UK Centre for Ecology & Hydrology

# Suitability of meteorological data for interpreting ammonia concentrations on Ballynahone Bog SAC

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# Contents

# 1 Introduction / background

Meteorology plays 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. An earlier study by Williams et al. (2021) compared how local prevailing wind patterns could affect atmospheric nitrogen dispersion and thus the measured $NH_3$ concentrations at Ballynahone Bog Special Area of Conservation (SAC).

Other meteorological variables that influence local $NH_3$ emissions and therefore N input to sensitive habitats, are temperature, precipitation and humidity. Studies have shown that increased temperature and humidity can be a direct driver of ammonia volatilisation rates due to the effect on the amount of $NH_3$ vapour pressure that is exerted on soil surfaces (Sutton et al., 2014). Precipitation can also influence the amount of wet deposition received by sites as precipitation can remove N-containing gases from the atmosphere and deposit them onto land surfaces (Sutton et al., 2011). SACs in NI are estimated to receive on average 57% of N deposition through wet deposition (CBED model output 2016 - 2018). To determine how local weather patterns influence $NH_3$ concentrations on the bog, we therefore need to investigate these other, potential confounding, meteorological parameters, in addition to wind direction and wind speed.

The Campbell Automatic Weather Station (AWS) installed on Ballynahone Bog in October 2020 (see Williams et al., forthcoming) records temperature, precipitation and humidity (in addition to wind speed and direction, located at site BB3 Figure 1). Continued parallel monitoring of these meteorological parameters and $NH_3$ concentrations on Ballynahone Bog is useful to capture an entire annual cycle of relevant emission sources and events and to help explain how these parameters may have influenced the measured concentrations.

**Figure 1**: Location of the 8 samplers and the new met station on Ballynahone Bog.

The aim of this study was to investigate local meteorological patterns and their temporal variability using locally measured weather data for the period October 2020 to September 2021.

This report aims to present:

- An assessment of local meteorological conditions at Ballynahone Bog for the period October 2020 to September 2021
- How meteorological conditions influence $NH_3$ concentrations
- How other local met stations compare to meteorological measurements taken at Ballynahone Bog
- An assessment of whether these time series meteorological measurements could be used to help interpret the $NH_3$ concentration time series collected on the bog since September 2014

# 2 Measured meteorological conditions at Ballynahone Bog for the period October 2020 to September 2021

Table 1 provides a summary of meteorological conditions recorded by the Campbell AWS installed on Ballynahone Bog for the one-year period October 2020 to September 2021. The AWS records at 30-minute intervals, which have been summarised by month in Table 1.

**Table 1:** Monthly meteorological parameters recorded by Campbell AWS located on Ballynahone Bog between October 2020 and September 2021.

| Month | Year | $NH_3$ Concentration (µg $NH_3$ $m^{-3}$) | Prevailing Wind Direction | Average Wind Speed (m / $s^{-1}$) | Total Precipitation (mm) | Average Temperature (°C) | Relative Humidity (%) |
|---|---|---|---|---|---|---|---|
| Oct | 2020 | 3.4 | WNW | 2.7 | 128 | 9.1 | 89.6 |
| Nov | 2020 | 3.4 | SSE | 2.4 | 103 | 7.9 | 91.6 |
| Dec | 2020 | 2.8 | SSW | 2.5 | 140 | 4.7 | 90.0 |
| Jan | 2021 | 3.3 | WNW | 2.0 | 114 | 3.2 | 89.3 |
| Feb | 2021 | 2.4 | SE | 3.7 | 118 | 5.0 | 83.2 |
| Mar | 2021 | 5.0 | SSW | 2.8 | 69 | 7.0 | 82.6 |
| Apr | 2021 | 4.6 | WNW | 2.2 | 23 | 6.2 | 77.5 |
| May | 2021 | 3.2 | SE | 2.7 | 121 | 9.3 | 79.2 |
| Jun | 2021 | 6.1 | NNW | 2.5 | 28 | 13.8 | 76.4 |
| Jul | 2021 | 4.3 | NNE | 1.7 | 31 | 16.3 | 81.1 |
| Aug | 2021 | 3.5 | WNW | 1.5 | 106 | 14.9 | 85.3 |
| Sep | 2021 | 3.4 | SSE | 0.9 | 60 | 14.0 | 87.3 |

## 2.1 Precipitation

Figure 2 presents total precipitation measured on Ballynahone Bog in weekly intervals for the period October 2020 to September 2021. During this period, December was the wettest month with 140mm of precipitation recorded. The driest month was April with 23mm of precipitation recorded (Table 1). June 2021 shows consistently low weekly precipitation (3 weeks were between 0.0 – 4.5mm). December 2020 and August 2021 have the highest weekly precipitation when compared across the annual cycle (53mm & 78mm, respectively Figure 2). The amount of precipitation recorded is likely to influence the agricultural activities taking place in the areas surrounding Ballynahone Bog. As the majority (~55%) of N depositing to NI is in the form of wet deposition (calculated from CBED 2016-2018 dataset), the amount of precipitation received is also a useful indication of potential N inputs through wet deposition for the period. However, the amount of wet deposited N depends on the origin and path of travel of the air mass passing over the site during precipitation events.

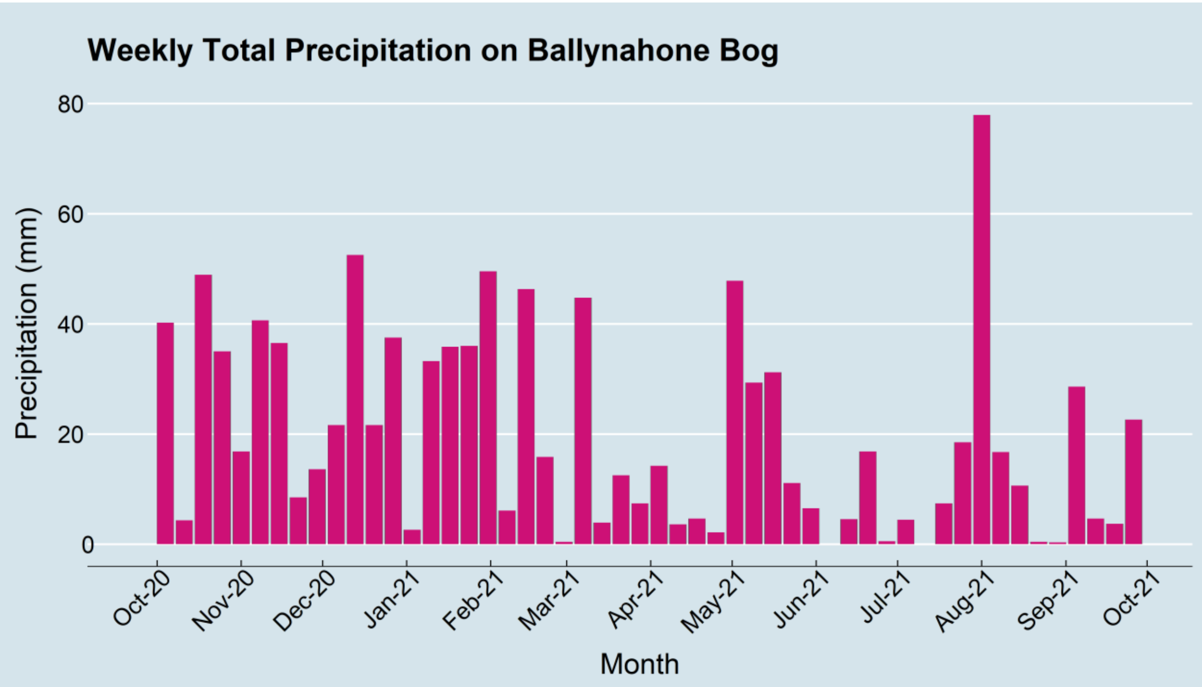



**Figure 2:** Weekly total precipitation recordings on Ballynahone Bog between October 2020 and September 2021.

## 2.2 Temperature

Figure 3 presents weekly mean air temperatures measured on Ballynahone Bog for the period October 2020 to September 2021. July 2021 was the warmest month with mean air temperatures of 16.3°C (Table 1). January 2021 was the coldest month with mean air temperatures of 3.2°C. Unsurprisingly, weekly mean air temperatures are higher in the summer months than the winter months. Spring tends to be associated with the majority of the land spreading activities and therefore is often associated with higher overall emissions than the rest of the year. As there is positive correlation between air temperature and ammonia volatilisation, higher air temperatures during slurry spreading periods may increase the amount of ammonia emitted (relative to cooler months with similar agricultural activities).

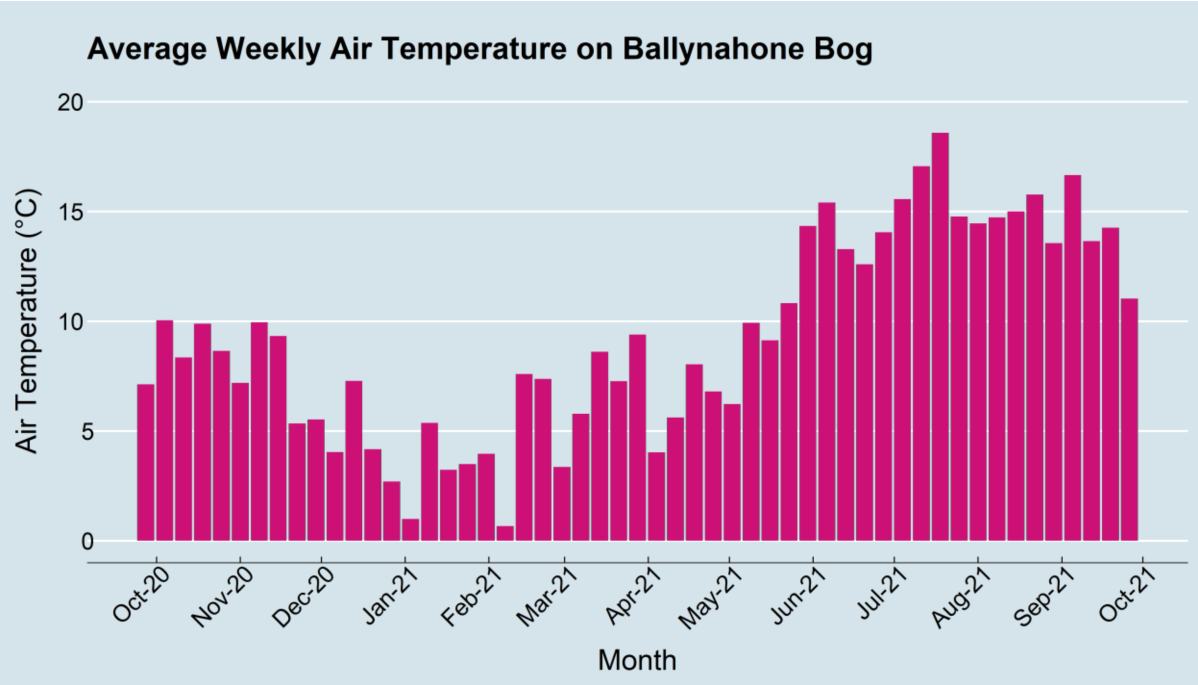



**Figure 3:** Average weekly air temperature recordings on Ballynahone Bog between October 2020 and September 2021.

## 2.3 Relative Humidity

Figure 4 presents weekly mean relative humidity measured on Ballynahone Bog for the period October 2020 to September 2021. During this period, humidity was highest in November 2020 (91.6%) and lowest in June 2021 (76.4%, Table 1). Unsurprisingly, the relative humidity is consistently higher in winter months than summer months (Figure 4). Humidity is an important parameter to monitor in combination with $NH_3$ concentrations as high humidity can increase the rate at which ammonia volatilizes.

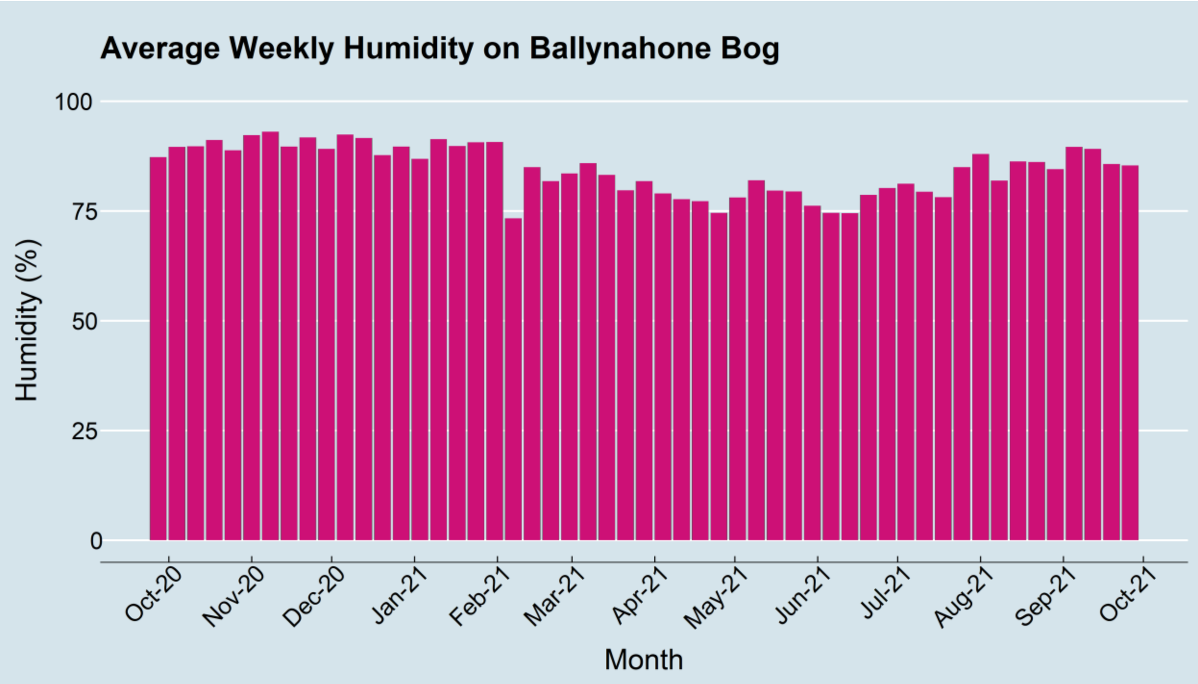



**Figure 4:** Average weekly relative humidity recordings on Ballynahone Bog between October 2020 and September 2021.

# 3 Ammonia concentrations at Ballynahone Bog

Ammonia concentrations have been recorded on Ballynahone Bog at monthly intervals since 2014, providing a near complete time series for now over 8 years. Tang et al. (2022) provide a summary report across the time series to January 2021. Full details of the $NH_3$ concentration and prevailing wind patterns over the more recent period from 2019 can be found in Thomas et al. (2020), Williams et al. (2021) and Williams et al. (forthcoming). Ammonia concentrations are currently measured at 9 locations across the bog (Figure 1). Site BB9 was added in June 2021, with the installation of a new greenhouse gas flux tower.

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 5). Only two $NH_3$ concentration measurements (~2% of measurements during this period) were below the 1 µg $NH_3$ critical level for lichens, mosses and bryophytes. Both of these measurements were recorded at Site 8, on the south-eastern edge of the site, furthest away from local emission sources. Samplers 1-5, which are situated along a transect across the bog (away from a local source) typically experienced the highest concentrations, with concentrations declining away from the site boundary.

During the period October 2020 to February 2021, $NH_3$ concentrations were relatively low compared to comparable measurements made in the rest of the year. This winter period corresponds with the closed period (where landspreading is not permitted under NAP rules) and where lower concentrations are expected across the wider landscape. 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 2021 (Figure 5). High concentrations are common in spring and are typically associated with manure spreading and synthetic fertiliser application across the region. Very high concentrations (>7 µg $NH_3$ $m^{-3}$) were recorded in June at a number of sample locations (1-3, 6 & 7) and remained >4 µg $NH_3$ $m^{-3}$ in July.

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.

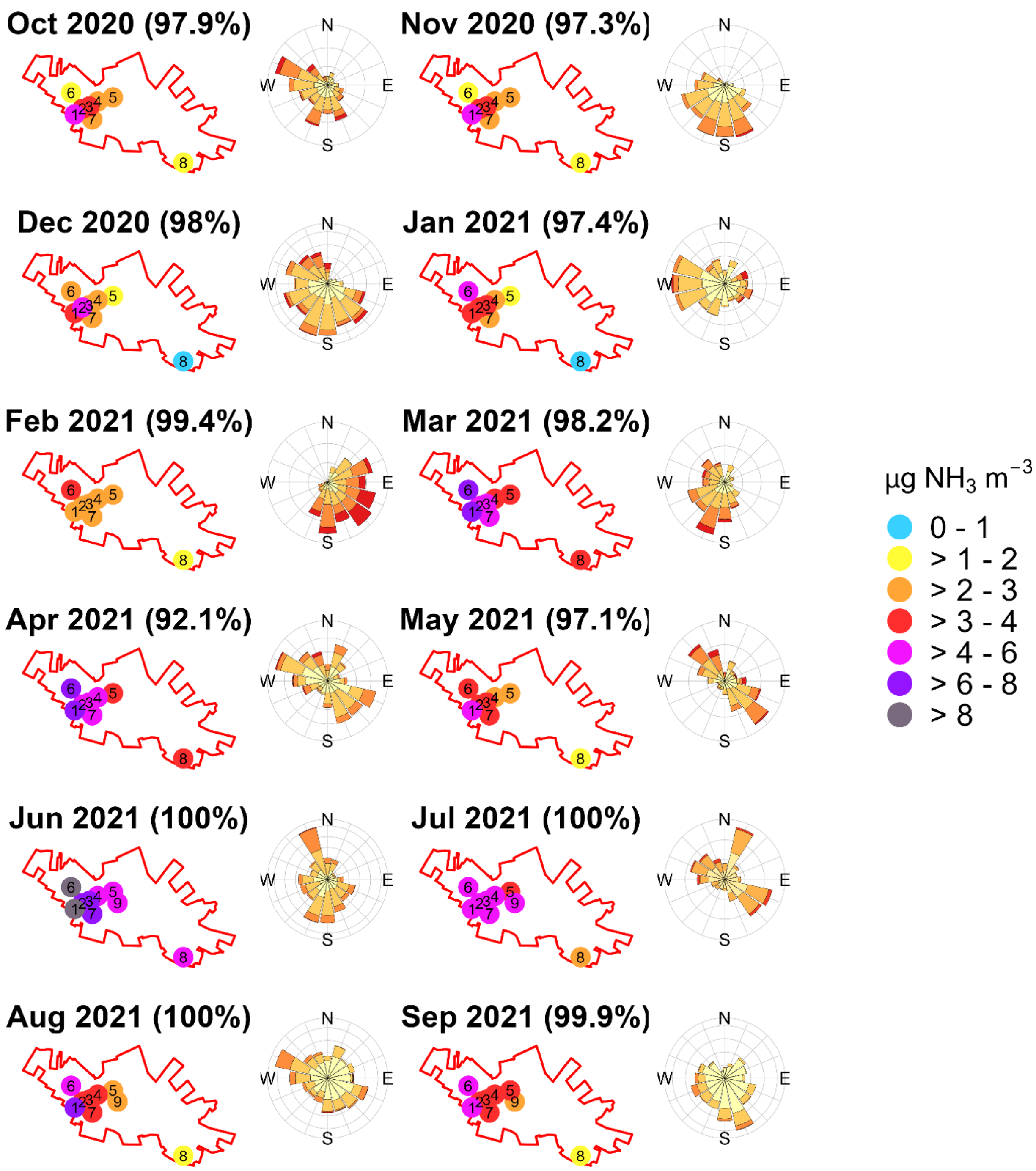



**Figure 5**: Monthly $NH_3$ concentration at measurement sites on Ballynahone Bog for the period 1st October 2020 to 30th September 2021. Missing wind data was gap filled between 25th May and 30th September 2021 using a new flux tower located 400m from the Ballynahone Bog met station. Percentages shown in brackets next to each month label indicate the proportion of measurements recorded by the Ballynahone AWS gap filled with the new flux tower. 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.

# 4 Comparison of meteorological conditions on and surrounding Ballynahone Bog

## 4.1 Other variables analysis

The following section investigates whether the two nearest meteorological stations to Ballynahone Bog (Lough Fea and Portglenone) experience similar meteorological conditions to Ballynahone Bog (Figure 6). The section compares recordings of precipitation, air temperature and relative humidity for the period 1st October 2020 to 31st March 2021. This comparison enables us to assess whether either of the two met stations could be used as a proxy to impute missing precipitation, air temperature and relative humidity data at Ballynahone Bog dating back to 2014, to match the atmospheric $NH_3$ concentration monitoring dataset.

### 4.1.1 Precipitation

During the period October 2020 to March 2021, both Portglenone and Lough Fea received higher amounts of precipitation than Ballynahone Bog. The total precipitation over this period was 672mm at Ballynahone Bog compared to 1678mm at Lough Fea and 1115mm at Portglenone.

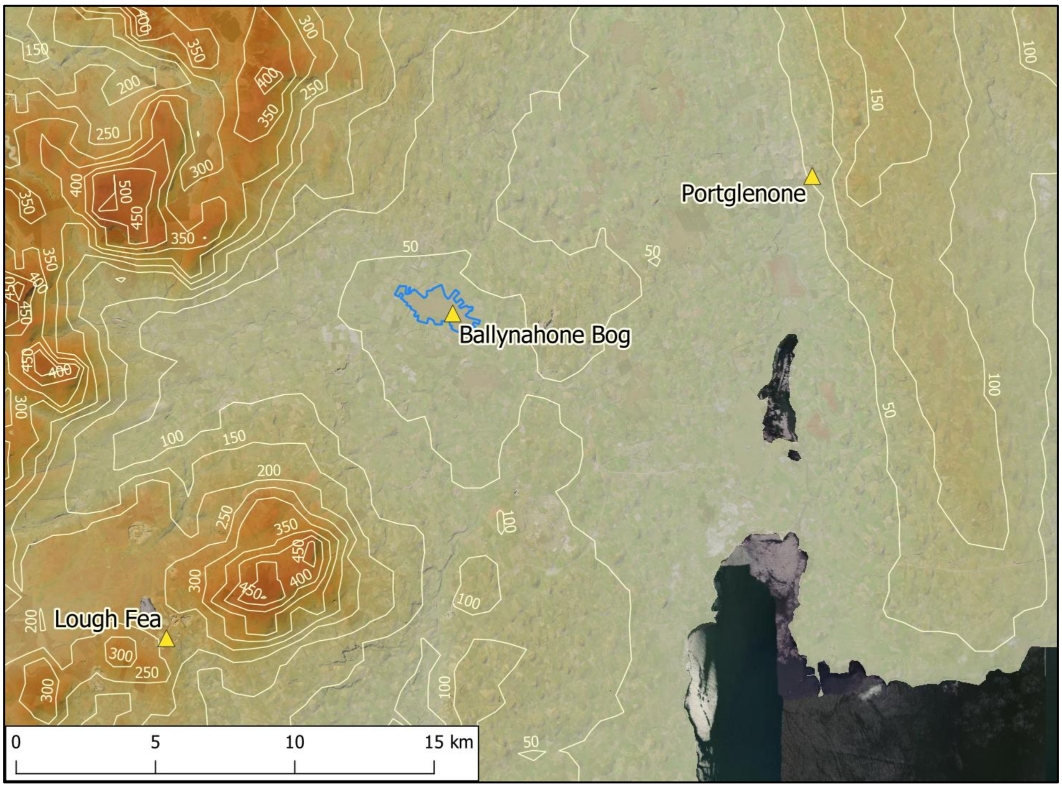



**Figure 6:** Map showing location of the Met Office MIDAS Portglenone and Lough Fea met stations in relation to Ballynahone Bog and terrain of the area. Uses OSNI Open Data 10M DTM as elevation data (Land and Property Services 2015). Contains public sector information licensed under the Open Government Licence v3.0.

A comparison was also made to establish whether days of no precipitation (where precipitation was < 1mm day$^{-1}$) were similar at Lough Fea and Portglenone compared to Ballynahone Bog. Periods of no precipitation appear to be similar at all sites (Figure 7). There were 86 dry days (< 1mm day$^{-}$1) recorded at Ballynahone Bog over the period October 2020 to March 2021. This is compared to 62 at Lough Fea and 73 at Portglenone. For the days that were dry at Ballynahone Bog, 72% were also dry at Lough Fea and 79% at Portglenone.

To assess whether there was a statistically significant relationship between weekly precipitation rates at Ballynahone Bog met station and each of the two other met sites, a linear model was fitted. Ballynahone Bog showed lower weekly precipitation rates compared to both Portglenone and Lough Fea, with 0.5mms of rainfall at Ballynahone for every 1mm at Portglenone, and 0.4 mm of rainfall for every 1mm at Lough Fea (Figure 8a & 8b). Portglenone weekly precipitation explained 80% and Lough Fea explained 92% of variation in Ballynahone weekly precipitation (Table 2).

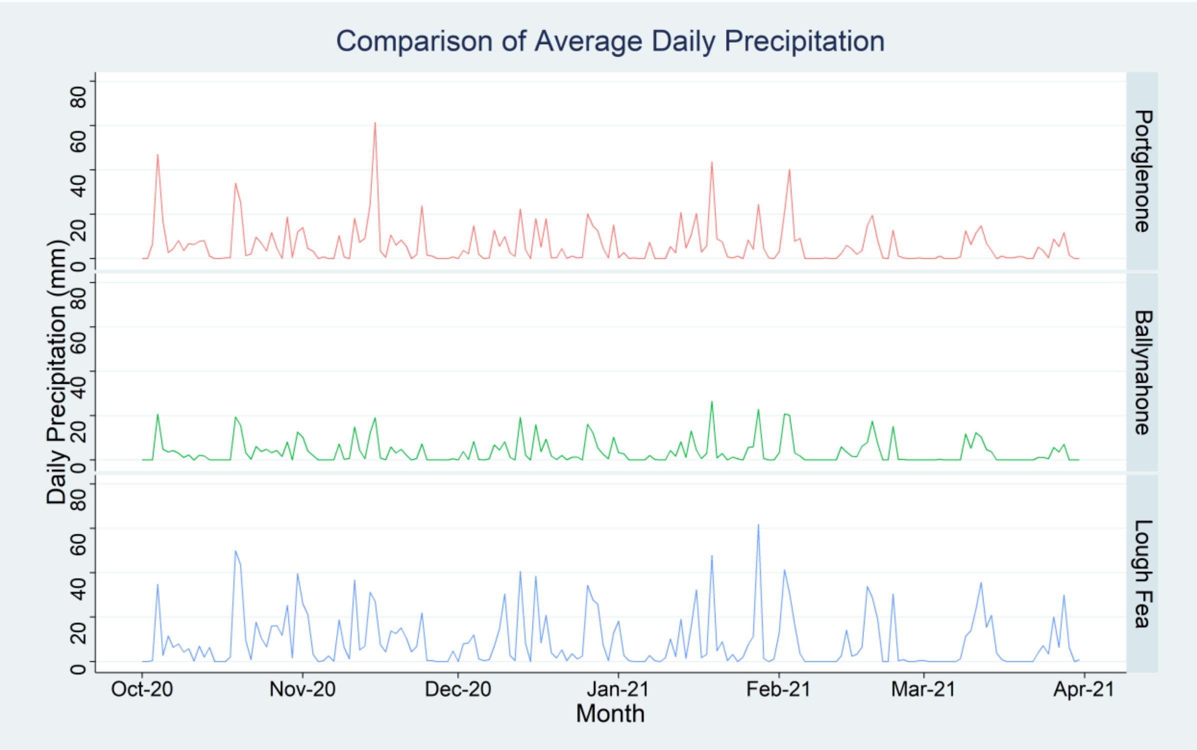



**Figure 7:** Comparison of total amount of daily precipitation (mm) recorded by Portglenone, Ballynahone Bog and Lough Fea met station between October 2020 and March 2021. Data have been subset to compare only the matching period(s) where data are available.

**8b)**

**8a)**

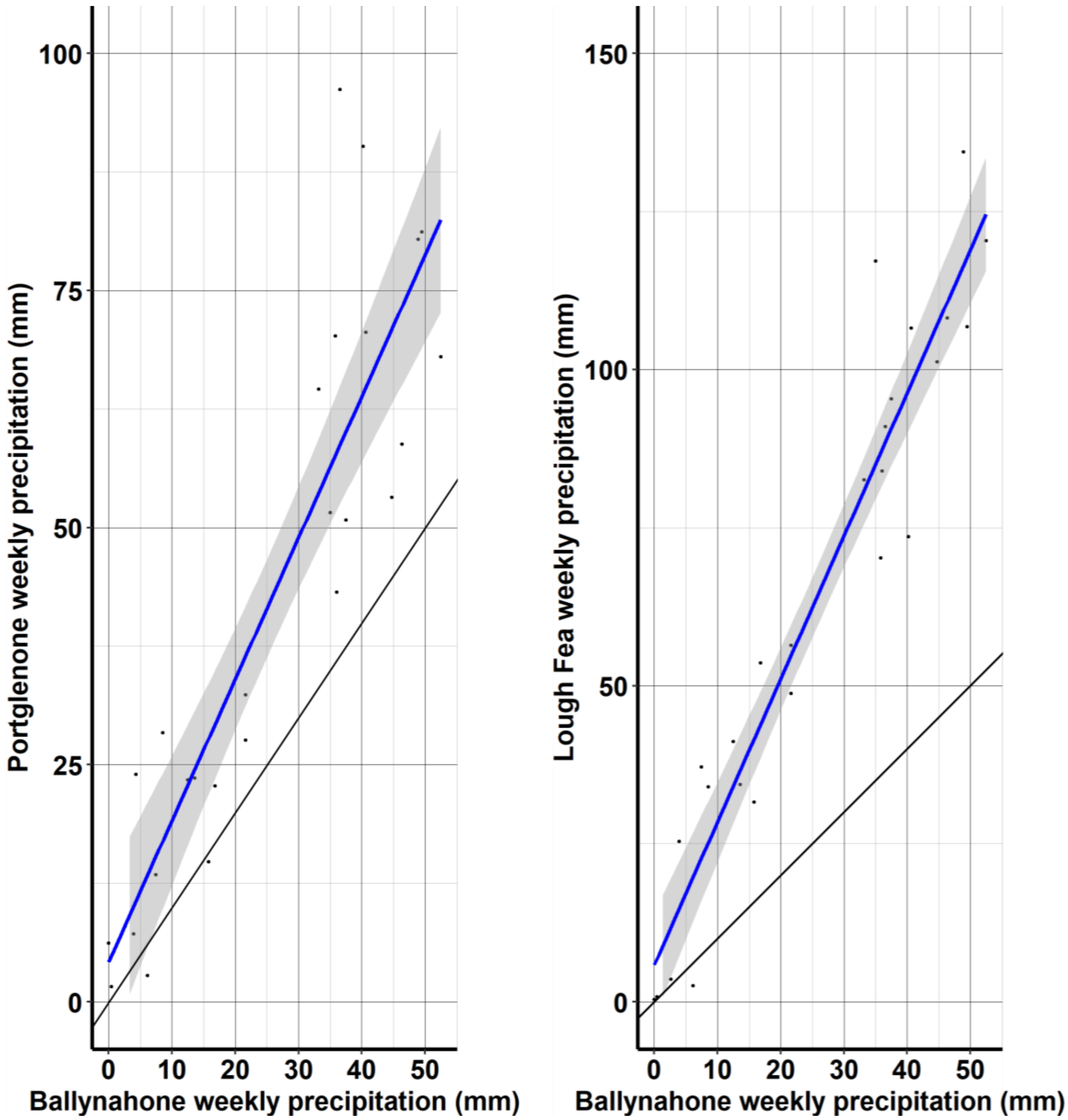



**Figure 8:** Linear model showing the difference in weekly precipitation recorded by 8a) Portglenone and Ballynahone Bog met stations & 8b) Lough Fea and Ballynahone Bog met stations. Data have been subset to compare only the matching period(s) where data are available, +/- 95% confidence interval.

### 4.1.2 Air temperature

Hourly air temperature patterns at Portglenone, Ballynahone Bog and Lough Fea are shown in Figure 9. The figure shows similar patterns between the three sites. To assess whether there was a statistically significant relationship between daily mean air temperature at Ballynahone Bog met station and each of the two other met sites, a linear model was fitted. Ballynahone Bog showed daily mean air temperatures that were similar to both Portglenone and Lough Fea, with 1 °C increase in air temperature for every 1°C increase at Portglenone and Lough Fea (Figure 10a & 10b). Portglenone and Lough Fea daily air temperature explained 95% of variation in Ballynahone daily mean air temperature (Table 2).

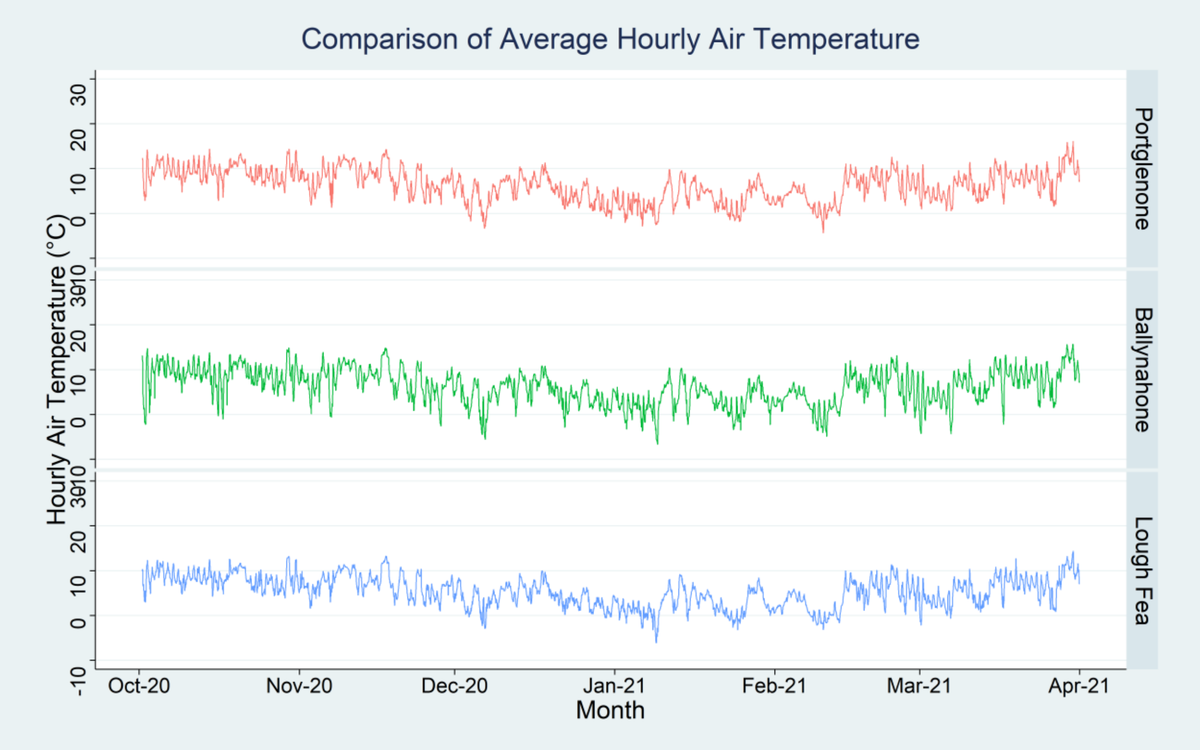
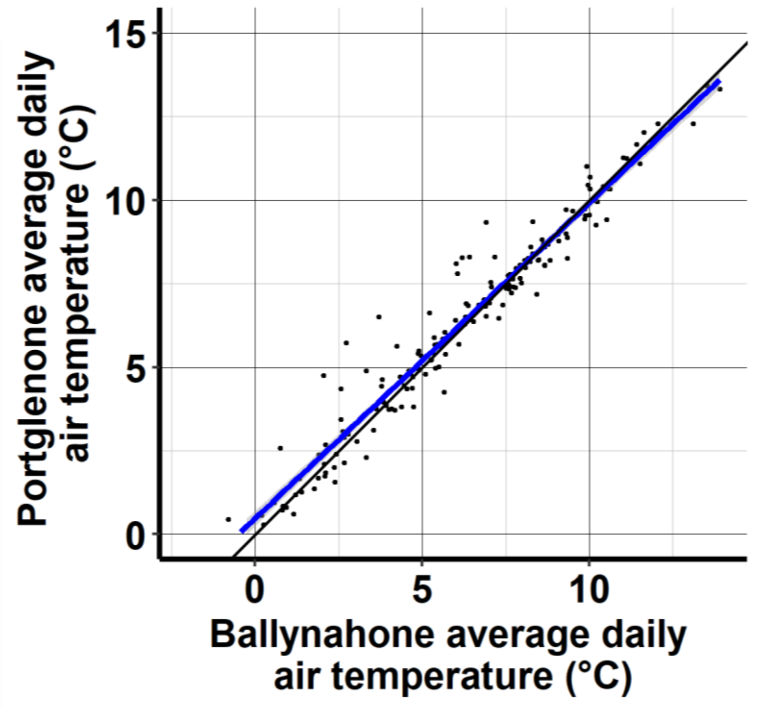



**Figure 9**: Comparison of average hourly air temperature (°C) recorded by Portglenone, Ballynahone Bog and Lough Fea met station between October 2020 and March 2021. Data have been subset to compare only the matching period(s) where data are available.

10a)




10b)

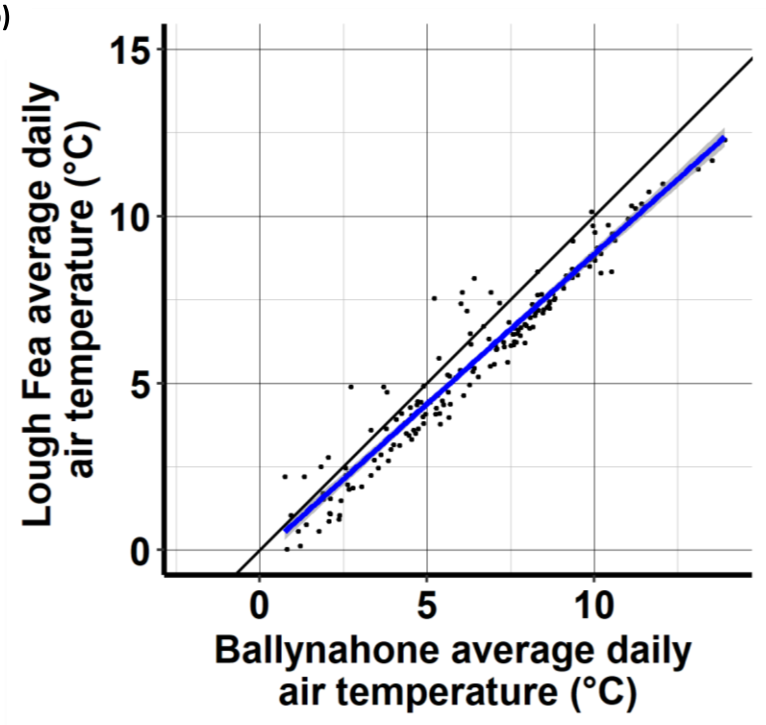



**Figure 10:** Linear models showing the difference in average daily air temperature recorded by 8a) Portglenone and Ballynahone Bog met stations & 10b) Lough Fea and Ballynahone Bog. Data have been subset to compare only the matching period(s) where data are available, +/- 95% confidence interval.

### 4.1.3 Relative Humidity

Relative humidity measurements at Portglenone, Lough Fea and Ballynahone Bog are compared in Figure 11. The figure shows similar average hourly relative humidity patterns at the three sites.

To assess whether there was a statistically significant relationship between daily mean relative humidity at Ballynahone Bog met station and each of the two other met sites, a linear model was fitted. Ballynahone Bog showed daily mean relative humidity that were similar to both Portglenone and Lough Fea, with 0.8% increase in relative humidity for every 1% increase at Portglenone and Lough Fea (Figure 12a & 12b). Portglenone daily mean relative humidity explained 75% and Lough Fea explained 74% of variation in Ballynahone weekly precipitation (Table 2).

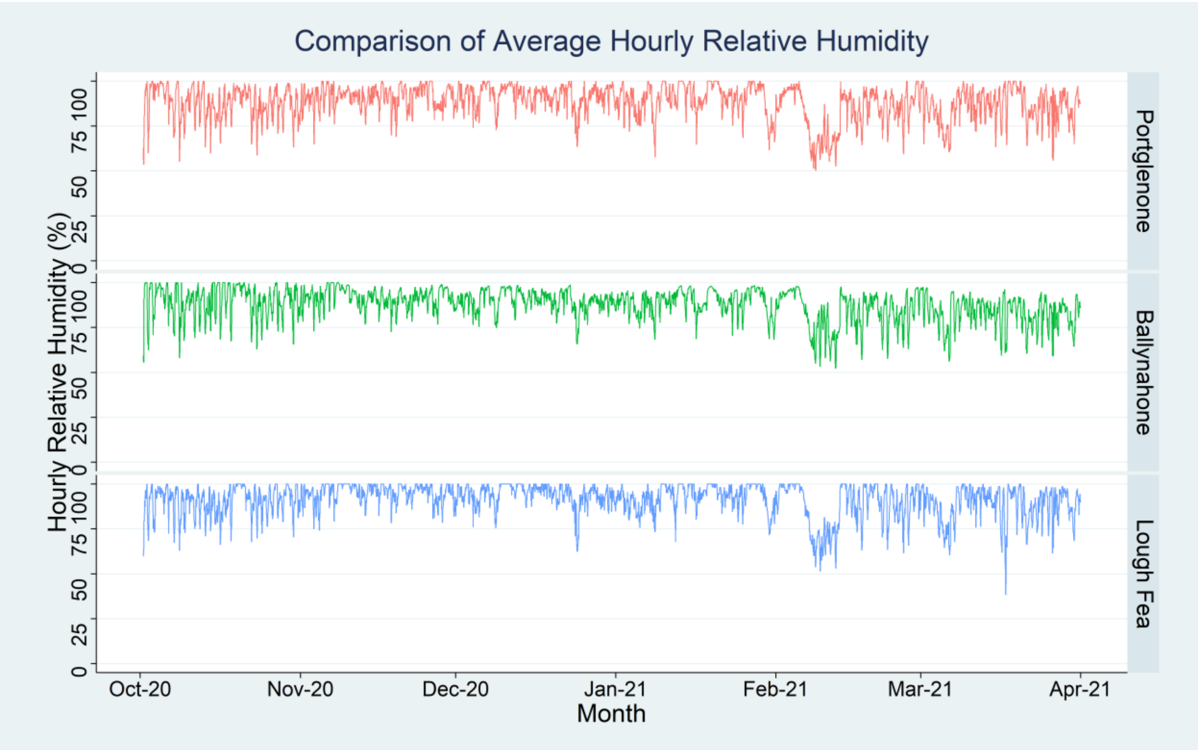
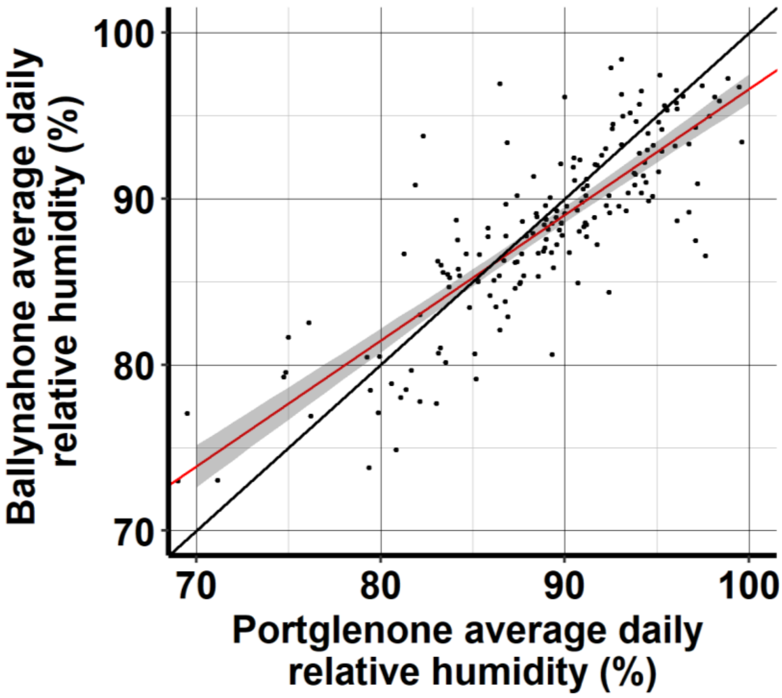



**Figure 11:** Comparison of average hourly relative humidity (%) recorded by Portglenone, Ballynahone Bog and Lough Fea met station between October 2020 and March 2021. Data have been subset to compare only the matching period(s) where data are available.

**12a)**




**12b)**

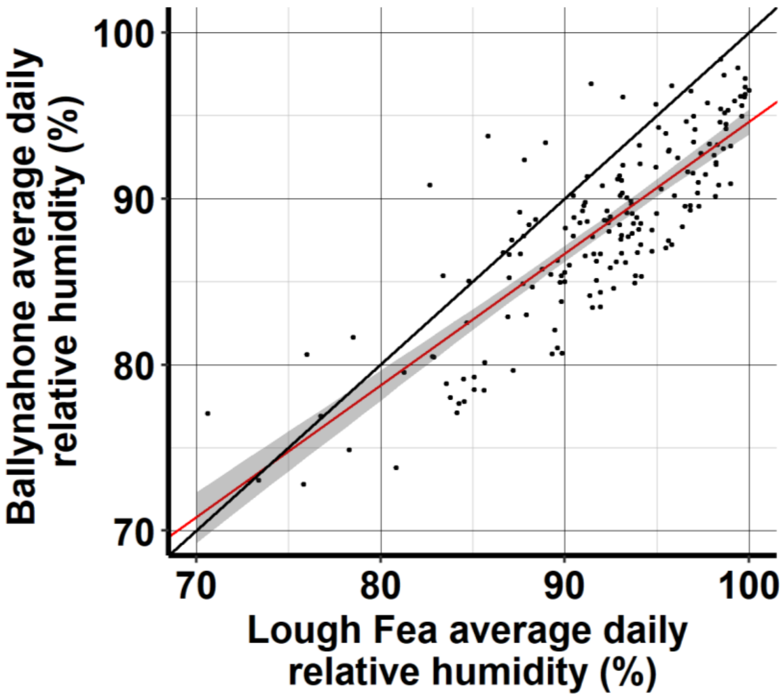



**Figure 12**: Linear models show the difference in average daily relative humidity recorded at 12a) Portglenone and Ballynahone Bog met stations and 12b) Lough Fea and Ballynahone Bog met stations. Data have been subset to compare only the matching period(s) where data are available, +/- 95% confidence interval.

The purpose of these analyses is to determine whether Portglenone or Lough Fea could be used as suitable proxies to gap fill for historic Ballynahone Bog met station data that has been missing on these parameters.

**Table 2:** Summary statistics for Ballynahone vs Portglenone and Lough Fea for weekly total precipitation, average air temperature and average relative humidity between October 2020 and March 2021. Mean values refers to mean values of proxy met station for each parameter.

| Parameters | Mean value | Coefficient value | Adjusted r | Root | P value |
|---|---|---|---|---|---|
| **Ballyahone ~ Portglenone** | | | | | |
| Weekly Precipitation | 44 | 0.5 | 0.80 | 22.30 | < 0.05 |
| Daily air temperature | 6 | 1.0 | 0.95 | 0.72 | < 0.05 |
| Daily relative humidity | 88 | 0.8 | 0.75 | 3.60 | < 0.05 |
| **Ballynahone ~ Lough Fea** | | | | | |
| Weekly Precipitation | 67 | 0.4 | 0.92 | 44.58 | < 0.05 |
| Daily air temperature | 9 | 1.0 | 0.95 | 1.08 | < 0.05 |
| Daily relative humidity | 91 | 0.8 | 0.74 | 4.96 | < 0.05 |

Table 2 shows that both met stations, particularly Portglenone, may be a suitable proxy for air temperature as there is a small root mean square value (0.72) so little variance between air temperature recordings and it has an adjusted R-squared value of 0.95, which means the goodness of fit of the model is very high. This suggests that the variance in daily air temperature at Ballynahone Bog is also seen in the daily air temperature recordings at Portglenone.

Portglenone and Lough Fea have high root mean square error values (22.30; 44.58) for weekly precipitation, however the weekly adjusted R-squared values for precipitation for Portglenone and Lough Fea are fairly high (adjusted R-squared values of 0.80 and 0.92). The relative humidity recordings comparing Portglenone and Lough Fea to Ballynahone Bog also have a relatively high goodness of fit (adjusted R-squared of 0.75 and 0.74), however a sizeable root mean squared error value (3.60 and 4.96). These parameters are often used in parallel as an indication of periods of high precipitation as during high rainfall relative humidity tends to be higher. For the purposes of interpreting how precipitation effects monthly ammonia concentrations on Ballynahone Bog, Lough Fea could be used as a suitable proxy as the model has a good fit for both parameters. However, any finer temporal analysis on the true precipitation and relative humidity mean of historic Ballynahone parameter values using Lough Fea met station would not be appropriate.

# 5 Discussion and conclusions

Previous findings reported by Carnell et al. (2021) established that Lough Fea was a more suitable proxy for historic Ballynahone Bog wind data than Portglenone met station as it was more representative of the conditions experienced at Ballynahone Bog. However, this report found that Portglenone appears to be more representative of the daily air temperature measurement data recorded by Ballynahone Bog met station. Portglenone could be a suitable proxy for extending the air temperature data at Ballynahone Bog SAC back to 2014, when $NH_3$ concentrations measurements began on the bog itself. For the purposes of interpreting how precipitation affects monthly ammonia concentrations, Lough Fea could be used as a suitable proxy back to 2014, as the statistical model has a good fit for both precipitation and relative humidity. However, any finer temporal analysis on the true precipitation and relative humidity mean values for interpreting historic Ballynahone $NH_3$ measurements would not be appropriate, as it would be likely to cause bias compared with actual precipitation patterns.

Utilising meteorological parameters other than wind direction and wind speed may be beneficial in explaining and predicting fluctuations in $NH_3$ concentrations on Ballynahone Bog, as periods of high precipitation can, for example, affect the timing of agricultural activities, such as delaying slurry spreading events. Higher temperatures are likely to lead to a higher proportion of available N (such as in slurry spread onto fields) to volatilise. The historic time series of met data as described in this report for a 6-month example period (where data from Ballynahone Bog and the two nearby met stations were available) could therefore be used in combination with the historic wind parameters as described by Carnell et al. (2021) to help interpret the patterns of monthly $NH_3$ concentration throughout the monitoring data series back to 2014. This would increase understanding of how meteorological parameters and agricultural activities interact and alter the ammonia concentrations that affect the sensitive species and habitats present on Ballynahone Bog.

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