Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-92:
Options for an enhanced ammonia monitoring network for Wales

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[1] UK Centre for Ecology and Hydrology

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Abbreviations Used in this Report

AGANet	Acid Gas and Aerosol monitoring Network
AURN	Automatic Urban and Rural Network
CAAP	Clean Air Advisory Panel
ECN	Environmental Change Network
EMEP	European Monitoring and Evaluation Programme
EUNIS	European Union Nature Information System
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
LSO	Local Site Operator
N	Nitrogen
NAMN	National Ammonia Monitoring Network
NH_3	Ammonia
SNAP	Shared Nitrogen Action Plan
SOP	Standard Operating Procedure
UKAS	UK Accreditation Service
UKCEH	UK Centre for Ecology & Hydrology
UKEAP	UK Eutrophying & Acidifying Network

Contents

1 AIMS AND OBJECTIVES

This document is an outline proposal of additional monitoring sites for atmospheric ammonia and acid gases to supplement the existing small number of sites in Wales, which are part of the UK's National Ammonia Monitoring Network (NAMN) and Acid Gas and Aerosol monitoring Network (AGANet).

The aim of the enhanced network is to provide a more detailed evidence base for atmospheric nitrogen concentrations and deposition across Wales, in the context of ongoing work at the Welsh Government (WG) to develop air quality targets for human health and the environment. One key impact of air quality pollutants on semi-natural habitats and designated sites is through atmospheric nitrogen input, mainly from ammonia (predominantly from agricultural emission sources) and nitrogen dioxide (NO_2, predominantly from combustion sources). A parallel work stream under the Clean Air Advisory Panel (CAAP) for WG has discussed the development of target options in this context in detail and is in the process of finalising recommendations (Rowe et al., 2023). The CAAP requested that the monitoring network options should aim to:

- enable the underpinning of future air quality targets and objectives;
- complement existing monitoring regimes where possible;
- help identify and reduce risks at the most sensitive receptors (and/or support nation-wide habitats exposure reduction);
- consider the potential combined role of new and traditional technologies to assess exposure risks, reduce gaps in coverage and support communications of air pollution in high risk areas.

The expanded network options (3 options depending on the level of ambition/resources available) proposed here were designed:

- to provide a balanced and representative enhanced monitoring network for Wales
    - geographically (i.e. covering the territory)
    - across concentration gradients (high, medium and low concentrations)
    - across dominant emission source types (dairy, beef, sheep, pigs & poultry etc.)
- to improve understanding of seasonal and spatial patterns
- to provide evidence to identify and track trends over time and space
- to improve data availability for comparison with/verification of atmospheric modelling outputs
- to be used to monitor progress towards achieving relevant targets in combination with modelled data (targets still under development)

In summary, the outline proposal focuses on the proposed additional sites (in the context of existing monitoring sites), to achieve a balanced and representative enhanced monitoring network for Wales.

2 PROPOSED NETWORK

The proposed network encompasses two scales:

- A **Wales-wide network** that is representative of atmospheric nitrogen being received by habitats and designated sites. The location of sites will evaluated under different criteria including: geographical location, modelled ammonia concentration, dominant ammonia emission sources (see Figure 1 - dairy, beef, sheep, mixed cattle, pigs & poultry, mineral fertiliser, mixed agriculture, non-agricultural sources; low/background emissions < 1 kg N ha^{-1} $year^{-1}$)
- A few **nested mini-networks** to quantify atmospheric N inputs and identify gradients **across selected designated sites**, for demonstrating local variability (and potentially observing the impact of spatially targeted measures to mitigate local emission hot spots). Indicatively, a mini-network would consist of around 5 samplers around a designated site. Potentially suitable designated sites are to be identified in the feedback to this first outline proposal.

The monitoring framework options described here have been prepared for three levels of ambitions, each costed separately.

- basic (a few additional samplers to enhance the existing Welsh sites)
- enhanced (a balanced network that fulfils all the aims outlined above)
- comprehensive (a network that would enable more detailed interpretation and analysis)

For the Wales-wide network there are 3 options proposed.

A) a basic option

B) an enhanced option

C) a comprehensive detailed network.

The options cover both

- passive ammonia samplers (ALPHA®, low-cost, no power supply needed, measuring NH_3 concentrations only), and
- active ammonia and acid gases and aerosol samplers (DELTA®, requires either mains power or wind/solar system, measuring a wide range of chemical components, important for model intercomparison and providing calibration for the ALPHA® sampler network).

In addition to a proposal for an enhanced and representative Wales-wide network, WG requested a proposal for several small nested mini-networks related to designated sites with N-sensitive habitats and species, for local monitoring of ammonia concentration gradients from nearby sources into the sites. These designated sites could also serve as candidate case studies for Shared Nitrogen Action Plans (SNAPs). An indicative number of 5 passive samplers is suggested per site, across 2 or 3 designated sites.

Table 2.1 summarises the number of sites proposed for each of the three levels of ambition, for both the Wales-wide representative network and the nested mini-networks (in the context of existing sites under the UK networks). Further details on the different options are provided in the following pages.

Table 2.1: Summary of proposed expanded air quality monitoring options in Wales.

Air pollutants	**Method**	**Sampling frequency**	**Existing no. of sites in UK national networks**	**Proposed additional sites**	**TOTAL in Wales (including existing sites in the UK network)**
Gas: NH_3	Passive ALPHA® samplers	Monthly	NAMN: 3	**Wales-wide network:** A) 10 (Basic option) B) 25 (Enhanced option) C) 35 (Comprehensive option) + **Nested mini-networks:** A+B) 10 sites (2 designated sites: 5 per site) C) 15 sites (3 designated sites, 5 per site)	**Wales-wide network:** A) Basic = 13 B) Enhanced = 28 C) Comprehensive = 38 + **Nested mini-networks** A+B) 10 sites (2 designated sites: 5 per site) C) 15 sites (3 designated sites, 5 per site)
Air pollutants	**Method**	**Sampling frequency**	**Existing no. of sites in UK national networks**	**Proposed additional sites**	**TOTAL in Wales (including existing sites in the UK network)**
Gases: NH_3, HNO_3, SO_2 Aerosols: NH_4^+, NO_3^-, SO_4^{2-}, Cl^-, Na^+, Ca^{2+}, Mg^{2+}	Active DELTA® system (low voltage: 10 – 36 V off mains power, or 12 V wind/solar power)	Monthly	NAMN/ AGANet: 3	**Wales-wide network:** A) 1 (Basic) B) 3 (Enhanced) C) 3 (Comprehensive)	**Wales-wide network:** A) 4 (Basic) B) 6 (Enhanced) C) 6 (Comprehensive)

Figure 2.1 shows the location of the existing ammonia monitoring sites in Wales in the UK NAMN and AGANet, overlaid on a map of dominant emission sources. This map is derived annually and is consistent with the UK's National Atmospheric Emission Inventory. An emission source is considered "dominant" when it is the largest source in a model grid square and also contributes >45% of the overall emissions in the square. The category "None" represents very low emission grid squares with emissions estimated to be <1 kg NH_3-N ha^{-1} $year^{-1}$. Figure 2.2 shows the same emission map with all existing and proposed additional monitoring sites (for all three options) overlaid, to illustrate the intended representativeness of the proposed additional sites

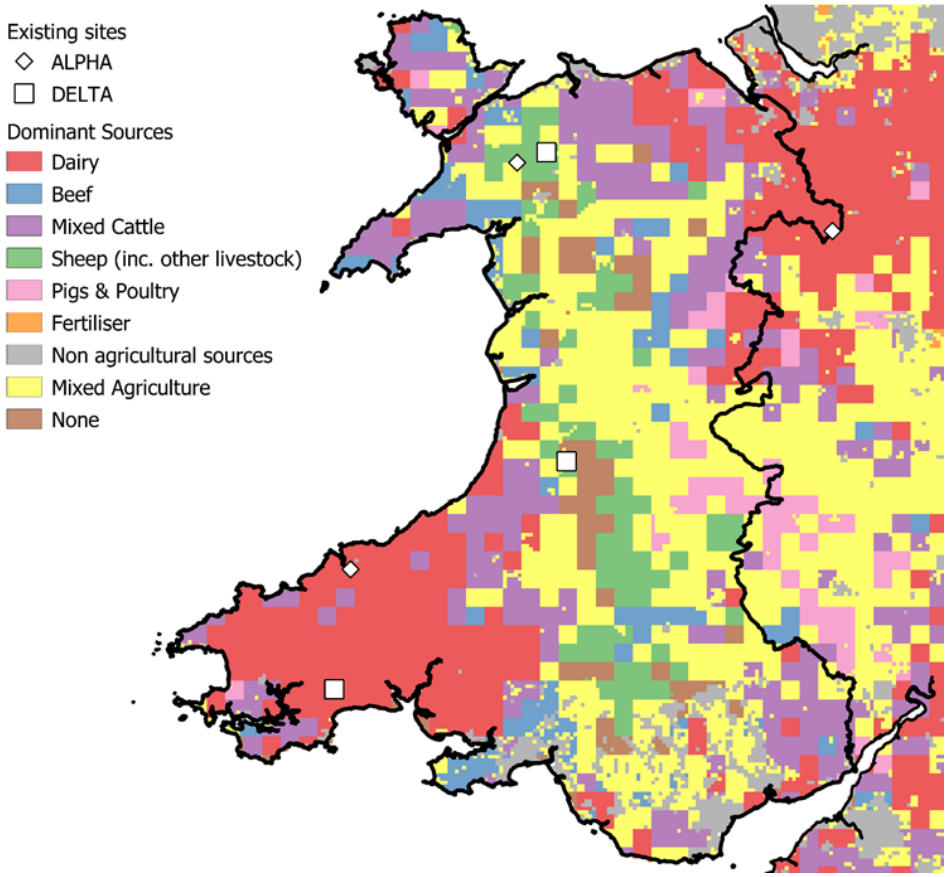

Figure 2.1: Non-disclosive dominant NH_3 emission sources (2020) across Wales and existing sampler sites.

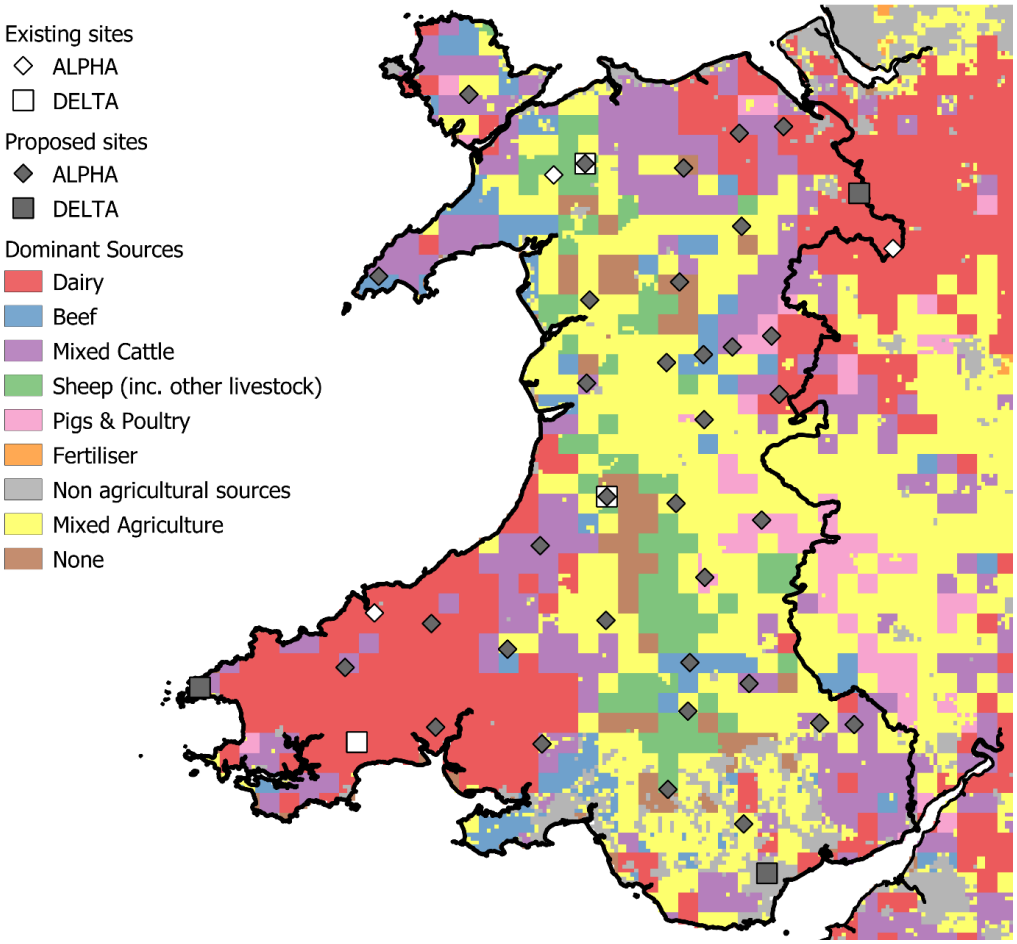

Figure 2.2: Non-disclosive dominant NH_3 emission sources (2020) across Wales with proposed and existing sampler sites.

Figure 2.3 shows a snapshot of monitoring sites from a large number of existing networks where additional ammonia monitoring network sites could be co-located, if appropriate. This assessment has not been carried out at this initial options appraisal, but would be taken into account if the Welsh Government were to establish additional monitoring network sites.

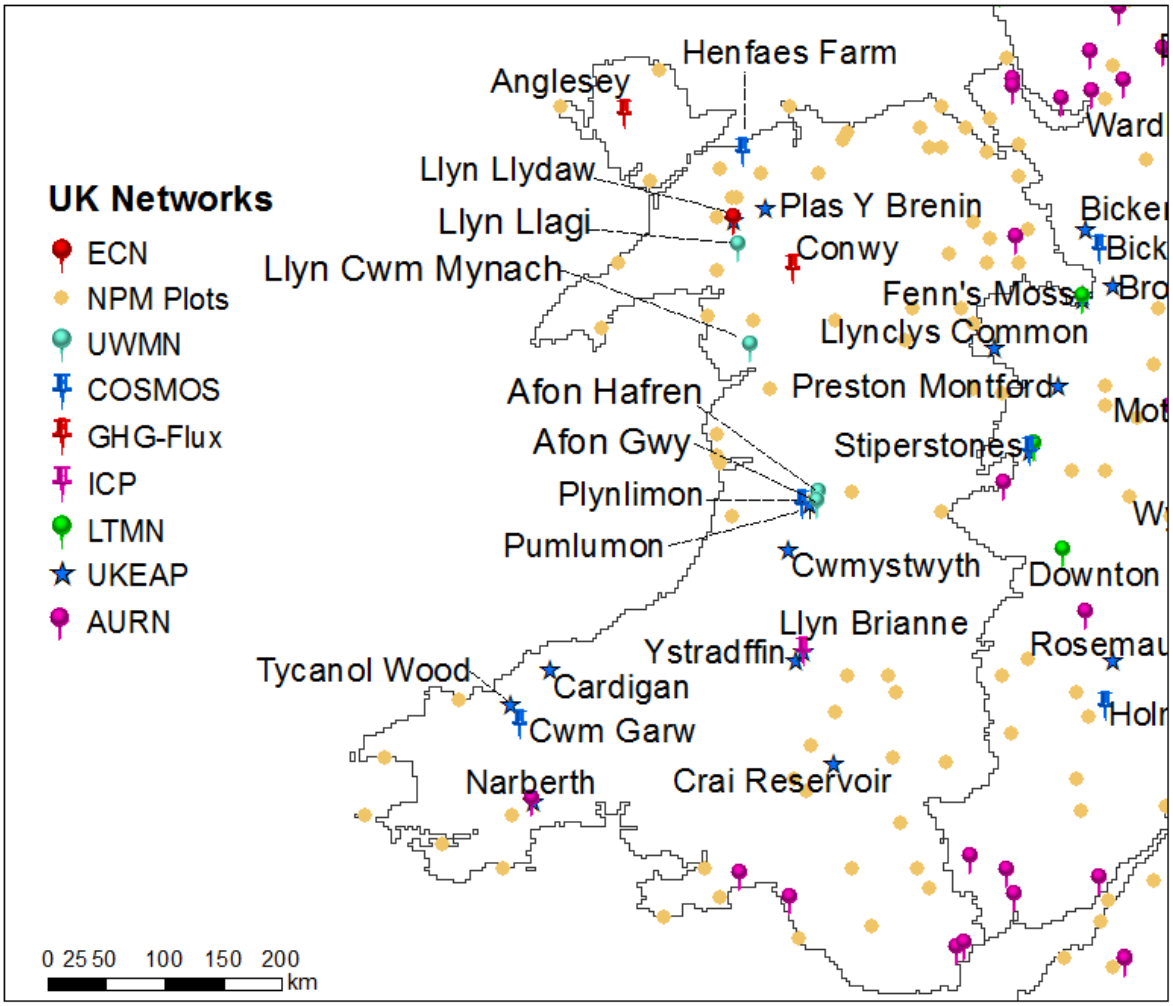

Figure 2.3: Map of long-term air quality and ecosystem monitoring networks and schemes in Wales, showing co-location where they occur. (N.B. This map was completed in 2018/19, and new sites have been added since then, including for the GHG flux network, etc. Also some sites have been closed. The latest available data will be taken into account when the detailed site assessment is carried out, if WG decide to commission additional network sites.

2.1 Atmospheric ammonia concentrations

Ammonia measurements made in the UK NAMN are carried out by a mixture of active and passive sampling. The passive sampler proposed is the ALPHA® (Adapted Low-cost High Absorption) sampler which is a badge-type diffusion sampler produced by UKCEH for the long term sampling of ammonia. The samplers are deployed in triplicate at each monitoring location and uptake rates are calculated by collocating a number of samplers with active samplers, DELTA® (Denuder for Long-Term Atmospheric sampling) produced by UKCEH. The sampling protocol for the ALPHA® sampler is based on the EN17436:2020 standard for NH_3 passive samplers. Further details of the ALPHA® and DELTA® methods can be found in e.g. the latest UKEAP project report[1]. The samplers are changed on a monthly basis by local site operators (LSO). For enhanced monitoring of atmospheric NH_3 concentrations in Wales the following approach is proposed:

- 10, 25 or 35 additional sites (ALPHA® samplers) in Wales in conjunction with the existing UK NAMN sites (refer to Figures 2.2 and 4 for proposed locations)
- Sites to be representative of the gradients of low/medium and high concentrations of ammonia across Wales (in conjunction with 3 existing NAMN ALPHA® sites: Cardigan, Llyn Llydaw and Fenn's Moss and 3 existing NAMN/AGANet DELTA® sites: Cwmystwyth, Narberth and Plas Y Brenin), and dominant emission source categories (as described above) (see Figures 2.2 and 2.4)
- All sites require short monthly visits by local site operators to swap the samplers and then post them to the laboratory for analysis.
- Monthly monitoring provides sufficient resolution to explore temporal patterns and to compare broad scale inter-annual meteorological differences. It is also a cost-effective way to provide concentrations fields from a high density network, and long-term trends in NH_3 concentrations.

[1] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2209290921_2021UKEAP_EA_final.pdf

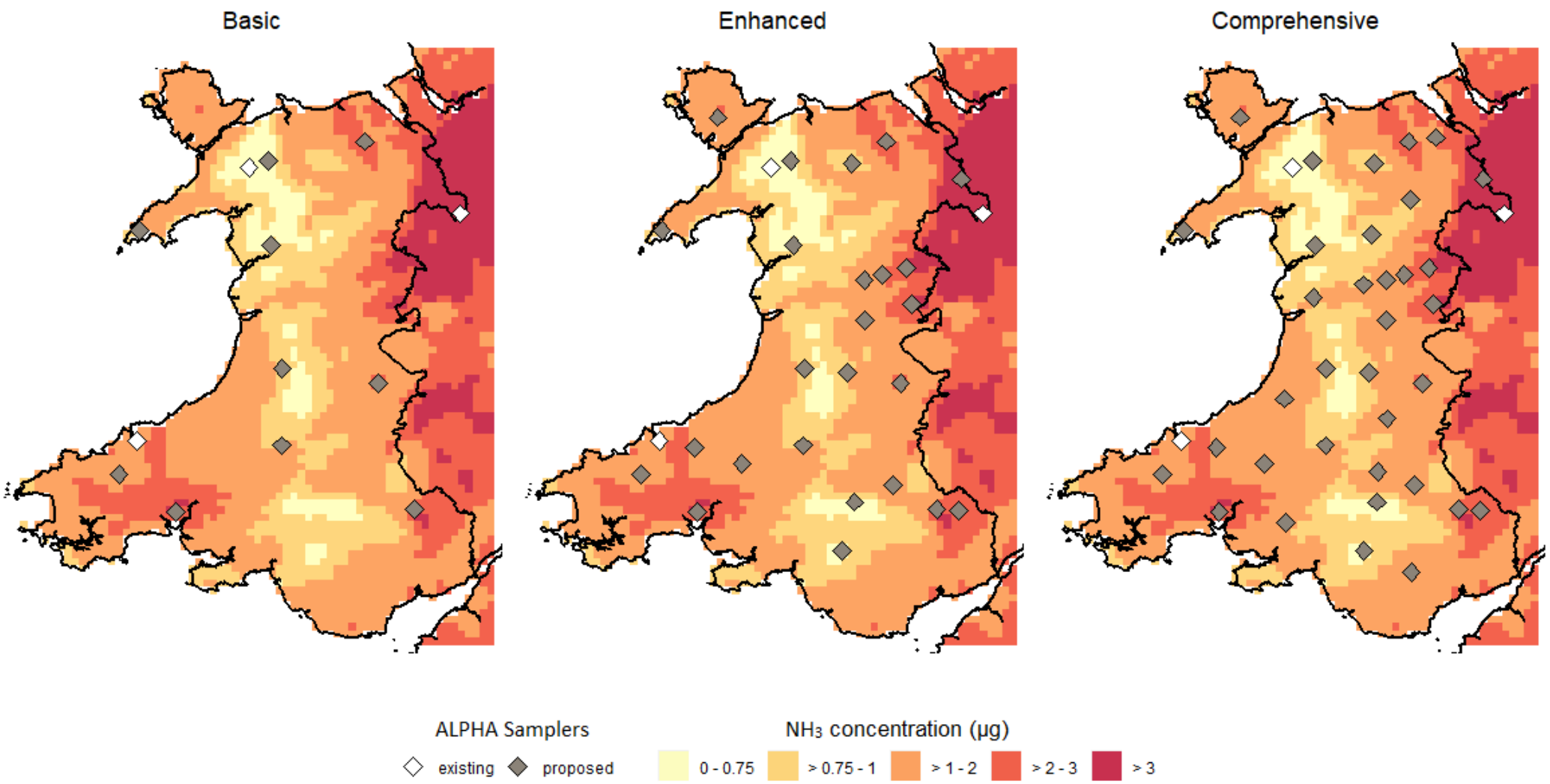

Figure 2.4: Modelled NH_3 concentrations (2019, EMEP4UK model) with existing and proposed ALPHA sampler locations for each of the three network ambition options (basic/enhanced/comprehensive).

2.1.1 Criteria for site selection (initial screening):

Candidate sites need to be selected using the following criteria, they must provide:

1. representative spatial coverage across Wales between existing and newly added sites.
2. representative coverage of dominant emission source sectors (Figure 2.5) between existing and newly added sites.
3. representative coverage in relation to EMEP modelled ammonia concentrations at a 5 km x 5 km grid level (using 2019 emissions, as available in 2022, UKCEH data) (Figure *6*) between existing and newly added sites. Measurement locations must include source and sink areas, to detect potential changes in ammonia concentrations following future policy interventions. Key area of high concentrations and variability expected from EMEP model: Welsh Borders/Shropshire. Ammonia air concentrations are more variable in high concentration areas, and more monitoring sites are required to characterize air concentrations in these areas, than in remote low concentration areas.
4. co-location of the sites in relation to other air quality (e.g. AURN) and ecosystem monitoring activities (e.g. ECN, ICP Forest level II), where possible in the context of criteria 1-3 above (c.f. Figure 2.3).
5. nature conservation interest of the site, particularly in relation to plant community sensitivity to nitrogen deposition and designation (EUNIS classification), where relevant/possible in the context of criteria 1-4 above.

2.1.2 Other considerations (stage 2 screening):

1. Identifying suitable site locations from Google Maps. Not too sheltered, or in woodlands (bias low), and > 300m from sources (bias high if within 300m of source), that will be representative of the 5 km x 5 km grid square.
2. Access permissions (from land searches etc.)
3. Site security (vandalism by humans, grazing livestock or other animals)
4. Sites must be visit-able by the appointed network contractor and local site contact (LSO, local site operator) to verify site suitability, meet with and train site operators, as well as to record details of the sampling location, servicing and to exchange samples on a monthly basis for the foreseeable future.
5. Availability and access to a willing and helpful local contact/LSO to exchange samples. The site operators are a central part of the network, without whom such a network would not be possible.

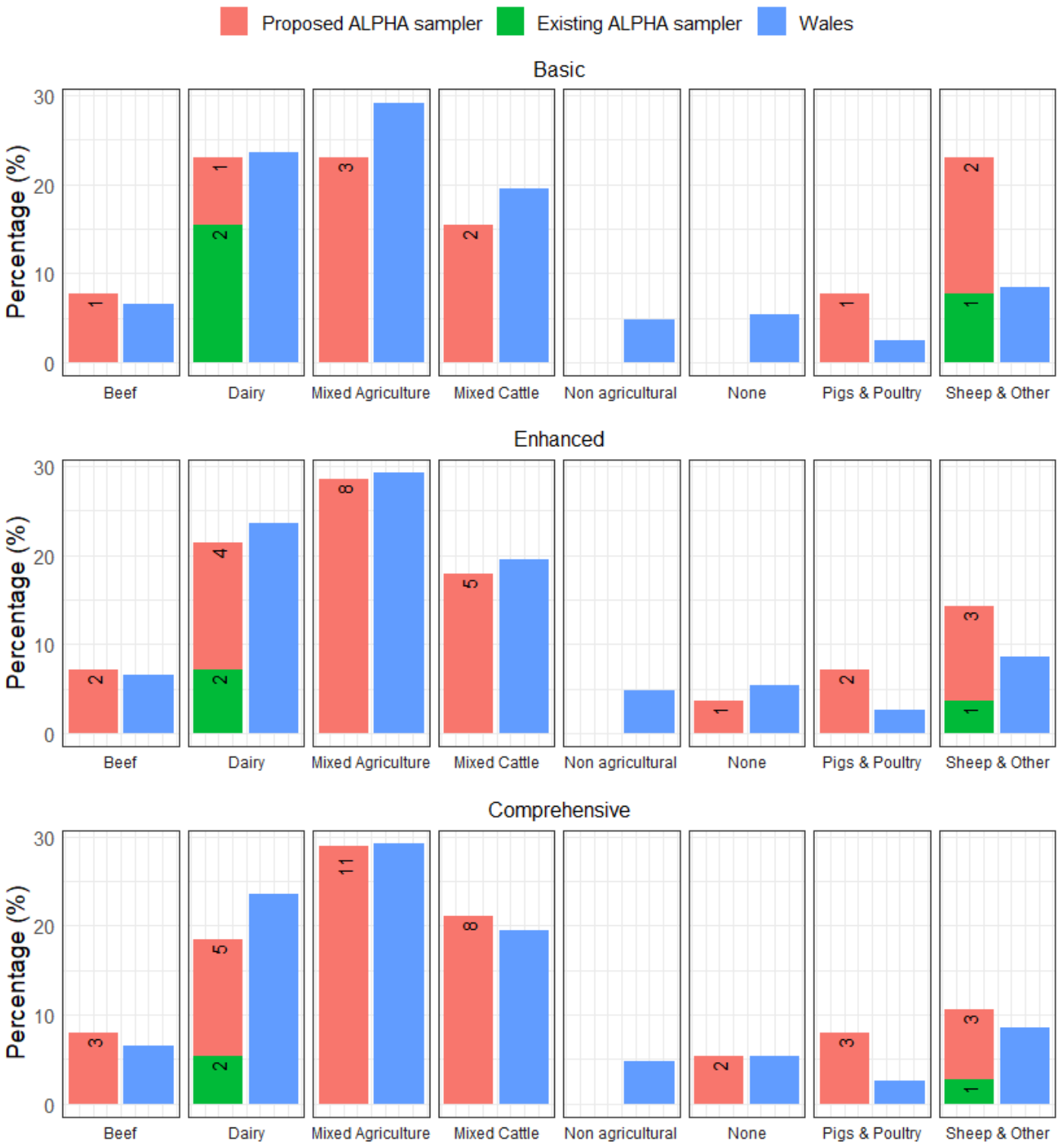

Figure 2.5: Proportion of 10/25/35 proposed ALPHA samplers in each dominant source category compared to national proportions for Wales.

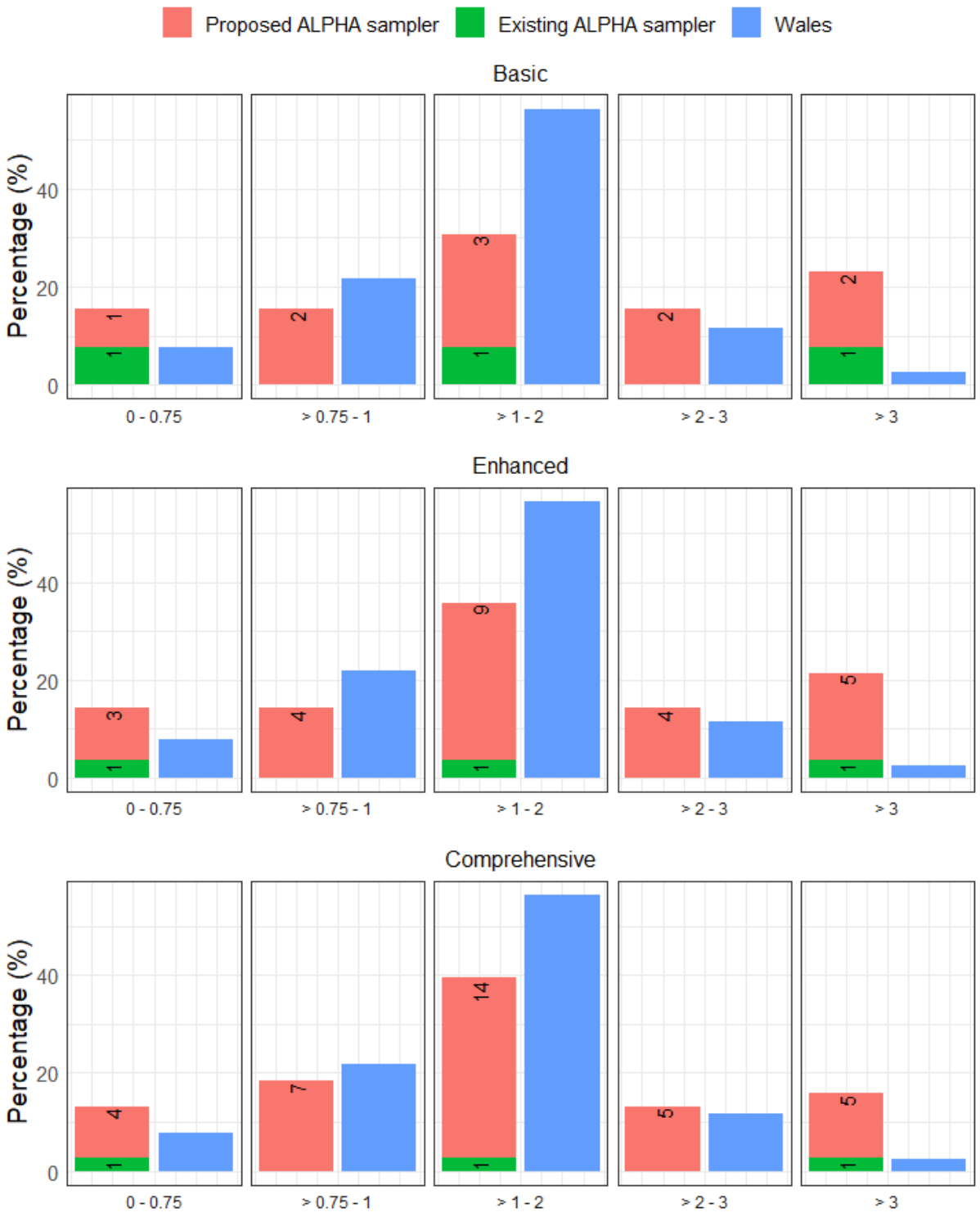

Figure 2.6: Proportion of ALPHA samplers in each EMEP NH_3 concentration band compared to national proportions for Wales.

2.2 Ammonia, acid gases and aerosols

- 1 (basic network) or 3 (enhanced/comprehensive network) additional DELTA® samplers – see Figure 6
- Samplers require connection to power either by i) mains electricity (10 – 36 volt with transformer) or ii) with wind and solar power set-up (12 volt).
- Locations to be representative of the gradients of low/medium and high concentrations of ammonia across Wales (in conjunction with three existing NAMN/AGANet DELTA® sites: Cwmystwyth, Narberth and Plas Y Brenin – Figure 7 above), and dominant emission source categories (see Figure 8)
- These sites require monthly visits by local site operators to swap the samplers
- These sites require annual visits to service the equipment
- These sites require annual calibration of the gas meters (gas meters swapped with pre-calibrated meter during annual site service).
- These sites require replacement of 6 volt air pump every year.

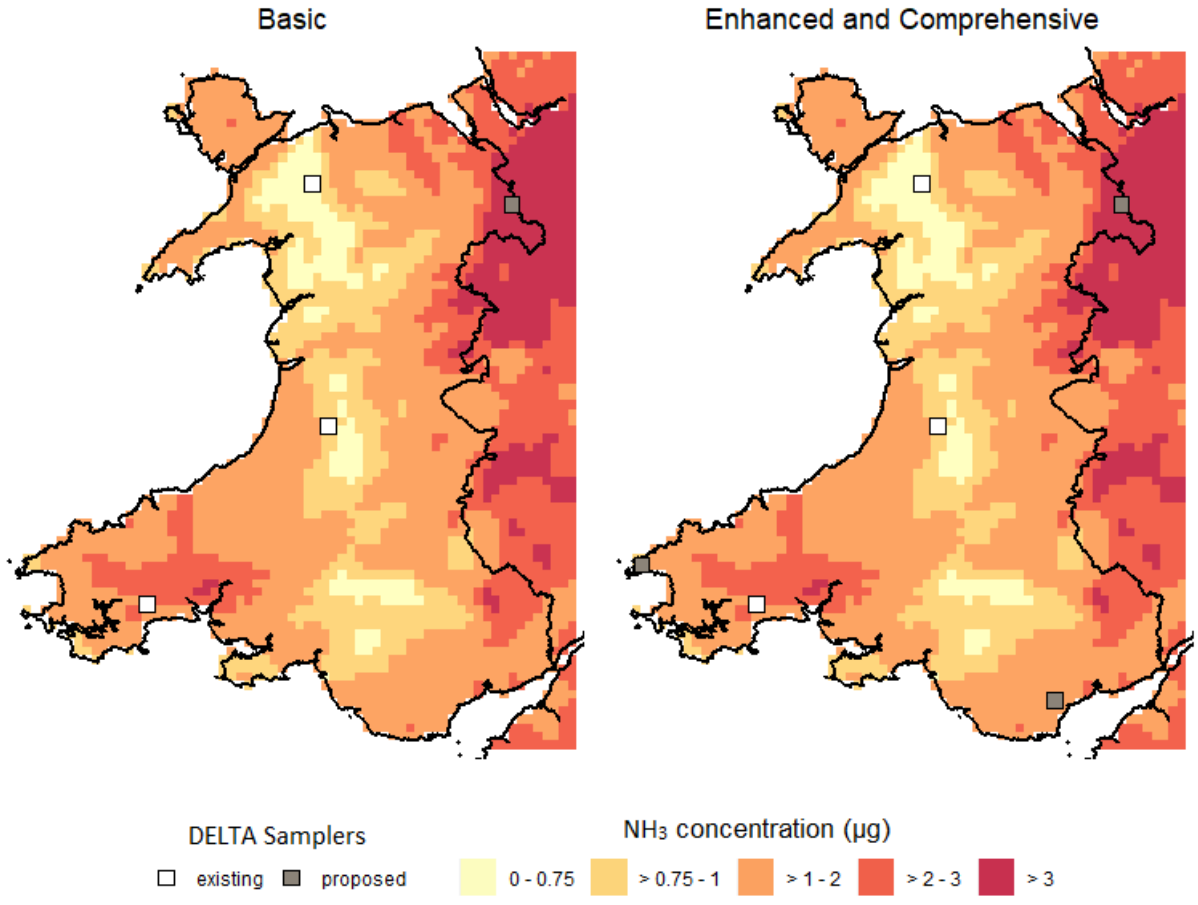

Figure 2.7: EMEP modelled NH_3 concentrations (2019) with existing and proposed DELTA sampler locations.

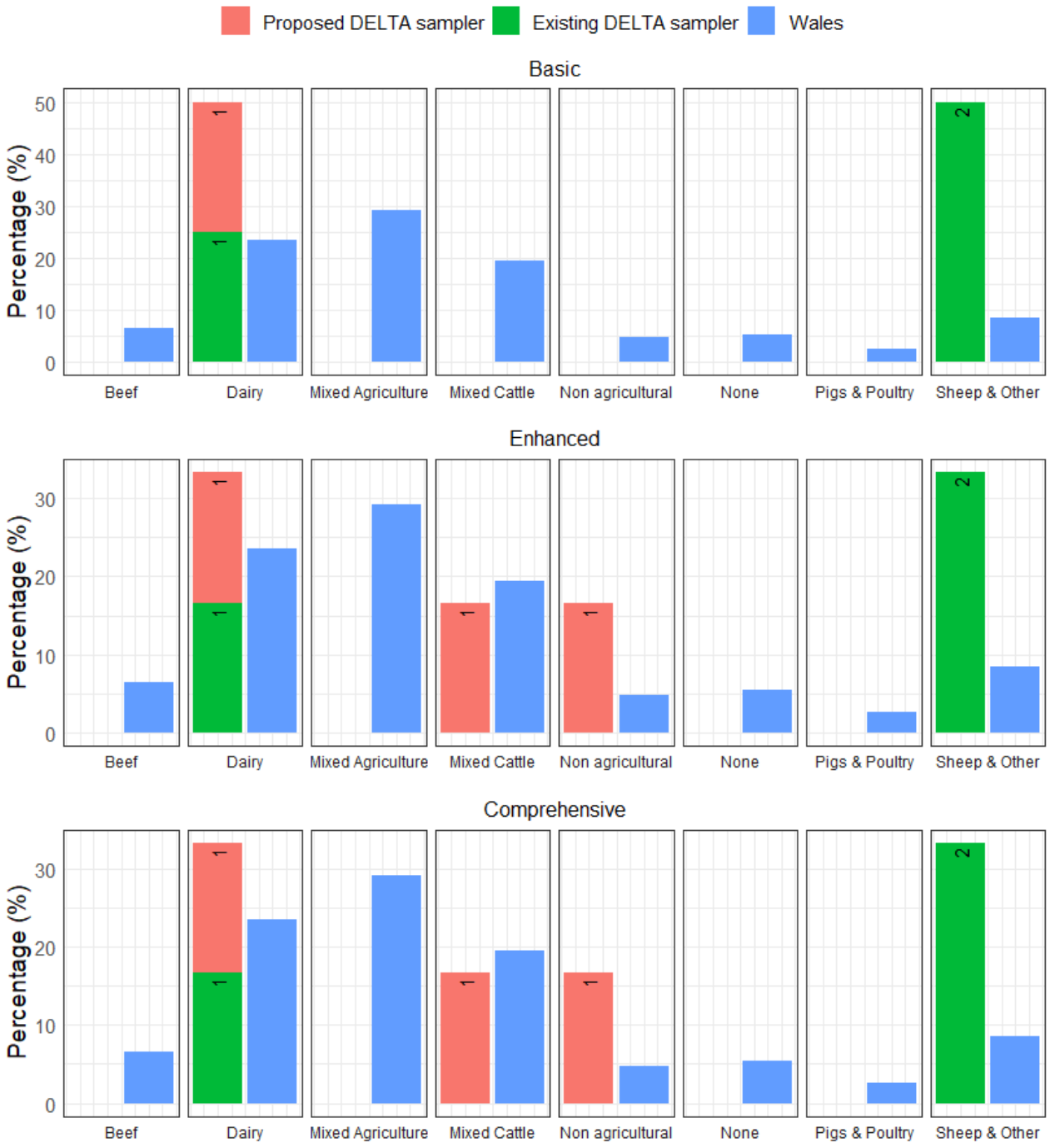

Figure 2.8: Proportion of DELTA samplers in each dominant source category compared to national proportions.

2.2.1 ALPHA-DELTA intercomparison sites

An annual calibrated ALPHA® sampling rate ($m^3\ h^{-1}$), derived from ongoing field calibrations in the UK National Ammonia Monitoring Network[2], is used to estimate volume of air sampled (m^3) by the ALPHA® sampler from the sample exposure duration (hours). The air concentration of NH_3 (µg $NH_3\ m^{-3}$) is then determined from the amount of NH_3 collected and the volume of air sampled (m^3) by the ALPHA® sampler.

The ALPHA® method is calibrated against the reference DELTA method[3] in the UK NAMN at 9 sites across a wide range of ambient NH_3 concentrations. The UKEAP NAMN/AGANet Narberth site in Wales is one of the nine intercomparison sites across the UK. Since there is currently only one intercomparison site in Wales with both an ALPHA and DELTA sampler present at the same location, it is recommended to add an additional two intercomparison sites in Wales across the range of ambient concentrations to be included in the calibration of the ALPHA® sampling rate. This is being achieved by locating two of the proposed new ALPHA samplers at the existing AGANet DELTA sites (same two sites across all three proposed options).

[2] https://uk-air.defra.gov.uk/networks/network-info? view=nh3

[3] EN 17346 Ambient air - Standard method for the determination of the concentration of ammonia using diffusive samplers, 2020.

3 ASSESSING THE IMPACT OF NUMBER OF MONITORING SITES ON UNCERTAINTY OF TEMPORAL TRENDS IN NH_3 CONCENTRATIONS

When designing a monitoring network, the following questions should be considered:

- How does the number of monitoring sites affect uncertainty in the estimate of temporal trends in NH_3?
- Is there a 'threshold' in the change in uncertainty that helps determine a minimum number of sites?

3.1 Method

The proposal is considering expanding the network of monitoring sites in Wales. There are currently very few monitoring sites in Wales, so it was not possible to use a simulation-based approach on existing data to optimise network design. In lieu of this we used a simulation based approach using the UK site monitoring network, with data collected from 1996 – 2019. This network contains 71 monitoring sites with monthly data collected, with varying start and end dates across sites. For this analysis we used monitoring sites that collected data for at least half of the 24 years (49 sites).

We fitted a generalised additive model to the full dataset of monthly log transformed NH_3 concentrations from the monitoring network over time, including site as a random effect (whereby the relationship between log-NH_3 and year could vary by site) – a model structure that had been tested through earlier UKCEH research.

We simulated the effect that reducing the number of monitoring stations had on estimating the trend and uncertainty in NH_3 concentrations from 1996 – 2019 by taking random samples of sites where the number of sites randomly chosen were at six 'levels': n = 6, 10, 15, 20, 30 and 40 sites. For each subset, we ran 50 iterations (random combinations of the n sites from the total 49 sites). We then calculated the average predicted log-NH_3 and average 95% confidence interval across the 50 iterations for each sample size.

3.2 Results

Figure 10 shows these predicted means and average 95% confidence intervals for the six levels of site numbers and the full model. The trend line is broadly conserved in comparison to the full model run in the majority of iterations with larger numbers of (e.g. 20, 30, 40 sites). The grey lines show that 'realisations' (each specific set of randomly chosen sites) are much more variable when the number of sites selected is low, and the confidence intervals are broader. Figure 3.2 shows the trend in reduction of variance in the model fits as more monitoring sites are included, with the highest reduction in variance seen with the increase from 6 – 30 monitoring sites. Ultimately, larger sample sizes resulted in lower uncertainty and this was most evident under 30 sites.

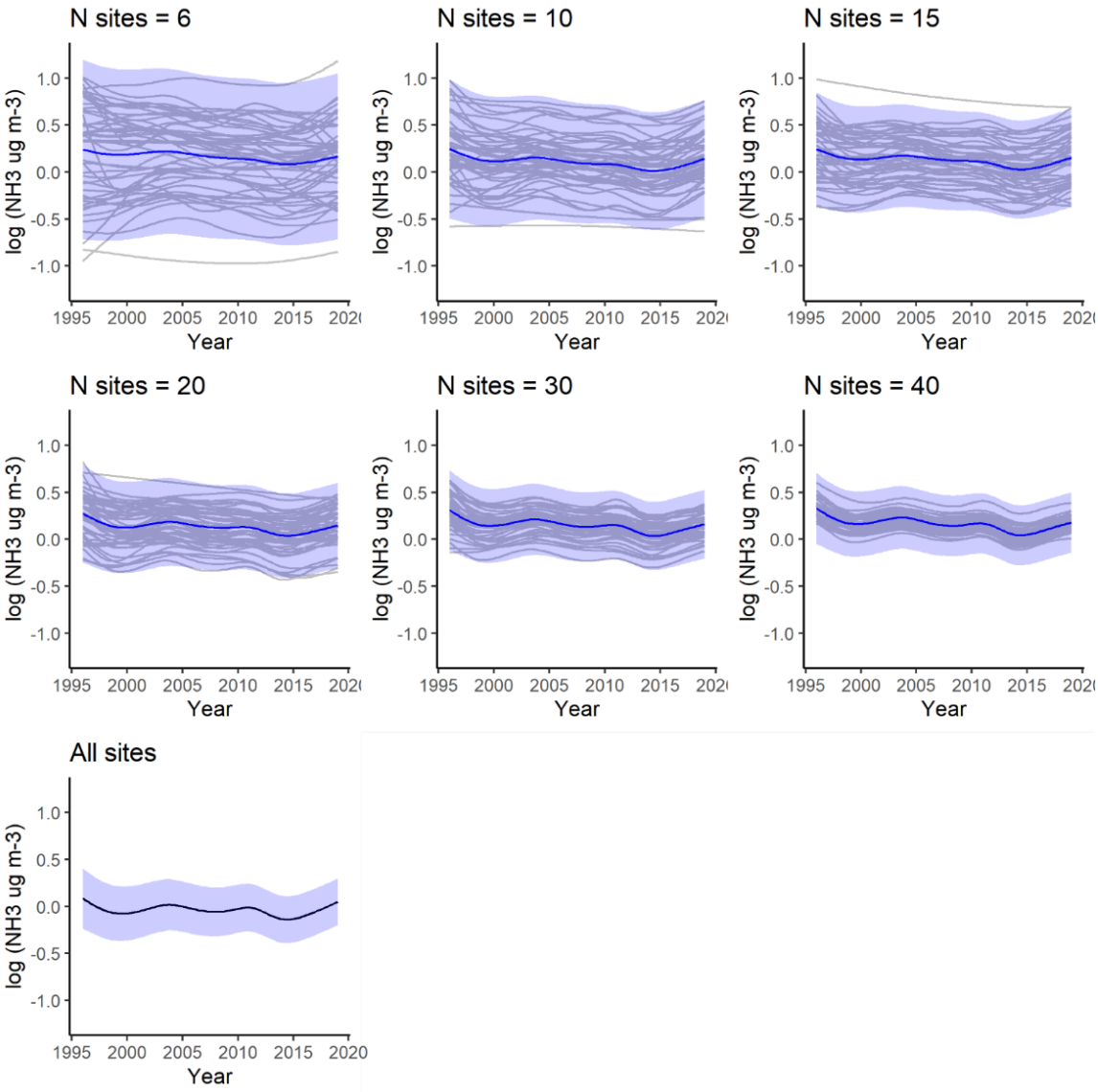

Figure 3.1. Trend of NH_3 concentration from 1996 – 2019 based on up to monthly data records from monitoring sites. Panels 1-6 show the trend lines from 50 iterations of sampling n sites from the 49 total sites. The blue trend line shows the average of these 50 iterations, and blue ribbon shows the average 95% confidence interval of these 50 iterations and the grey lines give the predictions over time for each random selection of sites. The 7th panel shows the single trend line (black) fitted from a generalised additive model including all 49 monitoring sites and 95% confidence intervals (blue).

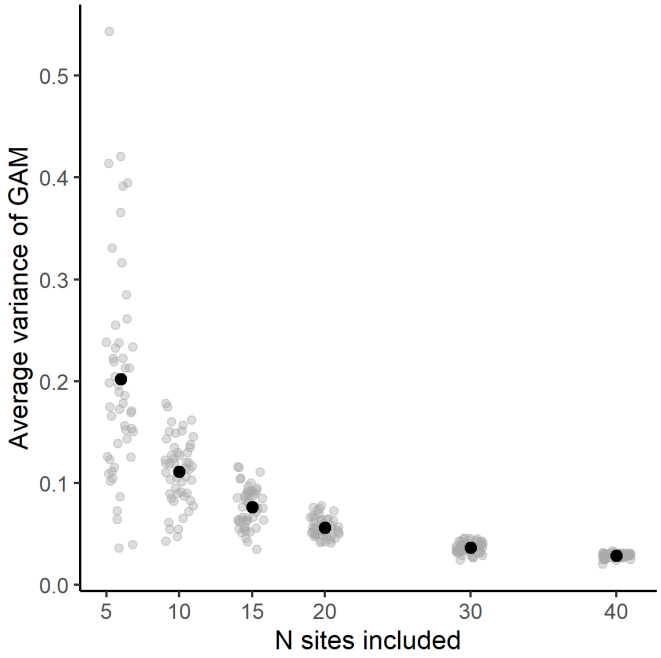

Figure 3.2. Grey dots show the average GAM variance for each of the 50 iterations in each subset of the monitoring site data. The black dot shows the overall average variance for each subset.

4 SUMMARY AND RECOMMENDATIONS

Three options of different levels of ambition are presented in this report, for a representative NH_3 monitoring network that aims to achieve the following aims: to underpin future air quality targets and objectives, to complement existing monitoring efforts and to help identify and reduce risks to the most sensitive receptors.

The expanded network options proposed here were designed:

- to provide a balanced and representative enhanced monitoring network for Wales
    - geographically (i.e. covering the territory)
    - across concentration gradients (high, medium and low concentrations)
    - across dominant emission source types (dairy, beef, sheep, pigs & poultry etc.)
- to improve understanding of seasonal and spatial patterns
- to provide evidence to identify and track trends over time and space
- to improve data availability for comparison with/verification of atmospheric modelling outputs
- to be useful for monitoring progress towards achieving relevant targets in combination with modelled data (targets still under development, proposals in (Rowe et al., 2023)

In summary, the outline proposal focuses on the proposed additional sites (in the context of existing monitoring sites), to achieve a balanced and representative enhanced monitoring network for Wales. In the context of reducing uncertainty in both measured NH_3 concentrations and their use for validating/calibrating model output, it is important that the number of sites in a network is sufficient for these purposes, and all three options presented would set the network on a much improved footing for achieving the Welsh Government's stated aims. In terms of recommendations for a Wales-wide network:

- Option 1 (basic) is recommended as a minimum viable improvement for Wales-focused assessments of NH_3 concentrations
- Option 2 (enhanced) is at a similar level to that adopted by Northern Ireland, which now has an additional 25 monitoring sites across the country (24 new passive ALPHA samplers, 1 new active DELTA sampler), as part of the UK-wide NAMN and AGANet. These sites were recently incorporated into the UK monitoring networks, after collecting three years of data under a research project.
- Option 3 (comprehensive) would provide further reductions in uncertainty, compared to Option 2 (see Section 4 for details).

The additional 2-3 nested mini-networks (depending on ambition) would create local case studies/demonstration sites for spatial targeting of measures near sensitive designated nature conservation sites. These could be utilised for a) demonstrating existing local NH_3 concentration gradients to all stakeholders and serving as a test bed for Shared Nitrogen Action Plans (SNAPs).

5 REFERENCES

Rowe., et al. (2023). Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-77: An Air Quality target for Wales in relation to biodiversity and ecosystems. Report to Welsh Government (Contract C210/2016/2017) (UKCEH 06297/06810)

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