. These sites were reviewed for potential inclusion in future phases of the NEMN, but will not be directly considered for this current phase.

The 2011 survey identified a variety of Annex I habitats, namely;

- Embryonic shifting dunes (2110)
- Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) (2120)
- Fixed coastal dunes with herbaceous vegetation (grey dunes)* (2130)
- Annual vegetation of drift lines (1210)
- Perennial vegetation of stony banks (1220)
- Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*) (2170)
- Humid dune slacks (2190)
- Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)* (2150)
- Machairs (* in Ireland) (21A0)
- *Juniperus communis* formations on heaths or calcareous grasslands (5130)

In any future monitoring programme, further selection of these habitats would be required. Some, such as Embryonic shifting dunes, Annual vegetation of drift lines and Perennial vegetation of stony banks, are in an open nutrient cycle with the sea and highly dynamic, therefore unlikely to be impacted by atmospheric deposition. Others have differential sensitivity to N (e.g. Fixed coastal dunes, and Atlantic decalcified fixed dunes), and may need separate consideration for monitoring. Note that sand dunes are considered sensitive to N deposition and have a relatively low critical load compared with other habitats (8-15 kg N ha^{-1} yr^{-1} for dry dunes, 10-20 kg N ha^{-1} yr^{-1} for dune slacks, depending on the habitat). Sites for potential future inclusion are listed in Appendix 4.

Oak Woodlands

Of the semi-natural woodlands in Ireland, sessile oak wood (91A0) may be the most relevant to atmospheric pollution to epiphytic communities therein. Of the 1320 sites included in NPWS old sessile oak woods and alluvial forests survey (O'Neill and Barron, 2013) 296 contain this Annex I Habitat. Of these sites, 61 were resurveyed in 2011 and 2012 – these 61 sites were selected to form a base for potential oak woods to be included within the NEMN. This habitat occurred on all 61 of these sites. These sites were reviewed for potential inclusion in future phases of the NEMN, but will not be directly considered for this current phase. Sites for potential future inclusion are listed in Appendix 4.

3.3.2 Ecological Monitoring Networks Summary

As the NEMN will include ecological monitoring on all sites, using a combination of Level I (ecological monitoring alone) and Level II (including air pollution monitoring), the most cost-effective design includes the use of sites already being monitored by another body, namely the NPWS. Using these sites as a basis for selection and communicating early with the NPWS will allow for these monitoring programmes to efficiently sit within the NEMN design. Figure 3-2. below presents the locations of all sites discussed within section 3.3.1.

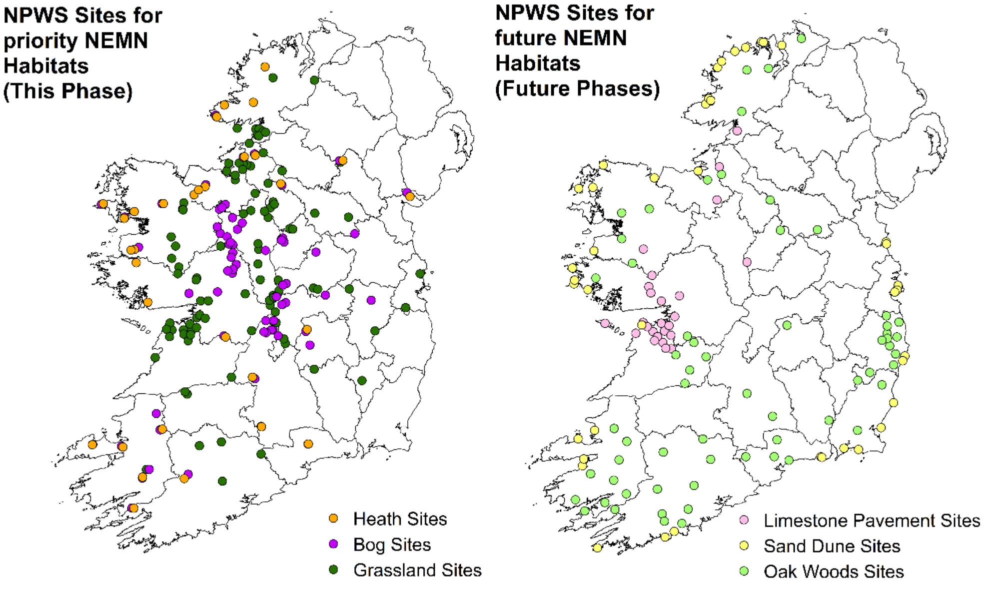


Figure 3-2. NPWS monitoring sites for potential inclusion within NEMN. Left – Priority habitats for this phase for inclusion within this phase of the NEMN. Right – Habitats to consider for future phases of the NEMN.

3.4 Applying risk to sites

While selecting sites from pre-existing national ecological monitoring networks ensures sites are representative of that habitat type, and synergies between networks is appropriately cost-effective, the NEMN needs to apply a risk-based approach. While this phase of the NEMN used best available modelling at the time to inform the risk based approach, as future phases are developed it is recommended that this approach is reviewed as new models become available. The primary air pollution impact of concern in Ireland is from nitrogen deposition and/or ambient ammonia, as such the 0.1°x0.1° EMEP deposition and concentration grids were used as the primary indicator of pressures (The Norwegian Meteorological Institute, NILU 2019). Recently developed Irish specific modelling of ammonia concentrations and nitrogen sensitive lichen communities (Kelleghan et al., 2019) were also integrated into the risk assignment to sites shown in Figure 3-3. The Nitroindex is an indicative scale of how many nitrogen-tolerant (+1) or nitrogen sensitive (-1) lichen species are in an area. Rainfall was also compiled for each site, as Level I site selection required consideration of the level of rainfall thereon in order to ensure analysis of samples were statistically robust. Ozone was excluded from risk assignation as its impacts in Ireland are not currently considered substantial. This exclusion should be reviewed in future phases as more information comes to light, it may need to be reintegrated into the network in the future and the network is capable of adapting in the future to meet this requirement.

The risk values for identified risk parameters shown in Figure 3-3. **Identified risk parameters for risk assignation. A. Nitrogen deposition. B. Sulphur deposition. C. NH3 concentration. D. NH3 concentration (finer resolution model). E. Nitroindex (based on nitrogen sensitive lichens). F. Rainfall from Met Éireann (1981-2010).**

were applied to all sites for each habitat type using GIS, which were subsequently ranked from high to low impact in order of;

- EMEP 2018 Total Nitrogen Deposition (The Norwegian Meteorological Institute, 2019).
- EMEP 2018 Total Sulphur Deposition (The Norwegian Meteorological Institute, 2019).
- EMEP 2018 NH3 concentration (The Norwegian Meteorological Institute, 2019).
- MARSH risk (Kelleghan et al. 2019)
- Nitroindex risk (Kelleghan et al., 2019)

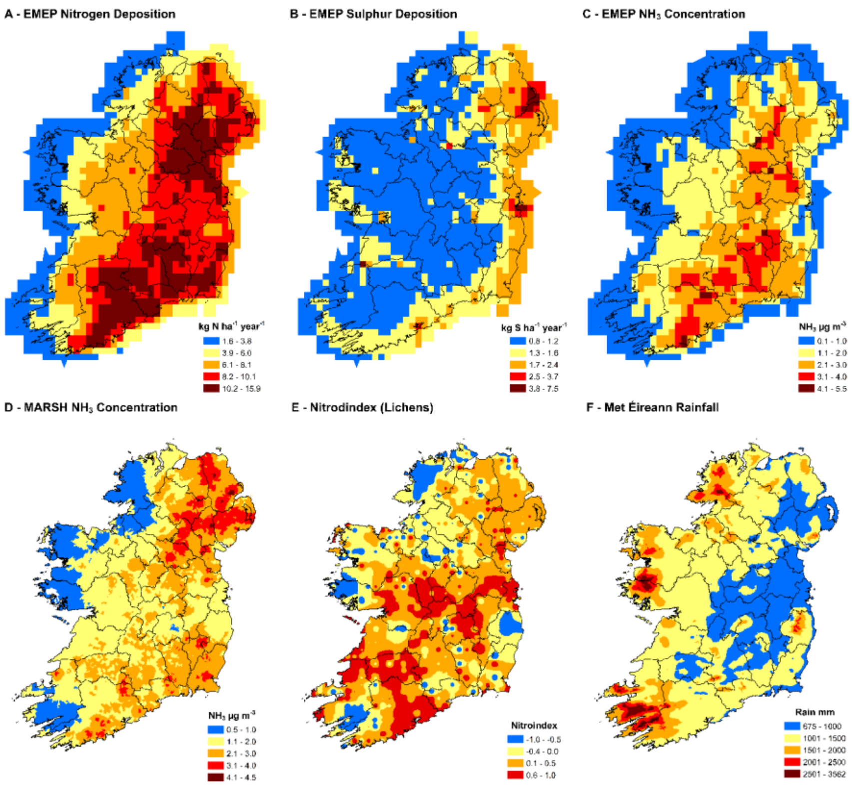


Figure 3-3. Identified risk parameters for risk assignation. A. Nitrogen deposition. B. Sulphur deposition. C. NH_3 concentration. D. NH_3 concentration (finer resolution model). E. Nitroindex (based on nitrogen sensitive lichens). F. Rainfall from Met Éireann (1981-2010).

Figure 3-4. below shows the total nitrogen deposition for sites containing selected habitats for potential inclusion within the NEMN. These are the sites presented in Figure 3-2, but with m applied risk from Figure 3-3.A. The colour coding presented is based on both the exceedance of critical loads (Bobbink and Hettelingh, 2011) or species community change points (where they have been calculated) for each specific habitat (Wilkins et al., 2016).

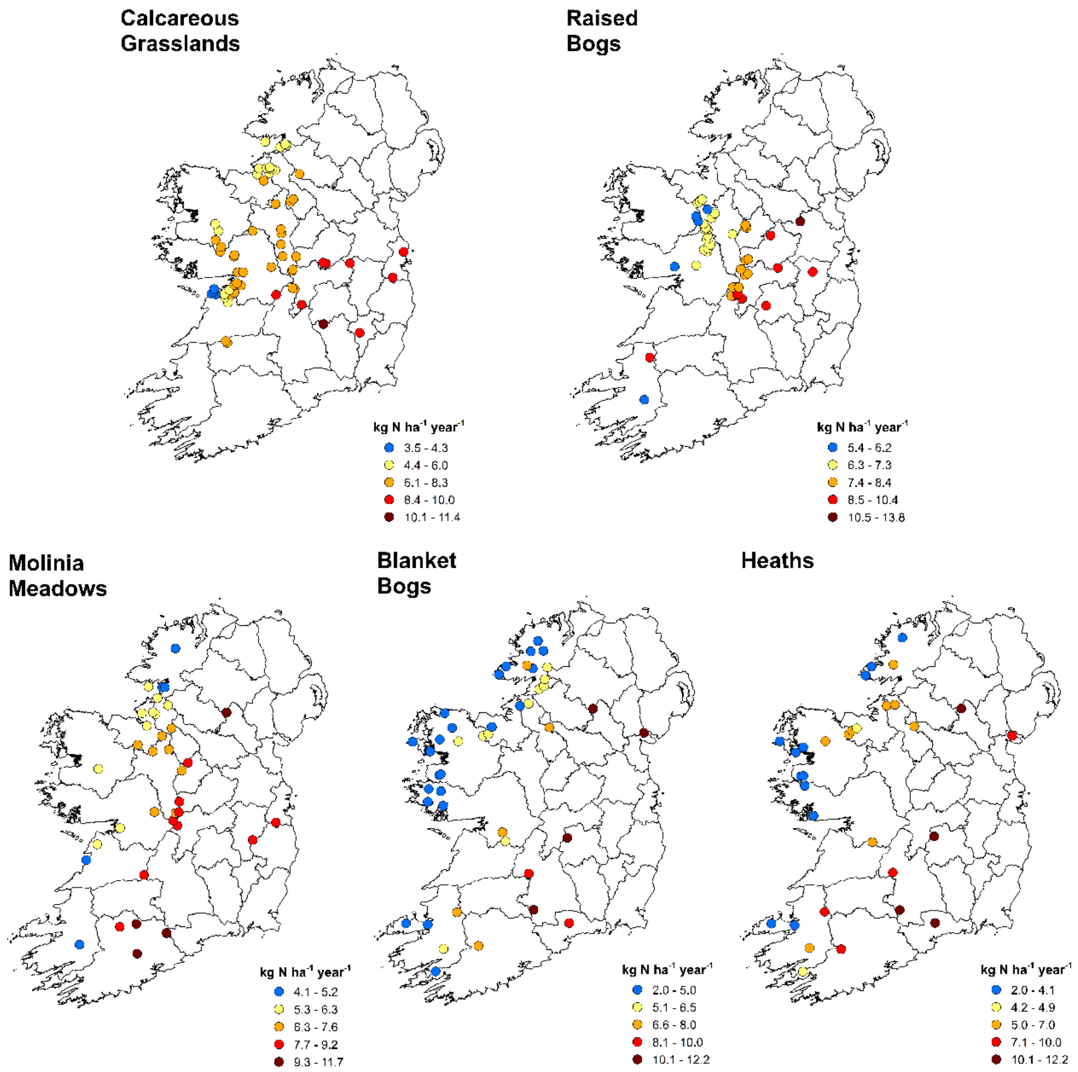


Figure 3-4. Figure 3-4. Nitrogen deposition on potential sites featuring priority habitats for inclusion within the NEMN.

3.5 Interpreting risk and other environmental gradients

A major influence on habitat sensitivity to N is *annual rainfall*, and selection of sites should aim to account for variation in rainfall where possible. This requires careful consideration because in Ireland the rainfall gradient is negatively correlated with N deposition rate – wet deposition of N tends to increase with rainfall, but high-rainfall areas in Ireland are generally in the cleaner West. Other co-varying factors could be considered, such as historic sulphur pollution, or past and current management. However, information to do so is mainly not readily available, and for sulphur at least the historic deposition of sulphur may not be as great an influence on acidification as it is in other countries such as UK. Many of these factors are also correlated with rainfall, so we consider that accounting for the interaction with rainfall will be sufficient, where this is possible, or appropriate for the habitat.

We propose to divide the N deposition and rainfall gradients into more-or less equal bands, and select sites within appropriate bands, to achieve balanced representation. The proposed approach to site selection is illustrated below for **four** habitat groupings:

For calcareous grasslands (Figure 3-5), the N deposition gradient is split into five classes, further filtered by rainfall band. For this habitat, since rainfall varies considerably across the gradient and is a potentially important co-varying factor, it is worth taking this into account, where possible, although this is not straightforward. Three sites will be selected within each N deposition category. We propose selecting sites primarily within the Medium rainfall band, but sampling from High or Low rainfall where necessary to achieve balanced representation. For example, in the N deposition band 5-6.5 kg N ha^{-1} yr^{-1}, one high (~1600 mm), one medium and one low-medium (~1000 mm) site might be selected to balance sites in adjacent N dep bands.

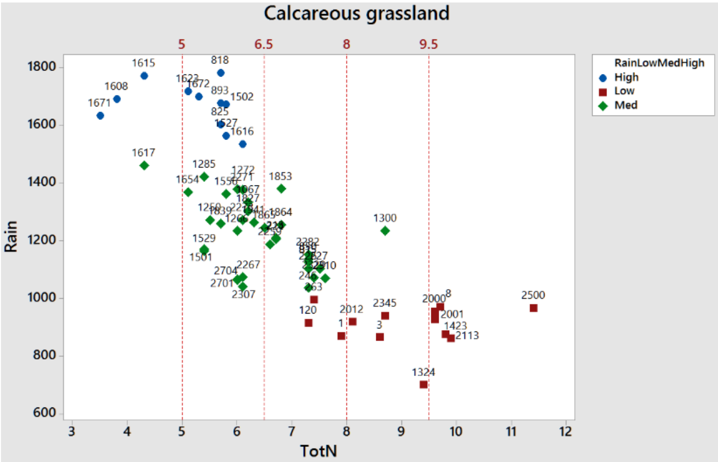


Figure 3-5. Potential approach to site selection for calcareous grasslands, showing additional filtering by rainfall band. N deposition is split into 5 bands, and symbols differentiate low (<1000 mm), medium and high (>1500 mm) rainfall sites.

Note the split of N deposition bands also takes into account representation across sites, and is not a simple split into equal width bands. Numbers next to points refer to specific sites within the GMS dataset. For raised bogs (Figure 3-6), rainfall co-varies along the gradient. We propose to select 3 sites within each N deposition band, avoiding the wettest site.

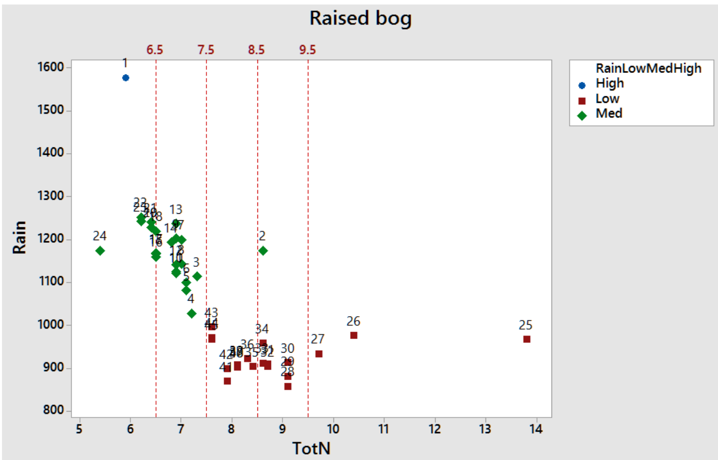


Figure 3-6. Potential approach to site selection for raised bogs. N deposition is split into 5 bands. Numbers next to points refer to specific sites within the bogs dataset.

For blanket bog and wet heaths (Figure 3-7), sites are evenly distributed along the rainfall gradient, such that this can be ignored in site selection. We propose that three sites are selected within each N deposition band.

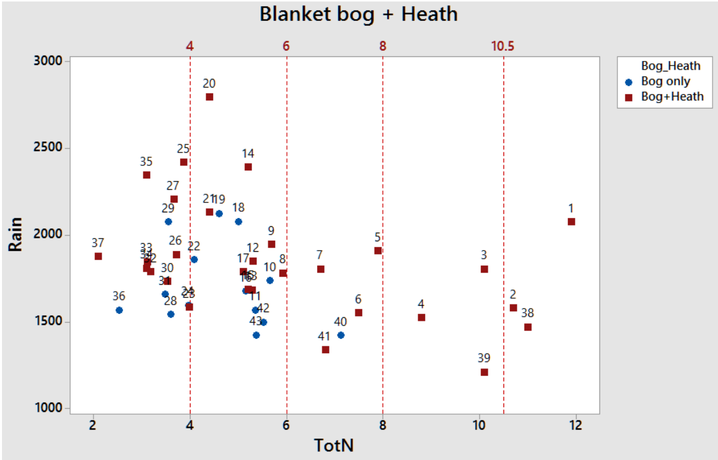


Figure 3-7. Potential approach to site selection for blanket bog and wet heaths. N deposition is split into 5 bands, Numbers next to points refer to specific sites within the blanket bog and wet heaths dataset.

For *Molinia* meadows (Figure 3-8.), sites are sufficiently distributed within the Medium rainfall category that three sites could be selected from each N deposition band, with the exception of band 7-8 kg N ha^{-1} yr^{-1}., or if selecting to encompass variation in rainfall as well, there are sufficient sites to ensure some sites with similar rainfall are selected from across the N deposition gradient.

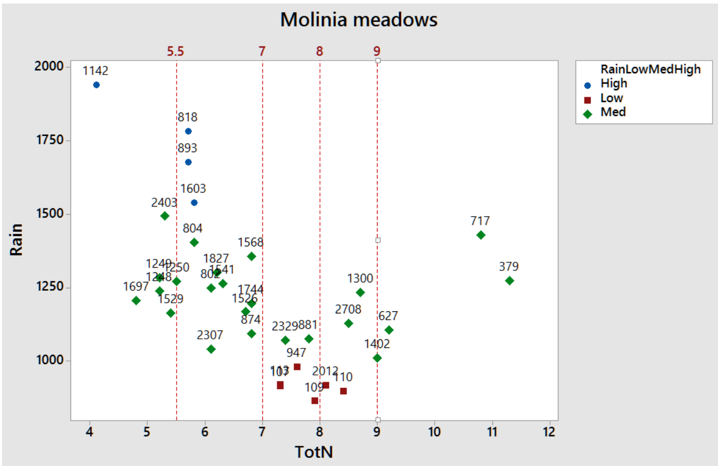


Figure 3-8. Potential approach to site selection for Molinia meadows. N deposition is split into 5 bands, Rainfall is split into High (>1500 mm), Med and Low (<1000 mm). Numbers next to points refer to specific sites within the GMS dataset.

3.6 Terrestrial Ecosystem Level I Site Selection

The NECD recommends a risk-based approach to site selection, including sites at high risk (i.e. with greater pollution pressure) and low risk. For ecosystems in Ireland, risk is mainly related to the nitrogen deposition gradient, but may also be affected by the type of nitrogen pollution, annual rainfall, previous exposure to acidifying pollutants, management, and other factors. To gain robust evidence for impacts on a given habitat, sufficient sites must be included to sample adequately the

N gradient, taking into account natural variability in the habitat, and other environmental factors. **We recommend monitoring 15 Level I sites for each habitat included in the NEMN.**

As indicated previously (Sect.3.5), this phase of the NEMN should focus on calcareous grasslands, Molinia meadows, raised bogs, blanket bogs and wet heaths as shown in Table 2-2. These habitats are, for the purposes of the NEMN equivalent to Annex I habitats below;

1. Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) important orchid sites (*6210)
2. *Molinia* meadows on calcareous, peaty, or clayey-silt-laden soils (*Molinion caeruleae*) (6410)
3. Active raised bogs* (7110)/Degraded raised bogs still capable of natural regeneration (7120)
4. Blanket bogs (*if active bog) (7130)
5. Northern Atlantic wet heaths with *Erica tetralix* (4010)

Due to the distinction between blanket and raised bogs, in terms of location, which NPWS survey they are included within, and species composition, they should be treated as separate and distinct habitat types. However, blanket bog monitoring typically overlaps with heath monitoring in the uplands within the same monitoring project. It is hence recommended that a set of sites is chosen to represent both blanket bog and wet heath. The survey of which will require additional relevés on site to cover both habitats but should be carried out during the same survey.

As the NEMN is an iterative process, it is likely that the identification and inclusion of Level I sites within this network is gradual and reliant on NPWS's monitoring calendar. Where upland surveys are due to begin in 2021, grasslands and raised bog surveys may not be commissioned again until 2022. NPWS aim to have all surveys carried out prior to 2025 Article 17 reporting. The NEMN-design team recommend a priority list below, based on both sensitivity of the habitat and the likelihood for impacts from air pollution. If during site selection When developing the network in practice, the NEMN-design team strongly recommend retaining at least 15 sites per habitat type and if the number of sites needs to be limited, they be limited based on the number of habitats not sites within each habitat.

The approach followed for site selection can be briefly described as follows:

Sites were split into 5 classes of N deposition, of more-or-less equal interval, as shown in the preceding section. Within each class, three sites were selected. Selection took into account the following factors: annual rainfall, existence of other routine or planned monitoring initiatives, size and access arrangements. Where possible, sites were stratified according to rainfall in order to account for co-variation in N deposition and rainfall in subsequent analysis. In practice this meant selecting some sites with similar rainfall across N deposition classes, and/or selecting sites with high, medium and low levels of rainfall within an N deposition class.

3.7 Terrestrial Ecosystem Level II Site Selection

Following identification as a potential Level I site, a number of suitable sites for inclusion within the Level II network were shortlisted. This selection process was based on both the risk of pressures and the positioning of sites across the country (avoiding clusters). The number of proposed Level II sites was based on their sensitivity to impacts and likelihood for impacts. Where six were chosen for raised bogs, four for calcareous grasslands, three for blanket bog / wet heath and two for *Molinia* meadows.

In order to best link air pollution impacts with observed ecological effects, at least 2 sites from each habitat type were selected at each end of the identified risk scale for inclusion as Level II core sites. The level of monitoring intensity is intended to vary between Level II and Level II core, where the most intensive monitoring will occur on Level II core sites. This design allows for the inclusion of less intensive NH_3 monitoring on a wider number of Level II sites, required due to high spatial variability of NH3. A number of shortlisted sites were visited in order to ascertain access and suitability for long term monitoring, detailed in Appendix 3.

Opportunities to integrate ICOS, EMEP and Teagasc Agricultural Catchment Programme monitoring into the Level II network should be exploited. Though these monitoring programmes typically do not occur on habitats of interest to the NEMN, the monitoring conducted is relevant. Carbon flux monitoring for example, will only be carried out on ICOS sites, and both existing monitoring within the EMEP network and proposed by Teagasc are intended to act as long-term sites. Integrating these locations into the NEMN will increase the resolution of monitoring improving validation of national models. Whether these sites could be categorised as Level II core, remains to be seen; however they could easily function at the very least as additional NH_3 monitoring sites within the broader Level II network.

3.8 Proposed Terrestrial Ecosystem Sites

Following site visits, the proposed network for this phase of the NEMN could be established (though further surveys may be required). The NEMN consists as previously described of three tiers of monitoring intensity. Where for new semi-natural habitats, all Level II sites are contained within the Level I network, and all Level II core sites are contained within the Level II network. The selected sites are based on the approach described previously, and are listed in Table 3-1, 3-2 and 3-3. Their locations are shown in Figure 3-9.

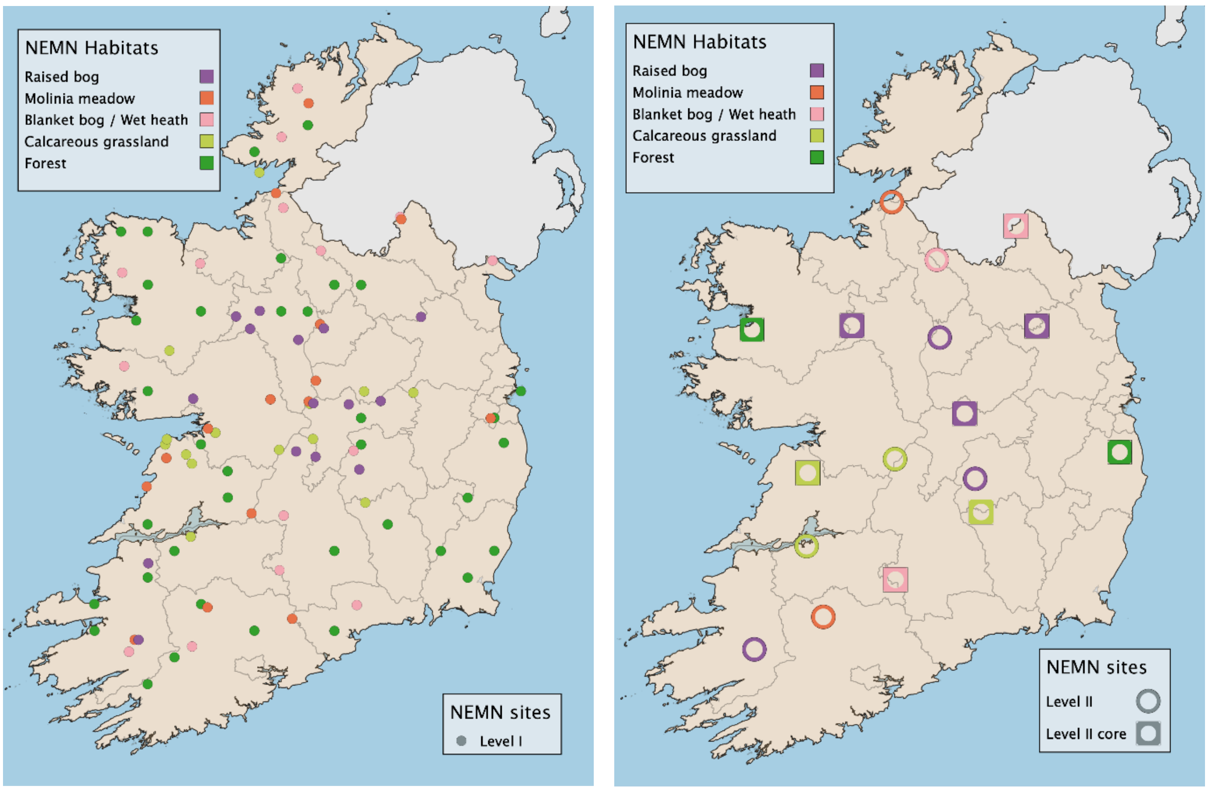


Figure 3-9. Locations of proposed and existing networks of terrestrial sites: left, Level I; right, Level II plus Level II core NEMN sites.

Table 3-1. Proposed forest ecosystem sites for this phase of the NEMN.

Habitat Type	Site	Level I	Level II	Level II Core	Status
Forest	Roundwood			Yes	Extant – no current monitoring
	Brackloon			Yes	
	CO. KERRY (Site Code 549)	Yes			Currently being monitored
	CO. KERRY (Site Code 555)	Yes			
	CO. MAYO (Site Code 1339)	Yes			
	CO. CORK (Site Code 2201)	Yes			
	CO. KERRY (Site Code 2233)	Yes			
	CO. CLARE (Site Code 2248)	Yes			
	CO. GALWAY (Site Code 2271)	Yes			
	CO. MAYO (Site Code 2303)	Yes			
	CO. MAYO (Site Code 2319)	Yes			
	CO. CORK (Site Code 3364)	Yes			
	CO. LIMERICK (Site Code 3396)	Yes			
	CO. CORK (Site Code 4502)	Yes			
	CO. GALWAY (Site Code 4546)	Yes			
	CO. MAYO (Site Code 4581)	Yes			
	CO. CLARE (Site Code 5716)	Yes			
	CO. CLARE (Site Code 5724)	Yes			
	CO. CORK (Site Code 6918)	Yes			
	CO. DONEGAL (Site Code 7049)	Yes			
	CO. ROSCOMMON (Site Code 8330)	Yes			
	CO. SLIGO (Site Code 8346)	Yes			
	CO. ROSCOMMON (Site Code 9775)	Yes			
	CO. DONEGAL (Site Code 9820)	Yes			
	CO. WATERFORD (Site Code 11000)	Yes			
	CO. TIPPERARY (Site Code 11024)	Yes			
	CO. LEITRIM (Site Code 11104)	Yes			
	CO. LAOIS (Site Code 12217)	Yes			
	CO. OFFALY (Site Code 12225)	Yes			
	CO. CAVAN (Site Code 12265)	Yes			
	CO. KILKENNY (Site Code 13238)	Yes			
	CO. WEXFORD (Site Code 15221)	Yes			
	CO. WEXFORD (Site Code 16070)	Yes			
	CO. CARLOW (Site Code 16094)	Yes			
	CO. WEXFORD (Site Code 16886)	Yes			
	CO. DUBLIN (Site Code 16926)	Yes			
	CO. DUBLIN (Site Code 17401)	Yes			

Table 3-2. Proposed freshwater ecosystem sites for this phase of the NEMN.

Habitat Type	Site	Level I	Level II	Level II Core	Status
Acid Sensitive Lake	Maumwee, Galway		Yes	Yes	Ongoing as Level II Freshwater – recommend including Level II core monitoring
	Upper Lake, Glendalough, Wicklow		Yes	Yes	
	Lough Veagh, Donegal		Yes	Yes	
	Upper Lake, Kerry		Yes	Yes	
	Lough Ankeeran	Yes			30-year historic monitoring – Requires link with NEMN to ensure future monitoring
	Lough Nabrackboy	Yes			
	Lough Strand	Yes			
	Derrynananta Lough	Yes			
	Lough Adanacleveen	Yes			
	Knocknahillian-Maumahogue	Yes			
	Lough Bray Upper	Yes			
	Cleevaun Lough	Yes			
	Lough Tay	Yes			
	Three Lakes (larger of 2)	Yes			
	Loch an Choimin (Lough Acummeen)	Yes			
	Lough Coumfea	Yes			
	Sgilloge	Yes			
	Lough Cummeenoughter	Yes			
	Lough Keal	Yes			
	Devils Punch Bowl	Yes			
	Lough Gal	Yes			
	Knochnagantee-Knockmoylents	Yes			
	near Lough Nambrackderg	Yes			
	Coomarkare Lake	Yes			
	Lake in Burrishoole Catchment	Yes			Currently receives monitoring from Marine Institute – Requires additional parameters to be monitored for inclusion within NEMN

Table 3-3. Proposed terrestrial ecosystem sites for this phase of the NEMN.

Habitat Type	Site	Level I	Level II	Level II Core	Status
Raised Bog	Bellanagare Bog	Yes			Previously monitored by NPWS during national surveys Require designation as permanent sites to be revisited Updated monitoring approaches Level II & Level II core sites not yet set up
	Brown Bog	Yes	Yes		
	Clara Bog	Yes	Yes	Yes	
	Corbo Bog	Yes			
	Corliskea/Trien/Cloonfelliv Bog	Yes			
	Kilcarren-Firville Bog	Yes			
	Killyconny Bog (Cloghbally)	Yes	Yes	Yes	
	Knockacoller Bog	Yes	Yes		
	Lough Corrib	Yes			
	Moanveanlagh Bog	Yes			
	Mongan Bog	Yes			
	Raheenmore Bog	Yes			
	Sharavogue Bog	Yes			
	Sheheree (Ardagh) Bog	Yes	Yes		
	Carrowbehy/Caher	Yes	Yes	Yes	
Calcareous Grassland	Ardrahan Grassland	Yes			
	Barrigone	Yes	Yes		
	Black Head-Poulsallagh Complex	Yes			
	Cullahill Mountain	Yes	Yes	Yes	
	East Burren Complex	Yes	Yes	Yes	
	Glenasmole Valley	Yes			
	Carrick Hil	Yes			
	Lissanisky	Yes			
	Ballyelly	Yes			
	Lough Derg, North-East Shore	Yes	Yes		
	Moneen Mountain	Yes			
	Mongan Bog & Pilgrim's Road Esker	Yes			
	Ridge Road, SW of Rapemills	Yes			
	Split Hills and Long Hill Esker	Yes			
	St. John's Point	Yes			
Wet Heaths / Blanket Bog	Arroo Mountain	Yes			
	Carlingford Mountain	Yes			
	Comeragh Mountains	Yes			
	Croaghonagh Bog	Yes			
	Cuilcagh - Anierin Uplands	Yes	Yes		
	Killarney National Park	Yes			
	Maumturk Mountains	Yes			
	Moanour Mountain	Yes	Yes	Yes	
	Mullaghanish to Musheramore Mountains	Yes			
	Owenduff/Nephin Complex	Yes			
	Rosroe Bog	Yes			
	Slieve Beagh	Yes	Yes	Yes	
	Slieve Bloom	Yes			
	Slievefelim to Silvermines	Yes			
	Sonnagh Bog	Yes			
Molinia Meadow	Ballyteige (Clare)	Yes			
	Blackwater River (Cork/Waterford)	Yes	Yes		
	Cloonakillina Lough	Yes			
	Glenasmole Valley	Yes			
	Ardachrin	Yes			
	Cream Point	Yes			
	Killure More	Yes			
	Dunlavin Marshes	Yes			
	Slieve Beagh SPA	Yes			
	Killarney National Park	Yes			
	Lough Fingall Complex	Yes			
	Lough Forbes Complex	Yes			
	Lough Melvin	Yes	Yes		
	Lough Ree	Yes			
	River Shannon Callows SAC	Yes			

3.9 Building synergies to deliver cost-effectiveness

NECD guidance suggests building on existing monitoring networks in Ireland (such as NPWS and LIFE-funded monitoring), by establishing NEMN sites as a subset of these networks. However, the NEMN will involve some additional monitoring costs, for example for air quality monitoring (Section 5), or to align floristic methods across the network (Sect. 4). These costs will have to be taken into account in designing the network.

Costs are mainly multiplicative (measurements costs * frequency * *n* habitats * *n* sites). The final design will be agreed after consideration of costs and benefits, and implementation of the network may have to be gradual. It is important to adequately sample each habitat included, so it is more effective to reduce costs by delaying the inclusion of entire habitats, rather than by reducing the set of measurements, or the number of sites per habitat included. Essentially, **15 is the minimum number of sites which can be used to interpret air pollution impacts for a habitat**. As such, it is recommended that if cost limits the extent of such a network, limits are placed on the number of habitats not the number of sites within that habitat type.

Site visits to maintain the proposed Level II network are a significant source of potential costs, linking with other networks and bodies with site operators (e.g. Figure 3.10) will reduce potential costs. Though monitoring networks listed in Figure 3.10. are not carried out on habitats of interest to the NEMN, both the monitoring conducted at these sites and the availability of site operators makes them suitable for inclusion within the Level II network of sites. Increasing the resolution of monitoring, particularly for ammonia will benefit validation of national models produced by the EPA. These models can then in turn be applied with greater confidence to proposed Level I sites within the NEMN. Linking with bodies/networks described in Figure 3-10 would expand the Level II network by 18 sites, increasing the amount of monitoring conducted at some select sites.

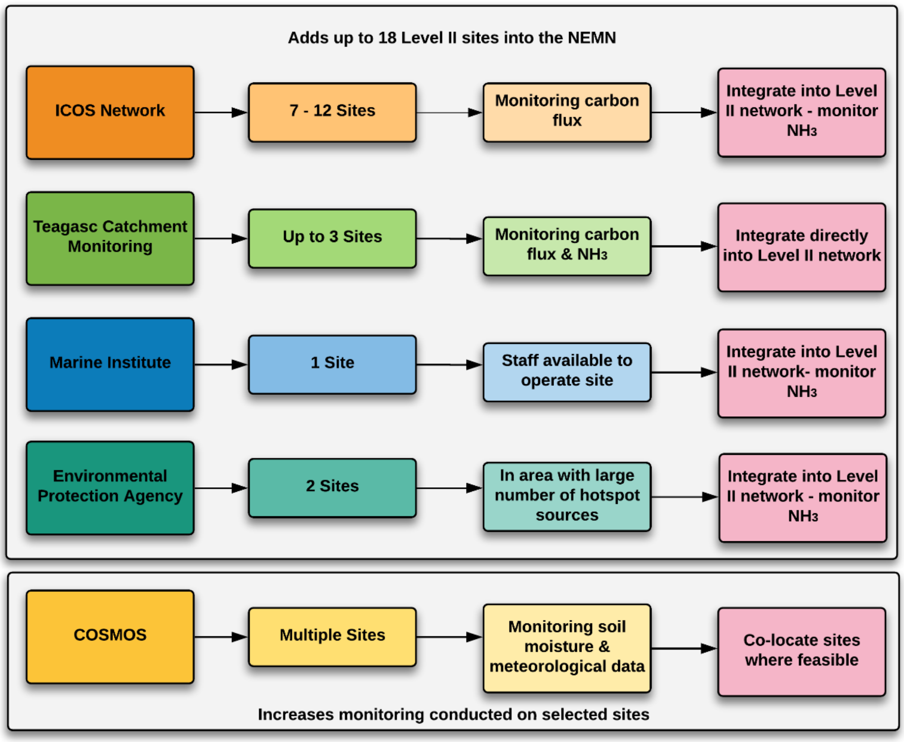


Figure 3-10. Synergies with other monitoring networks and bodies that should be sought for this phase of the NEMN.

ICOS monitoring will focus on carbon flux measurements from remote sites that will be regularly manned. Hence, passive monitoring of NH_3 at such sites would be relatively easy to integrate into existing monitoring due to the availability of local staff. Teagasc catchment monitoring has already a focus on NH_3 monitoring, alongside carbon flux, as such this data could be readily provided to the network. Though there may be potential delays due to permissions required. The Marine Institute similarly have a number of manned sites, including one which could be utilised as a Level II site. The COSMOS project aims to monitor soil moisture and meteorological data long term on some seminatural sites in Ireland, co-locating sites with those selected for inclusion within the NEMN would provide additional data from any sites included.

It is recommended that Kilroosky Lough Cluster SAC and Lough Oughter SAC be considered for inclusion as permanent Level II sites. This is due to the identification of critical level and load exceedance identified by assessments submitted to the EPA. These sites are proximal to a large number of hotspot sources in Cavan and Monaghan, alongside relatively dense cattle production. Though the qualifying features of these Natura 2000 sites are not priority for including within the NEMN, the potential risk from existing impacts highlighted warrants their inclusion as at least Level II NH_3 monitoring sites. Additionally, the EPA may be able to request additional NH_3 concentration monitoring as part of licenses granted. These sites monitored as part of licenses granted by the EPA could be potentially utilised as temporary Level II sites. This would provide additional valuable information at no additional cost to the network. While NPWS habitat monitoring should form the basis for Level I, and therefore Level II site selection for terrestrial ecosystems, synergies will be sought with any and all relevant networks. Enhancing the capabilities of the NEMN while keeping the network cost-effective requires the identification of potential partners for monitoring that may contribute directly to, or be allied or aligned to the NEMN. It is useful to include sites in existing monitoring networks, since the habitat is known, other information is likely to be available, for example meteorological data for calculating fluxes, and there is the potential to combine monitoring efforts. Inclusion or exclusion here should not be taken as indicative in any way. A summary of such networks identified by an extensive review of this project is listed in Table 3-4.

Table 3-4. Partners, networks, and synergies relevant to NEMN monitoring.

Partner	Network	Synergy	NEMN
NPWS	NATURA 2000 SACs, SPAs	Habitats Dir. Article 17 Reporting, Birds Dir. Article 12 Reporting, ICP Vegetation surveys, LIFE IP Project	Level I terrestrial
EPA	WFD waters	Water Framework Directive Article 15 Reporting, Water quality, biological indicators, ICP Waters	Level II lakes
DAFM Forest Service	NFI	Crown-condition survey ICP Forests	Level I forests
UCD	Level II sites	Deposition, soil solution ICP Forests	Level II forests
UCD	Level I sites	Soil solid chemistry BioSoil survey +	Level I forests
ICOS partners (TCD, NUIG, UCC, Teagasc)	ICOS Ireland	GHG, C-cycle ICOS RI	Level II terrestrial
Trent University	High-level lakes	Water quality, acid-sensitivity	Level I lakes
TU Dublin	Pollen & Fungal Spores	Colocation with NEMN	Level II terrestrial
Teagasc	Agricultural Catchments	Super-site instrumentation, air-quality monitoring, land use info.	Level II
Marine Institute	Burrishoole	Super-site instrumentation, water-quality, fish, long datasets	Level I lakes & II
Met Éireann	Met. stations	Atmospheric conditions	NEMN models
EPA	AAQ sites	CAFE monitoring Air quality, tropospheric ozone	NEMN models
COSMOS-IE	Agriculture	Soil moisture	NEMN models
LTER Ireland	Management	Lab, data hub, governance	NEMN services

4. Methods for monitoring impacts (Level I)

Air pollutants can negatively impact ecosystems by direct damage from exposure, and by accumulation in soil, vegetation and water. This accumulation can change the chemical balance of acidity and of nutrient availability, which in turn affects competition among plant species. Leaving aside the effects of greenhouse gases, air pollution impacts on ecosystems are mainly due to reactive nitrogen (N), ozone and sulphur. The eutrophying effect of N pollution is of particular concern for semi-natural habitats, which can become over-productive, resulting in increased ground-level shade and loss of sensitive species. Different types of deposited N (reduced vs. oxidised, and wet-deposited vs. dry-deposited) may have differential effects, and exposure to ammonia gas has clear damaging effects, particularly on epiphytic communities of lichens and bryophytes.

Acidification, due to both deposition of N and ongoing S pollution, remains a driver of biodiversity loss. Ozone damage to crop plants (including reductions in yield) is increasingly recognised as significant, and more evidence is needed regarding ozone effects on semi-natural ecosystems. The estimation of atmospheric nitrogen inputs (wet and dry deposition) is necessary to quantify both net nitrogen budgets and ecosystem responses to nitrogen (e.g. ecosystem biodiversity, net carbon exchange or net ecosystem productivity). Carbon flux measurements at Integrated Carbon Observation System (ICOS) sites with atmospheric nitrogen measurements, coupled to inferential deposition models, would permit interpretation of CO_2 fluxes and ecosystem responses in relation to atmospheric nitrogen inputs. Carbon flux monitoring is an optional indicator for inclusion within the reporting template, and does not need to be carried out on every site.

Methods for monitoring the impacts of air pollutants, such as chemical or biological measurements on soil, vegetation or freshwater, are reviewed in the following section. This will provide the evidence needed to determine the state of, and predict changes in, terrestrial and freshwaters ecosystems due to the impacts of air pollution, in particular by nitrogen (especially ammonia), ozone and sulphur. These changes include eutrophication, acidification, ozone damage and biodiversity loss.

4.1 Monitoring frequency for impacts measurements

The NECD reporting cycle is every four years, with results next due to be reported in 2023. To detect air pollution impacts, data on floristic composition and "slow" environmental variables such as soil pH or plant tissue N content are often most useful, since these metrics integrate change over time. It is not necessary to monitor or measure these every year, and we recommend that each plot in **the Level I network is monitored once every four years**. Since the Habitats Directive (HD) reporting cycle is every six years, this implies that an increase in monitoring frequency on HD sites may be required to link with NEMN requirements.

4.2 Forests

Surveys currently underway at ICP Forests Level I plots are an annual assessment of crown condition consisting of an estimate of defoliation, and exhaustive recording of damage parameters. Datasets are submitted as csv-format files, with strict and exhaustive data formats listed in the ICP Forests Online Documentation. For each network level, a "System Instalment" file is submitted at establishment, and when plot details change. For each survey within Level I or Level II, the submission may consist of a plot-level file, one or more survey files, and a quality metadata file. In the case of the Level I survey submitted for 2020, two files are in the database, a Crown Condition Parameters file and a Damage Parameters file.

More than 5,000 ICP Forests Level I plots were monitored in two forest soil surveys across Europe. The first took place between 1986 and 1996 and the second between 2004 and 2008 under the Forest Focus Regulation (EC No. 2152/2003). A third transnational soil survey is expected in coming years, and would be the ideal time to undertake this work at Level I plots. Note that the selection of plots has changed with time due to forest rotation turnover, and redefinition of the plot selection method, now aligned with NFI. In all cases the selection is representative of Ireland, but the robustness and suitability for long-term monitoring has increased.

Table 4-1 summarises ICP Forests plots in Ireland, including Roundwood and Brackloon NEMN Level II core candidates. Additional Level II sites among these surveys are at Ballinastoe (a replacement for Roundwood during 2002–2012), Cloosh, Dooary, and Ballyhooly**.** Where submission gaps are mentioned, more years are available than are in the ICP Forests database.

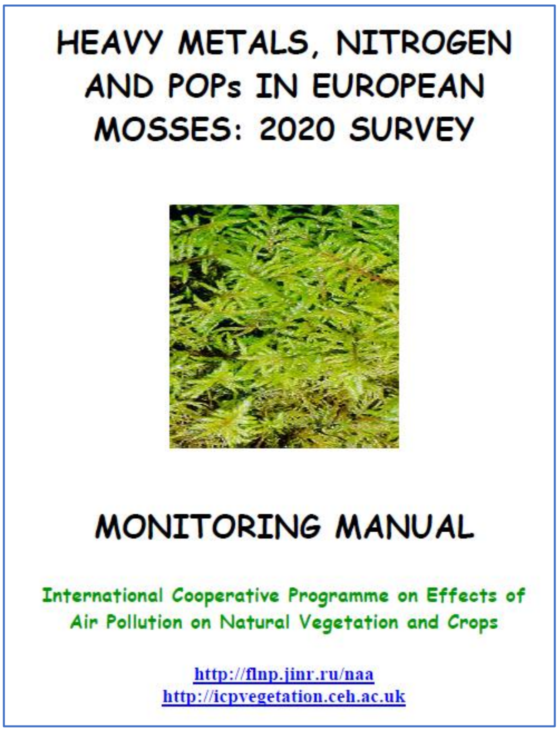
Table 4-1 Surveys at ICP Forests plots in Ireland.

Survey	Frequency	Survey data for Ireland	ICP Forests plots
Level I			
Crown condition	annually	1987–2012 2019–2020	c. 6000
Soil chemistry	every 10 years	1996, 2008 2 surveys	
Level II			
Crown condition	annually	1996–2003 2005–2010	797
Foliar chemistry	every 2 years	1996–2010 7 surveys	767
Soil chemistry	every 10 years	1996, 2008 2 surveys	738
Tree growth	every 5 years	1994–2010 6 surveys	769
Leaf area index		2009, 2010 2 surveys	
Ground vegetation	every 5 years	1997, 2010	723
Epiphytic lichens	test phase ongoing	Brackloon, once	90
Soil solution chemistry	continuously	1991–2017 (submission gaps)	254
Atmospheric deposition	Continuously	1990–2017 (submission gaps)	545
Ambient air quality	continuously	2009–2010	41
Meteorology	continuously	2010	209
Phenology	several times per year	2010	data validation ongoing
Litterfall	continuously	2009–2011 (submission gaps)	data validation ongoing

The ICP Forest Level I surveys are currently being carried out by a staff member within the Department of Agriculture Food and Marine. In line with recommendations made to the EC in relation to Ireland's NEMN, the NEMN-design team recommend carrying out two additional surveys which could be carried out by non-experts in the field. Namely, soil (for total N and C:N ratio analysis) and moss sample (for % N analysis) collection. Soils are intended to be sampled every 10 years, where sampling can potentially be carried out by non-experts. Analysis of samples will likely need to be sub-contracted to specialists.

Nitrogen deposition seems to have consistent effects on plant tissue N, in particular the N content of mosses, which are exposed mainly to atmospheric N. The N content in mosses is monitored every five years at some ICP Forests sites in Europe and reported to ICP Vegetation (ICP-Vegetation 2020), and NEMN data will make a useful addition. The ICP-Vegetation protocol recommends sampling one of a small set of species, chosen for being widespread and relatively easy to distinguish.

The NEMN-design team recommend sampling for tissue N (%) in specific moss species: *Hylocomium splendens* or *Pleurozium schreberi* in acidic habitats and *Pseudoscleropodium purum* in calcareous habitats. This would add significant benefit to ICP Forests Level I surveys, where the surveyor could collect samples and EPA could arrange for the analysis of tissue N.


HEAVY METALS, NITROGEN AND POPs IN EUROPEAN MOSSES: 2020 SURVEY

MONITORING MANUAL

International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

http://flnp.jinr.ru/naa
http://icpvegetation.ceh.ac.uk

Figure 4-1. ICP Vegetation manual cover.

4.3 Freshwaters

Monitoring data submitted for NEMN in 2019 included four lakes representing Ireland's contribution to ICP Waters, from existing monitoring under the Water Framework Directive. The following were submitted:

The variables submitted were: Country code, Site code national, Station, Area of water body, Water body type / Hydrological type, Elevation, Average depth, Catchment area upstream from site, Water temperature at sampling time, Alkalinity, Ntot, Ntot / Ptot, S (sulphates), NO_3-N, Cl, DOC, pH, Ca, Mg, Na, K, NH_4-N, Alinorg (labile), Specfic conductivity (25°C), Ptot, Acidification index, Eutrophication index, Species diversity, Species abundance, Acidification invertebrates.

It is recommended to continue this monitoring, as submitted in 2019 (noting information for average temperature, average precipitation, average catchment runoff, air temperature at sampling time, eutrophication index, acidification diatoms and acidification fish was not available) for the monitoring period to 2022/2023, to allow focus on establishing the new terrestrial monitoring. This should be reviewed for the subsequent reporting cycle.

An addition to freshwater ecosystem monitoring is the adoption of the upland lake survey operated by Trent University, which existing data for 1997, 2007 and 2017, plus a small set of lakes sampled annually. The NEMN design team recommend carrying out sampling of water chemistry in line with reporting requirements listed above once a every four years, for each site to be included. However, it is also recommended that consideration be given to resurvey of the full original selection for the fourth decadal cycle, during the next NEMN reporting cycle, centering on 2027.

The NEMN-design team also recommend the addition of passive ammonia monitoring on the four sites listed as Level II Freshwater sites. Their inclusion with this form of monitoring builds on the spatial representativeness of monitoring required.

4.4 Terrestrial Ecosystems

4.4.1 Measuring impacts of N and S on species composition and biodiversity

The occurrence of plant and lichen species within a fixed area ("relevé") is an extremely good indicator of environmental conditions at a site. The composition of plant communities and abundance of individual species is a good integrator of ecosystem impacts over time. Different components also tell a different story about impacts. For example mosses, liverworts and lichens are responsive to relatively short-term changes in deposition (3-5 years) while vascular plants tend to respond to changes on a longer time scale of decades. Data on floristic composition can be used to calculate mean values for traits indicative of air pollution impacts, such as mean "Ellenberg" score for productivity or acidity, and also related directly to biodiversity targets such as species-richness or abundance of positive indicator species. **We recommend repeated recording of presence and cover (visual estimation) for all vascular plant, bryophyte and lichen species within a set of relevés within each habitat at each site.**

Bryophytes and lichens have specific environmental requirements, and recording these to species level provides valuable information for bogs, heaths and grasslands.

A nested design (Figure 2-1) is preferable for floristic recording[*], since it ensures a systematic search of a wide area to ensure recording of less abundant species, and to sample sub-habitats such as hummocks and hollows. The latter is particularly important in coarse-grained habitats such as bogs, but can be useful in other habitats. Using the same relevé design for all habitats gives comparability and avoids subjectivity in deciding how coarse-grained a habitat or a site is. The procedure is to record the central 1 x 1 m plot first, and then only record extra species in each ring, moving out. In homogeneous habitats, surveying the outer rings is generally rapid.

In feedback on a draft of this report, this nested design was considered too time-consuming. We stand by this recommendation, but if costs preclude the use of a nested design, a 2 x 2 m relevé would also suitable for most habitats. Coarse-grained habitats could be sampled by increasing the number of 2 x 2 m relevés.

4.4.2 Spatial arrangement of Level 1 monitoring plots

To ensure adequate sampling of habitat variation within a site, we recommend monitoring **five replicate plots per habitat**. These must be sufficiently separated that they are not sampling the same vegetation patch, and that together they represent the range of variation within a site in terms of ecological condition of that habitat. Precise spacing of plots will depend on the size and variability of the site. The requirement to sample the whole site may not be practical for large sites, in which case plots should be located pragmatically, e.g. within 20 minutes walk of each other.

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[*] Cf. "X plots" as used in the UK Countryside Survey; see

http://www.countrysidesurvey.org.uk/sites/default/files/CS_UK_2007_TR2%20-%20Vegetation%20Plots%20Handbook.pdf

Existing NPWS condition assessment methods are often done on the basis of scoring four plots. Using five relevés per site (or for each habitat, if there is more than one at the site) allows calculation of constancy i.e. frequency of occurrence in five relevés. For NPWS condition scoring, four plots can be selected at random.

The use of **permanent plots** is important, since revisiting the exact same spot is important for assessing change. Vegetation can sometimes change radically over short time periods, for example with scrub or bracken invasion, or due to natural fluctuations in water-table depth in raised bogs. For this reason, it is hard to avoid subjectivity when mapping vegetation and positioning relevés. This is likely to lead to repositioning in similar vegetation, and underestimation of change. We recommend establishing permanent relevés that can be re-found, using a combination of aluminium or wooden markers, sketch-maps, location photos, and GPS. Marking and re-finding plots involves extra time and cost, but there are large benefits for detecting change.

Vegetation changes may result in a plot changing from one habitat to another. This requires a planned approach to maintaining or re-locating plots. It is important to maintain enough replication for the target habitat, so a new plot should be located within this habitat at the same site. Ideally, the original plot will also be maintained, so that such large changes are represented in the dataset, and because many habitat changes are reversible. Plots may also need to be relocated when markers are lost, access permission is not granted, or for other reasons. For individual plots, if markers are lost then the plot should be marked out again in the same location as closely as possible. Where a plot is irreparably damaged by some external factor (e.g. vehicle access), a new plot should be set up following the principles set out above. If access to a site is lost, then a replacement site should be found to maintain monitoring within that section of the pollution gradient.

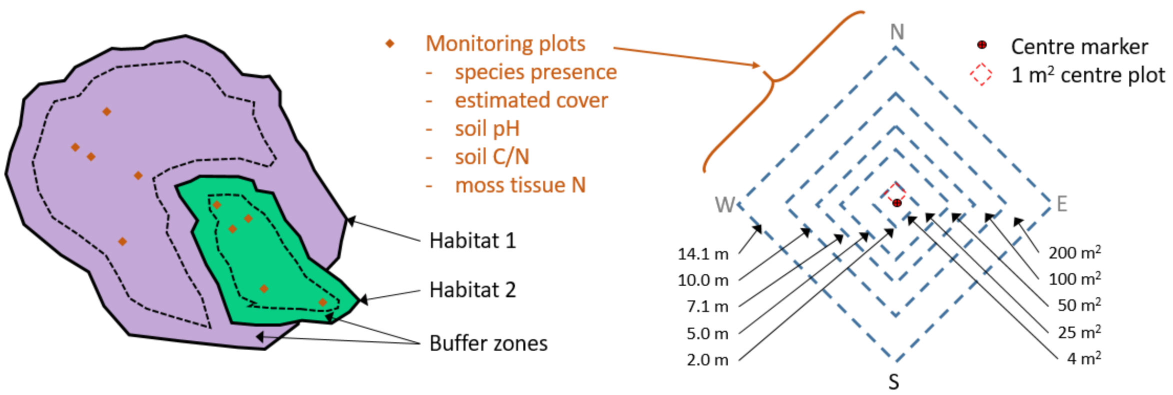


Figure 4-2: Layout of randomly-located plots within two habitats at a single site, showing sampling locations (floristic relevés and biogeochemical sampling) and land-management buffer zones.

Figure 4-3: Equipment needed for nested reléve and soil sampling.

4.4.3 Measuring biogeochemical impacts of N and S

Evidence of biogeochemical change is important to distinguish air pollution impacts from management change, climate change and other drivers. Soil properties are useful for determining likely responses to air pollution. Acidification and recovery can be assessed from soil pH, and N pollution can affect soil available N and total C/N ratio. Measurements of available N (e.g. KCl-extractable N) are subject to high levels of variability, so are not recommended for the initial phase of the NEMN. Soil total N is more useful as an indicator of longer-term trends, although it should be noted that soil C/N may increase as well as decrease with N pollution. Soil cation exchange capacity (which determines responses to acidification and recovery) is also worth measuring once per habitat per site, but is unlikely to change**.**

We recommend a repeated measurement (4 year cycle; one sample per habitat per site, composited from the five vegetation plots; 0-10 cm depth in the surface mineral layer) of soil organic matter content (%C), soil total C/N content, and soil pH (10 g soil in 25 mL deionised water)

The NEMN-design team also recommend sampling for tissue N (%) in specific moss species: *Hylocomium splendens* or *Pleurozium schreberi* in acidic habitats and *Pseudoscleropodium purum* in calcareous habitats for terrestrial ecosystem sites.

4.4.4 Recording site management

Other factors may affect ecosystem responses to air pollution, in particular site management. We recommend that at each site visit (every 4 years) a condition assessment is made using Habitats

Directive Article 17 reporting codes for pressures and threats[*] at site level, and where distinct at habitat level within each site.

4.4.5 Assessing impacts of ozone

The effects on ozone-sensitive species include visible foliar damage, a reduction in growth, yield quality and quantity for crops, flower number and seed production, and enhanced vulnerability to abiotic stresses such as frost or drought, and biotic stresses such as pests and diseases. Ground level ozone results in physical damage and reduced growth of agricultural crops, forests and semi-natural vegetation.

The only visible damage in terrestrial ecosystems that can be attributed directly to ozone is foliar damage. Ozone-specific foliar damage develops in light-exposed foliage of ozone-sensitive species during days with high ground-level ozone concentrations, high insolation, and sufficient soil moisture to allow open stomata. Some ICP Forests sites in Europe monitor ozone leaf injury once a year, using a dedicated light-exposed sampling site (LESS) associated with a measuring device. Ozone foliar damage is not mandatory under the ICP forests manual for countries in Northern Europe. Determining ozone foliar injury in the field remains a challenge, even for experts, although there are some species that show distinctive symptoms. Assessing known ozone-sensitive species (including crops, trees and semi-natural vegetation) for ozone foliar damage is generally done by trained experts, especially after ozone episodes. Assessments are sometimes carried out as part of the ICP Vegetation biomonitoring, therefore, assessment guidelines and short lists of priority species (including crops, trees and semi-natural vegetation) are available, although these lists are to cover the majority of Europe so not all species are present in each country. UKCEH Bangor staff can do assessments and/or provide training to surveyors, while work under the EPA-funded project NEC Indicators (2019-CCRP-LS.3) will facilitate observations, modelling, and application of monitoring indicators. The current priority is to understand implications and mechanisms of ozone injury before considering additional potential indicators for ozone impacts. Monitoring of growth and C flux await integration of injury assessment with quantitative growth determination, and will probably follow development of such methods under crop evaluation systems. Similarly, impacts on flower numbers cannot currently be extrapolated from visible-leaf damage. A limited number of sites for visible injury will provide an indication of effects and help with understanding processes, which can support the wider critical level assessment for ozone. There is need to develop a QA protocol to apply across all ecosystem types, by adapting those which are already available in existing ICP Protocols. As potential damage caused by ozone is difficult to determine, a methodology has been agreed for calculating flux based critical levels for ozone sensitive species of crops, forest and grassland, but are not yet developed for other semi-natural habitat types.

It is recommended to continue with annual ozone impacts modelling and produce annual sets of maps for ozone critical level exceedance, based on ozone fluxes to vegetation, for woodlands and grasslands. This can use EMEP4UK model for ozone concentrations, scaled to canopy height and spatial data for Ireland. Due to the current lack of evidence for ozone impacts in Ireland, it is not recommended to include ozone monitoring in this phase of the network. Though it should be reconsidered in future phases of the NEMN.

[*] http://cdr.eionet.europa.eu/help/habitats_art17

5. Methods for monitoring air quality pollutants

5.1 Air quality parameters

"The air pollution impacts of interest for ecosystem monitoring are in the first instance those relating to the substances for which reduction commitments are set in Annex II to the NEC Directive (i.e. SO_2, NO_X, NMVOC, NH_3 and $PM_{2,5}$), that is: acidification, eutrophication, and ozone damage to vegetation growth and biodiversity. While the impacts of other pollutants (e.g. heavy metals) are also of concern, a stepwise approach is appropriate and it is proposed that the first phase of monitoring focus on these three impacts" (EC, 2019a).

Recommendations for parameters to be monitored and frequency of monitoring are also provided in the guidance document, "Commission Notice on ecosystem monitoring under Article 9 and Annex V of Directive (EU) 2016/22848" (EC, 2019a).

Key indicators of atmospheric concentrations of pollutants for eutrophication and acidification and ozone damage for reporting in the Article 9 reporting template are:

- (Worksheet (5) O_3-air quality-carbon flux): **NH_3, NO_x, SO_2** and **ozone** gas concentrations.
- Worksheet (4)Terrestrial ecosystem liquid): **NH_4^+, NO_3^-, SO_4^{2-}** concentrations and **pH** in precipitation, including the other parameters conductivity, Cl, P, Alkalinity, N_{tot}, DOC, Ca, Ng, Na, K that are also usually analysed on precipitation samples (EMEP manual).

Optional indicators for monitoring air pollution impacts referred to in Article 9 of the Directive are listed in Annex V of the NECD. These are:

- Exceedance of critical levels and loads of acidification and eutrophication, policy tools that are widely adopted to assess the risk of change to ecosystems resulting from air pollution impacts.
- Ozone foliar damage to vegetation (forest and other woodlands, non-woody species).
- Exceedance of flux-based critical levels (e.g. PODy, AOT40).
- Carbon flux data, which would help to better understand C sequestration by ecosystems under pollution load, which is also important for climate change mitigation.

Under the amended NEC Directive (2016/228), Ireland is committed to further emissions reduction for the five key pollutants, relative to the emissions in 2005, for the years 2020 to 2029 (EPA, 2020). Greater reduction commitments will take effect as from 2030 (Figure 5-1).

5.2 Sulphur and Nitrogen

Sulphur emissions in Ireland have fallen to very low level, to below target thresholds (Figure 5-1) (EPA, 2020), although acidity critical load exceedance continues to be widespread, largely due to nitrogen deposition (EMEP, 2019). A smaller decrease in NO_x emissions (38%) was achieved since 1990 than with SO_2 (93%) (EPA, 2020). By contrast, NH_3 emissions have increased by 8.7 % since 1990, exceeding its ceiling over three consecutive years (2016, 2017 and 2018) (EPA, 2020). Projected emissions also predicts little change in NH_3 compared with NO_x. Together, NH_3 from agriculture and NO_x from vehicular sources are increasingly contributing to a larger fraction of the acidity load. Since NH_3 and NO_x are also two of the main sources of nitrogen pollution, indications are that NH_3 will be the most important acidifying and eutrophying pollutant. The monitoring effort should therefore focus on nitrogen, and in particular on NH_3, to help inform on policy. It is also necessary to continue to track effects of soil and vegetation responses to the changing chemical climate, in order to fully understand the impact of potentially continuing acidifying and eutrophying effects.

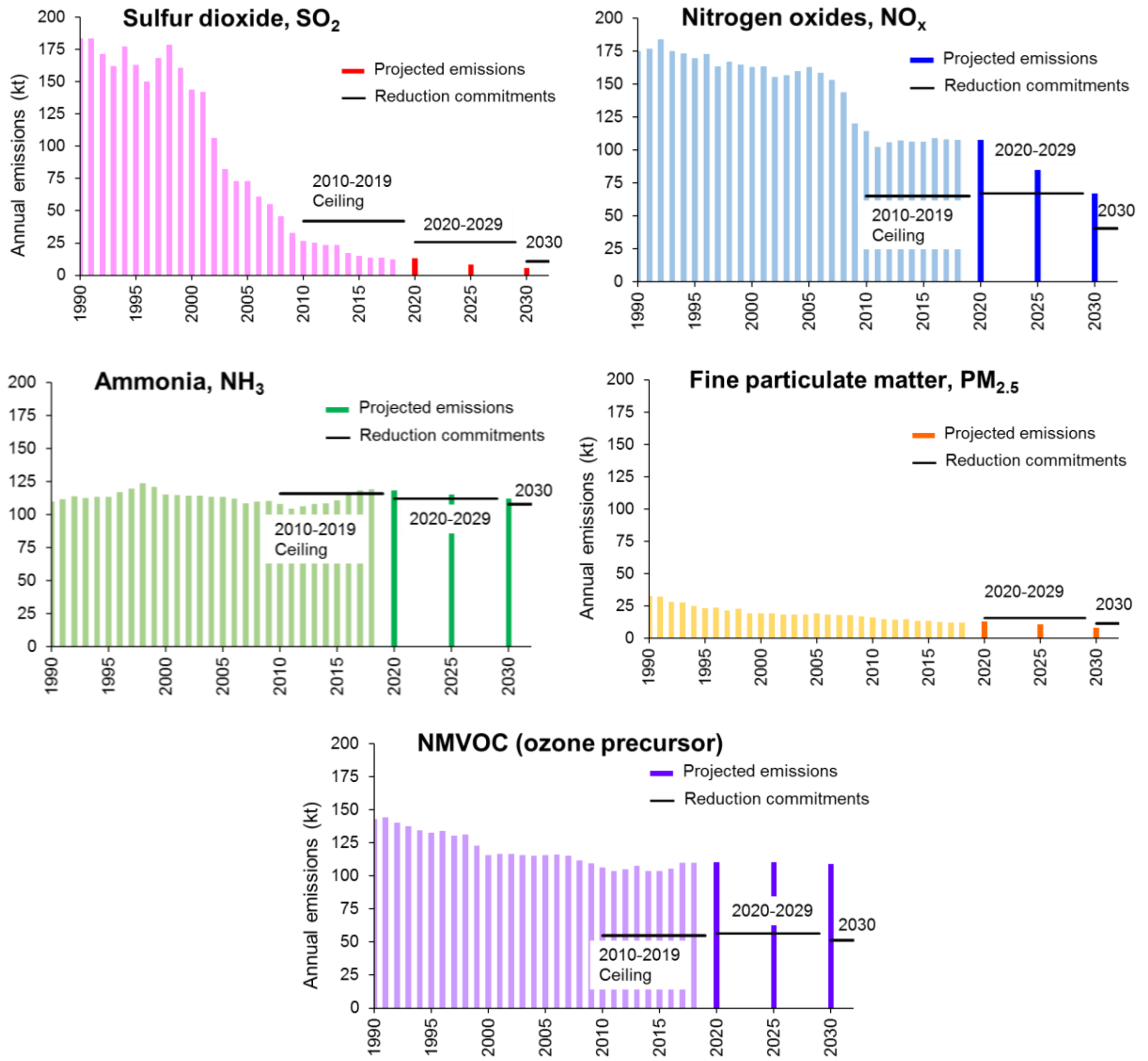


Figure 5-1. Trends, projected emissions and ceilings for target years in SO_2, NO_x, NH_3, $PM_{2.5}$ and non-methane volatile organic carbons, NMVOCs (1990 – 2030) in Ireland. (*Data source: Ireland's air pollutant emission 2018 (1990-2030), June 2020).*

5.3 Ozone

A long-term objective for the protection of vegetation from ground-level ozone is set under the Ambient Air Quality Directive to reduce the exposure of vegetation to 6 000 µg/m^3.hour or less. This long-term objective is in line with the critical level of ozone for the protection of crops defined by the UNECE CLRTAP (UNECE, 1979). In 2018, Ireland is among a small number of countries such as the UK, Portugal, Ireland and countries in Scandinavia and the Baltic states in meeting the long-term objective (ETC/ATNI, 2020). Ozone damage to crop plants is increasingly recognised as significant, and more evidence is needed regarding ozone effects on semi-natural ecosystems.

5.4 Air monitoring protocols

Article 9 (2) of the NEC Directive states that "*the methodologies laid down in the LRTAP Convention and its Manuals for the International Cooperative Programmes (ICP) may be used when collecting and reporting the information listed in Annex V*."

There is a broad interest in aligning with the existing ICPs under the UNECE Air Convention and especially for avoiding duplication of scientific work. Not all member states are participating in or using the ICPs manuals and the NECD does not oblige member states to apply the ICP protocols or methodologies. Furthermore, not all ecosystems that should be monitored under the NECD are covered by ICPs. Guidance from the commission for monitoring air pollutants under Article 9 recommends following air and chemistry protocols developed from existing international monitoring networks. This includes EU Directives reference methods, ICP protocols and EMEP monitoring manual, so that data reported across the EU can be compared. Where other protocols are adopted, details must be provided.

In this section we briefly review methods for measuring the pressure from pollutants, such as atmospheric concentration or deposition flux. A review of suitable methods is summarised in

Table **5-1. Summary table of air quality measurement methods and models for air quality parameters recommended for Article 9 monitoring and reporting.**.

Table 5-1. Summary table of air quality measurement methods and models for air quality parameters recommended for Article 9 monitoring and reporting.

Parameters	Methods: low time-resolution suitable for remote sites	Methods: high time-resolution, requires investment in infrastructure	Models
Gas: NH_3	Passive diffusion samplers: e.g. UKCEH ALPHA® (Level II sites) Active diffusion denuder-filter pack method: e.g. UKCEH DELTA® (Level II core sites)	Daily annular denuder systems: e.g. EMEP Level II monitoring (EMEP, 2016). Spectroscopic: e.g. Differential Optical Absorption Spectrometry (DOAS) (Berkhout et al, 2017) Quantum Cascade laser-based ammonia sensor (QCL) (Miller et al, 2014) Cavity Ring-Down Spectroscopy (CRDS) (Bobrutzki et al, 2010) Continuous wet chemistry – MARGA (hourly data) Provides supplementary data, where available and for calibration, where co-located with NH_3 passive samplers (note: there are no published reference methods (BS, or EU) for NH_3 (Martin et al., 2019))	EMEP4IE (www.EMEP4UK.ceh.ac.uk) EMEP MSC-W chemical transport model (e.g. Simpson et al. 2012) FRAME (www.pollutantdeposition.ceh.ac.uk/frame) And also JNCC N Futures work (for 2017), using MapEire emission data MARSH (Kelleghan et al., 2020)
Gas: NO_x	Passive samplers, e.g. Palmes-type diffusion tubes (Level II core sites)	EU reference method: BS EN14211: 2005 (NO_x) chemiluminescence analyser Provides supplementary data, where available and for calibration, where co-located with NO2 passive samplers	EMEP4IE EMEP MSC-W FRAME

Parameters	Methods: low time-resolution suitable for remote sites	Methods: high time-resolution, requires investment in infrastructure	Models
Gas: SO_2	Passive samplers: Not recommended – large uncertainty. Active diffusion denuder-filter pack method: e.g. UKCEH DELTA® (Level II core sites)	EU reference method: BS EN14212: 2005 (SO_2) UV-Fluorescence monitors Continuous wet chemistry – MARGA (hourly data) Provides supplementary data, where available and for calibration, where co-located with NO2 passive samplers	EMEP4IE EMEP MSC-W FRAME
Gas: O_3	Passive samplers, e.g. Ogawa (but data resolution not sufficient to determine PODy, which requires continuous monitoring)	EU reference method: BS EN14625: 2005 (O_3) UV absorption	EMEP4IE EMEP MSC-W FRAME
Wet deposition: SO_4^{2-}, NH_4^+ NO_3^-	Bulk precipitation collector (Level II core sites)	Daily Wet-Only Collectors (DWOC) Provides supplementary data, where available	CBED, EMEP MSC-W EMEP4IE FRAME
Dry deposition	Inferential modelling of dry deposition from measurement data All sites	COTAG (COnditional Time-Averaged Gradient system) Gradient flux method (resource intensive: suited to short-term campaigns) (Famulari et al. 2010)	CBED, EMEP MSC-W EMEP4IE FRAME

The following recommendations are laid out in the ICP Forests manual (UNECE ICP Forests Programme Co-ordinating Centre, 2016):

- Passive sampling can be used to achieve low-cost measurements at remote sites,
- Passive samplers should be combined with real time measurements for validation purposes,
- Individual countries are free in their choice of passive samplers, as long as criteria for quality assurance are met,
- All samples, or at least all samplers measuring the same variable, are analysed at the same laboratory per country,
- The laboratory should use and document well-defined sample handling and analytical procedures, according to either national and/or European standards for good laboratory practices (e.g. EN 13528 part 3).
- To participate in intercomparison tests of different types of passive samplers.
- Reference methods as described in Directive 2008/50 CE of the European Parliament and Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe and European Normative standards,
- Instruments run at an EMEP site in accordance to the EMEP Manual (EMEP/CCC/Report 1/15,NILU, Norway).

The ICP Forests manual Part XV on Monitoring of Air Quality (version 05/2016) states that ambient air quality at one site can be estimated by modelling or by interpolation of monitoring data from a nearby site. With the exception of ozone, the minimum sampling frequency is 4 weeks or monthly and should cover all 12 months of the year.

Table 5-2. Upper and Lower plausibility limits for passive monitoring of air quality

Pollutant (units)	Lower limit	Upper limit
O_3 (µg m^{-3})	5	100
NH_3 (µg m^{-3})	0.2	40
NO_2 (µg m^{-3})	0.2	30
SO_2 (µg m^{-3})	0.2	40

ICP Forests recommends the following data checks on passive samplers, summarised in and Table 5-3. Data completeness and measurement period and Table 5-3. below:

Table 5-3. Data completeness and measurement period.

Pollutant	Data completeness for measurement period
O_3	80% April - September
NH_3	80% whole year
NO_2	80% whole year
SO_2	80% whole year

Table 5-4. Data Quality Objectives (DQO).

Pollutant	Type of measurement	DQO
All pollutants	Field measurement	Data completeness ≥ 80%
All pollutants	Passive samplers co-located with active monitors	Data within ± 30% of reference value
All pollutants	Intercomparison for passive samplers	Data within ± 30% of reference value
All pollutants	Coefficient of variation among replicates	≤ 10%

5.5 Atmospheric concentrations of Ammonia, NH_3

The primary focus of ammonia measurements for Level II core monitoring is on robust methods for low-cost, long-term application, based on meeting the following criteria:

a) sampling frequency of 4 weeks or monthly,

b) detection limit of 0.2 µg m^{-3} for monthly monitoring (**Table 5-2**),

c) low-cost, low infrastructure requirement (e.g. no need for mains power),

d) cost efficiency by also providing simultaneous measurement of other acid gases (e.g. SO_2) and aerosol, where these are required.

Suitable methods include the UKCEH ALPHA® and DELTA® methods, detailed below:

ALPHA® passive sampler:

Of the different types of ammonia passive samplers that are available commercially (Figure 5-2), the ALPHA® method meets criteria a – c. It has a detection limit of 0.03 µg m^{-3} for monthly exposure and is included in European CEN standard for ammonia diffusive sampling, published this year (CEN standard, 2020). In an independent laboratory assessment, the ALPHA® sampler was also the best performing passive sampler across the range of concentrations tested (3 – 25 µg m^{-3}) (Martin et al., 2019). The ALPHA® is widely used, for example in the UK NAMN (Tang et al., 2018a) and has also been used to provide ammonia data for EMEP sites in Ireland since 2016. Quality procedures for the ALPHA samplers are described in detail in Tang & Sutton (2003), which includes deployment of replicated (triplicate) measurements to assess precision.

Field calibration of uptake rate: As part of quality assurance, the passive sampler method should be calibrated against an established active sampling reference method, to derive and apply a calibrated field uptake rate by the laboratory undertaking the measurements. Unlike the other gases such as NO_2 and SO_2 that are legislated under ambient air quality directives, there is no EU reference method for NH_3. The UKCEH DELTA® method is however a suitable reference method, described in the ammonia CEN standard (CEN, 2020). Co-location of ALPHA and DELTA methods at level II sites (minimum pf three sites covering range of anticipated concentrations) will provide the necessary ongoing calibration facility.

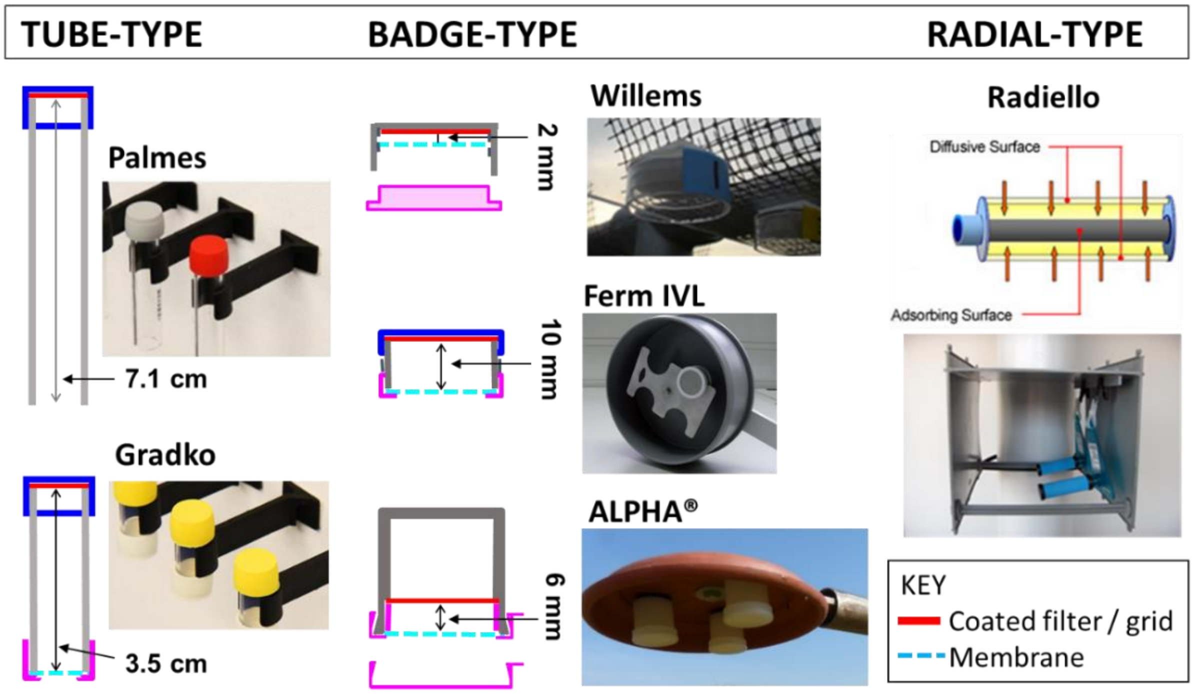


Figure 5-2: Types of passive diffusion samplers.

UKCEH DELTA® system:

This is an active diffusion denuder methodology that provides speciated measurements of both gases: NH_3, SO_2, HNO_3, (HCl) and aerosols (NH_4^+, SO_4^{2-}, NO_3^-, Cl^-, Na^+, Ca^{2+}, Mg^{2+}) (Figure 5-3). The method is currently used in the UK National Ammonia Monitoring Network (NAMN; Tang et al., 2018a) and also the UK Acid Gas and Aerosol Network (AGANet; Tang et al., 2018b). The method meets all 4 criteria, with a detection limit 0.02 and 0.06 µg m^{-3} for NH_3 and SO_2, respectively. In addition, it is used as a reference active method for the calibration of passive samplers (Tang et al., 2018; CEN standard, 2020).

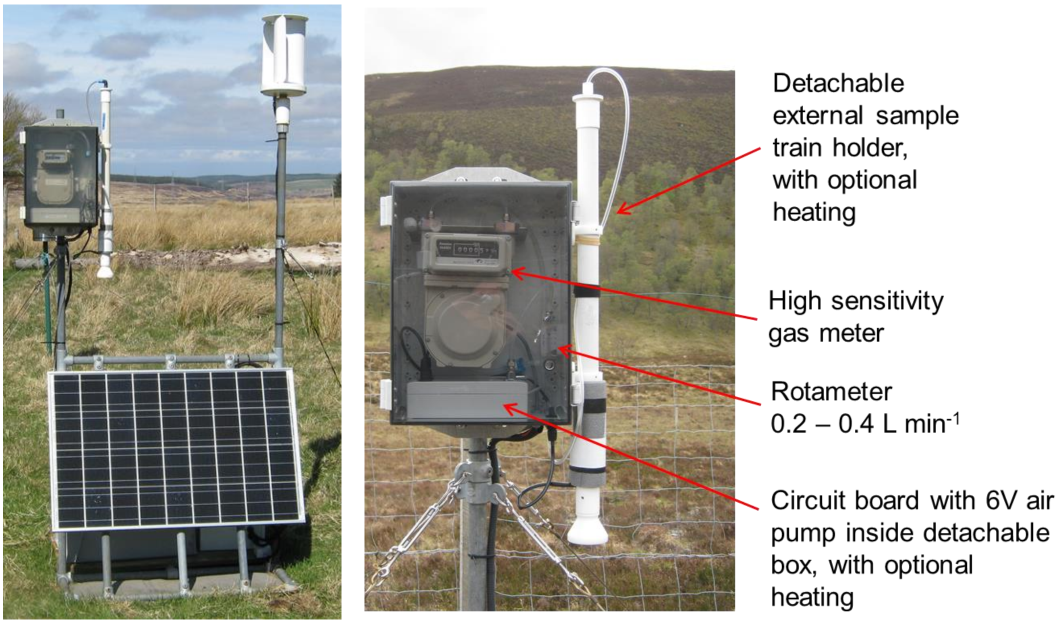


Figure 5-3. Left: wind-solar powered DELTA® system. Right: low voltage 6 volt DELTA® system. Denuder-filter pack sample trains are housed within the detachable external holder.

Using data collected from existing NH_3 measurements

Monthly ammonia measurements with UKCEH ALPHA® samplers have been carried out at a number of EMEP sites in Ireland for the EPA since 2016, summarised in Table 5-5. **Ammonia monitoring with ALPHA® samplers at EMEP sites in Ireland.**. Ammonia monitoring on these sites ceased in September 2020 and would need to be re-established.

Table 5-5. Ammonia monitoring with ALPHA® samplers at EMEP sites in Ireland.

Site ID	Site name	Active
EMEP 1	Carnsore Point	Yes, started Aug16
EMEP 2	Malin Head	Yes, started Aug16
EMEP 3	Mace Head Atmospheric Research Facility	Yes, started Aug16 (moved to less exposed location in Dec2019)
EMEP 4	Oak Park (Agriculture Research Station)	Yes, started Sep16
EMEP 5a	Monaghan Site	No: Aug16 to Jan17
EMEP 5b	Clones site	No: Feb17 to Jul18
EMEP 6	EPA Regional Inspectorate Monaghan	No, tbd

Table 5-6. Ammonia monitoring with DELTA ® samplers at EMEP sites in Ireland (Tang et al. 2020b). Acid gases (HNO_3, SO_2, HCl) and aerosols (NH_4^+, NO_3^-, SO_4^{2-}, Cl^-, Na^+, Ca^{2+}, Mg^{2+}) were also measured at the same locations (see Figure 5-4).

Site ID	Site name	Active
IE-Dri	Dripsey	No: 2006 – 2010 only
IE-Ca2	Carlow	No: 2006 – 2010 only
IE-Sol	Solohead	No: 2006 – 2010 only

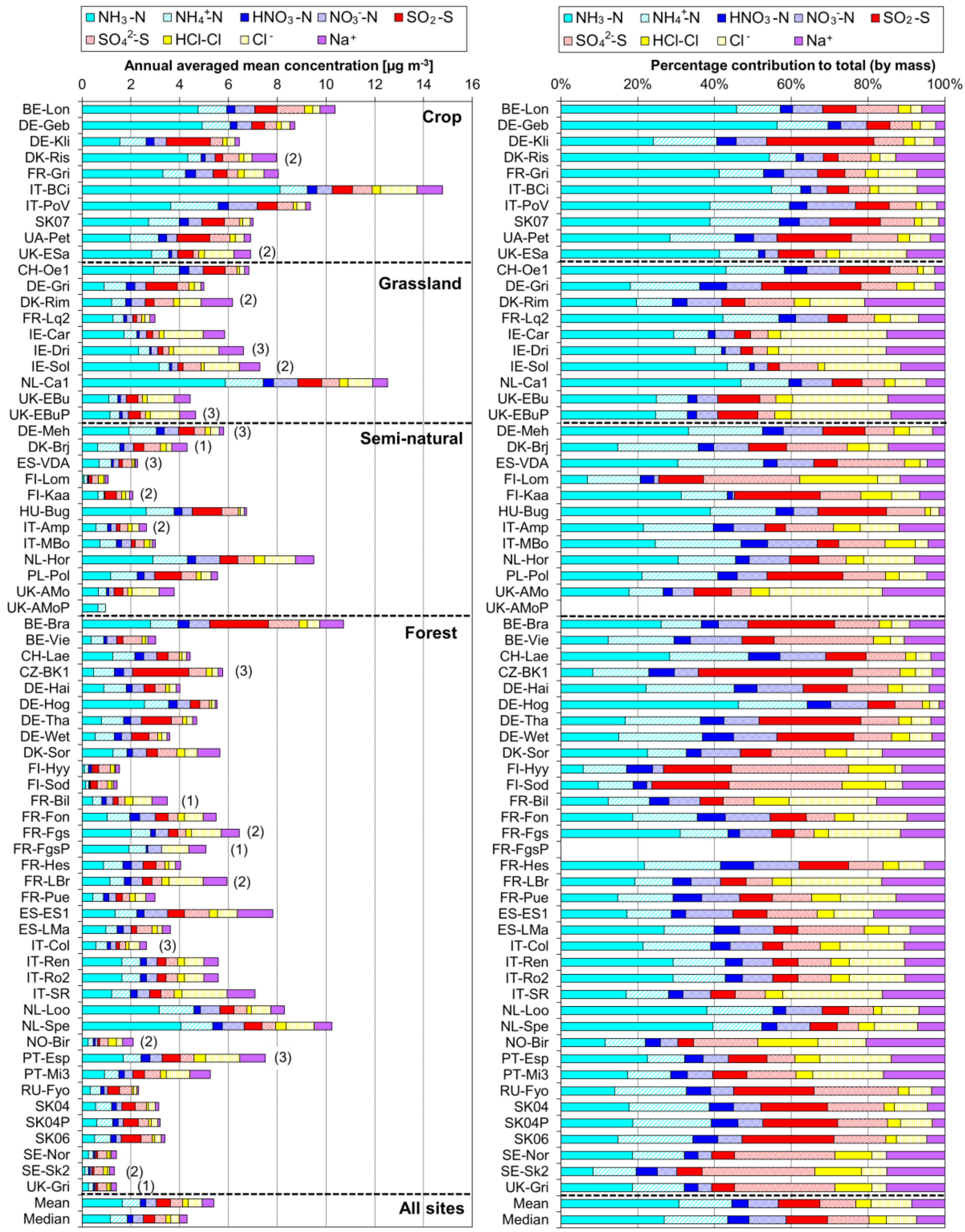


Figure 5-4. (LEFT) Annual averaged gas and aerosol concentrations (2007 – 2010) of sites in the pan-European NitroEurope DELTA® network, grouped according to ecosystem types: crops, grassland, semi-natural and forests. (RIGHT) the same data expressed as percentage composition of gas and aerosol components (Tang et al., 2020b). There were three sites from Ireland: Carlow, Dripsey and Solohead.

5.6 Atmospheric concentrations of Nitrogen Dioxide, NO_2

Indicative nitrogen dioxide (NO_2) diffusion tube sampling is deployed in the National Ambient Air Quality Monitoring Programme (AAMP) (EPA, 2019). These are the Palmes-type diffusion tubes (7.1 cm long with open inlet; Figure 5-2) that are also widely used in the UK NO_2 diffusion tube network (NO_2-net) (Conolly et al., 2016). Detection limit for diffusion tubes is <1.5 µg NO_2 m^{-3}, which is adequate for ambient monitoring. Method for the determination of the concentration of NO_2 by diffusive samplers is described in a European Committee for Standardisation (CEN) standard published in 2011 (CEN NO_2 standard, 2011).

Using data collected from existing NO_2 measurements

NO_2 monitoring data for Ireland is delivered through the Ambient Air Quality Directive (AAQD) network which provides hourly measurements of concentrations of NO_X and NO using the chemiluminescence reference method as required under the AAQD (

Table **5-1. Summary table of air quality measurement methods and models for air quality parameters recommended for Article 9 monitoring and reporting.**). The NO_2 concentrations are calculated within the reference method by subtracting the concentration of NO from the concentration of NO_X. Data are submitted annually to the EC by the EPA.

The AAQD network is composed of 57 mostly urban sites for compliance monitoring. Where they are located in rural areas close to selected to NEMN sites, data from these sites may be interpolated for the NEMN sites. The addition of rural measurements with NO_2 diffusion tubes will also benefit national mapping. NO_2 data from new NEMN sites will complement the automatic continuous measurements in AAQD, by providing a rural background for the modelling of NO_2 in Ireland for annual compliance mapping against Air Quality Objectives, Diffusion tube NO_2 data will also be available through the AAMP described above.

5.7 Atmospheric concentrations of Sulphur Dioxide, SO_2

Passive methods for the determination of SO_2 are highly uncertain, and not recommended for the monitoring of ambient SO_2. A diffusion tube method using the Palmes-type sampler has a detection limit of 4µg m^{-3}, which is not sufficient to monitor down to the low levels of SO_2 in ambient air. The UKCEH DELTA® method has the required sensitivity, with the added benefit of providing concurrent measurements of NH_3 and also aerosols, and is recommended.

SO_2 monitoring data for Ireland is also delivered at some of the sites in the AAQD network. Where these sites are located in rural areas close to selected NEMN sites, data from these sites may be interpolated for the NEMN sites.

5.8 Precipitation chemistry methods - wet deposition

For bulk wet deposition measurements, the ICP protocol recommends the use of a type of bulk precipitation collector described by the World Meteorological Organisation (WMO) that fulfils minimum requirements for correct precipitation quantity measurements (ICP Forests manual, Part XIV, 2018). We propose to use the NILU-type bulk rain collector that are already implemented at EMEP and Met Eireann sites in Ireland. In

Table 5-7, this is compared with the WMO specifications. The list of parameters for reporting in the Article 9 template from bulk wet deposition measurements is summarised in Table 5-8.

Table 5-7: A comparison of bulk precipitation collector design recommended by ICP (based on World Meteorological Organisation) versus the NILU collector design used in Ireland.

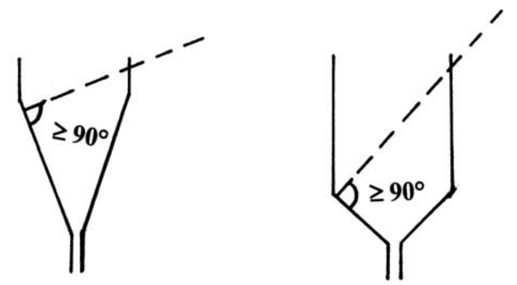
Features	ICP (WMO manual)	NILU design	Comments
Shape of Collection funnel	Recommends that the upper part of the collector should be very sharp and should go down vertically in the form of a cylinder. Vertical part of the collector should be deep enough to avoid any ejection or loss by wind of the incoming precipitation 		Meets ICP criteria
Sampling height	Recommend that the rim of the collector should be 1.0-1.5 m above ground		Meets ICP criteria
Bird deterrent	The upper exterior part of the collector could be surrounded by a so-called "bird wire" or "bird ring"	Uses 'bird ring'	Meets ICP criteria
Sieves and filters	A polyethylene net (mesh width 1 mm) sieve or other inert sieves (aquaristic filter fleece) should be placed at the top of the neck of the collector	Debris filter used	Meets ICP criteria
Sampling frequency	Recommends weekly to minimise artefacts due to evaporation or algal growth.	Monthly used in Met Eireann network. Monthly collection requires addition of biocides (e.g. thymol) to preserve samples.	**Deviation:** Recommend bi-monthly (= 24 site visits/year) for unpreserved wet deposition samples. Samples stored at 4°C can be bulked for monthly analysis..

Table 5-8. Reporting on parameters for acidification and eutrophication – bulk deposition measurements (Article 9 Template)

Parameter id	unit	Analytical technique	Comment
pH		pH meter	
Conductivity	µS/cm	Conductivity meter	
Ca	mg/l	Ion chromatography, ICP-AES	
Mg	mg/l	Ion chromatography, ICP-AES	
Na	mg/l	Ion chromatography, ICP-AES	
K	mg/l	Ion chromatography, ICP-AES	
NH_4-N	mg N/l	Ion chromatography, colorimetry	
NO_3-N	mg N/l	Ion chromatography	
SO_4-S	mg S/l	Ion chromatography	
Cl	mg/l	Ion chromatography	
PO4-P	mg/l	Ion chromatography	Not on list of parameters in EMEP manual (EMEP, 2014). PO4 important to identify contamination from potential bird strikes
Alkalinity	µeq/l	[Gran titration]	[Where pH > 5]
Ntot	mg/l	Inorganic N (NH_4-N + NO_3-N) and Organic N C:N analysers	
DOC	mg/l	C:N analysers	

SO_4-S(NM)		Estimated from SO_4-S and Na as tracer	Calculated from sea salt ratio

Daily wet-only method

Daily wet-only collections (DWOC) are also made with a wet-only sampler. Wet-only collectors (e.g. Eigenbrodt Daily wet only collector, Figure 5-5. Left: Eigenbrodt Daily wet only collector used at wet deposition sites in Ireland. Right: Map of both active and discontinued wet deposition measurements at EMEP and Met Eireann sites in Ireland. (https://www.eigenbrodt.de/en/products/sampler-collectors-instruments/nsa-181k-cooled/).

) open automatically at the onset of precipitation by the use of a sensor, and close at the end after rain has stopped, thus avoiding the collection of particles and gases during dry periods. Daily wet only samples are analysed for the same ions as the 2-weekly bulk rain samples (Table 5-8)

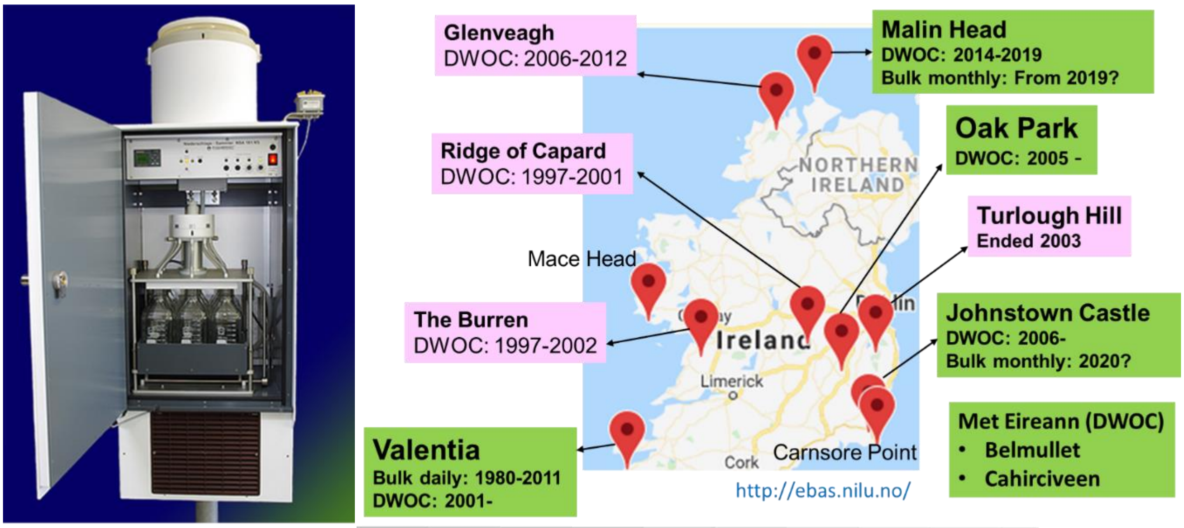


Figure 5-5. Left: Eigenbrodt Daily wet only collector used at wet deposition sites in Ireland. Right: Map of both active and discontinued wet deposition measurements at EMEP and Met Eireann sites in Ireland. (https://www.eigenbrodt.de/en/products/sampler-collectors-instruments/nsa-181k-cooled/).

Deposition fluxes of reduced and oxidised N, and S

It is recommended to review and recommend appropriate deposition models to estimate dry, wet and total deposition fluxes of sulphur, reduced and oxidise Nitrogen (see Sect.2.9). Data to feed into these models is also key and needs to be considered.

5.9 Ozone concentrations and fluxes

If in the future it becomes evident that ozone is impacting habitats in Ireland, the following approaches are recommended for its monitoring. It has increasingly been recognised that concentration based metrics and threshold based metrics such as AOT40 do not accurately predict areas of highest ozone damage to vegetation. Ozone damage is better reflected by ozone uptake into the leaves - the phytotoxic O_3 dose experienced by plants. This has been reflected in the recommendation to base risk assessment to vegetation on Phytotoxic Ozone Dose (POD). POD represents the accumulated ozone uptake over a specified growing period and is determined by a combination of the atmospheric ozone concentrations, and by climatic conditions that influence stomatal ozone and, therefore, ozone uptake through stomata (temperature, relative humidity, light intensity), soil moisture (affected by rainfall and soil type) and plant development (phenology).

For ozone, ICP Forests recommends sampling using passive samplers to be carried out on a 2-week basis and covers the period of 1 April – 30 September to provide average ozone concentration over each 2 week period. However, ozone monitoring to determine PODy requires continuous monitoring at hourly resolution, therefore, passive samplers cannot provide data at the resolution required for accurate determination of POD. Modelling of PODy for Ireland will be undertaken as part of the EPA-funded project NEC Indicators (2019-CCRP-LS.3).

5.9.1 Modelled concentrations

Ozone concentrations for Ireland may be derived from modelled gridded data using the most recent version of the EMEP4UK atmospheric chemistry transport model at 5×5 km^2 resolution (Vieno et al., 2010), based on daily mean calculated across the whole year (per grid cell). Ozone flux (accumulated uptake through the stomatal pores on the leaf surface), expressed as Phytotoxic Ozone Dose above a threshold flux of Y (PODy; $mmol/m^2$), may also be modelled for Ireland using EMEP4UK model. The methodology is described in detail in Sharps et al. (2019).

5.9.2 POD_y and exceedance flux-based critical levels: O_3

PODy is calculated over a stated accumulation period within a year (reflecting the main growing period of the vegetation in question), so it represents the PODy within a year, but not the whole year. Hourly ozone data is used to calculate the flux and continuous measurements over the growing period is therefore needed. Outside the stated accumulation period, the hourly flux is assumed to be zero. It is recommended to report PODy in preference to critical level, as it is the UNECE preferred metric.

Calculation of ozone fluxes (PODy; $mmol/m^2$) and exceedance of a flux-based critical level ($mmol/m^2$ projected leaf area) depends on the MAES ecosystem classification for each site. A key uncertainty will be vegetation type present at the NEMN sites. The same grid squares might have values calculated for specific crops, forest habitats and semi-natural vegetation. If the NEMN monitoring site within a grid square is a forest, the calculated ozone flux and critical level exceedance will be different than for grasslands or crops. Modelled flux-based critical level exceedance maps can be produced across the UK at 5km grid resolution or higher. This will provide coverage across the whole climate and pollution gradient, for crops, forest and grassland habitat types, provided the vegetation information is available to allow mapping.

5.10 Modelling concentrations and deposition of Nitrogen and Sulphur

This section presents an overview of modelling approaches that may be applied to provide air concentrations and depositions for the relevant acidifying and eutrophying air pollutants (see Sect. 2.1). A summary of modelling approaches is presented in Table 5-9.

Establishment of modelling approaches for Ireland requires additional resources, including staff from both Met Éireann and the EPA. Key recommendations are:

- Identify, develop and maintain air pollutant concentrations and deposition models suitable for Ireland.
- Meteorological data: The involvement of Met Éireann is essential. e.g. provision of high resolution met.data since this is an Important component of models.
- Detailed emission inventory for Ireland at higher resolution (e.g. 1km) than the 0.1° x 0.1° data reported to EMEP, to improve the accuracy of any model output.
- Inventory should be updated annually - expertise of national inventory team in the EPA could manage this process
- Existing expertise on air modelling should be used to assist with this project

Table 5-9. Summary of modelling approaches for acidifying, eutrophying air pollutants and ground level ozone.

Model	Details
EMEP MSC-W EMEP, 2020 www.emep.int EMEP MSC-W HOME	• Depositions of sulphur (S) and nitrogen (N), and air concentrations of ozone (O_3) and particulate matter (PM), as reported in the annual EMEP status reports. • Gridded data on NetCDF format on EMEP 0.1º x 0.1º longitude-latitude grid. • Model results are routinely evaluated and validated against measurements that have been collected from the EMEP monitoring network.
FRAME FRAME (Fine Resolution Atmospheric Multi-pollutant Exchange) Dore et al., 2012	• Annual average concentrations and deposition of NH_3, HNO_3, NO_x and SOx, ammonium aerosols, base cations and heavy metals (1 km and 5 km resolution). • Annual mean deposition of reduced and oxidised nitrogen and sulphur at both standard (5 km) and high (1 km) resolution across the UK. • Uses annual averaged meteorology (e.g. UK met office data for UK maps) • Model is calibrated with NH3 data from UK NAMN to produce a calibrated UK concentration field for the UK that is used in CBED to map NH3-N dry deposition. • Mapped deposition results are used to calculate the exceedance of critical loads for future emissions scenarios. The model is also used to calculate the exceedance of the critical level for ammonia concentrations and to generate source-receptor matrices of secondary inorganic aerosol concentrations and deposition for use in the UK Integrated Assessment Model.
WRF-EMEP4UK (based on EMEPMSC-W model Vieno et al., 2016	• The Weather Research Forecast (WRF) model is used as the main meteorological driver (www.wrf-model.org). • Maps hourly to annual average atmospheric concentrations of SO_2, NH_3, HNO_3, NO_x, and O_3, PM_{10}, $PM_{2.5}$, secondary organic aerosols (SOA), elemental carbon (EC), • Maps Dry and Wet deposition of NH_x, NO_x and SO_x pollutants. • Resolution ranges from 100 km to 1 km. • Example modelled concentrations and deposition maps for Ireland are shown in Figure 5-6 and Figure 5-7. Modelled dry and wet nitrogen deposition for Ireland – EMEP4UK. • 5-7, respectively. • Currently being developed into **EMEP4IE** by UKCEH
MARSH Kelleghan et al, 2019	• Maps risk to Natura 2000 sites from atmospheric NH_3 impacts based on density of sources and contribution to national emissions, validated by national monitoring.
UK CBED (Concentration Based Estimated Deposition) Smith et al., 2000 Vieno, 2005 Flechard et al. 2010	• 5x5 km resolution maps of wet and dry deposition of sulphur, oxidised and reduced nitrogen, and base cations from measured concentrations of gases and particulate matter in air and measured concentrations of ions in precipitation. • Habitat-specific S and N data are provided for (i) moorland/short vegetation, and (ii) forest. Additionally, the grid square average over multiple land cover types (i.e. arable, grassland, forest, moorland, urban) is also calculated. • The habitat-specific data are recommended for use with critical loads for the calculation of critical load exceedances. • CBED datasets are provided as a 3 year rolling mean (e.g. 2016-2018) with each consecutive year updated on an annual basis.
Dutch IDEM Bleeker et al., 2004	• Deposition of sulphur and nitrogen, and also base cations • Site specific deposition estimates and critical load exceedances of sulphur and nitrogen and extrapolation to a European wide scale.
Environment **Canada model** Zhang et al., 2003	• Dry deposition of gases (including NH_3)
CMAQ (Community Multiscale Air-Quality Modeling System) Cooter et al. 2010	• Regional air quality conditions for a wide range of chemical species throughout the United States (U.S.)

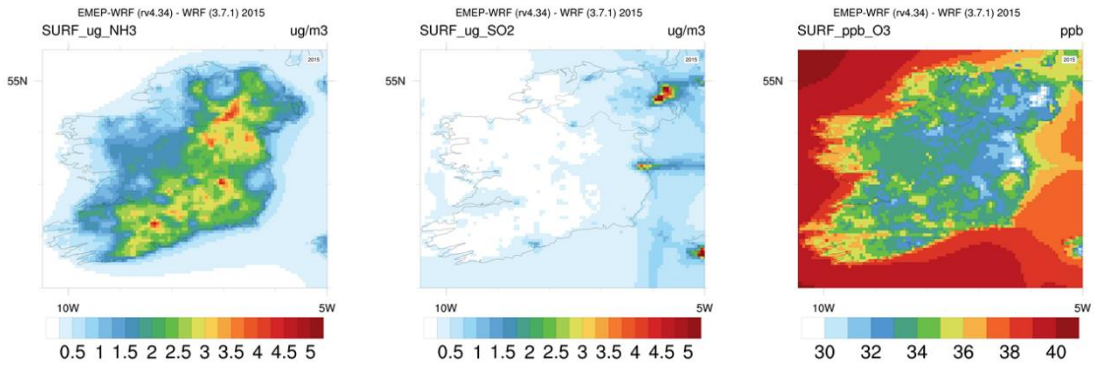


Figure 5-6.Modelled NH3, SO2 and O3 for Ireland – EMEP4UK.

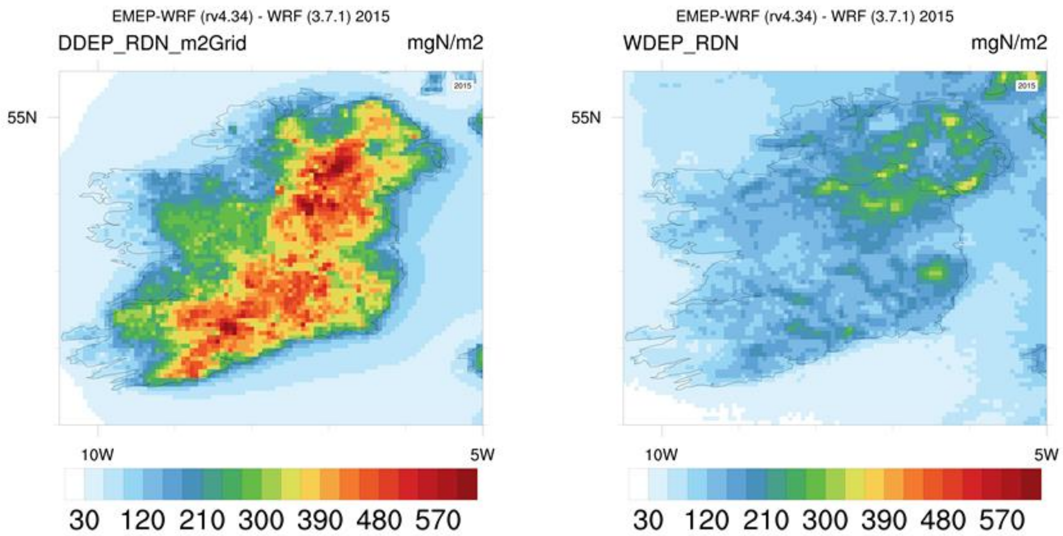


Figure 5-7. Modelled dry and wet nitrogen deposition for Ireland – EMEP4UK.

5.11 Remote sensing

Remote sensing of gas pollutants (e.g. ozone, SO_2, NO_2, and NH_3) and aerosols are available at increasingly high precision and spatial resolution (e.g. https://so2.gsfc.nasa.gov/measures.html, Geddes et al., 2015). For example, the first global map of NH3 was produced in 2009 from Infrared Atmospheric Sounding Interferometer (IASI) satellite observations (Clarisse et al., 2009).

Satellite observations offer wide spatial coverage which cannot be matched by any ground-based monitoring networks. Major challenges remain however in how to effectively apply satellite data in air pollution monitoring. These include missing data due to cloud cover and high surface reflectance, satellite retrieval errors, column height and validation of satellite data with ground-based observations. For ammonia, satellite methods work well in hot sunny locations where there is not too much wind. The method needs strong thermal contrast, lack of interfering water (cloud), and benefits from a nice deep boundary layer build-up.

IASI measurements are with a pixel footprint of 12 km along the satellite track, and provides global coverage twice a day (9:30 and 21:30 mean local solar time) by scanning along a swath of 2,200 km off-nadir. Stronger thermal contrast in daytime and spring–summer months produces more accurate NH_3 measurement from IASI than at other times (van Damme, 2014a, 2014b).

Comparisons have been made between retrieved IASI NH_3 data with ground-based measurements in Europe, China and Africa (van Damme et al. 2015), and more recently over China, the US and Europe (Liu et al. 2019). The areas of major uncertainties include:

- Comparison of the retrieved NH_3 columns (IASI has an elliptical footprint of 12 km by 12 km, at nadir) with ground-based point measurements, since NH_3 is spatially heterogeneous (e.g. see Tang et al., 2018a).
- The single IASI orbit in the morning (9:30) may not be representative of the daily average NH_3 concentration, given its short lifetime.
- The IASI-NH_3 measurements do not provide vertical information. The conversion of total column ammonia (molecules.cm^{-2}) into near-surface concentrations (µg.m^{-3}) requires combining IASI NH_3 column measurements with modelled NH_3 vertical profiles (e.g. GEOS-Chem) (Van Damme et al., 2014, 2015), a major source of uncertainty.

In such cases, there is a great opportunity to monitor ammonia trends (rather than absolute) from space (van Damme et al., 2015, 2018). However, for cold, cloudy, windy Ireland this is still a major challenge. Ground-based measurements of NH_3 will therefore continue to be important for the foreseeable future and will provide the necessary data for validation of satellite observations.

Satellite work on NH_3 and NO_2 were presented by the Environment Agency at a recent UK-US collaboration on air quality modelling and exposure science workshop (Brown, 2020). For NH_3, clear trends in seasonal and monthly data in the UK and Ireland were demonstrated by the satellite data (Figure 5-8), while deriving annual mean data were deemed uncertain due to incomplete data coverage across the year. The EPA in Ireland is the contact for satellite air quality / greenhouse gas applications in Ireland environmental regulators.

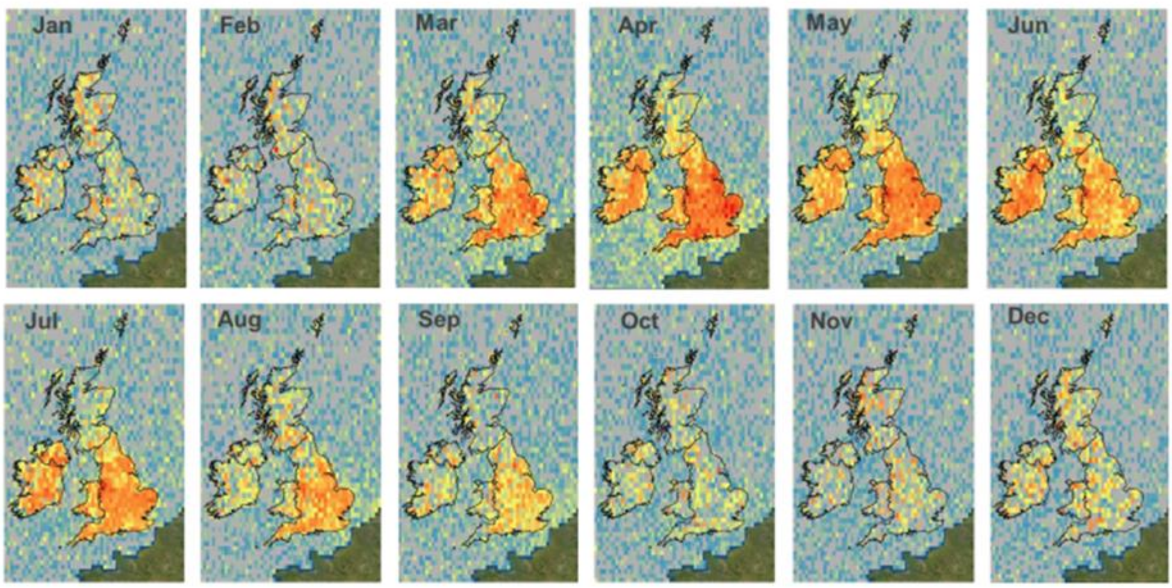


Figure 5-8. IASI satellite NH3 data (total column NH3, molecule cm-2) from 2008 – 2018, averaged in calender month “bins” (reproduced from Brown, 2020).

6. Conclusions and Recommendations

In summary, this phase of the NEMN meets the need for a representative, risk-based, cost effective approach under the National Emissions Ceilings Directive (2016/2284/EU). This proposal focuses on monitoring impacts across specific habitat types, which can be expanded in the future using information provided alongside this report. Linking with monitoring carried out by National Parks and Wildlife Service is an ideal synergy, optimising the number of sites and costs by monitoring collaboratively. Linking with other countrywide networks such as ICOS and Teagasc Agricultural Catchments Programme will also benefit the Level II network, which with additional sites operated by other networks will improve national concentration and deposition modelling, improving estimates at all Level I sites. This report has identified a number of recommendations to both ensure this network meets its requirements, and those benefits are maximised. These recommendations are subdivided into categories Habitats, Sites and Monitoring, which follow.

6.1 Sites

The proposed network consists of Level II core sites (pollutant concentrations and deposition), Level II sites (pollutant concentrations and wet deposition on blanket bog and wet heaths), Level I sites (ecosystem impacts) and Level 0 sites (other NPWS national biomonitoring).

The NEMN design team **recommends** the site selections presented here, though it should be noted that the selections of sites presented are flexible. The authors suggest if a site is deemed to be unsuitable due to access or for other reasons, an alternative site proximal to its location on the risk gradient (Appendix 4) be selected. As the sites included are all part of past or present NPWS monitoring schemes, we expect that the majority of these sites are accessible at least for Level I monitoring. Installation of Level II equipment would still require agreement with the land owner or site operator, while screening for Appropriate Assessment will be required. Theoretically, any Level I site could be upgraded to Level II, and any Level II to Level II core. The sites presented within this phase provide the best representation of likely impacts across the selected habitats.

In total the NEMN-design team recommend retaining existing **37 ICP Forest Sites** (2 Level II and 35 Level I), expanding to **25 Freshwater Sites** (4 Level II and 21 Level I), and developing **60 Terrestrial Ecosystem Sites** (nested design, 15 Level II, 7 Level II core). In total this proposed network would consist of monitoring on **122 sites**, in collaboration between the NPWS, DAFM and the EPA. Linking with other networks such as ICOS, Teagasc catchment monitoring, Marine Institute and COSMOS will increase the resolution of monitoring required to adequately validate national models, which can be subsequently applied to Level I sites to enhance our understanding of impacts.

It is **recommended** that as future concentration and deposition models become available (e.g. EMEP4IE in 2021) the risk assigned to sites be updated to include inevitable improvements in modelling approaches. Similarly, this monitoring network should be utilised to validate such models, similar to approaches taken in the UK, Netherlands and Denmark.

This report **recommends** the selection of 15 Level I sites per habitat, and strongly encourages that if number of sites be cost limited, the number of habitats should be reduced, not the number of sites per habitat. Fifteen is the minimum number of sites required in order to ensure impacts across the range can be detected. Similarly, upon each site at least five relevés should be carried out for each selected habitat type. There may be significant cost savings where more than one habitat is present on a site. Though this is limited by the type of surveys being carried out, where for example the synergy applied to wet heaths and blanket bogs proposed as those habitats will be surveyed by the same experts during the same survey by NPWS. The same could not be said for a site which had both a raised bog and grassland habitat, where these national surveys are carried out by different experts at different times. There is limited benefit in this case, though selecting Level II or Level II core sites with multiple habitat types is significantly beneficial, as it increases the number of habitats represented by air quality impacts on site.

As the majority of proposed Terrestrial ecosystem sites are within the Natura 2000 network, **appropriate assessment** screening is required on Level II and Level II core sites. It may be appropriate to decide to carry out a full detailed appropriate assessment as the installation of equipment permanently on Natura 2000 sites should be assessed in detail, with plans to reduce potential impacts developed.

Based on the proximity of the previously identified Level II site Split Hills and Long Hill Esker SAC to another proposed Level II site Clara Bog SAC, and following the site survey, it is recommended that Split Hills and Long Hill Esker SAC should be removed as a Level II selection. In the current design it has been retained as a Level I site.

The NEMN-Design team agree inclusion of Kilroosky Lough Cluster SAC and Lough Oughter SAC should be considered for inclusion as additional Level II NH_3 monitoring sites, due primarily to the potential for impacts previously modelled on these sites.

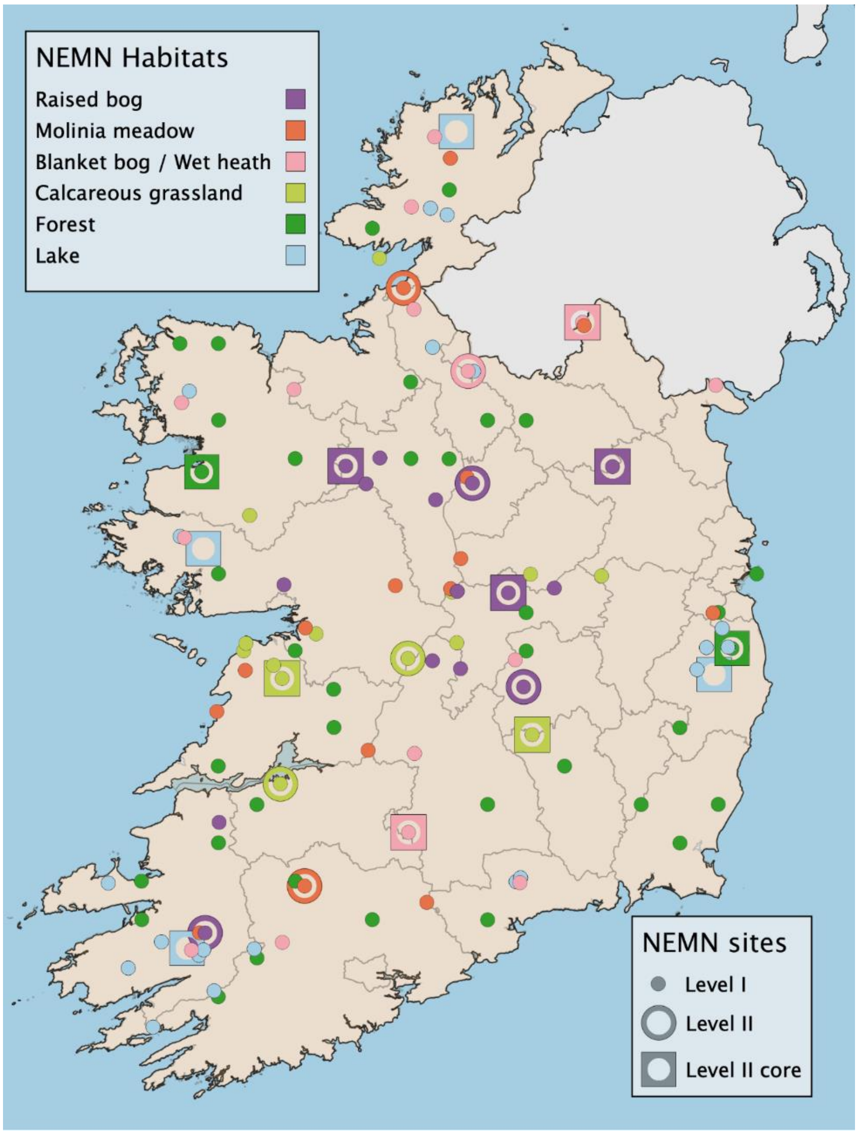


Figure 6-1. Existing and proposed sites for NEMN.

6.2 Surveys

Surveys which are envisaged or may be considered in further iterations of the NEMN reporting cycle:

- Soil pit sampling, part of third transnational soil survey under ICP Forests, Level I forests.
- Soil solution sampling, ion chemistry, Level II core terrestrial plots.
- Moss tissue sampling for nitrogen content on Level I & II terrestrial plots, part of ICP Vegetation surveys.
- Moss tissue sampling for nitrogen content, Level I forests, expanding ICP Vegetation work
- Freshwater chemistry in Level I lakes, as part of decadal-interval resurvey.

It is recommended that monitoring protocols be developed in order to ensure uniformity of data collection by different surveyors. Particularly for vegetation, soil and moss sampling recommended.

Table 6-1. Surveys recommended for NEMN in reporting cycle ending 2022/2023.

Survey	Method	Species	Plots	Frequency
Site installation	GPS positioning	Plot, sub-plots, fixed equipment, stock exclosures	Level II	At establishment
	GPS positioning, detailed descriptions	Relevés	Level I	At establishment
Ambient air quality	UKCEH ALPHA®	NH_3	Level II, terrestrial, forest	Monthly
	Palmes-type diffusion tubes	NO_x	Level II core, terrestrial, forest	Monthly
	UKCEH DELTA® denuder–filter-pack	Gaseous NH_3, NO_x, SO_2; particulate NH_4^+, NO_3^-	Level II core, terrestrial, forest	Monthly
Bulk deposition	[NILU-type bulk precipitation collector, open area]	pH, conductivity, Ca, Mg, K, Na, NH_4-N, NO_3-N, SO_4-S, Cl, P, Alkalinity, Ntot, DOC	Level II core, terrestrial, forest	Twice monthly
	[NILU-type bulk precipitation collector, under forest]		Level II core, forests	Twice monthly
Soil chemistry	0–10 cm, funnel-auger	pH, C, N, CEC, exchangeable cations	Level I & II plots, terrestrial, forest	Every four years
	0–10 cm, funnel-auger	CEC	Level I & II plots, terrestrial, forest	At establishment
Vegetation	Permanent nested relevés	Vascular plants, mosses, lichens	Level I & II plots	Every four years
	Moss sampling	Foliar Nitrogen	Level I & II plots, terrestrial, forest	Every four years
Crown condition	Defoliation, damage parameters	Forest trees	Level I forest	Every year
Water quality	Aquatic biota	Acidification index, species diversity, species abundance, acidification invertebrates	Level II lakes	Every year
	Water chemistry	Water temperature, alkalinity, Ntot/Ptot, SO_4, NO_3-N, Cl, DOC, pH, Ca, Mg, Na, K, NH_4-N, Al inorg, conductivity, Ptot	Level II lakes	Every year
	Water chemistry	[ICP Waters]	Level I lakes	Every four years

6.3 Habitats

This phase of the NEMN design focuses on identifying sites which meet the recommendations for MAES habitats to be included. For each habitat included, a representative number of sites is needed, so in the first phase we **recommend** that for terrestrial ecosystem impacts monitoring (Level I) is focused on five sensitive and important habitats: raised bog, blanket bog–wet heath colocations, calcareous grassland, and *Molinia* meadow.

No expansion of the forest network is currently recommended to cover additional habitats, though future iterations could consider expanding to include ecological surveys of semi natural forests.

The NEMN design team **recommends** that existing monitoring of upland lakes at decadal intervals be integrated formally into the NEMN to act as a Level I network for freshwater sites. This would require a commitment to continued funding by EPA.

The NEMN design team **recommends** the future development of the network to include other habitats assessed using the risk-based approach developed within the report. Expanding to include other sensitive habitats in Ireland is recommended, including, but not limited to, limestone pavement, sand dunes, dry heath, and semi-natural oak woodlands.

6.4 Management

It is **recommended** that further site visits be carried out, to increase the team's familiarity with local conditions, provide more opportunities for establishing local contact, and incrementally increasing confidence in the selections or replacing sites ultimately found not to be suitable.

The frequency of site visits varies by survey. The NEMN design team **recommends that** Level II core sites will need to be visited bi-monthly to change wet deposition samplers, Level II sites should be visited once monthly to change passive ALPHA samplers. This should be carried out by either a local site operator or EPA staff. Level I terrestrial sites should be assessed every 4 years, either by ecological survey, ICP Forests Level I survey or freshwater monitoring. An exception is for the Cuilcagh - Anierin Uplands SAC Level II site, where bimonthly wet deposition monitoring is also recommended in addition to NH_3 concentration measurement, due to the significance of its contribution to nitrogen deposition in upland areas associated with high rainfall.

It is not possible to cost such a network in its entirety, as many services required (e.g. laboratory work, site maintenance, etc) will be required to go to public tender. Where available, potential costs have been provided in Appendix 1, and separately in spreadsheets provided directly to the EPA.

The NEMN design team **recommends** the establishment of a strategy for long-term curation of datasets from monitoring. This should include information from relevant previous surveys on sites identified and listed for inclusion within the network. This could take the form of collaboration with an organisation such as eLTER if established in Ireland, who's focus would be long term ecological monitoring. Alternative options are detailed within Appendix 4 of this document. The information compiled should be publicly available and easily accessible.

Linking with the NPWS is an essential, cost effective strategy for Level I monitoring. To make best use of this synergy, the NEMN design team **recommends** modification of survey practice and frequency to (1) use permanent relevés, (2) ensure at least 5 relevés per designated habitat type per site are collected, and (3) ensure Level I sites are included in future NPWS surveys.

Modification of monitoring practices to align with NEMN requirements would confer a cost to NPWS, which should be considered before this synergy can be exploited.

Linking with other networks monitoring atmospheric pollution, such as ICOS or Teagasc will allow for the potential expansion of the Level II network. This could, at the very least, be utilised as part of Ireland’s national ammonia concentration network. As ammonia is highly spatially variable, increasing its resolution of monitoring would be extremely beneficial. In addition, this would significantly improve the validation of national atmospheric concentration and deposition modelling.

Existing monitoring on sites should be expanded, to include soil and moss sample collection on ICP Forest Level I sites; air quality monitoring on both ICP Forests Level II sites and Freshwater Level II sites.

The risk-based approach applied to heaths and blanket bog sites identified a number of sites previously surveyed by NPWS, but upon which surveys are not planned for at least the next 10 years. NPWS efforts for that period will be focused on monitoring sites within the Wild Atlantic Nature Life Programme, of which most sites fall on the lower end of the risk gradient. As the NEMN is required to cover the whole gradient of impacts, it is recommended that an additional survey be contracted through the NPWS to obtain the ecological data required from these sites.

7. References

Aherne, J., Burton, A., Scott, H., Whitfield, C., Wolniewicz, M., 2013. *Assessing the Influence of Transboundary Air Pollution on Acid-sensitive Lakes and Soils*, CCRP Report Series No. 31. Environmental Protection Agency, Johnstown Castle, Ireland. https://www.epa.ie/pubs/reports/climatechange/CCRP_31_web.pdf

Aherne, J., Burton, A., Scott, H., Whitfield, C. and Wolniewicz, M., 2014. *Influence of Transboundary Air Pollution on Acid-sensitive Ecosystems.* CCRP Report Series No. 31. Environmental Protection Agency, Johnstown Castle, Ireland.

Aherne, J., Henry, J. and Wolniewicz, M., 2017. *Development of Critical Loads for Ireland: Simulating Impacts on Systems (SIOS).* Environmental Protection Agency, Johnstown Castle, Ireland.

Aherne, J., Wilkins, K., & Cathcart, H., 2020. *Critical Loads and Soil-Vegetation Modelling,* EPA Research Report (2012-CCRP-MS.7). Environmental Protection Agency, Johnstown Castle, Ireland. https://www.epa.ie/pubs/reports/research/climate/Research_Report_323.pdf

APIS (Air Pollution Information System) website, UK Centre for Ecology & Hydrology,. http://www.apis.ac.uk/

Berkhout, A. J. C., Swart, D. P. J., Volten, H., Gast, L .F .L., Haaima, M., Verboom, H., Stefess, G., Hafkenscheid, T., and Hoogerbrugge, R., 2017. Replacing the AMOR with the miniDOAS in the ammonia monitoring network in the Netherlands, *Atmospheric Measurement Techniques*, 10, 4099–4120, doi:10.5194/amt-10-4099-2017.

Bleeker, A., Reinds, G. J., Vermeulen, A. T., de Vries, W., and Erisman, J. W.: Critical Loads and Present Deposition Thresholds of Nitrogen and Acidity and Their Exceedances at the Level II and Level I Monitoring Plots in Europe, ECN report ECN-C–04-117, Petten, The Netherlands, December 2004.

Bobbink, R., Hettelingh, J.-P., 2011. Review and revision of empirical critical loads and dose-response relationships: Proceedings of an expert workshop, Noordwijkerhout, 23-25 June 2010. National Institute for Public Health and the Environment, Bilthoven, the Netherlands.

Brown, A. Application of satellite air quality and greenhouse gas measurements to regulatory activities: preliminary studies. Presentation at the UK-US Collaboration on Air Quality Modelling & Exposure Science Workshop, 16 November 2020.

Clarisse, L., Clerbaux, C., Dentener, F. et al. Global ammonia distribution derived from infrared satellite observations. Nature Geosci 2, 479–483 (2009). https://doi.org/10.1038/ngeo551

Conolly, C., Davies, M., Knight, D., Vincent, K., Sanocka, A., Lingard, J., Richie, S., Donovan, B., Collings, A., Braban, C., Tang, Y.S., Stephens, A., Twigg, M., Jones, M., Simmons, I., Coyle, C., Kentisbeer, J., Leeson, S., van Dijk, N., Nemitz, E., Langford, B., Bealey, W., Leaver, D., Poskitt, J., Carter, H., Thacker, S., Patel, M., Keenan, P., Pereira, G., Lawlor, A., Warwick, A., Farrand, P. and Sutton, M.A., 2016. *UK Eutrophying and Acidifying Atmospheric Pollutants (UKEAP) Annual Report 2015.* https://uk-air.defra.gov.uk/assets/documents/reports/cat13/1611011543_UKEAP_annual_report_2014_Issue_v1_161115.pdf

Cooter, E.J., Bash, J.O., Walker, J.T., Jones, M.R. and Robarge, W. Estimation of NH3 bi-directional flux from managed agricultural soils, Atmospheric Environment, 44, 2107 – 2115, 2010.

Delaney, A., Devaney, F.M., Martin, J.R., Barron, S.J., 2013. Monitoring survey of Annex I sand dune habitats in Ireland, *Irish Wildlife Manuals.* National Parks and Wildlife Service, Dublin, Ireland.

Dore, A. J., Kryza, M., Hall, J. R., Hallsworth, S., Keller, V. J. D., Vieno, M., and Sutton, M. A.: The influence of model grid resolution on estimation of national scale nitrogen deposition and exceedance of critical loads, Biogeosciences, 9, 1597–1609, https://doi.org/10.5194/bg-9-1597-2012, 2012.

Doyle, Brian, Thomas Cummins, Cara Augustenborg, and Julian Aherne, 2017. Ambient Atmospheric Ammonia in Ireland, 2013–2014 (2012-CCRP-MS.8). EPA Research Report No. 193. Environmental Protection Agency. https://www.epa.ie/pubs/reports/research/air/EPA%20RR%20193%20Essentra%20web%20(1).pdf

EC, Additional clarifications to the reporting on ecosystem monitoring (NEC Directive 2016/2284, Art. 9-10). Final version 10 April 2019, 2019b

EN 13528 part 3. Ambient air quality - Diffusive samplers for the determination of concentrations of gases and vapours – Guide for selection, use and maintenance. CEN, Brussels, 2003

EN 16339 Ambient air - Method for the determination of the concentration of nitrogen dioxide by diffusive sampling, CEN, Brussels, 2013.

EN 17346:2020 Ambient air - Standard method for the determination of the concentration of NH_3 using diffusive samplers. CEN, Brussels, 2020

EC, Communication from the Commission: Commission notice on ecosystem monitoring under Article 9 and Annex V of Directive 2016/2284 (NECD), 20 February 2019, C(2019)1328 Final, 2019a.

EMEP, 2014. *EMEP Manual for Sampling and Analysis*. Norwegian Institute for Air Research. Kjeller, Norway. www.nilu.no/projects/ccc/manual/, 2014.

EPA report, Air Quality in Ireland 2019, published 2020

ETC/ATNI, European air quality maps for 2018 - PM10 , PM2.5, ozone, NO2 and NOx spatial estimates and their uncertainties, Eionet Report ETC/ATNI 2020/10, European Topic Centre on Air pollution, transport, noise and industrial pollution, 2020.

European Communities, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. *Official Journal of the European Communities* L327(43), 1–72.

European Union, 2015. *Report on the status and trends for habitat types and species covered by the Birds and Habitats Directive for the 2007-2012 period as required under Article 17 of the Habitats Directive and Article 12 of the Birds Directive*. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015DC0219&from=EN

Famulari, D., Fowler, D., Nemitz, E., Hargreaves, K.J., Storeton-West, R.L., Rutherford, G., Tang, Y.S., Sutton, M.A. and Weston, K.J., 2010. Development of a low-cost system for measuring conditional time-averaged gradients of SO_2 and NH_3. *Environmental Monitoring and Assessment*. 161, 11–27, https://link.springer.com/article/10.1007%2Fs10661-008-0723-6.

Fernandez, F., Connolly, K., Crowley, W., Denyer, J., Duff, K., Smith, G., 2014. Raised Bog Monitoring and Assessment Survey 2013, *Irish Wildlife Manuals*. National Parks and Wildlife Service, Dublin, Ireland.

Geddes, J.A., Martin, R.V., Boys, B.L., van Donkelaar, A. Long-Term Trends Worldwide in Ambient NO_2 Concentrations Inferred from Satellite Observations. *Environmental Health Perspectives*, 124(3):281-289. doi: 10.1289/ehp.1409567, 2015..

ICP Forests Manual. Part XIV: Sampling and Analysis of Deposition. Version 05/2016 (updated 03/2018)

Juggins, S., 2007. *C2 Version 1.5 User Guide. Software for ecological and palaeoecological data analysis and visualisation*. Newcastle University, Newcastle upon Tyne, UK.

Kelleghan, D.B., Hayes, E.T., Everard, M., Curran, T.P., 2019. Mapping ammonia risk on sensitive habitats in Ireland. *Science of The Total Environment* 649, 1580–1589. https://doi.org/10.1016/J.SCITOTENV.2018.08.424

Martin, J.R., O' Neill, F.H., Daly, O.H., 2018. The Monitoring and Assessment of Three EU Habitats Directive Annex I Grassland Habitats, *Irish Wildlife Manuals*. National Parks and Wildlife Service, Dublin, Ireland.

Martin, N. A., Ferracci, V., Cassidy, N., Hook, J., Battersby, R. M., di Meane, E. A., Tang, Y. S., Stephens, A. C. M., Leeson, S. R., Jones, M. R., Braban, C. F., Gates, L., Hangartner, M., Stoll, J-M., Sacco, P., Pagani, D., Hoffnagle, J. A., and Seitler, E., 2019. Validation of ammonia diffusive and pumped samplers in a controlled atmosphere test facility using traceable Primary Standard Gas Mixtures, *Atmospheric Environment*, 199. 453-462. doi:10.1016/ j.atmosenv.2018.11.038, 2019

Miller, D. J., Sun, K., Tao, L., Khan, M. A., and Zondlo, M. A., 2014. Open-path, quantum cascade-laser-based sensor for high-resolution atmospheric ammonia measurements, *Atmospheric Measurement Techniques*, 7, 81–93. doi:10.5194/amt-7-81-2014, 2014.

Moran, P., Wilson-Parr, R., 2014. Hen Harrier Special Protection Area (SPA) Habitat Mapping Project, *Irish Wildlife Manuals*. National Parks and Wildlife Service, Dublin, Ireland.

O'Neill, F.H., Barron, S.J., 2013. Results of a monitoring survey of old sessile oak woods and alluvial forests, *Irish Wildlife Manuals*. National Parks and Wildlife Service, Dublin, Ireland.

Perrin, P.M., Barron, S.J., Roche, J.R., O'Hanrahan, B., 2010. Guidelines for a national survey and conservation assessment of upland vegetation and habitats in Ireland. Version 1.0, *Irish Wildlife Manuals.* National Parks and Wildlife Service, Dublin, Ireland.

Perrin, P.M., Barron, S.J., Roche, J.R., O'Hanrahan, B., 2014. Guidelines for a national survey and conservation assessment of upland vegetation and habitats in Ireland. Version 2.0, *Irish Wildlife Manuals.* National Parks and Wildlife Service, Dublin, Ireland.

Pitcairn, C. E. R., Leith, I. D., Sheppard, L. J., Sutton, M. A., Fowler, D., Munro, R. C., Tang, S., and Wilson, D.: The relationship between nitrogen deposition, species composition and foliar nitrogen concentrations in woodland flora in the vicinity of livestock farms, Environmental Pollution, 102, 41-48, https://doi.org/10.1016/s0269-7491(98)80013-4, 1998.

ROTAP: Review of Transboundary Air Pollution: Acidification, Eutrophication, Ground Level Ozone and Heavy Metals in the UK. Contract Report to the Department for Environment, Food and Rural Affairs. Centre for Ecology & Hydrology, http://www.rotap.ceh.ac.uk/, 2012.

Rowe, E.C., Jones, L., Dise, N.B., Evans, C.D., Mills, G., Hall, J., Stevens, C.J., Mitchell, R.J., Field, C., Caporn, S.J., Helliwell, R.C., Britton, A.J., Sutton, M., Payne, R.J., Vieno, M., Dore, A.J. & Emmett, B.A., 2017. Metrics for evaluating the ecological benefits of decreased nitrogen deposition. *Biological Conservation,* 212: 454-463. doi: 10.1016/j.biocon.2016.11.022. http://nora.nerc.ac.uk/516913/

Sharps, K., Harmens, H., Sawicka, K., Vieno, M., Steadman, C. & Hayes, F., 2019. *NECD Reporting 2019 - Quantifying and mapping exceedances of ozone flux-based critical levels for vegetation in the UK (2014 – 2016)*. Centre for Ecology and Hydrology, UK.

Sutton, M. A., Tang, Y. S., Miners, B., Fowler, D., 2001. A new diffusion denuder system for long-term, regional monitoring of atmospheric ammonia and ammonium. *Water, Air and Soil Pollution*, Focus, 1, Part 5/6, 145-156.

Tang Y.S. PhD Thesis "Development and application of low-cost monitoring approaches for atmospheric ammonia, acid gases and ammonium aerosols. University of Edinburgh, 2020.

Tang, Y. S., Braban, C. F., Dragosits, U., Dore, A. J., Simmons, I., van Dijk, N., Poskitt, J., Dos Santos Pereira, G., Keenan, P. O., Conolly, C., Vincent, K., Smith, R. I., Heal, M. R., and Sutton, M. A., 2018. Drivers for spatial, temporal and long-term trends in atmospheric ammonia and ammonium in the UK. *Atmospheric Chemistry and Physics*, 18, 705–733, doi: 10.5194/acp-18-705- 2018.

Tang, Y. S., Cape, J. N., and Sutton, M. A., 2001. Development and types of passive samplers for monitoring atmospheric NO_2 and NH_3 concentrations. *Scientific World Journal*, 1, 513–529, https://doi.org/10.1100/tsw.2001.82, 2001.

Tang, Y. S., Braban, C.F., Dragosits, U., Simmons, I., Leaver, D., van Dijk, N., Poskitt, J., Thacker, S., Patel, M., Carter, H., Pereira, M. G., Keenan, P.O., Lawlor, A., Connolly, C., Vincent, K., Heal, M.R., Sutton, Mark A., 2018. Acid gases and aerosol measurements in the UK (1999–2015): regional distributions and trends. *Atmospheric Chemistry and Physics*, 18 (22). 16293-16324. https://doi.org/10.5194/acp-18-16293-2018

Tang, Y.S. & Sutton, M.A, 2003. Quality management in the UK National Ammonia Monitoring Network. In: *Proceedings of the International Conference "QA/QC in the field of Emission and Air Quality Measurements" 21 – 23 May 2003.* Prague, Czech Republic.

Tang, Y. S., Flechard, C. R., Dämmgen, U., Vidic, S., Djuricic, V., Mitosinkova, M., Uggerud, H. T., Sanz, M. J., Simmons, I., Dragosits, U., Nemitz, E., Twigg, M., van Dijk, N., Fauvel, Y., Sanz-Sanchez, F., Ferm, M., Perrino, C., Catrambone, M., Leaver, D., Braban, C. F., Cape, J. N., Heal, M. R., and Sutton, M. A.: Pan-European rural atmospheric monitoring network shows dominance of NH_3 gas and NH_4NO_3 aerosol in inorganic pollution load, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-275, in press, 2020.

The Norwegian Meteorological Institute, 2019. *EMEP MSC-W modelled air concentrations and depositions.* https://emep.int/mscw/mscw_moddata.html

Van Damme, M., Clarisse, L., Dammers, E., Liu, X., Nowak, J. B., Clerbaux, C., Flechard, C. R., Galy-Lacaux, C., Xu, W., Neuman, J. A., Tang, Y. S., Sutton, M. A., Erisman, J. W., and Coheur, P. F., 2015. Towards validation of ammonia (NH_3) measurements from the IASI satellite. *Atmospheric Measurement Techniques*, 8, 1575–1591, https://doi.org/10.5194/amt-8-1575-2015, 2014a.

Van Damme, M., Clarisse, L., Heald, C. L., Hurtmans, D., Ngadi, Y., Clerbaux, C., Dolman, A. J., Erisman, J. W., and Coheur, P. F.: Global distributions, time series and error characterization of atmospheric ammonia (NH3) from IASI satellite observations, Atmos. Chem. Phys., 14, 2905–2922, https://doi.org/10.5194/acp-14-2905-2014, 2014b.

Van Damme, M., Clarisse, L., Dammers, E., Liu, X., Nowak, J. B., Clerbaux, C., Flechard, C. R., Galy-Lacaux, C., Xu, W., Neuman, J. A., Tang, Y. S., Sutton, M. A., Erisman, J. W., and Coheur, P. F.: Towards validation of ammonia (NH3) measurements from the IASI satellite, Atmos. Meas. Tech., 8, 1575–1591, https://doi.org/10.5194/amt-8-1575-2015, 2015.

Van Damme, M., Erisman, J. W., Clarisse, L., Dammers, E., Whitburn, S., Clerbaux, C., Dolman, A. J., and Coheur, P.-F. Worldwide spatiotemporal atmospheric ammonia (NH_3) columns variability revealed by satellite, *Geophys. Res. Lett.*, 42, 8660– 8668, 2015. doi:10.1002/2015GL065496.

Van Damme, M., Clarisse, L., Whitburn, S., Hadji-Lazaro, J., Hurtmans, D., Clerbauz, C. & Coheur, P-F. Industrial and agricultural ammonia point sources exposed. Nature 564, 99–103. https://doi.org/10.1038/s41586-018-0747-1, 2018.

Vieno, M., Dore, A.J., Stevenson, D.S., Doherty, R., Heal, M.R., Reis, S., Hallsworth, S., Tarrason, L., Wind, P., Fowler, D., Simpson, D. and Sutton M.A., 2010. Modelling surface ozone during the 2003 heat-wave in the UK. *Atmospheric Chemistry and Physics*. 10, 7963-7978, doi: 10.5194/acp-10-7963-2010, 2010.15.

Vieno, M., Heal, M. R., Williams, M. L., Carnell, E. J., Nemitz, E., Stedman, J. R., and Reis, S.: The sensitivities of emissions reductions for the mitigation of UK $PM_{2.5}$, Atmos. Chem. Phys., 16, 265–276, https://doi.org/10.5194/acp-16-265-2016, 2016.

von Bobrutzki, K., Braban, C. F., Famulari, D., Jones, S. K., Blackall, T., Smith, T. E. L., Blom, M., Coe, H., Gallagher, M., Ghalaieny, M., McGillen, M. R., Percival, C. J., Whitehead, J. D., Ellis, R., Murphy, J., Mohacsi, A., Pogany, A., Junninen, H., Rantanen, S., Sutton, M. A., and Nemitz, E., 2010. Field inter-comparison of eleven atmospheric ammonia measurement techniques. *Atmospheric Measurement Techniques*, 3, 91–112, https://doi.org/10.5194/amt-3-91-2010.

WER (Wageningen Environmental Research), 2019. *First analysis of ecosystem monitoring as required under Art 9 of the NECD*. Ref. 3417/B2017/EEA Wageningen Environmental Research, Netherlands.
https://ec.europa.eu/environment/air/pdf/reduction_reports/Final%20report%20ecosystem%20monitoring%20network%20Nov2019.pdf

Wilkins, K., Aherne, J., Bleasdale, A., 2016. Vegetation community change points suggest that critical loads of nutrient nitrogen may be too high. *Atmospheric Environment,* 146, 324–331. doi:10.1016/j.atmosenv.2016.07.016

Wilson, S., Fernández, F., 2013. National survey of limestone pavement and associated habitats in Ireland, *Irish Wildlife Manuals*. National Parks and Wildlife Service, Dublin, Ireland.

Zhang, L., J. R. Brook, and R. Vet (2003), A revised parameterization for gaseous dry deposition in air-quality models, Atmos. Chem. Phys., 3, 2067–2082.

Zhang, L., Brook, J.R. & Vet, R, A revised parameterization for gaseous dry deposition in air-quality models, Atmospheric Chemistry & Physics, 3, 2067 – 2082, 2003.

Zhang, L., Wright, L. P., and Asman, W. A. H. Bi-directional air-surface exchange of atmospheric ammonia: A review of measurements and a development of a big-leaf model for applications in regional-scale air-quality models, J. Geophys. Res., 115, D20310, doi:10.1029/2009JD013589, 2010.

Abbreviations

Abbreviation	Full name	Links
AAQD	Ambient Air Quality Directive	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0050
Al	Aluminium	
AQ	Air quality	
C	Carbon	
CBED	Concentration Based Estimated Deposition	
CEC	Cation exchange capacity	
Cl	Chlorine	
CLe	Critical Level	
CLo	Critical Load	
CLRTAP	Convention on Long-range Transboundary Air Pollution	https://unece.org/fileadmin//DAM/env/lrtap/full%20 text/1979.CLRTAP.e.pdf
DAFM	Department of Agriculture, Food and the Marine	
DOC	Dissolved organic carbon	
EC	European Commission	
EMEP	European Monitoring and Evaluation Programme	https://www.emep.int/
EPA	Environmental Protection Agency	
GHG	Greenhouse gas	
GIS	Geographical Information System	
GMS	Grassland Monitoring Survey	http://www.botanicalenvironmental.com/projects/habitat-studies/monitoring/monitoring-and-assessment-of-three-eu-habitats-directive-annex-i-grassland-habitats/
HD	Habitats Directive	https://ec.europa.eu/environment/nature/legislation/habitatsdirective/
HONO	Chemical formula for nitrous acid	
ICOS	Integrated Carbon Observation System	https://www.icos-cp.eu/
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests	http://icp-forests.net/
ICP M&M	International Cooperative Programme on the Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends	https://unece.org/modelling-and-mapping
ICP Vegetation	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Vegetation	https://icpvegetation.ceh.ac.uk/

ICP Waters	International Cooperative Programme for assessment and monitoring of the effects of air pollution on rivers and lakes	http://www.icp-waters.no/
K	Potassium	
LTER	Long Term Ecosystem Research	
MAES	Mapping and Assessment of. Ecosystems and their Services	
Mg	Magnesium	
N	Nitrogen	
Na	Sodium	
NECD	National Emissions Ceilings Directive	https://www.eea.europa.eu/themes/air/national emission-ceilings/
NEMN	National Ecosystems Monitoring Network	
NFI	National Forest Inventory	
NHA	Natural Heritage Area	
NH_4, NH_4-N	Ammonium, Nitrogen content of ammonium	
NH_3	Ammonia	
NIEA	Northern Ireland Environment Agency	
NMVOCs	Non-methane volatile organic compounds	
NO_2	Nitrogen dioxide	
NO_3, NO_3-N	Nitrate, Nitrogen content of nitrate	
NO_x	All nitrogen oxides collectively	
N_2O	Nitrous oxide	
NPWS	National Park and Wildlife Service	
NSUH	National Survey of Upland Habitats	
Ntot	Total nitrogen	
O_3	Ozone	
P	Phosphorus	
PAN	Peroxyacetylnitrate	
POD_y	Phytotoxic Ozone Dose above a threshold flux of Y	
PO_4-P	Phosphorus content of phosphate	
POPs	Persistent organic pollutants	
PM	Particulate matter	
Ptot	Total phosphorus	
SAC	Special Area of Conservation	
SPA	Special Protection Area	
SO_2	Sulphur dioxide	

SO_4-S	Sulphur content of sulphate	
SUAS	Survey of Upland Acidic Systems	https://www.epa.ie/pubs/reports/climatechange/CCRP_31_web.pdf
TCD	Trinity College Dublin	
TUDublin	Technological University Dublin	
UCC	University College Cork	
UCD	University College Dublin	
UKCEH	United Kingdom Centre for Ecology and Hydrology	https://www.ceh.ac.uk/
UNECE	United Nations Economic Commission for Europe	https://unece.org/environment-policy/air
UWT	Ulster Wildlife Trust	
WFD	Water Framework Directive	https://ec.europa.eu/environment/water/water-framework/

Appendix 1: Approximate costs of options

A1.1 Air quality monitoring: NH_3 with passive samplers

Table A1.1.6-2: Indicative costs of monthly monitoring of NH_3 measurements with **ALPHA® samplers**. Actual costs have been censored to ensure open fair competition.

Items	Details	Costs per site per annum
Measurement frequency	Monthly, continuous	
Infrastructure requirement	Minimal: passive samplers	
Resources: capital purchase	Posts + shelters to expose air samplers	Post + bracket = X Standard tubeclamp fittings, or wooden posts to suit site requirements Shelter
Resources: ALPHA measurements OPTION A: Purchase ALPHA® samplers and source laboratory in Ireland to make measurements	Need to purchase sufficient components for measurements with Triplicate ALPHA per site Allow for turnaround time Lab + field blanks	Approx. X per ALPHA sampler Costs will vary depending on quantity
Resources: ALPHA measurements OPTION B: laboratory UKAS accredited laboratory (preparation and analysis)	Triplicate ALPHA per site 12 sets of triplicate ALPHA®. including lab + field blanks per site, per year.	Sample preparation + Analytical costs (ammonium analysis) - 12x3 = 36 ALPHA sampler extracts per year per site - Lab + field blanks Postal exchange with site
Resources: local site operators	Site visit every month to change over samples. Exchange of samples with lab. via normal mail, or courier.	site-dependent
Data management • Database to manage sample information and data, and to export data in an agreed format for NECD reporting. • QAQC of data • INSPIRE compliance • See also Appendix 5)	Example: A database (Microsoft Access - Oracle) has been developed by UKCEH to manage ALPHA samples and data. Generates unique sample codes, sample labels and record cards for every batch of samples. Calculates air concentrations (from sample information and chemistry data imported directly from LIMS), Assigns EMEP flags Outputs data in Defra UK-Air formats See also Appendix 5.	Costs will depend on in-house or outsourced
Calibration against a suitable NH_3 reference method, e.g. DELTA (see Table 1.2 below)	Co-location of ALPHA and DELTA sites at a minimum of three sites, covering the full range of expected NH3 concentrations (e.g. low, mid, high concentration sites) Ongoing parallel measurements to check annual calibration on a continuous, long-term basis	Costs of extra ALPHA measurements at NEMN DELTA sites.
Reporting, science input (analysis and interpretation)	Scope needs to be defined	
Estimated costs for operation of NEMN network	Site maintenance: 2-yearly visit to check post/bracket and refresher training for LSO	

A1.2 Air quality monitoring: NH_3 + SO_2 with DELTA® system

Table A1.2: Indicative costs of DELTA® systems and laboratory analyses. Actual costs have been censored to ensure open fair competition.

	Details	Costs per site per annum (ex. vat)
Measurement frequency	Monthly, continuous	
Infrastructure requirement	Access to mains power. Or wind-solar power delivery system at remote locations	site dependent: Mains power - costs for electrical installation Remote site: costs for wind-solar system (see below)
Capital purchase: Low-voltage (10 – 36V) DELTA® system	Does not include supply of any posts or fittings to set up the equipment.	Approx. X for one DELTA system. these costs are indicative only Costs will vary depending on quantity
Capital purchase: Wind-solar power delivery system for DELTA system:	Solar panel Wind turbine Batteries + regulators + weather-proof box. Frame Labour costs to build.	X estimate for one system. These Costs are indicative only Costs will vary depending on the spec. of components.
Resources: Laboratory UKAS accredited laboratory (preparation and analysis)	12 sets of denuder-filter pack sample trains, including lab + field blanks. Quarterly reporting in line with UK Air Quality Networks. DELTA® denuder-filter pack sample trains for monitoring gases: HNO_3, SO_2, NH_3 and aerosols: NO_3^-, SO_4^{2-}, NH_4^+, Cl^-, Na^+, Ca^{2+}, Mg^{2+}. Quarterly reporting in line with UK Air Quality Networks.	Sample preparation + Analytical costs 12 sample trains per site per year Lab + field blanks Postal exchange
Resources: local site operators	Site visit every month to change over samples. Exchange of samples with lab via post (An Post / Royal Mail)	site-dependent
Data management	The UKCEH AAGA database also manages DELTA data (see Table A1.1).	
Reporting, science input (analysis and interpretation)	Scope to be defined	
Estimated costs for operation of NEMN network	Site installation – initial outlay, Site maintenance: Annual visit to check equipment Network management Annual gas meter calibration	

A1.3 Air quality monitoring: NO_2 with passive samplers

Table A1.3. Indicative costs of NO_2 monitoring with diffusion tube. Actual costs have been censored to ensure open fair competition.

	Details	Costs per site per annum (ex. vat)
Measurement frequency	Monthly, continuous	
Infrastructure requirement	None: passive samplers	
Resources: capital purchase	Posts + shelters to expose air samplers	Post + bracket = X Shelter ~ depends on design Standard tubeclamp fittings, or wooden posts to suit site requirements
Resources: Capital OPTION A: Purchase of Diffusion tubes and identify laboratory in Ireland to make measurements	Need to buy enough for: Triplicate diffusion tube per measurement Allow for turnaround time Lab + field blanks	UK Suppliers Gradko ET enviro technology services price on application
Resources: NO2 diffusion tube measurements OPTION B: Gradko	Gradko offers NO2 diffusion tube measurement service	price on application
Resources: NO2 diffusion tube measurements OPTION C: ET	ET enviro technology services offers NO2 diffusion tube measurement service	price on application
Resources: NO2 diffusion tube measurements OPTION D: Ricardo EE	Ricardo EE manages the UK national rural NO_2 diffusion tube network https://uk-air.defra.gov.uk/networks/network-info?view=no2net	
Diffusion tube calibration (bias adjustment factor)	e.g. A database of bias adjustment factors determined from co-location studies throughout the UK https://laqm.defra.gov.uk/bias-adjustment-factors/national-bias.html	Co-location of NO2 diffusion tube measurements at AAQD sites. Coordinate with indicative diff. tube measurements under AAMP for cost-savings
Resources: local site operators	Site visit every month to change over samples. Exchange of samples with lab via post (royal mail)	site-dependent
Data management	Set up database to manage data	
Reporting, science input (analysis and interpretation)	Scope to be defined	
Estimated costs for operation of NEMN network	Site maintenance: 2-yearly visit to check post/bracket and refresher training for LSO	

A1.4 Air quality monitoring: Bulk precipitation

Table A1.4. Indicative costs of bulk deposition measurements with bulk precipitation collectors. Actual costs have been censored to ensure open fair competition.

	Details	Costs per site per annum (ex. vat)
Measurement frequency	continuous exposure, twice-monthly collection Monthly collections NOT recommended as potential loss of NH_4^+ and NO_3^-, even with addition of biocides such as thymol	
Infrastructure requirement	Fenced area with stake mounts Agreement from landowner and access	
Resources: Capital Purchase of Precipitation collectors and consumables	NILU Precipitation Collector: Precipitation funnel, (200mm diameter) Debris filter 2,5 litre bottles (x2) Stand and ground spike, Spare components: Funnel + 2,5 litre bottle,	Quotation on 09/10/2020
Resources: Laboratory: Chemical analysis OPTION A: UKCEH	2-weekly collections = approx.. 26 samples per year Full suite chemical analysis UKCEH Lancaster operates the UK Environmental Change Network (ECN), which has made long-term wet deposition measurements	UKAS accredited UKCEH Lancaster laboratory on request
Resources: Laboratory: Chemical analysis OPTION B: Ricardo EE	Ricardo EE manages the UK national rural NO_2 diffusion tube network https://uk-air.defra.gov.uk/networks/network-info?view=precipnet	on request
Resources: Laboratory: Chemical analysis OPTION C: Met Eireann	EMEP manual parameters (measured and submitted by Met Eireann): SO4, NO3, NH4, pH, Na, Ca, Mg, Cl, K, Cond, Cd, Pd, Cu, Zn, As, Cr, Ni	
Resources: local site operators	Site visit every 2 weeks to change over water bottle. Exchange of samples with lab via post/courier	site-dependent
Data management	Set up database to manage data	
Reporting, science input (analysis and interpretation)	Scope to be defined	
Estimated costs for operation of NEMN network	Site maintenance: Annual site service recommended	

A1.5 Air quality monitoring: GHG and ozone fluxes

Instrument costs and power supply:

- The instrumentation used to measure CO_2, CH_4 and O_3 fluxes can all be run on low power systems, so a mains power supply is not essential but will reduce the initial outlay for the equipment. The approximate costs for the various components and some options are listed below:
- CO2 Exchange and Meteorology Instrument packages
- Campbell Scientific CO2/H2O Enclosed Path Sensor with Ancillary Meteorological sensors and short mast £45 k (ex VAT & delivery)
- Campbell Scientific IRGASON open-path CO2/H2O and Turbulence sensor with Ancillary Meteorological sensors and short mast £35 k (ex VAT & delivery)
- Licor Li7200 Closed path CO2/H2O with Ancillary Meteorological sensors and short mast £50k (ex VAT & delivery)
- Licor Li7500 Open Path CO2/H2O with Ancillary Meteorological sensors and short mast £40 k (ex VAT & delivery)
- Data SIM for 4G access £350 pa
- Power Supply
- Methanol Fuel Cell with approx. 1 year's fuel £8k (ex VAT & delivery)
- Solar Panels and charge regulator £1k (ex VAT & delivery)
- Batteries and ancillary parts £1.5k (ex VAT & delivery)
- Wind turbine and charge regulator £1.2 k (ex VAT & delivery)
- Methane sensor
- Licor Li7700 Open path methane sensor £40k (ex VAT & delivery)
- Ozone Instruments
- Fast Ozone Sensor (CEH supplied, if available) £5k + £1k consumables pa
- Enviscope Fast Ozone Sensor ~£15k + £1k consumables (not looked at availability recently)
- Compact standard ozone monitor £8k

In terms of quantifying carbon budgets and ozone exposure the minimum needed would be a CO2/H2O & meteorology system with a standard ozone monitor, as ozone uptake can be reasonably well modelled using the other measurements but ideally a fast ozone sensor would be included as measurements over different vegetation and climates are limited. The Campbell IRGASON system is the cheapest, as well as lowest power, and works quite well in our experience, however the Licor 7200 enclosed path is the standard used by the ICOS program.

A1.6 Modelling air pollutant concentrations and deposition

It is recommended that the EPA pursue the generation of regularly updated atmospheric models which can be supported by this network. The cost of such modelling will depend on what approach the EPA prefer, and who generates such models. It is not possible at this time to estimate these costs.

Appendix 2: Synergies

The NEMN relies on integration with other long-term monitoring networks, where it has already integrated two Level II ICP Forests sites, and four ICP Waters Sites. Though the number of EMEP sites has reduced to three operational sites, it may make sense to redevelop some of these as NEMN sites depending on location. The following pertains to the most relevant synergies required for this phase of the NEMN, suggestions for further development are detailed in the following Appendix.

Table A.2.1. List of possible Level II sites where monitoring already occurs

Network	Site	NEMN link
WFD, Acid Sensitive Lakes	Lough Maumwee + feeder streams	Level II site
WFD, Acid Sensitive Lakes	Lough Veagh	Leve II site
WFD, Acid Sensitive Lakes	Glendalough Lake Uppper	Level II site
ICP Forests	Roundwood	1991–2017
ICP Forests	Brackloon	1991–2017
NATURA 2000	Clara Bog	Proposed Level II site

Table A.2.2. List of surveys with potential linkages to Level I network of NEMN

Network	Institution	Monitoring	NEMN link
EMEP	EPA, Met Éireann	Deposition	Deposition
EPA air quality network	Air quality	Air quality	Air pollution
National Forest Inventory	Forest Service, DAFM	ICP Forests Level I Crown Condition	Indicator of air pollution impact
6-year survey	NPWS	100 core grasslands 16+4 (99) uplands 48 raised-bog ecotopes	Level I grasslands Level I heaths Level I bogs
	Wild Atlantic LIFE	24 blanket-bog SACs	Potential Level I bogs
High-level Lakes	Trent University, EPA	Trace metals, Hg POPs GHG [? In the lake?] soils, physicochemical	Potential Level I lake sites
Acid Lakes Network	EPA	WFD lake monitoring programme, mid-1980s to...	Three Level II lakes come from this former network
ICP Waters Lakes	EPA, ICP Waters	ICP Waters monitoring	A subset of the former EPA Acid Lakes Network

A.2.1. ICP Vegetation

Ireland participated in the 2015 European Moss Biomonitoring Survey, where the impact of atmospheric deposition of pollutants was assessed (Aherne et al., 2020*). A national survey for *Hylocomium splendens* and *Pleurozium schreberi* was conducted, where the nitrogen content in plant tissue was assessed. Moss samples were collected from 130 sites across Ireland, selected based on a 25 km^2 grid. The most common of the two mosses observed was *Hylocomium splendens*, which is ubiquitous across Ireland in acidic habitats. The recommended method for NEMN-Ireland (see Section 4.4.1) is compatible with this, but we also recommend sampling *Pseudoscleropodium purum*, a species ubiquitous in more calcareous habitats.

A.2.2. Ammonia monitoring

Annual ammonia concentration monitoring has been carried out nationally on three occasions. Two national networks were set up, one in 1999 -2000 (de Kluizenaar and Farrell, 2000*) and repeated in 2013 – 2014 (Doyle et al., 2017). The network in the 2013 – 14 study monitored concentrations across 26 sites (range = 0.48 – 2.96 µg NH_3 m^{-3}), whereas the previous study monitored 40 sites) range = 0.18 – 3.21 µg NH_3 m^{-3}). Both studies were focused on ambient monitoring, and hence sites were intentionally located at least 2 km from intensive sources (i.e. pig and poultry farms). These monitoring sites were not linked with any annex I habitats, and as both monitored for just a year, these sites are not considered priority for inclusion within the NEMN.

Monitoring on 12 Natura 2000 sites in 2017 provided NH_3 concentrations of between 0.47 – 4.59 µg NH_3 m^{-3} and total N deposition of between 5.93 – 17.78 kg N ha^{-1} $year^{-1}$ (Kelleghan, in press*). This project focused on monitoring sensitive habitats, with a focus on raised bogs. Every raised bog monitored exceeded both its critical level and critical load for impacts from NH_3 and nitrogen respectively. Since Natura 200 sites are also annex I habitats, many of these sites are included in the shortlisting for site identification.

A.2.3. TUDublin Pollen & Fungal Spores network

Fungal and pollen monitoring by David O'Connor, TU Dublin, under EPA-funded projects POMMEL: Pollen monitoring and Modeling 2017-CCRP-FS.35, FONTANA: Fungal mOnitoring ANd Algorithm 2018-CCRP-MS.53, and an EPA–Irish Research Council scholarship "Investigation into the sampling, modelling and chemical interactions of pollen via novel methodologies" (Emma Markey) may offer opportunity to co-locate at NEMN sites.

A.2.4. CAFE – Ambient Air Quality Monitoring Network

The Clean Air for Europe Directive (CAFE) is specifically referred to in the NEC Directive and the associated guidance from the Commission on establishing ecosystem monitoring network. In Ireland, ambient air quality monitoring sites are managed by the EPA in conjunction with local authorities. Whilst the data from this network is central to monitoring the levels of ambient air pollution and potential impacts on human health, the current locations of these ambient monitoring sites are predominantly in urban or rural population centres as opposed to natural unpopulated ecosystems. As such, it is not proposed to co-locate NEMN sites with CAFE sites for Phase 1 of the network. It may be necessary to co-locate some passive NO_2 monitoring at one of the CAFÉ continuous NO_x monitoring sites for quality control and calibration purposes.

A.2.5. Marine Institute, Newport Catchment facilities

The Marine Institute operates long-term monitoring of fish and catchment ecosystem at laboratory facilities in Furnace, Newport, Co. Mayo. The Burrishoole catchment has been an international index site for migratory fish since the 1950s. Fish monitoring includes capture of every fish entering and leaving the upper lake, and some of the longest fish datasets in Europe for salmon and eels. Biological sampling is undertaken in rivers every year in May, with an intensive survey of invertebrates, and in the two lakes monthly sampling of phytoplankton (algae) and zooplankton. This sampling is now running two decades in Burrishoole, allowing development of a total food web of the catchment.

Fish data collection is complemented by environmental monitoring, consisting of automated stations on Loughs Feeagh and Furnace and on three of the rivers, the Srahrevagh, the Black and the Glenamong, measuring temperature, oxygen, conductivity, pH, every 2 minutes, supported by weekly and monthly spot samples to check sensors and as an independent long-term measurement. Meteorological monitoring builds on a climatological station in the Met Éireann network operating daily since 1959, including sunshine and evaporation instruments still operational and ongoing recording of cloud cover and hours of sunshine, now supplemented since 2005 by an automatic station. Both lake monitoring stations also include automatic weather stations for lake-surface conditions. These monitoring installations are described by Elvira de Eyto here[*].

The Burrishoole Ecosystem Observatory Network 2020, BEYOND 2020[†], hosted at Dundalk Institute of Technology, is a research cluster building on the ecosystem monitoring at the Marine Institute infrastructure at Newport, with work packages on nutrient dynamics, environmental observation, sensor development, metagenomics, microbiome, genetic architecture, and network science and modelling. Monitoring at Burrishoole includes carbon dynamics, with lake-surface measurements done, and link to proposed freshwater GHG flux measurement within ICOS. With monitoring of pCO2 at Lough Feeagh, exploratory measurement of CO_2 flux, and stream measurements, this constitutes the first lake ecosystem GHG flux assessment and first carbon cycle assessment for a lake in Ireland.

A.2.6. LTER Ireland proposal

ILTER Ireland Irish Long-Term Ecosystem Research Network is proposed community and research infrastructure aspiring to be part of the LTER and eLTER networks, providing research infrastructure, organisational and management capability for long-term ecosystem research in Ireland, and a basis for developing and implementing networks. Waterford IT and Carlow IT prepared a business case for an LTER infrastructure to be developed in Ireland (funding was provided through the EPA research programme.

A.2.7. Bord na Móna

The commercial semi-state company Bord na Móna has moved out of peat harvesting for energy in 2020, with immediate redirection of staff capability into peatland restoration. Significant monitoring capacity is expected to be developed, and large ecosystems centred on peatlands undergoing rewetting, recovery from harvesting, or other states of recovery following earlier cessation of harvesting, as well as associated wetland and waterway entities, will be available.

A.2.8. Coillte

The commercial semi-state company Coillte manages extensive forests including many semi-natural ecosystems, and significant non-forest lands including many heaths and peatlands. Coillte

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[*] https://www.youtube.com/watch?app=desktop&v=2IpGh7MUaw0&feature=youtu.be&ab_channel=marineinstituteIRL

[†] https://www.dkit.ie/beyond-2020

has provided access for long-term monitoring at ICP Forests sites, and is the landowner for the currently-proposed sites at Brackloon and Roundwood.

A.2.9. Department of Agriculture, Food and Marine

In addition to maintaining the NFI, DAFM centres provide annual evaluation of cereal varieties, from which recommendations for culture are made. This controlled environment is extended to a small number of commercial installations, and represents a potential environment where screening for ozone impacts could be done. Note also that drought impacts may be observed but are not systematically documented. Technical expertise, crop variation, experimentally robust plot layout, and data structures are present.

Table A.2.3. List of potential partners and stakeholders in National Ecosystem Monitoring Network Ireland.

Institution	Contact	Link to NEMN
EMEP	nilu.no/ccc	EMEP stations
EPA	Pat Kenny	EMEP stations
Met Éireann	agromet@met.ie	Agricultural Meteorology Unit
EPA	Deirdre Tierney	Water Framework Directive sites ICP Waters sites
NPWS	Andy Bleasdale	NATURA 2000 network
UCD	Thomas Cummins	ICP Forests network ICP Integrated monitoring site
Marine Institute	Elvira de Eyto	Newport Catchment Facilities, Burrishoole site
AFBI	Suzanne Higgins	COSMOS-UK network
UKCEH	Sim Tang	ECN network, COSMOS-UK network
UCD	Florence Renou-Wilson	AUGER project - Clara Bog site - bog sites
Coillte	Pat Neville	forest sites
AgMet	Klara Finkele	soil-moisture network, modelling
COSMOS-UK	Suzanne Higgins	Agri-Food & BioSciences Institute, Northern Ireland
TU Dublin	David O'Connor	Fungal & Pollen Network
Teagasc	Macdara O'Neill David Kelleghan	Agricultural Catchments Programme - Lysimeter stations - Met. Stations, Class A pans - PastureBase - Teagasc Research stations and farms
UKECN	Sim Tang	UKCEH, Edinburgh
ILTER Ireland	Mark White Owen Naughten	WIT IT Carlow
ICP Forests	Thomas Cummins	Level II forest sites
ICP Forests	Luke Heffernan John Redmond	Level I forest sites; National Forest Inventory, Department of Agriculture food and the Marine
ICP Integrated Monitoring	Thomas Cummins	Brackloon Level II forest site; UCD
ICP Vegetation	Felicity Hayes	UKCEH
ICP M&M	Ed Rowe	UKCEH
DAFM	Luke Heffernan John Redmond	Level I forest sites; National Forest Inventory
DECC (formerly DCCAE)	Eoin Riordan	Departmental oversight of EPA

A2.10. ICOS

The Integrated Carbon Observation System (ICOS) is a network combining national networks of stations monitoring greenhouse gas concentrations in the atmosphere, as well as carbon fluxes between the three domains of atmosphere, ecosystems, and oceans, each with a thematic centre, and with standardisation and open data. Member and Observer countries are recognised, and the network integrates with other networks, and interfaces with policy arenas. The ICOS network is currently being developed in Ireland with buy-in from Universities, Teagasc, Bord na Móna, and others. These sites will feature long term continuous monitoring, and though this may not always occur on a suitable habitat they should still be considered for inclusion within the NEMN. The presence of site operators would allow for easy integration of monitoring a number of relevant parameters, including for example ammonia. As national ammonia concentration and nitrogen deposition models cannot be validated due to a lack of a continuous monitoring network, any additional sites would benefit the NEMNs ability to carry out this task. This would in turn, improve the estimation of pressures on Level I sites using such models. The ICOS sites shown in Figure 3.3 are currently provisional and are likely to change, it is advised that lines of communication remain open between both networks to ensure the synergy is fully economised upon. Clara Bog, for example, has been identified as a site for inclusion in both networks, as it occurs on a raised bog. Figure 3.2 . below shows the current proposed ICOS sites, past EMEP monitoring locations and sites identified for early inclusion in the NEMN (ICP Forests and ICP Waters).

ICOS research infrastructure (ICOS RI) represents core national stations complying with qualifying criteria, and a member country must participate in monitoring of all three domains. Progress towards participation in ICOS RI, plus a more extensive network to be known as ICOS Ireland, includes recognition of historic and proposed measurement sites, evaluation of compliance of instrumentation, communication across multiple networks and site infrastructures, and costing for support and operation. ICOS objectives relevant to NEMN include siting at ecosystem sites, development of a national research hub, centralised laboratory, and technical support, sharing of equipment and technical expertise, national data platform and repository, providing near-realtime data, and identifying links to other projects and networks. This infrastructure will benefit from parallel networks such as the Met Éireann synoptic automatic weather stations. The ICOS community links to the SMARTBOG Observation Group, currently focussing on instrumenting the Clara Bog site, and the TERRAIN-AI proposal to Science Foundation Ireland. ICOS sites currently operational and proposed are listed in Table A4.2

Table A2.4: ICOS stations in Ireland, where ICOS RI refers to primary research infrastructure sites and ICOS Ireland refers to secondary ICOS sites.

Site	Type	Status	Operator
Clara Bog	ICOS RI	Operational	TCD
Glencar Bog	ICOS RI	Operational	UCC
Johnstown Castle	ICOS RI	Proposed	Teagasc
Dooary	ICOS RI	Operational	UCD
Lullymore	ICOS Ireland	Operational	Bord na Móna
Cavemount	ICOS Ireland	Operational	Bord na Móna
Garryduff	ICOS Ireland	Chambers; no tower	[not identified]
ACP1	ICOS Ireland	Proposed	Teagasc
ACP2	ICOS Ireland	Proposed	Teagasc
ACP3	ICOS Ireland	Proposed	Teagasc
ACP4	ICOS Ireland	Proposed	Teagasc
All Saints Bog	ICOS Ireland	Operational	NPWS

A2.11. Teagasc

As part of Teagasc's catchment monitoring program, they are developing a network of DELTA denuders and ALPHA samplers to monitor different concentrations proximal to different sources. They will use this data to calculate ammonia and nitrogen flux within these agricultural areas. It is currently envisioned this will take the form of ammonia monitoring in 9 locations using ALPHA samplers, supported by three DELTA denuders. Sites currently proposed for inclusion within this Teagasc network are Castledockrell and Ballcanew in Co. Wexford alongside Timoleague in County Cork. These sites have been selected to represent typical tillage, low intensity, and high intensity farming. This monitoring will hence focus on agricultural habitats, namely improved agricultural grassland, and tillage. Though not priority habitats for inclusion within this network, they would enhance the spatial resolution of the Level II sites.

A2.12. CANN Project

The CANN project is currently monitoring NH_3 concentration on two Natura 2000 sites south of the border. These sites are Slieve Beagh SPA in Co. Monaghan, and Cuilcagh - Anierin Uplands SAC in Co. Cavan. While the current monitoring is covering multiple sites therein, it is recommended that at least one NH_3 monitoring location from each site be adapted into a continuous Level II site under the NEMN. These sites could potentially be maintained through collaboration between the EPA, Ulster Wildlife Trust and the NIEA. These two Natura 2000 sites are included within the proposed Level I and II networks...

A2.13. EMEP Air quality monitoring sites

As part of the CLRTAP, parties are asked to operate monitoring stations to comply with and contribute to the European Monitoring and Evaluation Programme (EMEP). EMEP monitoring objectives include both long-term monitoring of key air pollutants including the inorganic composition of PM, pollutant gases, and other species such as Persistent Organic Pollutants (POPs). EPA and Met Éireann share a Memorandum of Understanding under which it is agreed that they will continue to collaborate in the operation of the specified EMEP sites.

High-resolution ozone and meteorological observations are available at Valentia and Mace Head and at sites in the Ambient Air Quality Network. These could be used to calculate ozone flux and exceedance of critical levels.

A2.14. Co-location arrangements

Where networks or researchers propose to co-locate with NEMN, research managers should at proposal stage contact EPA to discuss the suitability of the site and compatibility of research objectives. Researchers must take responsibility for permissions around access, screening for appropriate assessment, insurance cover, and operational planning. Installations, equipment and material are the responsibility of those researchers, and must be removed from site at close of work, including provision for removal in the case of longer-term work. No liability may transfer or be assumed to transfer to EPA.

Appendix 3: Site visits

A3.1 Site Visits

Sites visits were conducted during August–October 2020, in conjunction with local NPWS staff where available. Field maps of habitats of interest on site were prepared for surveyors, including satellite imagery for ease of interpretation. Enquiries regarding access and suitability focused on NPWS Conservation Rangers, though other individuals were approached where relevant e.g. Within Ulster Wildlife Trust, NIEA, and land owners.

With the time restrictions of this design phase, it was not possible to visit all candidate Level II sites. Additionally, upon visits some sites would eventually be excluded from the Level II network.

Table A.3.1: Candidate Level 2 sites visited, 2020

Site Name	Co.	SAC	Habitats, qualifying interests	Ownership	Visit date
Split Hills and Long Hill Esker	WH	001831	6210	public/private	12-Aug-2020
Clara Bog	OY	000572	7110 7120 7150 91D0 6210	public	23-Sep 2020
Slieve Beagh	MN	004167	6410 4030 7130	private	24-Sep 2020
Derrycunnihy	KY	000365	91A0 7130 4010	public	1-Oct 2020
Sheheree Bog	KY	000382	7120 7110	private	1-Oct-2020
Gortlecka Meadows	CL	001926	6210	public	2-Oct 2020
Kilconny Bog	CN	000006	7110 7120	private	13-Oct 2020
Killeglan	RN	002214	6210	private	14-Oct 2020
Moanour Heath	Tipp	002257	4010 4030	private	15-Oct-2020
Mongan Bog	OY	000580	7110 7120 7150	public	16-Oct-2020
Brown Bog	LD	002346	7110 7120 7150	[private TBC]	16-Nov 2020
Pilgrim Road Esker	OY	001776	6210	private	16-Oct-2020
Glenasmole	DB	001209	6210 6410 7220	public [TBC]	13-Oct 2020
Carrowbehy Bog	RN	000597	7110 7120 7150	public	20-Oct 2020
Cullahill Mountain	KK	000831	6210	private	23-Oct 2020

Derrycunnihy Wood is part of Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC. Gortlecka Meadows is part of East Burren Complex SAC.

Split Hills and Long Hill Esker SAC (Westmeath)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) [6210]

Two locations on the esker were visited, the south location along the main R446 and a former quarry on the north side of the SAC. Contact was made with the NPWS ranger (Therese Kelly), and a general operative as well as the landowner of the north location were contacted while on site. Access is very good for both sites, with parking along the road. Both sites visited are highly visible to the public, although little pedestrian activity was seen directly. The south location is along a busy main road, with some pesticide impacts observed in the area possibly from management for ease of public access. The north location is a former quarry and is sheltered due to the steep slopes remaining. Size of the sites may be an issue for both locations as the area for both is limited.

Clara Bog (Offaly)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (*important orchid sites) [6210]; Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]; Depressions on peat substrates of the *Rhynchosporion* [7150]; Bog woodland [91D0]

Dr. Matt Saunders provided information for this site, as he is involved with the ICOS network, and provided directions to the ICOS station which is located in the center of the western side of the bog. Access to this location is good and separate from the main tourist boardwalk. Planks of wood lead you to the ICOS station ~1km for the edge of the bog. Intensive agriculture surrounds the bog although impacts were not observed directly. The ICOS station has solar panels for power supply. It is a vast remote location and it is exposed to the weather.

Slieve Beagh (Monaghan)

Blanket bog [7130], European dry heaths [4030], *Molinia* meadows [6410]

Rory Sheehan- CANN project officer for Sliabh Beagh is the contact for this site. Slieve Beagh heath is located on the eastern side of the road running through the site. Ammonia ALPHA samplers can be found on the heath and access is good from the road. The heathland covers a large area with little activity. An Taisce announced on 18-September 2020 the acquisition of property at Sleve Beagh, consisting of 2200 acres in counties Monaghan and Tyrone, former grouse shooting areas, and overlapping the SAC as well as Slieve Beagh SPA (hen harrier).

The *Molinia* meadows are located on the western side of the road, and can be accessed relatively easily. Cattle are currently grazing parts of the meadows while other areas are under-grazed despite a lack of fencing dividing up the site. Further north towards the border with Northern Ireland, blanket bog is present on either side of the road. Access to this part of the bog is very easy compared with another area of the bog visited further west, however this area is much more visible to the public and there is turf cutting currently taking place here.

Derrycunnihy (Killarney National Park, Kerry)

Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC Many habitat types, including Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles [91A0], Blanket bogs (* if active bog) [7130], Northern Atlantic wet heath [4010]

Mary Sheehan is the park ranger for this site and provided detailed information. Access is good when the correct access point is used, and a 4X4 vehicle can travel the whole length of the site on a walking path. The site contains bog, heath and oak woodland which is grazed by deer and goats year-round. Some flooding occurs on the path in winter which also covers parts of the bog and heath habitats. The pathway also gets a lot of tourists in summer and cyclists, but the area is a vast unaltered landscape with plenty of secluded locations.

Sheheree Bog (Killarney, Kerry)

Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]

Daniel Buckley is the ranger for East Kerry and he provided the information for this SAC. Access is very good on the eastern side of the bog through an agricultural field. The land owner appears to be open to research taking place at this location but confirmation would be required. The bog is surrounded by intensive agricultural fields.

Gortlecka Meadows (Clare)

East Burren SAC. Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (*important orchid sites) [6210]; Limestone pavements [8240]

Emma Glanville is the ranger, and met us on site. Access is very good with road frontage, though pedestrian marked walks through the site may give undue attention in parts, while others are quite concealed. The site has been partly reclaimed (c. 1980s), was partly developed for a large structure (c. 1990), while two further parts had earth materials extracted, one backfilled with unspecified waste fill and topsoil. Notwithstanding this extensive disturbance, management including active grazing is maintaining a biodiverse sward, which combines intimately with biodiverse rock outcrops and limestone pavement areas.

Killyconny Bog (Cavan/Meath)

Killyconny Bog (Cloghbally) SAC, Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]

Information from David McDonagh, but a new contact would be required for any further visits. Access is very good to this site, and a small lane runs along the western side of the bog. There are information signs about the site and warning signs about the danger, as public use of the lane must be high. Planks of wood were found on the edge of the bog so there may be plans of a boardwalk in the future. The bog is surrounded by intensive agriculture fields on all sides and indicators of eutrophication were observed. Some scientific equipment remains on the bog and drain blocking has taken place. The bog and surrounding cutaway land are treacherous to walk on so sticking to the previously marked out path to the bog would be safest.

Killeglan SAC (Roscommon)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (*important orchid sites) [6210]

Laura Gallagher, an NPWS ranger, is the contact for this site. Ownership of the site is complex with 13 different owners. Access to the site is very good with a farm road leading up to the southern edge of the grassland. The ground is very rough and large rocks are scattered everywhere, so vehicle access stops at the entrance gate. The most accessible area of grassland looks to be periodically grazed with cattle/sheep and there is no observed pedestrian impact. The SAC is surrounded by agricultural fields and is not very visible to the public. Contact with the relevant landowners depending on which area of the site is suitable for use would be important, and Laura Gallagher would be helpful for this. While the area is large, some parts are heavily grazed with cattle while other parts have been recently reclaimed, possibly making them unsuitable.

Moanour Heath SAC (Tipperary)

Northern Atlantic wet heaths with *Erica tetralix* [4010]; European dry heaths [4030]

Sean Breen is the NPWS Ranger contact for this site, and the landowner is also positive about research taking place here. Access is very good for this site and it can be accessed from two sides.

Parking in the landowner's yard and a short walk up to the heath. The south side of the heath is grazed periodically with sheep and gorse has begun taking over the heath here also. It is a large area but travel within the site is difficult due to the gorse.

Mongan Bog SAC (Offaly)

Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]; Depressions on peat substrates of the *Rhynchosporion* [7150]

Jack McGauley, the Living Bogs LIFE Project Manager, was contacted for this site. Access is excellent, and an old Board na Mona railway runs along the southeast side of the site. There is an information sign at the edge of the bog but no public impact was observed on the bog. Intensive agriculture surrounds the bog, especially on the south edge, and a Bord na Móna railway line still in use runs into the bog on the east side, but does not impact most of the bog.

Brown Bog SAC (Longford)

Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]; Depressions on peat substrates of the *Rhynchosporion* [7150]

Local contact is Sue Moles, NPWS ranger. Access is by a track at first, with a short part walking without paths through woodland. Air monitoring equipment has been carried out here before. There are no public accessing the site and no active management by NPWS. It is rewetting but this has not, so far, stopped significant encroachment of pine into the bog. Cattle, intensive pig farming and forestry are the main land uses surrounding the bog.

Pilgrim Road Esker SAC (Offaly)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (*important orchid sites) [6210]

Jack McGauley the Living Bogs LIFE Project Manager was contacted for this site. Access is good for the esker, and it is located very close to Mongan Bog SAC, however parking is difficult as the road running through the esker is narrow. The esker is owned by several different landowners and it is split into strips of different ownership. It is currently grazed with cattle and some soil erosion due to this was observed. The part of the esker on the southern side of road is more accessible, but appears to have been abandoned as vegetation has grown very long.

Glenasmole Valley SAC (Dublin)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) [6210]; *Molinia* meadows on calcareous, peaty, or clayey-silt-laden soils (*Molinion caeruleae*) [6410]; Petrifying springs with tufa formation (*Cratoneurion*) [7220]

No local contact was identified for this site. The site appears to be in public ownership as part of the reservoir lands, requiring confirmation. Excellent access from public walkways accessible by vehicle from reservoir access in care of Office of Public Works and Dublin City Council. Sites were observed to be in sheep and cattle grazing. Some off-road access by walkers. The site has a complex hydrology and geomorphology, with calcareous gravels and associated springs perched on quartz-rich rocks.

Glenasmole Valley SAC (Dublin)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) [6210]; *Molinia* meadows on calcareous, peaty, or clayey-silt-laden soils (*Molinion caeruleae*) [6410]; Petrifying springs with tufa formation (*Cratoneurion*) [7220]

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Carrowbehy (Roscommon)

Carrowbehy/Caher Bog SAC. Active raised bogs [7110]; Degraded raised bogs still capable of natural regeneration [7120]; Depressions on peat substrates of the *Rhynchosporion* [7150]

Local contact is Pat Ryan, NPWS Ranger. Carrowbehy, the location accessed, is part of a complex of peat domes with much intact raised bog, including in this case rewetted areas with drain blocking seen, and vegetation changes apparently underway with increased surface wetness, though tension pools are long-extant features. The local community is active in developing a walkway, partly gravelled with a locked barrier (for which the key may be sought through Pat), and with planned extension onto a timber walkway, with signage installed. Monitoring of water levels at a weir is active, presumed part of The Living Bog LIFE project (LIFE 14 NAT/IE/000032).

Cullahill Mountain (Kilkenny)

Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) [6210]

The local contacts for this site are Jimi Conroy the NPWS Ranger, and the landowner. Some scrub removal has been undertaken. Grazing of horses occurs year-round, and cattle in winter. The site has a management plan under development. Strong local support for monitoring, including fixed equipment, with necessary stock fencing of a small area. Note that shallow soil over limestone bedrock constrains placement of stakes.

Appendix 4: Risk Applied to Sites

A full list of sites assessed for risk based on both this phase of the network (raised bog, calcareous grasslands, blanket bog/heath and molinia meadows) and future phases of the network (limestone pavement, sand dunes, oak woodlands and upland lakes) is available to download from the UCD Research Repository (https://researchrepository.ucd.ie/).

Table A4.1. Example of risk applied to NPWS biomonitoring sites.

NEMN ID	Level I	Site Name	Total Nitrogen Depostion	Sulphur Deposition	NH_3 concentration	MARSH	Nitroindex	O_3	Rain
			kg N ha^{-1} year^{-1}	kg S ha^{-1} year^{-1}	µg m^{-3}	µg m^{-3}	(+ 1 to -1)	µg m^{-3}	mm
RB_25	Yes	Killyconny	13.8	1.1	4	2	0.1	33.6	966.8
RB_26	Yes	Knockacoller	10.4	1	3	1.8	-0.3	33.5	975
RB_27	Yes	Sharavogue	9.7	1	2.7	1.8	0.2	33.6	932.8
RB_28		Ballynafagh	9.1	1.3	2.2	1.7	0.3	33	856.9
RB_29	Yes	Clara Bog	9.1	1	2.3	1.6	0.6	33.4	880.3
RB_30	Yes	Raheenmore	9.1	1	2.2	2.2	0.2	33.7	912.3
RB_31		Clonfinane	8.7	1.1	2.1	2.1	0	33.6	908.3
RB_32		Ballyduff	8.7	1.1	2.1	2	-0.1	33.6	903.6
RB_2	Yes	Moanveanlagh	8.6	1.4	2.2	1.8	0.3	34.5	1173.2
RB_33		Firville	8.6	1.1	2.2	1.9	0.3	33.6	911.3
RB_34		Garriskil	8.6	0.9	2	1.6	0.1	33.7	956.7
RB_35	Yes	Kilcarren	8.4	0.9	2.3	1.8	0.4	33.5	903.3
RB_36		Carn Park	8.3	1.1	1.8	1.7	0.8	33.5	920.7
RB_37		Ferbane	8.1	1.2	1.8	1.7	0.8	33.6	904
RB_38		Moyclare	8.1	1.2	1.8	1.7	0.7	33.6	901.7
RB_39		Crosswood	8.1	1.1	1.7	1.5	0.8	33.5	906.5
RB_40	Yes	Mongan	8.1	1	1.8	1.5	0.9	33.8	901.7
RB_41		All Saints	7.9	1.1	1.8	1.7	0.7	33.8	868.5
RB_42		Redwood	7.9	1	1.9	1.7	0.7	33.8	898.1
RB_43		Ballykenny	7.6	1.1	1.6	2	0	33.5	994.6
RB_44		Fisherstown	7.6	1.1	1.6	1.8	0.1	33.5	970.7
RB_45	Yes	Brown Bog	7.6	1.1	1.6	1.6	0.1	33.5	966.7
RB_3		Camderry	7.3	0.9	1.6	1.8	0.5	33.7	1113.1
RB_4	Yes	Corbo	7.2	1.1	1.6	1.9	0.5	33.9	1027
RB_5		Lisnageeragh	7.1	0.9	1.7	2	0.5	33.8	1079.7
RB_6		Kilsallagh	7.1	0.9	1.7	1.9	0.3	33.8	1098.5

Appendix 5: Data management

A5.1 Options for future work as part of framework

Objectives: Database, reporting tool (database) and web presence for NEMN

Proposed research work:

Task 1: Database

To develop a database for integrated data collation, curation and management of data from NEMN.

Task 2: Reporting tool

Develop reporting tool and on-going integrated data management for the next submission in 2022 (monitoring sites) and 2023 (data).

Task 3: Website for NEMN

Identify a suitable platform/website for hosting Irish NEMN (National Ecosystem and Monitoring Network) web information and data,

Develop web pages and content for Irish NEMN, in consultation with EPA and stake holders,

Develop agreed functionalities.

It is envisaged to cover four areas:

Map Tool

The main tool, offering spatial interaction with the NEMN sites and the national air quality / ecosystem network locations linked to them.

Summary data for each site will be provided from the NEMN database, along with links to the networks that the site is a part of.

NEMN Info

Summary information on Irish government obligations, including on NECD Article 9 reporting, requirements and links to relevant websites.

Information on reporting cycles for NEMN data

NEMN Data

What it is, what it contains and how it is formed.

What has been submitted and links to Eionet for submitted files.

Integration with other networks in Ireland

Brief summaries of the networks the NEMN sites are part of and links to relevant websites

Link to protocols and further information

Establish reporting metrics and reporting cycle (e.g. annual) for different Article 9 parameters into the NEMN.

Collection of air quality and ecosystem data and information in one place on the NEMN web site for stakeholders, researchers and interested parties.

Maintain and update annual NEMN data collation to contribute to 4-yearly reporting cycles of Article 9 NECD reporting.

Update web pages following annual reviews of networks and links.

INSPIRE data compliance

- Steps to publish data that meets INSPIRE standards:
- Step 1: Evaluate and select data sets - Which datasets will have to be published?
- Step 2: Create INSPIRE compliant metadata - Metadata provides the means for data users to discover what data exists and what services are available, or vice versa.

- Two types of discovery metadata:
- Metadata for the dataset being published.
- Metadata for the network services (e.g. epa) being used to publish the data.

- Step 3: Check compliance with licencing terms
- Step 4: Register data and services on epa.ie
- Step 5: Publish data - Under INSPIRE it is not sufficient to just publish the dataset on the website or to provide an interactive map.
- INSPIRE specifies network service to directly stream data into other applications that
- Allow datasets to be searchable (**Discovery Service** provided by data.gov.uk)
- Allow datasets to be visualised (**View Service**)
- Provide access to data content (**Download Service**)Step 6: Transform data to INSPIRE standards

Table A5.1: Reporting cycles

Networks	Data reporting	Frequency	Last submission?	Next submission
NEMN	EU Eionet https://www.eionet.europa.eu/reportnet	Every 4 years	Sites: 01.07.2018 Data: 01.07.2019	Sites: 01.07.2022 Data: 01.07.2023
ICP Level I and II Forests	ICP Forests database http://icp-forests.net/	Annual	09-Oct 2020	Continuous
NPWS	Article 17 reporting	Every 6 years	2019	2023
EMEP	National emission model	Annual	2019	2020
AQD Ireland	Urban air quality	Annual	2019	2020
Acid Lakes	Chemistry & Invertebrates	Annual	2019	2020
New NEMN sites: Air quality parameters	NEMN database	Annual	Not started	
New NEMN sites: Surveys / Biology parameters	NEMN database	Every 4 years	Not started	Sites: 01.07.2022 Data: 01.07.2023
New NEMN sites: Chemistry parameters	NEMN database	Annual	Not started	Sites: 01.07.2022 Data: 01.07.2023
Water Framework Directive	EU Eionet	Every 6 years*	2018	22.12.2024
Habitats Directive	EU Eionet	Every 6 years	2019 (covering period 202013 – 2017)	31.09.2019

* https://rod.eionet.europa.eu/obligations/763