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Ballynahone Bog SAC Wind Data Analysis October 2020 to September 2021

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Williams M. R, Carnell E. J., Tang Y. S., Stephens A. C. M., Iwanicka A. K., Duarte F., O'Reilly Á., McCourt A. and Dragosits U.

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UKCEH contact details	Ulli Dragosits: ud@ceh.ac.uk
Author	Williams M. R., Carnell E. J., Tang Y. S., Stephens A. C. M., Iwanicka A. K., Duarte F., O'Reilly Á., McCourt A. and Dragosits U.
Approved by	Ulli Dragosits
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1 Introduction / background

Local prevailing wind patterns play a key role in atmospheric nitrogen (N) input to designated sites, in terms of local ammonia (NH_3) concentrations and N deposition originating from local, regional and transboundary sources. The aim of this study is to investigate local wind patterns and their temporal variability using locally measured weather data for the period October 2020 to September 2021. These data were analysed in conjunction with NH_3 measurements within and surrounding Ballynahone Bog SAC (Thomas et al. 2020; Williams et al. 2021).

This report aims to:

- Assess local wind patterns for the period October 2020 to October 2021
- Establish how local wind patterns influence NH_3 concentrations

2 Wind measurements on Ballynahone Bog (October 2020 – September 2021)

2.1 Background

A new meteorological (met) station was installed on Ballynahone Bog SAC in September 2020 and has been operational since 1st October 2020. The met station was funded by DAERA NIEA and was installed to replace an existing Davis met station on the site that had become increasingly unreliable and stopped recording data on 17th June 2020. The new met station, a Campbell Automatic Weather Station (AWS), has been installed at NH_3 monitoring site BB3 (Figure 5). This report focuses on analysing the wind conditions at Ballynahone Bog SAC and interpreting their influence on NH_3 concentrations. However, in addition to wind direction and speed, other meteorological variables are also recorded, including air temperature, relative humidity and precipitation. Wind speed and wind direction are recorded at 10-minute intervals and measurements can be downloaded remotely and aggregated to half hourly recordings. This is a considerable improvement to the previous met station, as downloading the data remotely enables periods of low data capture to be identified very rapidly, and any necessary repairs and maintenance to be carried out.

2.2. Wind data

This report covers the period between 1st October 2020 (14:00) to 30th September 2021 (23:30). During this period there were 1768 measurements where wind speed was recorded as 0 m s^{-1}, representing ~10.1 % of all records for the period (Figure 1). During periods of no wind (0 m s^{-1}), wind direction is recorded as northerly (0 degrees) by default, this data is invalid and removed from the dataset (Figure 2). The weather station is recording all other meteorological variables during these periods, so is assumed to be operational in all other respects. The met station recorded more instances of no wind (0 m s^{-1}) in August and September 2021 than in other months, indicating that it needed to be serviced (Figure 1). In September (2021) 43% of wind speed measurements were recorded as 0 m s^{-1} compared to previous months where no wind typically represented only ~1 - 5 % of the total. All measurements of 0 m s^{-1} wind speed (i.e., below the detection threshold by the weather station) have been removed from Figure 3 to prevent any bias in wind direction (to North, which is recorded by this station during periods of 0 m s^{-1}). A second Campbell AWS was installed on the bog (as part of the greenhouse gas flux tower), about 400m to the east of the main Ballynahone Bog met station and began recording on 26th May 2021, where an additional ALPHA® sampler was placed (BB9, Figure 5). The Campbell AWS has a 3D sonic which has a higher sensitivity for recording lower wind speeds (<0.5 m/s). Data from this new AWS was used to gap-fill data from the AWS at Site BB3 between May and September 2021. Of the 1768 half hourly measurements, 331 data points that were recorded as 0 m s^{-1} could not be gap filled by this second AWS, as these mostly

pre-date the installation of the additional met station (with 1 missing recording in September 2021, Figure 2).

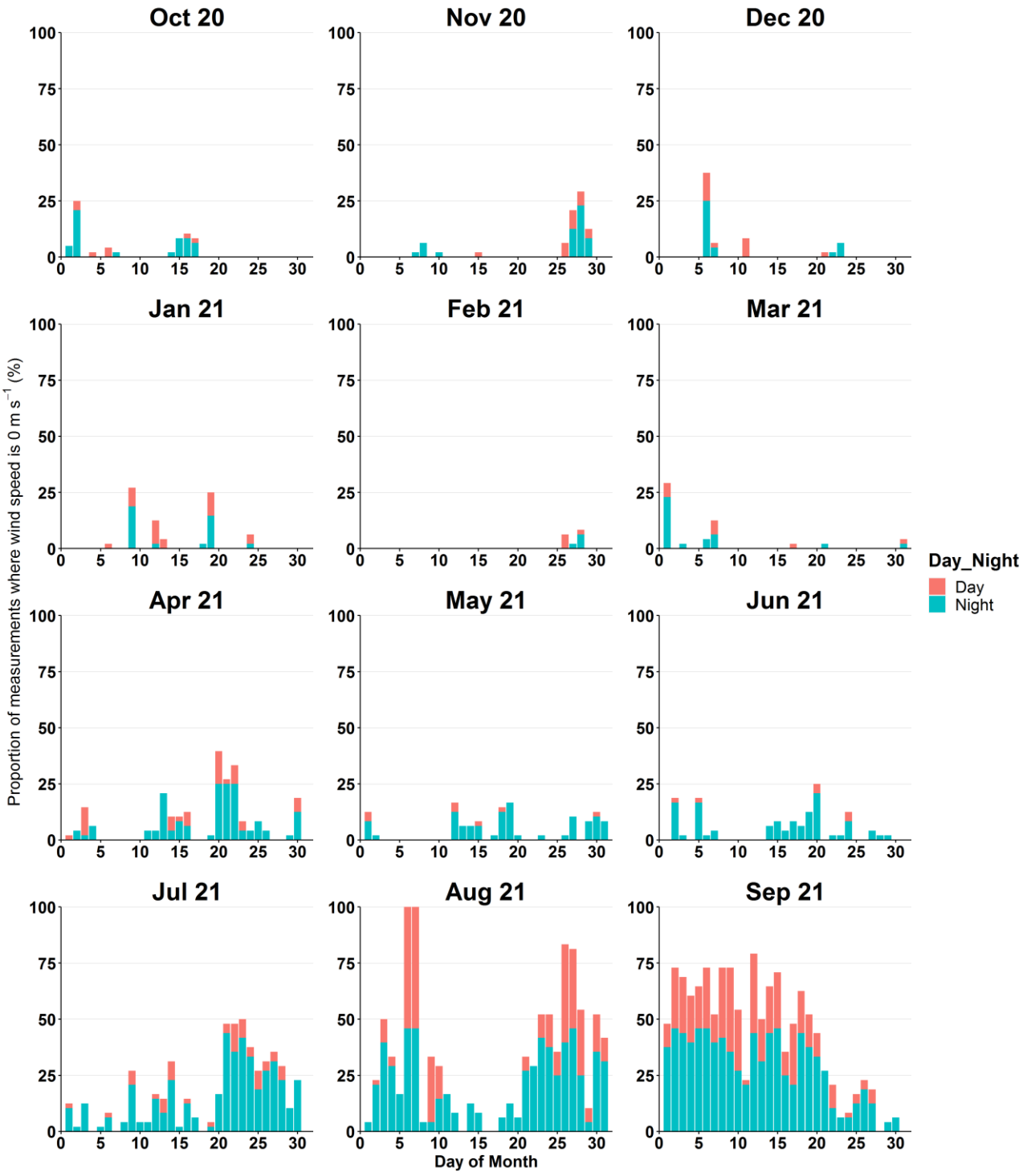

Figure 1: The graphs show the proportion of measurements of wind speed per day which were recorded as 0 m s^{-1} by Ballynahone Bog met station between 1st October 2020 and 30th September 2021.

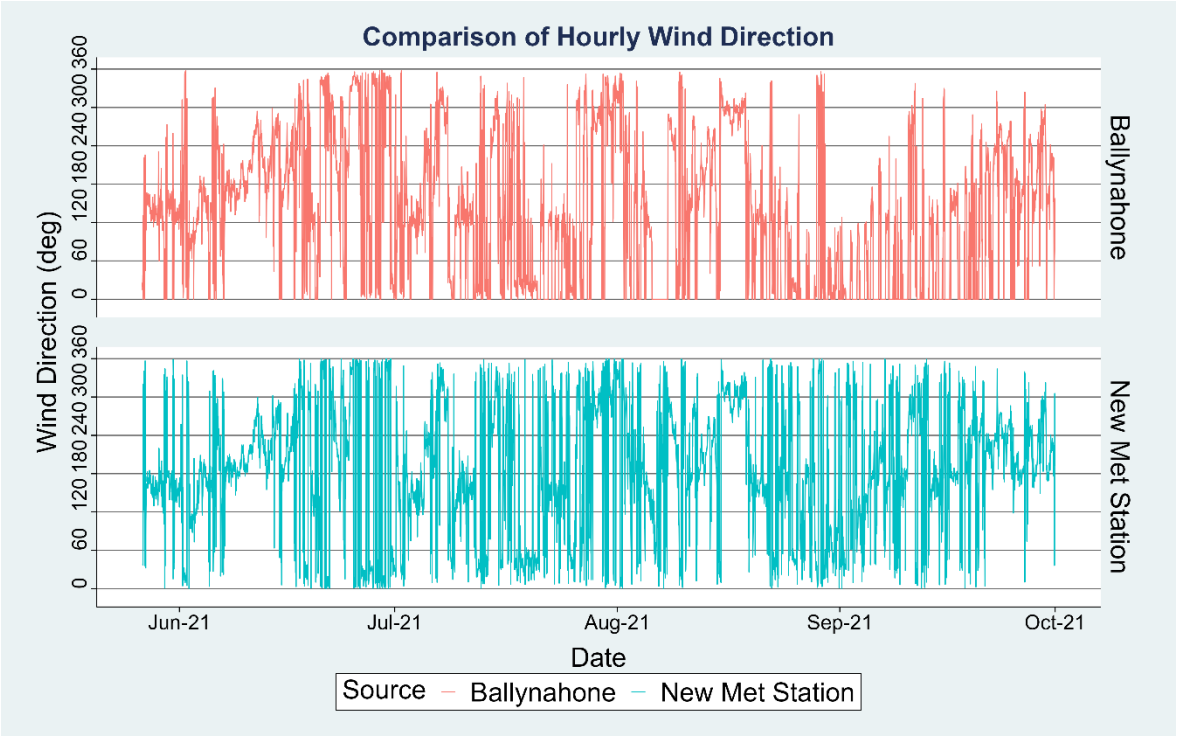

Figure 2: A graph comparing the mean hourly wind direction (degrees) measurements for Ballynahone Bog met station (ALPHA® site BB3) and the newly installed met station (ALPHA® Site BB9) between 25th May 2021 and 30th September 2021.

Overall, the wind patterns on Ballynahone Bog for the period October 2020 to the end of September 2021 were fairly mixed, with no clear prevailing wind direction. The highest wind speeds were from a south-easterly direction, with some high winds also from the south-westerly and north-westerly direction (Figure 3). The majority of the wind recorded on the bog is from the southern half of the wind rose (Figure 3).

Wind speeds on the bog are mostly <4 m s^{-1} (~80% of measurements). February shows the strongest wind speeds with ~60% of measurements >4 m s^{-1}, and up to 12 m s^{-1} (Figure 4). Other periods of noticeably high recorded wind speeds were during the months of October 2020, and March and May 2021.

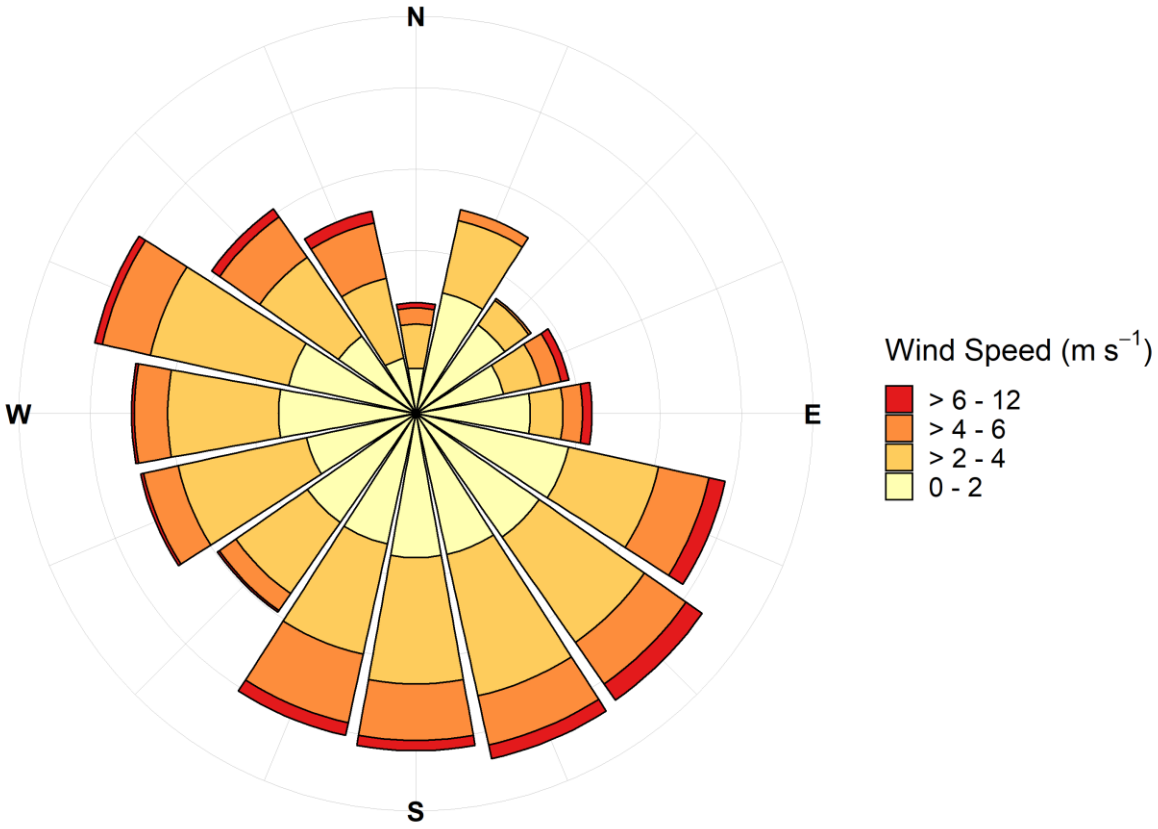

Figure 3: Annual wind rose for Ballynahone Bog Automatic Weather Station (AWS) produced using gap-filled data from the adjacent GHG flux tower AWS for the period 1st October 2020 to 30th September 2021, showing wind speed and direction.

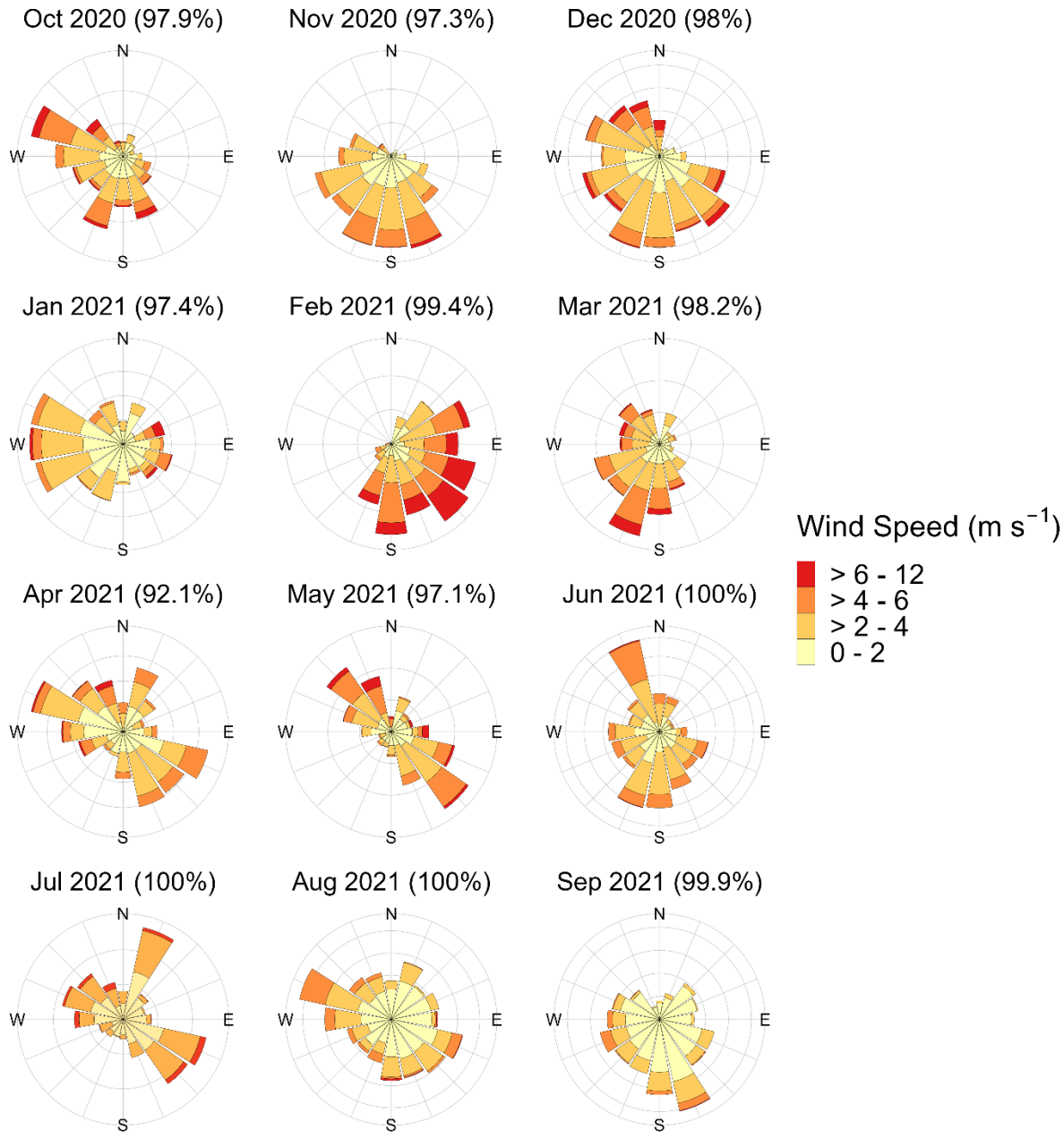

Figure 4: Monthly wind roses for Ballynahone Bog met stations between 1st October 2020 and 30th September 2021. Percentages shown in brackets next to each month label indicate the proportion of measurements recorded by the Ballynahone AWS that are > 0.5 m-s.

3 NH_3 concentrations on Ballynahone Bog SAC

3.1 Background

Ammonia concentrations have been measured on Ballynahone Bog at monthly intervals since 2014, providing a near complete time series for over 7 years. Full details of the NH_3 concentration measurements can be found in Tang et al. (forthcoming). Ammonia concentrations are measured at 9 locations across the bog (Figure 5). Site BB9 was added in May 2021, with the installation of a new greenhouse gas flux tower (and new AWS).

Figure 5: Location of the 9 ALPHA samplers on Ballynahone Bog.

This report focuses on the period October 2020 to September 2021, as this is the first full year of concurrent measurements of wind speed/direction and NH_3 concentrations on the bog.

NH_3 concentrations were measured using ALPHA® samplers (Tang et al., 2001) and are exchanged at monthly intervals. Due to the SARS-Covid19 outbreak in 2020, the

sampler exchange in October 2020 was not possible due to movement restrictions and samples were not collected until late November. The NH_3 concentrations for October and November therefore represent a two-month average (Figure 6). Although samplers are usually exchanged each month, the October/November sampler is unlikely to have reached saturation point and can therefore be viewed as an accurate reflection of ammonia concentrations at the site over the two-month period. All other months were unaffected, and samplers were collected as planned.

3.2 Results

October 2020 – September 2021

The monthly ammonia concentrations on the bog ranged from ~1 µg NH_3 m^{-3} to ~9 µg NH_3 m^{-3} over the period October 2020 to September 2021 (Figure 6). The background measurements on the bog were recorded at Site BB8, on the south-eastern edge of the site.

October 2020 to February 2021

During the period October 2020 to February 2021, NH_3 concentrations were relatively low compared to measurements made in the rest of the year. A two-month average of NH_3 concentrations was taken across October - November 2020, as samplers could not be exchanged due to SARS-Covid19 travel restrictions. It should also be noted that due to Covid-19 restrictions, October samples remained exposed for two months, to the end of November 2020, resulting in a 2-month average instead of monthly data.

This winter period corresponds with the closed period (where landspreading is not permitted under Nitrate Action Programme (NAP) rules) and where lower concentrations are expected across the wider landscape. This corresponds with the two measurements <1 µg NH_3 m^{-3} recorded at Site 8.

In January 2021, a concentration above >4 µg NH_3 m^{-3} was recorded at Site 6, which may potentially be associated with the prevailing westerly wind direction, this is not seen so strongly in any of the other months in this report (Figure 6). The high south easterly winds in February 2021 appear to correspond with lower concentrations on the site transect, likely promoting dispersal and dilution of the plume away from the measurement transect.

March – April 2021

Some of the highest monthly NH_3 concentrations (>4 µg NH_3 m^{-3}) for the year were recorded across several measurement sites in March and April (Figure 6). High concentrations were recorded on the south-westerly edge of the bog, with concentrations declining away from the site boundary. High concentrations (>3 µg NH_3 m^{-3}) were also recorded at Site 8, which normally has concentrations <2 µg NH_3 m^{-3} for most of the year. High concentrations are common in March and April as these months are typically associated with manure spreading and synthetic fertiliser application across the region.

May – July 2021

NH_3 concentrations remained relatively high between May and July 2021. There was a slight decline in concentrations in May 2021, which may correspond to high south-easterly and north-westerly winds. Very high concentrations (>7 µg NH_3 m^{-3}) were recorded in June at several sample locations (1-3, 6 & 7) and remained >4 µg NH_3 m^{-3} in July. June had prevailing south-easterly winds and July southerly winds which may indicate that emissions were predominantly dispersed across the bog from a south/south-east direction. June and July were also very warm and dry months in comparison to previous years (28 and 33mm rainfall, refer to Tang et al. forthcoming), consequently this may have contributed to elevated NH_3 concentrations.

August – September 2021.

The low wind speeds during these months indicates a lack of dispersion of nitrogen across the bog and therefore an accumulation of concentrations on the transect. This indicates that the likely source of these concentrations is local. Although concentrations at Site 8 were below 2 µg NH_3 m^{-3}, which suggests a decrease in background concentrations across the wider landscape surrounding the bog.

N.B. Monthly met data are summarised for calendar months (e.g. 31 days in January), whereas monthly exposure periods for the measured NH_3 concentrations are generally one calendar month +/- 5 days. This difference of a few days is not expected to change the wind rose profile for comparison with NH_3 data.

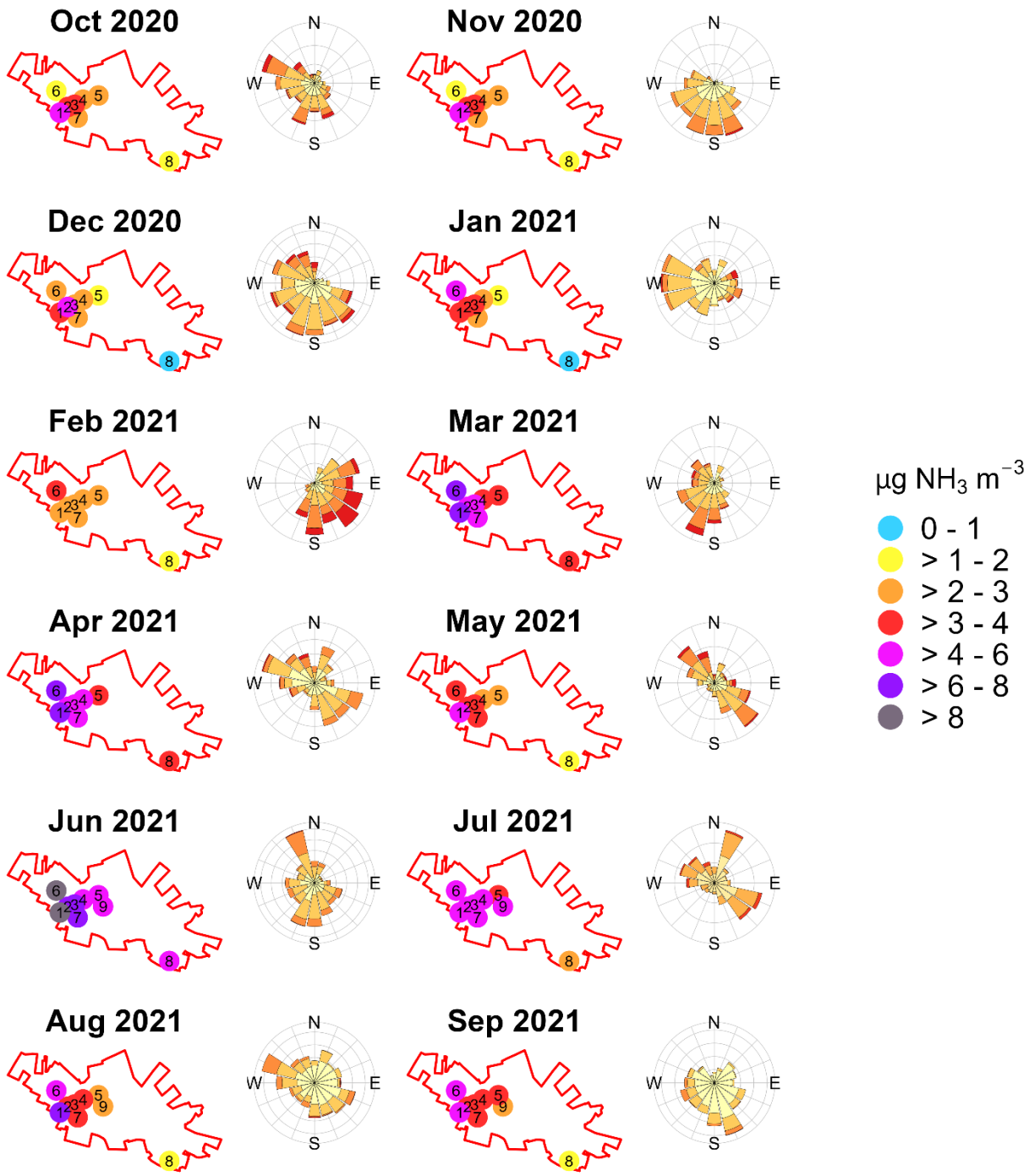

Figure 6: Monthly NH_3 concentration at measurement sites on Ballynahone Bog for the period 1st October 2020 to 30th September 2021, Wind roses from the Ballynahone Bog met station, with monthly data capture of ~90%. Missing wind data was gap filled between 25th May and 30th September 2021 using a new flux tower located 400m from the Ballynahone Bog met station. A two-month average of NH_3 concentrations was taken across October - November 2020, as samplers could not be exchanged due to SARS-Covid19 travel restrictions.

Ammonia concentrations - comparison to previous years

Ammonia concentration measurements in 2021 broadly follow the trends of previous years for each site (Figure 7a, 7b). Figure 7a has variable y-axes maximising the detail for each site, whereas Figure 7b enables better comparison across all sites, with identical y-axes. Sites 1 and 2 show the highest NH_3 concentrations consistently out of all the nine sites on Ballynahone between 2014 and 2021.

The 2018 winter season (October to December) had substantially higher concentrations for all sites compared to previous years (Figure 7a,b). The concentrations at Site 5 between July to September 2020 were substantially higher than those of the other years (>10 µg NH_3 m^{-3}). Sites 6, 7 and 8 recorded higher concentrations in June 2021 than in previous years.

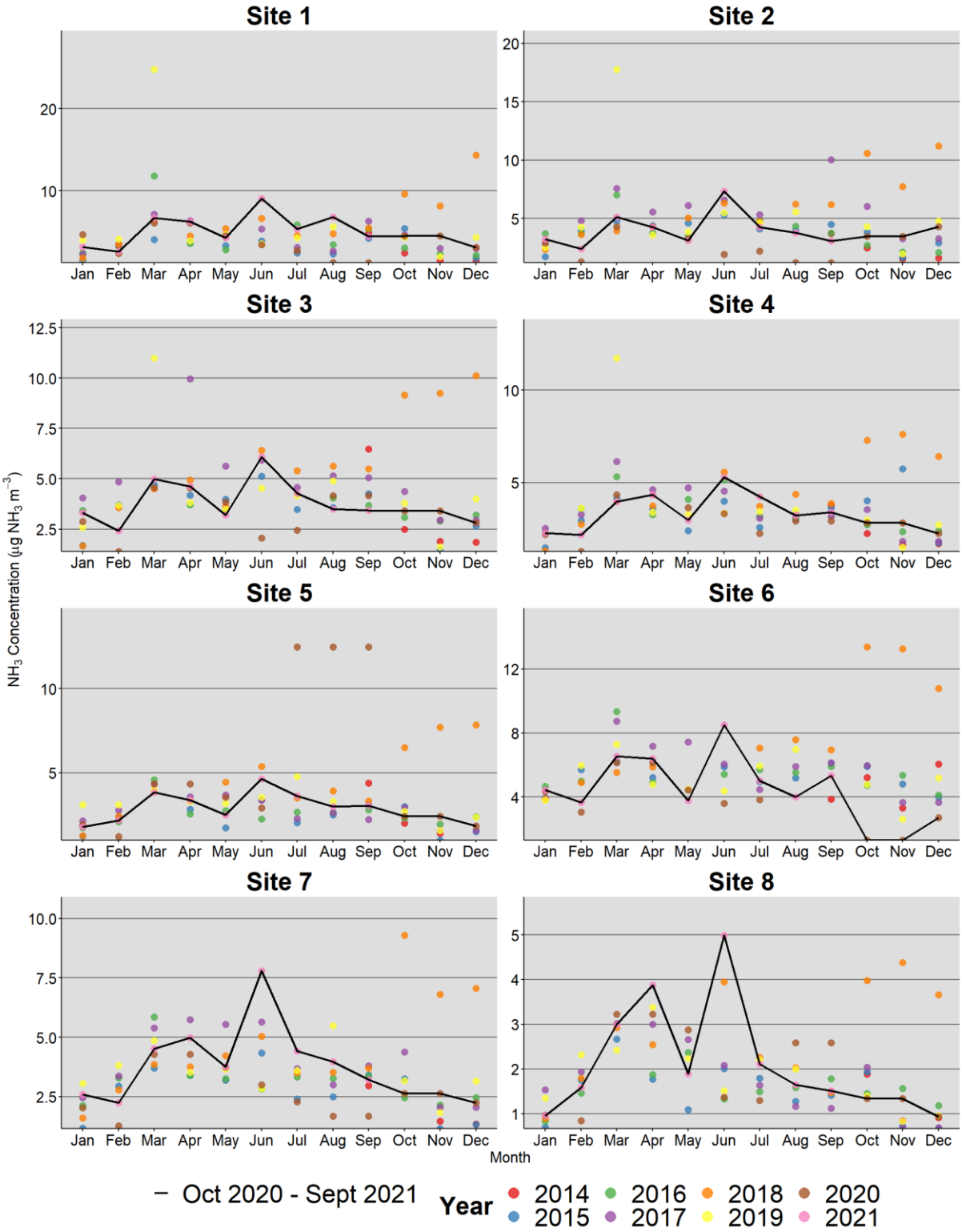

Figure 7a: A comparison of monthly NH_3 concentrations at each measurement site on Ballynahone. Site 9 has not been included as there are limited temporal data with sampling only beginning in May 2021. N.B. The range in the values on the y-axis changes between sites, Figure 7b presents the same data with fixed values on the y-axis.

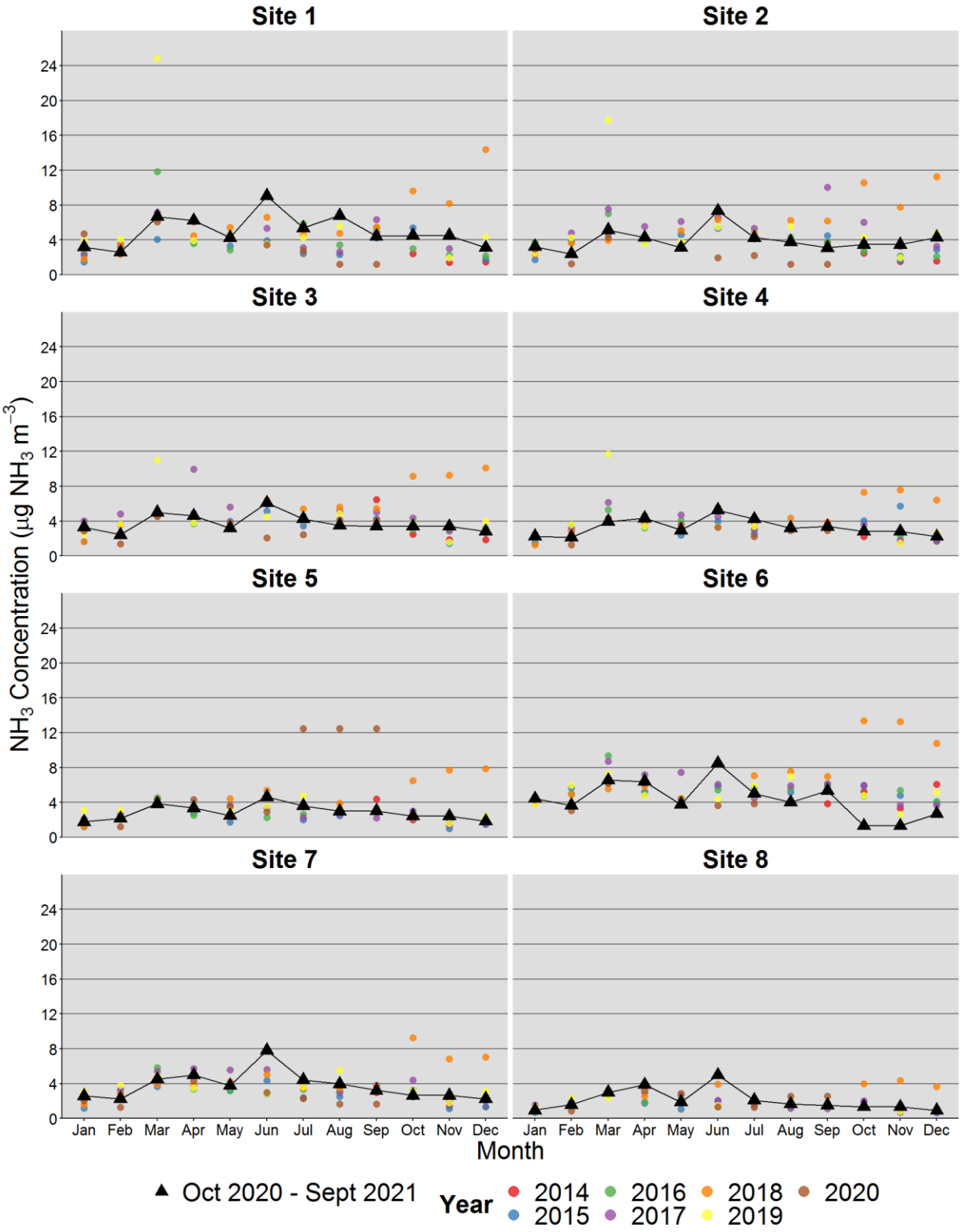

Figure 7b: A comparison of monthly NH concentrations at each measurement site on Ballynahone Bog in 2014 to 2021. Site 9 has not been included as there are limited temporal data with sampling only beginning in May 2021.

4 NH_3 concentrations surrounding Ballynahone Bog SAC

4.1 Background

Ammonia concentration data have been collected by nine ALPHA® sampling sites surrounding Ballynahone Bog from February 2019 until to May 2022 (Figure 8). The ammonia monitoring network surrounding Ballynahone Bog was established in the 5km grid square containing the Ballynahone Bog to better understand ammonia emission sources (and subsequent elevated concentrations and deposition) in the area surrounding the Bog. Data for the period 1st October 2020 to 30th September 2021 are described in this report.

4.2 Results

The ammonia monitoring network surrounding Ballynahone Bog was established to better understand ammonia emission sources (and subsequent elevated concentrations and deposition) in the area surrounding the site. Monthly ammonia concentrations between 0.2 to 9 µg m^{-3} NH_3 were recorded at several measurement sites between October 2020 and September 2021 (Figure 8).

October 2020 to January 2021

Low monthly ammonia concentrations (1-3 µg m^{-3}) were recorded between October 2020 and January 2021, apart from Site 6 (>4 µg m^{-3}) in October. The low ammonia concentrations during this period align with the closed season, when no slurry spreading is permitted across Northern Ireland. Low temperatures and high rainfall typically seen in winter months also tend to reduce NH_3 emissions and concentrations.

February – April 2021

Ammonia concentrations of 2 to 10 µg m^{-3} NH_3 were recorded at several measurement sites between February and April 2021, coinciding with local land spreading activity.

May – July 2021

There was a drop in ammonia concentrations in May (majority between 2-4 µg m^{-3}) before another period of elevated concentrations in June and July 2021 (2 to 10 µg m^{-3} NH_3). This likely coincides with landspreading of slurry following cutting.

August – September 2021.

Following the high concentrations in June and July 2021, a drop in concentrations was recorded in August (2 to >4 µg m^{-3}). September 2021 has a number of sites (4, 5, 6, 7 & 9) with relatively high concentrations of 4-7 µg m^{-3} NH_3 (Figure 8) which could indicate further local land spreading activity

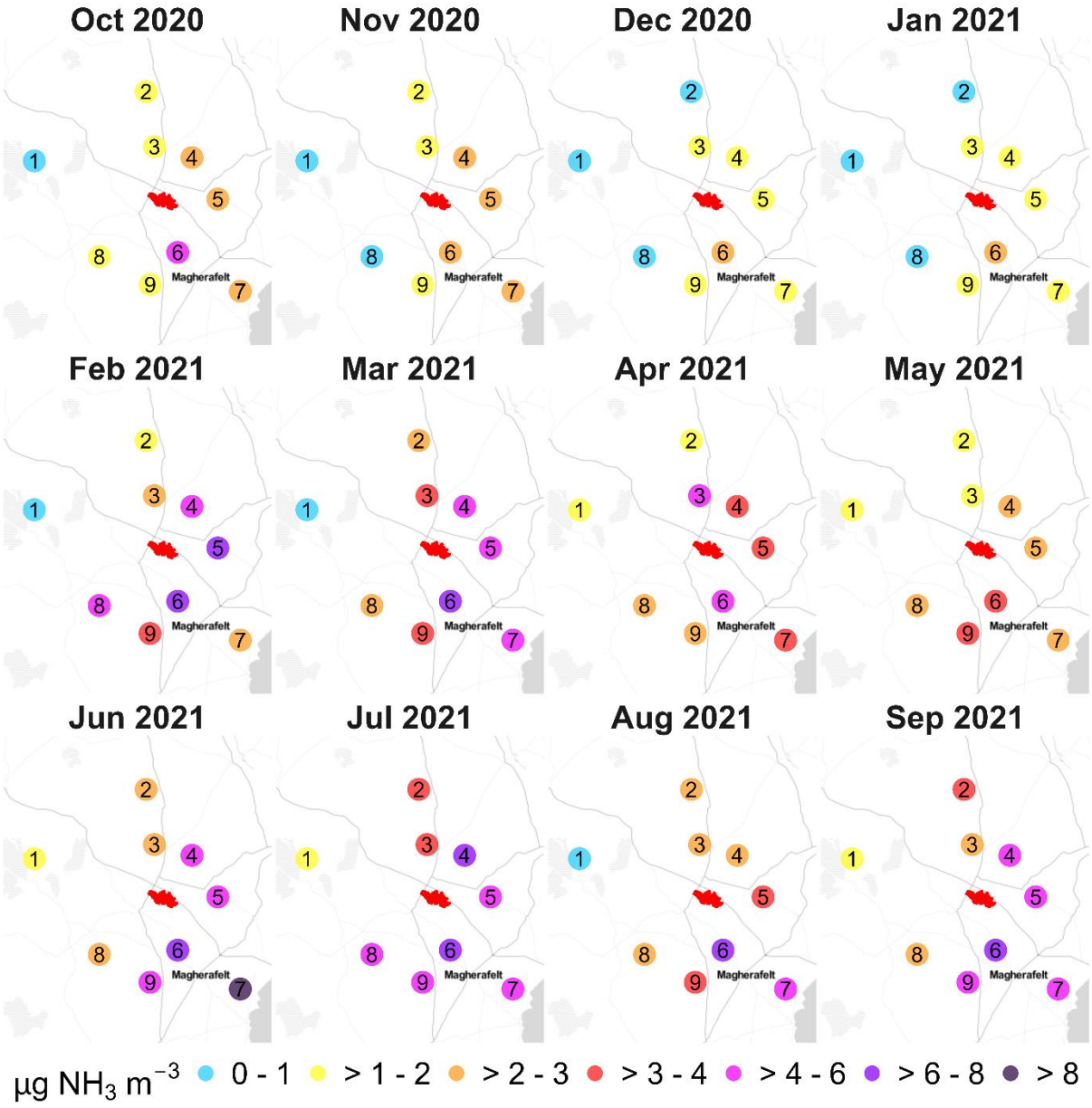

Figure 8: Monthly NH_3 concentrations at measurement sites surrounding Ballynahone Bog SAC (shown in the centre of each map in red) between October 2020 and September 2021. The boundary of Ballynahone Bog SAC is shown in red in the centre of each monthly plot.

5 Discussion and conclusions

Wind direction data can provide a valuable insight for inferring the sources of high ammonia concentrations measured at a site. This is the first year that a whole cycle of relevant emissions sources and events could be captured in the interpretation of the NH_3 concentration data, as previously the old met station at Ballynahone bog only worked intermittently. The new met station, installed 30th September 2020 at BB3, has been working well for the most part, however on further inspection had a faulty bearing and uses a cup anemometer which has a sensitivity of >0.5 m/s so is unable to record wind speeds below this accurately (this became apparent in April 2021, Figure 1).

A new Campbell Automatic Weather Station (AWS, greenhouse gas flux tower) was installed at NH_3 monitoring site BB9 (Figure 5) and has been operational since 26th May 2021. This met station has a 3D sonic with higher sensitivity for recording lower wind speeds (<0.5 m/s) and has been used in this report to gap-fill missing data for the relevant period (25th May 2021 to 30th September 2021). This solution results in minimal bias as the two stations are located within 400 metres from one another and are subjected to similar weather conditions. Wind speed and direction comparison between the two met stations is shown in Figure 1 and 2, Williams et al. (2022) has investigated weather conditions recorded by both stations. Overall, the new NIEA met station has substantially increased the reliability and accessibility of the wind data allowing data to be accessed remotely. The under-recording of low wind speeds was only discovered during detailed analysis of the data, as it was not obvious from quick screening of the data for obvious faults. It is recommended that weekly checks are carried out on the met station data in the future to ensure early diagnosis of any possible malfunctions.

Complete met data have been collected from 14:00 1st October 2020 to 23:30 30th September 2021. Some of the lower ammonia concentrations on the bog during this annual period have been recorded between October and December 2020 with a prevailing south-westerly wind (Figure 6). However, this winter period shows concentrations at the higher end of the spectrum when compared to previous years (discounting site 6, Figure 7a, b). This winter period corresponds with the closed period (where landspreading of slurries and manures is not permitted under NAP rules) and where lower concentrations are normally expected across the wider landscape.

January and August 2021 wind data show similar contributions from all wind sectors with a slight prevalence for west/north-west (Figure 6). This is the probable cause of why Site 6 has a much higher NH_3 concentration than other sites for both of these months (Figure 6).

February normally indicates the start of the landspreading season for farmers (open period in the NAP) and is key in terms of ammonia emissions due to land spreading of slurries and manures in the wider area. However, the low NH_3 concentrations seen in February 2021 may indicate that the landspreading season did not fully start until March 2021 as February had a large amount of rainfall (Figure 6 and 7).

This annual cycle of wind and ammonia concentration data highlights the importance of more diffuse sources, such as land spreading, across the wider area during the

spring months and the closed season during winter months. The contrast between, for example, February and June 2021 (Figure 6) gives a good illustration of the importance of wind patterns on local NH_3 concentrations in general, and an indication of the role of wind direction in influencing ammonia concentrations across Ballynahone Bog, in particular.

Carnell et al (2021) found that alternative met stations surrounding Ballynahone bog could not be used reliably as a proxy for wind direction and speed data to fill data gaps in wind data between 2019 and 2020. Therefore, these data could not currently be used to generate multi-year time series of measurements at Ballynahone Bog dating back to September 2014. Further investigations on whether surrounding met stations could be used as a proxy to provide additional weather data, such as temperature, rainfall and humidity, to help explain NH_3 concentration patterns across the bog is under way.

6 Reference

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BANGOR
UK Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor
Gwynedd
LL57 2UW
United Kingdom
T: +44 (0)1248 374500
F: +44 (0)1248 362133

EDINBURGH
UK Centre for Ecology & Hydrology
Bush Estate
Penicuik
Midlothian
EH26 0QB
United Kingdom
T: +44 (0)131 4454343
F: +44 (0)131 4453943

LANCASTER
UK Centre for Ecology & Hydrology
Lancaster Environment Centre
Library Avenue
Bailrigg
Lancaster
LA1 4AP
United Kingdom
T: +44 (0)1524 595800
F: +44 (0)1524 61536

WALLINGFORD (Headquarters)
UK Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire
0X10 8BB
United Kingdom
T: +44 (0)1491 838800
F: +44 (0)1491 692424

enquiries@ceh.ac.uk

www.ceh.ac.uk