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Publication date	2021-02-15
Publication information	Kelleghan, David B., Enda T. Hayes, Mark Everard, and Thomas P. Curran. “Predicting Atmospheric Ammonia Dispersion and Potential Ecological Effects Using Monitored Emission Rates from an Intensive Laying Hen Facility in Ireland” 247 (February 15, 2021).
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/12191
Publisher's version (DOI)	10.1016/j.atmosenv.2021.118214

Title: Predicting atmospheric ammonia dispersion and potential ecological effects using monitored emission rates from an intensive laying hen facility in Ireland.

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Predicting atmospheric ammonia dispersion and potential ecological effects using monitored emission rates from an intensive laying hen facility in Ireland.

Abstract

Agriculture is responsible for 98% of atmospheric ammonia (NH_3) in Ireland, of which pigs and poultry produce 7%;with laying hens specifically contributing 0.6%. Though a small proportion of the national NH_3 total emissions, the ecological impacts on sensitive sites attributed to laying hen farms can be substantial. NH_3 emission monitoring was conducted in Spring (February to March) and Summer (July to August) 2016 to account for seasonal variation. The total average emission and ventilation rate was 0.25 g bird^{-1} day^{-1} and 931 cm^3 s^{-1} bird^{-1}. This is lower than the previously used emission factor for the Irish national inventory of 0.5 g bird^{-1} day^{-1}, but broadly similar to factors reported in the United Kingdom (UK) and the European Union (EU). Dispersion modelling using monitored data indicated potentially acute effects within 84 m, critical level exceedance within 312 m and exceedance of 0.3 kg N ha^{-1} year^{-1} deposition within 2.9 – 5.2 km. The sensitivity of the model was tested using SCAIL-Agriculture emission and ventilation rates which showed P-values for one tailed critical level below 0.01 for all models, indicating that when normalised the maximum extents modelled by AERMOD were significantly different. This analysis showed emission rate having more influence than ventilation rate. Both parameters combined had the greatest increase in dispersion extent, on average 55.8 % greater than the use of monitored rates. A deposition rate of 0.3 kg N ha^{-1} year^{-1} was reached within 5.1 – 7.7 km when using SCAIL-Agriculture rates, indicating that the use of SCAIL-Agriculture recommended emission and ventilation rates would have been sufficiently precautionary to assess negative ecological effects on a Natura 2000 site under the Habitats Directive (92/43/EEC). In relation to Appropriate Assessment (AA) screening, the use of any contribution from a source within a set distance may be an appropriate full AA trigger.

1. Introduction

Egg production in the Republic of Ireland accounts for €49 million of agricultural output per annum, with c. 250 producers employing 800 people (Department of Agriculture Food and the Marine, 2015). Approximately 45,000 tonnes of eggs are produced annually (Food and Agriculture Organization, 2014). In 2015, Ireland reported a total of 67,000 kg of ammonia (NH_3) emissions from laying hens, accounting for 0.6% of Ireland's total (European Environment Agency, 2017). Due to the production of eggs typically in intensive laying hen farms, they are associated with higher local concentrations of NH_3 (Tang et al., 2018) contributing to ecological impacts (Sutton et al., 2011, Sutton, 2007). On the other hand, the majority of ammonia emissions (91%) is generated from more diffuse sources such as cattle, slurry spreading and synthetic fertilisers (European Environment Agency, 2017). As these are diffuse sources, there is a lower risk for high ammonia concentrations; though their contribution to impacts should not be discounted. In line with the Industrial Emissions Directive (2010/75/EU) (European Union, 2010), European BAT (Best Available Technology) reference documents recommend a number of systems in which laying hens should be housed. These include aviaries, deep litter with a manure pit, and enriched cage systems. Guidance recommends a number of practices to reduce emissions for each housing system (European Commission, 2013). In the case of aviaries and cage systems, these recommendations include removal of manure either weekly with additional drying or bi-weekly with no drying. A number of approaches are recommended for deep litter systems, which generally have much higher emission rates than caged or aviary systems (Hayes et al., 2006; Starmans and Van Der Hoek, 2007; Hill et al., 2014); including forced air drying of manure, enhanced ventilation, air blowing from below via a perforated floor, etc. (European Comission, 2017). Battery production systems have been banned in the European Union since the Council Directive (1999/74/EC) on the protection of laying hens (European Comission, 1999).

The ventilation rate plays an integral role in housed poultry management, where it influences both the welfare of the birds indoors (Wathes et al., 1983), and the NH_3 emission rate (Alberdi et al., 2016) in addition to the extent of the NH_3 dispersion plume from the house. Estimation of ventilation rates using Carbon Dioxide (CO_2) mass balance is a longstanding practice both in Europe and America (Seedorf et al., 1998; Li et al., 2005; Mosquera et al., 2012; Hill et al., 2014). This method requires a series of equations calculating the animal activity, total heat and CO_2 production to estimate the ventilation rate of a livestock building. These equations have been derived from work produced by the International Commission of Agricultural Engineering (Pedersen & Sällvik, 2002).

The United Nations Economic Commission for Europe (UNECE) has set "critical levels" for atmospheric ammonia, which are atmospheric concentrations above which adverse ecological effects can be expected - these are set at 1 µg NH_3 m^{-3} for lichens and moss species and 3 µg NH_3 m^{-3} for higher plants (United Nations Economic Comission For Europe, 2007). Critical loads require the calculation of deposition velocities, where a critical level acts as a useful tool which can directly indicate potential impacts without further calculation or estimation. Recent work has shown that internationally applied empirical critical loads for nitrogen may be too high to represent impacts in Ireland, which occur at lower deposition rates. Wilkins et. al. (2016) identified species change points in Ireland within a range of 3.9 to 15.3 kg N ha^{-1} yr^{-1} compared to imperial critical loads of 5 to 30 kg N ha^{-1} yr^{-1}. For example, species change points of 4.9 and 4.1 kg N ha^{-1} yr^{-1} were observed for Northern Atlantic wet heaths with *Erica tetralix* [Annex I Habitat Code 4010] and European dry heaths [Annex I Habitat Code 4030], respectively, which are both significantly lower than previously used empirical critical load ranges of 10–15 and 10–20 kg N ha^{-1} yr^{-1} (Bobbink & Hettelingh, 2011).

A common purpose of the EU Habitats Directive (92/43/EEC) (European Economic Committee, 1992) and EU Birds Directive (2009/147/EC) (European Comission, 2009) is to preserve and

maintain favorable conservation status on designated sensitive sites across Europe, comprising the Natura 2000 network. The Habitats Directive (92/43/EEC) (European Economic Committee, 1992) introduced a tiered approach to environmental assessments specific to Natura 2000 sites under Article 6 (3) of this Directive, stating that "…any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives". This assessment process takes a tiered approach, where stage one is intended to screen out any potential significant effects. If, after stage one, potential negative effects have not been ruled out, or there is remaining uncertainty, the assessment process must move to stage two for a full Appropriate Assessment (AA). Different Member States have quantified the potential for significant ecological effects arising from atmospheric NH_3 differently. The UK, for example, uses a 1% exceedance of critical levels and loads as an indicator of significance (Hicks et al., 2011), and the Dutch approach considers any contribution, even less than 0.001 kg N ha^{-1} $year^{-1}$ (0.02% of 5 kg N ha^{-1} $year^{-1}$), to require a detailed assessment. The Dutch Nitrogen Case (C 293/17 & C 294/17)(CJEU, 2019) however found the Dutch approach was non-compliant with the Habitats Directive (92/43/EEC) (European Economic Committee, 1992) as any contribution to a Natura 2000 site already impacted could be constituted as a significant negative effect thereon (Anker et al., 2019). While the level of significance is likely to vary between countries, as a combination of internal government policies and ambient concentrations nationally, previous European guidance states only contributions of 0.3 kg N ha^{-1} $year^{-1}$ or above need to be considered for full appropriate assessment (IMPEL, 2017). This rate of 0.3 kg N ha^{-1} $year^{-1}$ is based on the approach in Germany, which may also be non-compliant with the Habitats Directive (92/43/EEC) (European Economic Committee, 1992) following the Dutch Nitrogen Case. Current guidance from the outcomes of the Dutch Nitrogen Case (C 293/17 & C 294/17)(CJEU, 2019) implies any

contribution of additional NH_3 or nitrogen to a Natura 2000 may require a full AA (Anker et al., 2019).

The SCAIL-Agriculture tool, which was developed for use in the UK and adapted for Ireland, utilizes AERMOD, a dispersion model developed by the United States EPA, to screen potential contributions of atmospheric NH_3 to Natura 2000 sites (Hill et al., 2014). Though AERMOD was initially developed to model dispersion from industrial stacks, it has been employed in a number of studies researching atmospheric dispersion of pollutants from poultry houses (Hadlocon et al, 2015; Huang & Guo, 2019; Baker et al., 2020). The potential for negative ecological effects on Natura 2000 sites from atmospheric NH_3 is substantial, not just from contributions from hotspot sources such as laying hen farms. In Ireland, 80% of these sites are estimated to exceed the lower critical level of 1 µg m^{-3}, and 6.9% to exceed the critical level for higher plants at 3 µg m^{-3} (Kelleghan et al., 2020). Contributions from hotspot sources are likely to be much higher, for example contributions of up to 34 µg m^{-3} was monitored on Moninea Bog as a result of a laying hen facility (Sutton, 2007; Sutton et al., 2011). This site was downwind of an intensive laying hen farm in operation since the early 1990s, which had upgraded to incorporate manure removal by conveyor belt and drying in 2005 (Sutton, 2007). On a number of trees downwind of this laying hen house, epiphytic lichens had been replaced with a thick algal slime indicative of severe eutrophication with NH_3 concentrations of 8 µg m^{-3}. Sutton et al. (2011) estimated that more than 90% of *Cladonia* and *Sphagnum* species were eradicated or degraded within 200 m downwind of the farm. This site is typical of a bog with acute impacts from atmospheric NH_3 due to high contributions from the neighboring laying hen farm. Since the closure of this farm, the site has begun to slowly recover from these effects though the precise rate of recovery is not yet fully understood (van Dijk, 2019).

The objectives of this study were to:

- Monitor the NH_3 emission and ventilation rates for a modern layer house with manure drying, weekly removal and mechanical ventilation.
- Model dispersion of NH_3 into the atmosphere using AERMOD to gauge the layer building's contribution to local ecological impacts.
- Assess the sensitivity of the model using rates recommended by SCAIL-Agriculture, testing the effect of recommended and monitored emission and ventilation rates on modelled dispersion extents and severity of impacts.
- Review the suitability of a presumed *de minimis* deposition rate of 0.3 kg N ha^{-1} $year^{-1}$ and percent thresholds for stage 1 AA screening under the Habitats Directive (92/43/EEC) (European Economic Committee, 1992).

2. Methods

2.1. Farm description

An intensive laying hen farm in Ireland exposed to a temperate oceanic climate was monitored as part of this study. This farm utilised three operational laying hen houses, where they were housed for a 56 – 60 week laying cycle and are generally removed when 72 – 76 weeks old. This farm uses enriched cage houses. All three houses are of identical size and layout, covering 78 x 16 m and standing 7.7 m tall. Each house has the capacity for c. 42,000 laying hens. Water is supplied ad-lib through button nipple drinking system, minimising leakages. All laying hen houses on site are mechanically ventilated, controlled by temperature and humidity. Due to the combination of ventilation type, heat produced by laying hens and insulation, no additional heating is required for laying hen houses on site. During ammonia emission monitoring, the bird's diet contained a 16% protein content.

The resulting litter from the production process, comprising entirely bird droppings, is dried prior to removal on the conveyor belt using recirculated air. The farm is estimated to produce 3,688 m^3 of manure per year, which is sold as an organic fertiliser. Manure is removed weekly

via conveyor belt and is stored in a naturally ventilated manure storage facility located on the north end of the site directly adjacent laying hen houses. The manure storage facility was not monitored or modelled as part of this project. Though manure storage is likely to contribute to local NH_3 concentrations, this is expected to be minimal as manure in storage was dried and covered from rain.

2.2. Monitoring

The Los Gatos Research Ultraportable Ammonia Analyser (UAA) was used to monitor indoor concentrations of atmospheric ammonia. The UAA was tested in laboratory conditions and accurately measured known concentrations of 25 ppm, which is within its operational range of 0 – 200 ppm. The UAA was evaluated against a number of other similar NH_3 sensors during field trials in Edinburgh, UK supervised by the Centre for Ecology and Hydrology (Twigg et al., 2018), where it showed the lowest relative deviation from the mean than a number of other advanced sensors. An older model, the Los Gatos Research "Ammonia Analyser – Trace" has been used by Ricardo-AEA in the UK to monitor concentrations of NH_3 inside UK poultry houses (Leonard, 2014, pers. comm.).

An eight-inlet multiport unit was used to allow for sampling of six locations inside the house, in addition to a single sample location outside. Indoor CO_2 concentrations were monitored using a K30 CO_2 sensor (Senseair, Sweden), which has a measurement range of 0 – 10,000 ppm with an accuracy of ± 3% of measured value. This sampled the outflow of the UAA which allowed for monitoring of CO_2 and NH_3 in the same locations inside the laying hen house. Outdoor CO_2 measurements for the monitoring period were obtained from Ireland's only ambient CO_2 monitoring station on Mace Head.

The six indoor sample locations were divided into two sets of three, each within an aisle between cages. The sample inlets were placed above the bottom three cages, aligned with the fifth cage and above the sixth cage below exhaust fan (Figure 1). All records obtained from the UAA and

K30 sensors were averaged per minute. Temperature was monitored indoors using an Elitech temperature data logger.

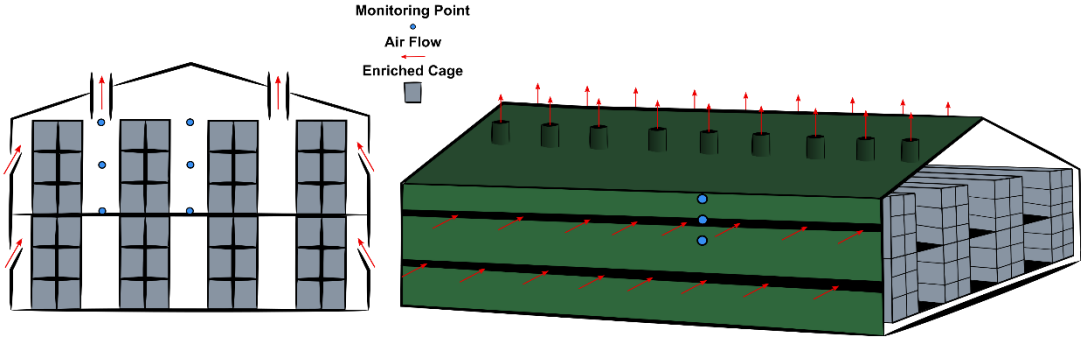

Figure 1. Monitoring layout.

Monitoring was conducted over 67 days covering two stages of the year in order to account for seasonal variability; monitoring ran over the Spring months (14/02/2016 – 20/03/2016) and Summer months (20/07/2016 – 20/08/2016). Temperatures were typical of monthly averages from 2014 – 2017.

2.3. Data management

A record was produced every second for indoor NH_3 concentration, and every two seconds for CO_2 concentration in the same location with each sampling point recorded in sequence. Every sampling location was monitored for 40 minutes, which was followed by 20 minutes of outdoor monitoring in order to regularly flush the UAA. Outdoor monitoring was excluded from data analysis, but provided reliable breaks in monitoring data where concentrations decreased to outdoor levels between indoor sampling periods.

The data representative of both increasing and decreasing concentrations shown in Figure 2 was removed, leaving only the concentration plateau, which was averaged for each minute and coupled with the corresponding CO_2 measurements in Microsoft Excel. These measurements were averaged per minute.

2.4. Calculating ventilation & emission rate

CO_2 mass balance was used to calculate the ventilation rate of the building for every averaged minute record. This required the use of a series of equations, based on animal activity, heat production and CO_2 production (Pedersen & Sällvik, 2002). This produced a semi-continuous emission rate for each sample location inside the laying hen house. Box and Whisker plots for the monitored emission rates for the house monitored were generated using the R statistical programme (R Core Team, 2013). These Box and Whisker plots were used to analyse the relationship of emissions with season, month, day of week, and hour of day. As monitoring took place in both warm and cold seasons, the overall average produced was intended to account for this variability.

2.5. Modelling atmospheric dispersion and deposition of ammonia

Local meteorological data (2016) was obtained from the closest synoptic Met Éireann station, which was 35 km from this farm. As this study focuses on testing the effect of monitored ventilation and emission rates on dispersion modelling, the use of any continuously monitored meteorological data would have been appropriate, regardless of proximity to layer house. Lakes Environmental © AERMOD v. 9.6 was used to model the dispersion of atmospheric NH_3 using the average rates observed for the monitoring period. Modelling was conducted to compare four scenarios based on differing emission and ventilation rates; 1. Monitored Emissions & Monitored Ventilation rates (MEMV), 2. Monitored Emissions & SCAIL Ventilation (MESV), 3. SCAIL Emissions & Monitored Ventilation (SEMV), 4. SCAIL Emissions & SCAIL Ventilation (SESV).

Table 1. List of data required and sources for running atmospheric dispersion modelling in AERMOD 9.6.

Data	Source
Meteorological data	Met Éireann Dunsany Meteorological Station (2016)
Topographical data	Shuttle Radar Topography Mission 1/3 – 30 m resolution
SCAIL-Agriculture Emission Factors & Ventilation Rates	Hill et al. (2014)
Monitored Emission Rates	Average of monitoring conducted by this study
Ventilation Rates	Average of monitoring conducted by this study
Source Height	7.7 m – Local authority planning application
Gas Exit Temperature	24.3°C – Monitored Average
Effective Diameter	4.24 m - Measured on site and with satellite imagery

As both monitoring and modelling conducted estimates a ventilation rate for the building and not for each exhaust independently, a total effective diameter was calculated for the building (Hill et al., 2014). This summed the area of all fans, and then calculated the diameter presuming a single outlet, as below;

$$total\ fan\ area = (\pi \times fan\ radius^2) \times no.of\ fans$$

$$effective\ diameter = (\sqrt{(total\ fan\ area/\pi)}) \times 2$$

This was applied to the equation below in order to calculate the exit velocity of air from the building;

$$\frac{flow\ rate}{\pi \times effective\ radius^2}$$

Contours from AERMOD modelling were set to best reflect potential negative ecological effects. These were set to indicate potential severe effects (8 and 5 µg m^{-3}), critical level exceedance (3 and 1 µg m^{-3}), presumed *de minimis* deposition values (0.06 and 0.04 µg m^{-3}), and percent threshold exceedance values (0.12, 0.04, 0.03 and 0.01 µg m^{-3}). These percent threshold values are those recommended by Hicks et al. (2011) for 1 – 4 % of critical levels, which in practice are

also intended to be applied to critical load exceedances. Dry deposition of NH_3 was modelled in Excel, presuming deposition velocities as presented in the SCAIL-Agriculture report for woodland (3 cm s^{-1}) and other surfaces (2 cm s^{-1}) (Hill et al., 2014).

3. Results

3.1. Concentration monitoring example

Monitoring at all locations was carried out it sequence, with each point being monitored for 40 minutes as shown in Figure 2. Figure 2 is an example highlighting an initial increase in monitored concentration as the sample was transported from the location inside the house to the sensor stored outdoors through PTFE tubing, a concentration plateau representative of the actual indoor concentration and an eventual decline as monitoring outdoors began. The plateau was used to represent monitored concentration at that location.

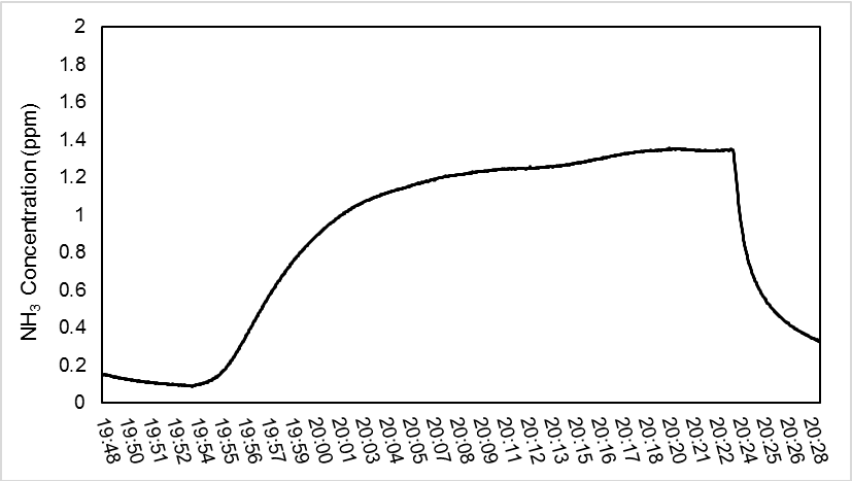

Figure 2. Example of Indoor NH_3 concentration trend during one monitoring period.

3.2. Emission Monitoring

The average daily NH_3 emission rates from the monitored laying hen house are shown in Table 2. As the Irish EPA currently report emission factors in g $bird^{-1}$ day^{-1}, this was used throughout this paper. Emission rates are also presented in kg $bird^{-1}$ $year^{-1}$, g day^{-1} kg^{-1} and g day^{-1} LU^{-1} (Livestock Unit, i.e. 500 kg) in Table 2. The average NH_3 emission rate for the full 63-day monitoring day period is 0.25 g $bird^{-1}$ day^{-1}, which is composed of cold and warm season emission rates of 0.20 and 0.29 g $bird^{-1}$ day^{-1}, respectively. Further dividing seasonal emissions into the months during which monitoring took place, sees the lowest emission rate in February of 0.16 g

262 bird^{-1} day^{-1} increasing to 0.23 g bird^{-1} day^{-1} in March. The highest rate occurred in July, with a rate
263 of 0.33 g bird^{-1} day^{-1} reducing to 0.27 g bird^{-1} day^{-1} in August. These rates correspond with
264 average temperature for these periods, also listed in Table 2. Lower emission rates, ventilation
265 rates and exit velocities occur during cold weather. Table 2 also details average emissions based
266 on the day of the week, where emissions are highest at 0.35 g bird^{-1} day^{-1} on Sunday, reducing
267 to 0.11 g bird^{-1} day^{-1} on Wednesday. The ventilation rate observed during monitoring was 38.55
268 m^3 s^{-1}, equivalent to 931.16 cm^3 s^{-1}bird^{-1}.

269 **Table 2. Averaged ventilation rates, exit velocities and emission rates over different periods.**
270 **Representative SCAIL-Agriculture ventilation & emission rates included.**

Averaging Period	Outside Temperature (°C)	Ventilation Rate (m^3 s^{-1})	Ventilation Rate (cm^3 s^{-1} bird^{-1})	Exit Velocity (m s^{-1})	NH_3 (g bird^{-1} day^{-1})	NH_3 (kg bird^{-1} year^{-1})	NH_3 (g day^{-1} kg^{-1})	NH_3 (g day^{-1} LU^{-1})
AmmoniaN2K	9.99	38.55	931.16	2.73	0.25	0.09	0.13	64.60
SCAIL	9.99	28.57	690.1	2.02	0.33	0.12	0.17	86.52
Cold	4.94	26.55	641.3	1.88	0.20	0.07	0.11	53.61
Warm	15.34	51.24	1237.68	3.63	0.29	0.11	0.15	76.23
February	3.67	21.21	512.32	1.50	0.16	0.06	0.08	41.35
March	5.60	29.31	707.97	2.08	0.23	0.08	0.12	59.96
July	15.46	56.80	1371.98	4.02	0.33	0.12	0.18	87.72
August	15.29	48.83	1179.47	3.46	0.27	0.10	0.14	71.23
Monday	9.43	38.21	922.95	2.71	0.34	0.12	0.18	89.03
Tuesday	10.98	41.38	999.52	2.93	0.20	0.07	0.11	52.97
Wednesday	9.34	35.79	864.49	2.53	0.11	0.04	0.06	28.74
Thursday	9.57	38.88	939.13	2.75	0.16	0.06	0.09	43.34
Friday	10.04	37.51	906.04	2.66	0.25	0.09	0.13	66.93
Saturday	10.41	41.16	994.2	2.91	0.31	0.11	0.16	82.45
Sunday	10.22	36.90	891.3	2.61	0.35	0.13	0.18	91.07

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Figure 3 below shows real time NH_3 emissions based on minute averages collected during the monitoring period. Diurnal, weekly and seasonal variation in emissions are apparent within this graph. These trends are further analysed in the Box and Whisker Plots in Figure 4. Detailed rates presented are overlaid by the respective monthly average emission rate, highlighting the high peaks that occur beyond this average throughout the week.

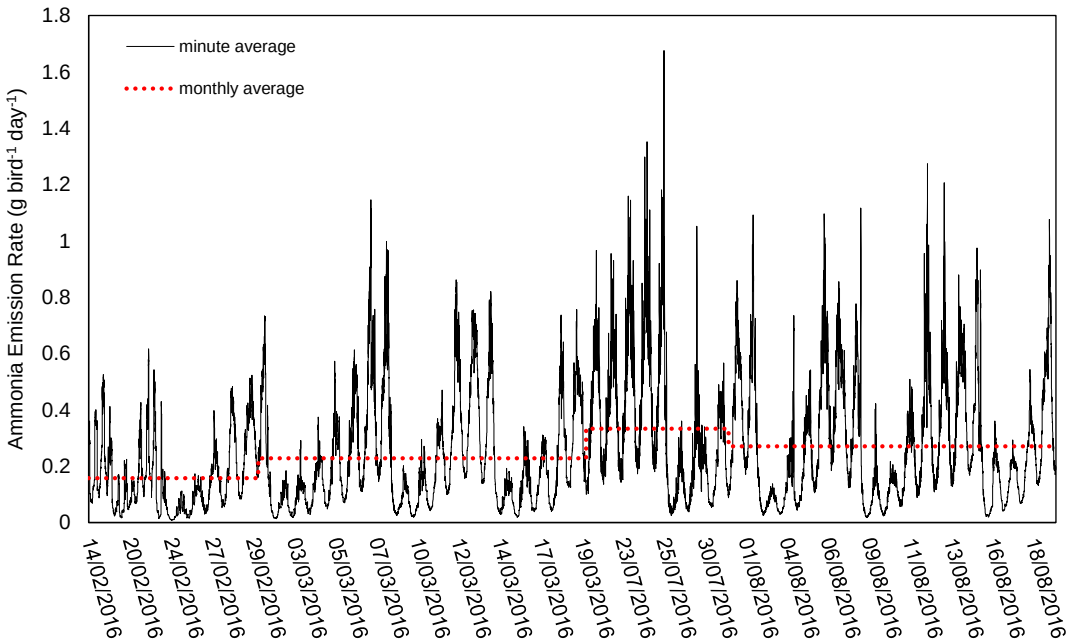

Figure 3. Emissions from laying hen house during two seasons.

Box and Whisker Plots were generated to display the variation of emission rates during the monitoring period. Figure 4.A. shows the Box and Whisker Plot for emissions during spring and summer months. Where the median and upper extremes are lower for the cold period compared to warm. The same pattern is observed for both the upper and lower quartiles. Figure 4.B. clearly shows much lower emission rates in February compared to other months. The upper whisker for March emissions increases from February with increased temperatures. Both July and August show similar median emission rates, though August's upper extreme is less than July's. Figure 4.C. shows the weekly emissions from the laying hen house, where a clear trend in median emission rates is observed increasing from Wednesday to Monday and decreasing following manure removal on Tuesday. Emissions occurring on Wednesdays also exhibit a lower

diversity of emission rates with tighter upper and lower extremes. Hourly variation of emissions is presented in Figure 4.D. where peaks occur just prior to and following mid-day at 11:00 and 13:00, with lowest emissions occurring at midnight.

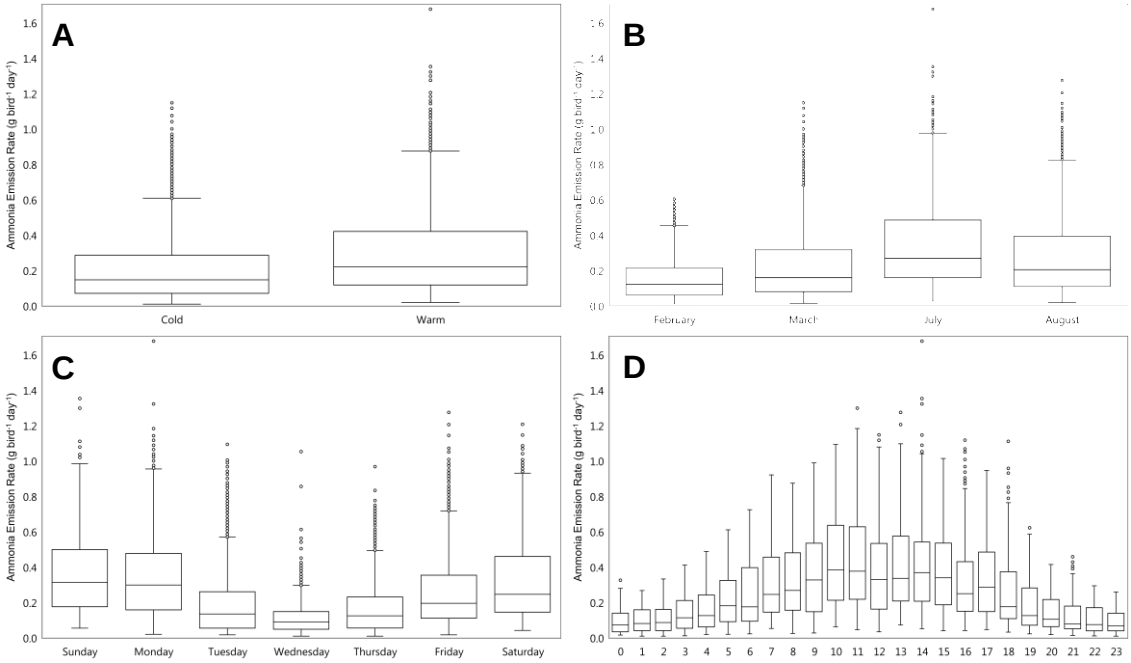

Figure 4. Box and Whisker Plots of averaged NH_3 emission rates from laying hen house per season (A), per month (B), per day of week (C) and per hour (D).

3.3. Concentration & dry deposition modelling

Atmospheric dispersion modelling conducted using Lakes © AERMOD, compared the maximum dispersion extent of models created using monitored and guidance rates from SCAIL-Agriculture (Hill et al., 2014). Average rates for "AmmoniaN2K" (Overall average monitored rates) and "SCAIL" (Recommended figures from SCAIL-Agriculture guidance) from Table 2 were used to generate models. Table 3 details the maximum extent downwind to which contours were modelled for four scenarios, based on combinations of monitored and recommended ventilation and emission rates to apply to dispersion models in practice. The four modelled scenarios included the following combinations;

- Monitored Emission and Monitored Ventilation (MEMV)
- Monitored Emission and SCAIL-Agriculture Ventilation (MESV)
- SCAIL-Agriculture Emission and Monitored Ventilation (SEMV)
- SCAIL-Agriculture emission and SCAIL-Agriculture Ventilation (SESV)

Table 3 summarises the maximum distance downwind modelled concentrations occurred from four scenarios listed. These predicted concentration and deposition rates do not include background concentrations of NH_3 or deposition of nitrogen. Modelled contributions from the farm alone exceeded the lower critical level of 1 µg m^{-3} within 312, 367, 400 and 468 m for MEMV, MESV, SEMV and SESV respectively. While the higher critical level of 3 µg m^{-3} is exceeded from the housing alone within 118, 150, 160 and 194 m for MEMV, MESV, SEMV and SESV. These critical level exceedances are highlighted by the modelled contours presented in Appendix 1. A concentration of 5 µg m^{-3} is exceeded within 84, 106, 106 and 122 m for MEMV, MESV, SEMV and SESV.

Table Error! No text of specified style in document.**. Maximum distance downwind of farm where concentrations of NH_3 are modelled for 2016, comparing AERMOD dispersion model outputs generated using monitored, EPA and SCAIL-Agriculture emission rates.**

NH_3 Concentration ($\mu g\ m^{-3}$)	Dry Deposition (kg N $ha^{-1}\ yr^{-1}$)		Farthest Distance (m)			
	Other	Woodland	Monitored Emissions & Ventilation (MEMV)	Monitored Emissions & SCAIL Ventilation (MESV)	SCAIL Emissions & Monitored Ventilation (SEMV)	SCAIL Emissions & Ventilation (SESV)
0.01	0.05	0.08	27419	27644	30312	32002
0.03	0.16	0.23	6808	7681	9361	9659
0.04	0.2	0.3	5227	5259	7504	7705
0.06	0.3	0.5	2980	3370	4825	5104
0.12	0.6	0.9	1675	1923	2722	2857
1	5.2	7.8	312	367	400	468
3	15.6	23.4	118	150	160	194
5	25.9	39	84	106	106	122
8	41.6	62.3	0	71	68	95

The *de minimis* value for dry deposition of nitrogen from a hotspot agricultural source was set at 0.3 kg N ha^{-1} $year^{-1}$ by the European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) (IMPEL, 2017). Modelled scenarios for dry deposition across low vegetation (i.e. grasslands and bogs) indicate this rate is achieved within 2980, 3370, 4825 and 5104 m for MEMV, MESV, SEMV and SESV, respectively. This range is extended when modelled over high vegetation (i.e. woodlands) occurring within 5227, 5259, 7504, and 7705 m from the farm border for MEMV, MESV, SEMV and SESV. This information is visualised in contours presented in Appendix 2, alongside Table 3.

The maximum distance downwind of the farm where 1% of critical levels were exceeded were 27.4 and 6.8 km; where 4% was exceeded within 5.2 and 2.9 km for 1 $\mu g\ m^{-3}$ and 3 $\mu g\ m^{-3}$ respectively. The extent of models incorporating SCAIL-Agriculture rates also spread much

farther compared to monitored rates; the most significant of which is SESV which predicts 1% of 1 µg m^{-3} being reached as far as 32 km downwind, reducing to 30.3 km for SEMV and 27.6 km for MESV.

The model outputs presented in Table 3 were normalised using standard normal variate transformation (Rinnan et al., 2009) and analysed using t-Tests (paired two sample for means) (Ruxton & Neuhäuser, 2010)This was intended to compare the significance of altered model inputs on the maximum concentration and deposition extents. The output from t-Tests are presented in Table 4. P-values for one tailed and critical levels were below 0.01 for all models, indicating that when normalised the maximum extents modelled by AERMOD were significantly different. The level of significance varied between models, with the model generated using both SCAIL-Agriculture emission and ventilation rates having a more significant difference to the model generated using monitored rates, than any other combination. Altering the emission rate had a more significant effect that altering the ventilation rate, while altering both had the most significant effect. The increasing difference between model outputs is also represented by the increasing difference between t-Stat and the t-Critical two-tail values presented in Table 4. This difference increases from 1.46 to 19.09 to 27.15 for MESV, SEMV and SESV respectively.

Table 4. Output from T-test comparing statistical significance of modelled scenarios extent difference from Monitored Emissions & Monitored Ventilation (MEMV).

	Observations	Pearson Correlation	Hypothesized Mean Difference	df	t Stat	P(T<=t) one-tail	t Critical one-tail
Monitored Emissions & SCAIL Ventilation (MESV)	9	-0.96	0	8	3.77	2.72E-03	1.86
SCAIL Emissions & Monitored Ventilation (SEMV)	9	0.65	0	8	21.4	1.19E-08	1.86
SCAIL Emissions & Ventilation (SESV)	9	0.1	0	8	29.46	1E-09	1.86

The difference between model outputs summarised as percentages is presented in Table 5, where the use of the SCAIL-Agriculture ventilation rate increased the dispersion extent for modelled concentrations between 0.6 – 27.1%, on average 14.1%. Using the SCAIL-Agriculture emission rate increased this difference to a range of 26.2 – 62.5%, on average 38.2%. The greatest dispersion extent was observed when both SCAIL-Agriculture emission and ventilation rates were used with a difference of between 16.7 – 71.3% compared to the monitored data, with an average difference of 50.9%.

365 **Table 5. Percent differences of model outputs compared to models produced using monitored**

366 **emission and ventilation rates (MEMV).**

NH_3 Concentration (µg m-3)	Dry Deposition (kg N ha^{-1} yr^{-1})		% Greater than Monitored Emissions & Ventilation (MEMV)		
	Other	Woodland	Monitored Emissions & SCAIL Ventilation (MESV)	SCAIL Emissions & Monitored Ventilation (SEMV)	SCAIL Emissions & Ventilation (SESV)
0.01	0.05	0.08	0.8	10.6	16.7
0.03	0.16	0.23	12.8	37.5	41.9
0.04	0.2	0.3	0.6	43.6	47.4
0.06	0.3	0.5	13.1	61.9	71.3
0.12	0.6	0.9	14.8	62.5	70.6
1	5.2	7.8	17.6	28.2	50
3	15.6	23.4	27.1	35.6	64.4
5	25.9	39	26.2	26.2	45.2
Average			14.1	38.3	50.9

367

368 ## 4. Discussion

369 ### 4.1. Emission monitoring

370 Monitoring conducted as part of this study indicated an overall average NH_3 emission rate of
371 0.25 g $bird^{-1}$ day^{-1}. Emission rates had a strong association with ambient temperature, where
372 average temperatures of 3.67, 5.6, 15.46 and 15.29°C for February, March, July and August
373 elicited emission rates of 0.16, 0.23, 0.33 and 0.27 g $bird^{-1}$ day^{-1}, respectively. Previous work on
374 NH_3 emissions from laying hen units in Ireland has also shown seasonally variable NH_3 emission
375 rates, where 0.1 g $bird^{-1}$ day^{-1} was observed in spring for a battery caged house with manure
376 removal, and 0.5 g $bird^{-1}$ day^{-1} for summer emissions from a laying hen house with a deep pit
377 (Hayes et al., 2006). As the monitoring by Hayes et al. (2006) was carried out on two different

house types, the full influence of temperature was not apparent at the time. Though not directly comparable to monitoring conducted in this study due to different housing types, monitored spring emissions were higher than those observed from the battery cage at 0.20 g bird^{-1} day^{-1} and lower than summer emissions from the deep pit at 0.29 g bird^{-1} day^{-1}. Emission rates reported for laying hens in battery cages ranged from 0.03 to 0.47 g bird^{-1} day^{-1} in Germany and England respectively (Groot Koerkamp et al., 1998). This shows a significant diversity of emission rates for battery cages within different countries, however battery cages are currently illegal throughout Europe under Council Directive (1999/74/EC)(European Comission, 1999).

The UK emissions inventory provides a mean emission factor of 60 g NH_3 day^{-1} LU^{-1} (Livestock Unit), while they use a weighted average of 50.4 g NH_3 day^{-1} LU^{-1} (Misselbrook et al., 2016). This is equivalent to 0.19 – 0.23 g bird^{-1} day^{-1}. The Irish inventory reported an emission rate of 132.5 g day^{-1} LU^{-1} for caged laying hens in 2003 (Hyde et al., 2003), which is equivalent to 0.5 g bird^{-1} day^{-1}. Hyde et al., (2003) stated that the emission factors used for Irish poultry houses differ from the UK figures due to a difference in average weight class categories used. Data provided to this study from the EPA identify the use of an emission rate of 0.42 g bird^{-1} day^{-1} (Hyde, 2013, pers. comm). National inventory reporting currently differs to Annual Environmental Report / Pollutant Release and Transfer Register reporting, where emission factors are no longer used to calculate emissions. Instead, the national inventory is currently based on the quantity of nitrogen excreted by livestock and the availability of the nitrogen excreted for volatilisation as NH_3 (Hyde, 2018, pers. comm).

BAT Annual Emission Limits for laying hens are set between 0.05 to 0.22 g bird^{-1} day^{-1} for caged laying hens, which increases to 0.68 g bird^{-1} day^{-1} if manure drying such as that carried out on the monitored farm is applied (European Comission, 2017). Emission rates reported for a similar house in Spain were 0.14 and 0.09 g bird^{-1} day^{-1} in the summer and winter, respectively. These rates are likely lower than those monitored by this study as manure was removed via conveyor

403 belts every 3 – 5 days, unlike every seven days on the monitored farm (Alberdi et al., 2016).
404 Emission rates varied throughout the week during this monitoring programme, where they were
405 highest on Sunday at 0.35 g bird^{-1} day^{-1} and lowest on Wednesday at 0.11 g bird^{-1} day^{-1}. This was
406 due to the build-up of manure during the week prior to removal on Tuesdays. This supports the
407 concept that more frequent manure removal reduces emissions. A study in the United States
408 also showed a daily ammonia emission rate of 0.14 ± 1 g bird^{-1} day^{-1} which is comparable to other
409 manure belt caged houses in the US, but lower than high rise cage houses (Zhao et al., 2013).
410 The farm in Zhao's study utilised recirculated air to dry the manure and also removed manure
411 every three days. Similarly, the standardised rate in the Netherlands for NH_3 emission rate is 0.1
412 g bird^{-1} day^{-1} (Groot Koerkamp et al., 1998), which is likely achieved by increasing frequency of
413 manure removal. Altering the frequency of manure removal has the potential to influence how
414 dry the manure is prior to storage, which may influence emissions following removal from the
415 house.

416 The ventilation rate of 931 cm^3 s^{-1} bird^{-1} in this study was higher than the equivalent rate of 690
417 cm^3 s^{-1} bird^{-1} recommended by SCAIL-Agriculture (Hill et al., 2014), which was derived from
418 previous research (Seedorf et al., 1998). There was a substantial difference in ventilation rate
419 observed in the cold and warm periods, with 641 and 1237 cm^3 s^{-1} bird^{-1}, respectively; both of
420 which are higher than the relevant rates recommended in SCAIL-Agriculture, of 560 and 830 cm^3
421 s^{-1} bird^{-1} for winter and summer. It has been previously pointed out that increasing ventilation
422 rates increases emissions, and modern houses focusing on animal welfare reducing indoor
423 concentrations may be as a direct result increasing their emissions (Ndegwa et al., 2008).

424 As the exceedance of annual critical levels is the most precautionary approach to protect
425 habitats and species (Sutton et al., 2008), the annual average emission and ventilation rates are
426 the most suitable factor for environmental conservation. The detailed monitoring conducted
427 will benefit future studies, providing valuable information on diurnal and seasonal variations in

428 emissions. BAT guidance suggests laying hens have stable emission patterns and suggests
429 splitting six sampling days within the year to one randomly selected day every two months
430 (European Commission, 2017). This work has shown that in houses with belt removal of manure
431 this is not sufficient, as a linear increase in emissions after manure removal would need to be
432 considered when monitoring emission rates which vary depending on frequency of manure
433 removal. The approach recommended for pigs or broilers may be more appropriate, but on a
434 smaller scale as broilers undergo much longer periods of increases (from 0 to 37 days) compared
435 to a weekly laying hen cycle of emissions observed on this farm.

436 **4.2. Concentration Modelling**

437 The extent to which contours were modelled was determined by pre-selected values, intending
438 to represent concentration and deposition rates relevant to negative ecological effects.
439 Modelling of both concentration and dry deposition was intended to mimic the process used in
440 SCAIL-Agriculture, which intentionally excludes dry depletion of ammonia, and chemical
441 conversion followed by wet deposition as ammonium (Hill et al., 2014). The SCAIL-Agriculture
442 report indicates that excluding both depletion and atmospheric transformation results in an
443 overestimation of impacts by c. 10%, which for the purposes of AA screening is considered
444 precautionary (Hill et al., 2014). Monitoring and modelling for this study was only conducted on
445 the bird housing; the dry manure store adjacent to these houses was excluded. Housing was
446 estimated to contribute 70% of national emissions for poultry in Ireland, where storage accounts
447 for only 3% (Hyde et al. 2003). As the manure had been dried, its anticipated contribution should
448 be minimal, though even a small contribution should not be discounted in the AA process.

449 The highest concentration modelled was 8 µg m^{-3}, intended to represent acute negative
450 ecological effects observed on Moninea bog from contributions of the farm alone (Sutton, 2007).
451 This concentration was not observed when modelling was conducted using only the monitored
452 rates, but was for every other modelled scenario. The use of SCAIL-Agriculture emission and

453 ventilation rates (SESV) indicated this concentration could occur 95 m downwind from the farm
454 border. As it is unlikely that any farm would be situated in an area with no ambient concentration
455 of ammonia, 5 µg m^{-3} was also modelled. This was intended to represent the area within which
456 acute effects could be observed, including the highest ambient concentration monitored in
457 Ireland: 3.21 µg m^{-3} (de Kluizenaar and Farrell, 2000). Depending on model inputs, this
458 concentration was predicted to occur within 84 – 122 m downwind of the farm border. Critical
459 levels of 1 and 3 µg m^{-3} were exceeded within 312 – 468 m and 118 – 194 m respectively,
460 depending on model inputs. These exceedances are representative of contributions from the
461 farm housing alone, as the highest recorded ambient baseline concentration already exceeds
462 these critical levels.

463 **4.3. Influence of Emission and Ventilation Rates**

464 A statistically significant difference was observed between monitored data, and all modelled
465 outputs using SCAIL-Agriculture emission and ventilation rates. Though all outputs were
466 significantly different, the level of significance varied depending on model inputs used. Use of
467 the SCAIL-Agriculture emission rate had a greater influence on the model output compared to
468 using the SCAIL-Agriculture ventilation rate. The difference between the model outputs were
469 summarised as percent greater than the models generated using monitored data, the model
470 output created using the SCAIL-Agriculture emission rate was on average 38.2% greater than the
471 one created using only monitored data, where the model created using the SCAIL-Agriculture
472 ventilation rate was on average 14.1% greater. The greatest difference was observed when use
473 of both the SCAIL-Agriculture emission and ventilation rates were used, with a 50.9% difference
474 on average. This validates the use of SCAIL-Agriculture emission and ventilation rates for
475 screening potential effects as part of stage 1 AA where a precautionary approach is required. If
476 a more detailed assessment is required as part of stage 2 AA, detailed emission monitoring could
477 produce rates which could reduce the number of Natura 2000 sites modelled to be included in

an AA. This study does not recommend using emission and ventilation rates monitored for this house to conduct environmental assessments as these factors are based from a study in a single house. Development of emission and ventilation factors such as those used in SCAIL-Agriculture are based on numerous studies, to which this study is intended to contribute.

4.4. Determining Ecological Impacts

In reality, ambient or baseline concentrations would need to be considered when determining ecological impacts from such a farm. These can be highly spatially variable (Singles et al., 1998), with monitored ranges in Ireland of 0.18 – 3.21 µg m^{-3} (de Kluizenaar and Farrell, 2000), 0.48 – 2.96 µg m^{-3} (Doyle et al., 2017) and 0.5 – 4.6 µg m^{-3} (Kelleghan et al., 2020). These three studies monitored different locations across Ireland, highlighting the spatial variation that occurs in concentration due to agricultural activity. A baseline concentration may differ from ambient as it is intended to include contributions from other hotspot sources, i.e., all sources excluding contributions from a proposed development (IAQM, 2019). Ambient monitoring conducted in Ireland (Doyle et al., 2017; de Kluizenaar and Farrell, 2000) intentionally excluded monitoring within 2 km from hotspot sources, and as such is not representative of concentrations where these sources occur. Similarly, in the UK where emissions, concentration and deposition are averaged over 1 or 5 km grids (Hallsworth et al., 2010), potential contributions of such hotspot sources may be underpredicted. When performing an AA on a Natura 2000 site contribution to local concentration and deposition of the new development should be assessed in combination with the baseline concentration, not the ambient. Modelled ambient concentrations across Ireland indicate a range of 0.38 – 4.47 µg m^{-3} (Kelleghan et al., 2019), indicating exceedance of critical levels on Natura 2000 sites of 80.1% for concentrations of 1 µg m^{-3} and 5.9% exceeding 3 µg m^{-3}. Considering 34.3 % of Natura 2000 sites exceed 2 µg m^{-3}, contributing an additional 1 µg m^{-3} within 312 – 468 m as identified within this study, could contribute to the baseline concentration exceeding the critical level for higher plants.

503 The European Union Network for the Implementation and Enforcement of Environmental Law
504 (IMPEL) had previously set the *de minimis* value for contributions to dry deposition of nitrogen
505 from hotspot NH_3 sources at 0.3 kg N ha^{-1} $year^{-1}$. The IMPEL guidance states, below this
506 deposition rate contributions "cannot be realistically attributed to a particular project they
507 should rather be described as diffuse part of the background deposition". However, The Dutch
508 Nitrogen Case (C 293/17 & C 294/17)(CJEU, 2019) clarifies any additional contribution, even
509 below previously identified *de minimis* values may contribute towards a Natura 2000 site not
510 achieving favourable conservation status. In this instance, the Dutch Nitrogen Case is referring
511 to sites which have already exceeded their site-specific critical thresholds. Hence, if a site is
512 already impacted in the eyes of the European Court of Justice, any additional contribution could
513 be considered a significant impact under the Habitats Directive (92/43/EEC) regardless of how
514 minute.

515 This study modelled the dispersion extent at which IMPEL's *de minimis* threshold to deposition
516 occurred. Dry deposition was modelled using the two deposition velocities provided in SCAIL-
517 Agriculture, intended to represent deposition across woodland and other surfaces (Hill et al.,
518 2014). Modelling indicated IMPEL's *de minimis* values from laying hen housing occurred within
519 2.9 – 5.1 km and 5.2 – 7.7 km for other surfaces and woodland, respectively. For every model
520 produced, such deposition only occurred within the 10 km distance threshold (currently used by
521 Ireland's National Parks and Wildlife Service (NPWS, 2009) to screen potential effects on Natura
522 2000 sites). However, a 5 km distance threshold used by some organisations would have failed
523 to adequately account for potential contribution to impacts (Environment Agency, 2018).

524 The United Kingdom uses a percentage of process contribution to indicate significance of effects
525 on Natura 2000 sites to trigger when a stage 2 AA is required. Originally it was envisioned within
526 the UK that the contribution of 1 – 4% of a critical level or load was not significant alone or in
527 combination (Hicks et al., 2011). Since then, advice has been changing in line with outcomes of

national court cases, and is likely non-compliant with the Habitats Directive (92/43/EEC) (European Economic Committee, 1992) based on the findings of the Dutch Nitrogen Case (C 293/17 & C 294/17)(CJEU, 2019). Guidance currently out for consultation by Natural Resources Wales indicates that the currently used 1% threshold is not adequate to screen effects from "in-combination assessments". It remains to be seen how this updated guidance will influence cumulative impact assessments, a requirement of the Habitats Directive (92/43/EEC) (European Economic Committee, 1992) for every Appropriate Assessment. This guidance goes on to clarify, where a habitat is particularly sensitive to negative effects from atmospheric NH_3 or nitrogen deposition, contributions below 1% may be considered significant (Natural Resources Wales, 2020). The maximum distance an exceedance of 1% was modelled from the current study ranged from 27.4 to 32 km depending on inputs, a difference in 4.5 km could easily influence the approval of local authority planning applications, highlighting the need for detailed monitoring to ensure the most appropriate emission and ventilation rates are being used to model effects on the environment. In practice, including Natura 2000 sites 22.2 – 24.5 km away in an NH_3 impact assessment is counter intuitive, as due to the low dispersion potential of NH_3 it is typically dry deposited near the source (Krupa, 2003; Pitcairn et al., 2002). Atmospheric dispersion models such as AERMOD (utilised by the SCAIL-Agriculture tool) predict the dispersion of a pollutant into the atmosphere along a gradient until it eventually reaches a zero concentration. The percent threshold currently recommended within the UK of 1% for sensitive Natura 2000 sites (critical level of 1 µg m^{-3}) extends as far as 27.4 km for monitored data downwind. Therefore, using the percent thresholds for stage 1 screening of this farm would potentially require detailed stage 2 assessment for any Natura 2000 containing sensitive conservation features such as bogs, heath or Atlantic oak woodlands within 27.4 km from the farm. The application of IMPEL's *de minimis* 0.3 kg N ha^{-1} $year^{-1}$ would include sites within 5.2 and 2.9 km for woodlands and other habitats, respectively. For this example, the potential difference in the use of both thresholds ranges from 22.2 – 24.5 km. In practice, this could result in an over-

precautionary approach assessing impacts across a greater range than they potentially occur. If IMPEL guidance is followed and "only project contributions above the cut off criterion (0.3 kg N ha^{-1} $year^{-1}$) have to be considered within appropriate assessment in combination with other projects" (IMPEL, 2017), the UK's percent thresholds may be over-precautionary. In this case, stage 2 AA should only be triggered when modelled deposition on a Natura 2000 site exceeds 0.3 kg N ha^{-1} $year^{-1}$, or is in receipt of equivalent concentrations (0.04 & 0.06 µg m^{-3} depending on deposition velocity used). This also applies to the findings of the Dutch Nitrogen Case which requires AA for any contribution, even below previously identified *de minimis* contributions, where the lower the concentration screened the greater the model extent.

Following chemical transformation to particulate matter as ammonium (NH_4), it can spread much greater distances and potentially impact Natura 2000 sites via wet deposition. This wet deposition, however, is not what these models in practice assess, as they would require different model parameters and model set up. Hence, using a 1% threshold or lower for the requirement of a stage 2 AA may not be additionally precautionary, unless limited by a distance threshold. Recommendations from the Dutch Nitrogen Case (C 293/17 & C 294/17)(CJEU, 2019) have clarified that unless detailed baseline conditions, inclusive of contributions from local hotspot sources are understood, the trigger should be set based on any contribution to the Natura 2000 site. Authors of this paper recognise, that unless factors such as chemical transformation and dry depletion are included in screening models, a distance threshold for exceedance should be recommended, as the dispersion potential for NH_3 is limited. A better understanding of all contributing sources of NH_3 on Natura 2000 sites would benefit such assessments, identifying sites close to or already exceeding their critical level or load.

4.5. Influence of Meteorological Data

Meteorological data influences predicted concentrations and extents from dispersion models, based both on the source of data and the period modelled. This study utilised data from the

nearest synoptic meteorological station, though conditions are likely to vary on the site due primarily to topographical differences between sites (Ulman et al., 2005). In practice, when carrying out modelling assessments meteorological data 35 km from the point of interest would likely be not representative of local conditions (Environmental Protection Agency, 2019). As in this case, modelling was intended to act as a case study of conditions from a farm which could be located anywhere in the country; as such the inclusion of any long term monitored meteorological data would be appropriate. The full meteorological year is required when modelling the annual exceedance of critical levels and loads, in order to account for the full effect of seasonal variation both of emissions and meteorological conditions. Modelling conducted by Kelleghan et al. (2020) validates the requirement of modelling multiple years when conducting an environmental assessment. Previously, it has been recommended that when conducting an environmental assessment, modelling should be conducted separately for the five most recent years and the outcome predicting the worst impacts be applied (Environment Agency, 2010). Kelleghan et al. (2020) notes that this could include both the year with maximum dispersion potential and the year with the lowest, due to potentially increased local levels of concentration and deposition. Though dispersion of NH_3 can vary significantly throughout the day and over seasons, the use of annual exceedances is more precautionary than over any other time period (Sutton et al., 2008). As such, this should be paired with representative annual meteorological conditions, considering the worst-case scenario for potential impacts.

4.6. Emission & Impact Reduction

The management system used by this particular laying hen house, by drying and continuously removing manure enhances the farm's ability to control emissions and subsequent contributions to local concentrations and deposition. By increasing the frequency of manure removal, the contribution of emissions from the house can be effectively managed and potentially reduced. However, consideration should be given to how this influences emissions from the dry manure

store. As the manure is dried prior to storage, it is likely to reduce environmental impacts compared to wet manure; which has a much higher emission rate (Meisinger & Jokela, 2000). The protein content in the feed at 16% is already considered to be a very low concentration (Nahm, 2003), with research showing reducing by an additional percentage has an observable influence on emissions (Roberts, 2007). However, Roberts' study showed that increasing the dietary fibre could also further enhance emission reductions. Planting woodland as a barrier to NH_3 emissions is a potential measure to mitigate unwanted effects downwind (Tyndall, 2008; Jerez, et al., 2016). If dry deposition is encouraged in planted woodlands near the farm, it can reduce downwind impacts to potentially sensitive sites. Any methods for reducing emissions will also contribute to reductions in local concentrations and deposition, thereby decreasing potential ecological effects. Reducing emissions therefore has benefits both for compliance with the EU NEC (2016/2284/EU) and Habitats Directives (92/43/EEC) (European Economic Committee, 1992).

5. Conclusions

This study monitored the NH_3 emission and ventilation rates for one enriched caged laying hen house in Ireland. The emission rates showed substantial seasonal, weekly and daily variation, with an overall average NH_3 emission rate of 0.25 g bird^{-1} day^{-1}. The average ventilation rate was 931 cm^3 s^{-1} bird^{-1}. Monitoring indicated that increasing the frequency of manure removal is an effective method of reducing emissions, which increase every day until manure is removed via conveyor belt.

The maximum extent of modelled concentrations using monitored and SCAIL-Agriculture rates were significantly different. The use of SCAIL-Agriculture emission and ventilation rates would have been suitable for Appropriate Assessment of this farm, as including the emission and / or ventilation rate resulted in significantly greater ammonia dispersion extents. Detailed emission and ventilation monitoring could be conducted on a site-specific basis in order to improve predictions of potential negative ecological effects. Additionally, this highlights the use of a higher emission rate and lower ventilation rate may generate more precautionary models for Appropriate Assessment.

Deciding what contribution from a hotspot source such as a layer farm elicits as a potential significant effect on a Natura 2000 site is a contentious issue. The outcome from the Dutch Nitrogen Case (C 293/17 & C 294/17) identifies any contribution, even below the previously presumed *de minimis* 0.3 kg N ha^{-1} yr^{-1} could result in an inability of a Natura 2000 site to meet its conservation objective. The use of percent thresholds as a trigger for requiring a detailed AA is in direct conflict with this decision, as it excludes assessment of baseline conditions. Modelling however also needs to give cognisance to the dispersion potential of NH_3 as modelling such low concentrations substantially expands the extent modelled, increasing the number of Natura 2000 sites included in the assessment. A more appropriate approach may be to use any exceedance within a set distance from the source as a trigger for full AA.

6. Acknowledgements

This research was undertaken as part of the AmmoniaN2K Project funded by the Irish Environmental Protection Agency through their STRIVE Programme. The authors also wish to acknowledge the support of the AmmoniaN2K Project Steering Committee. Though the farm on which monitoring was undertaken has been anonymised, the AmmoniaN2K project owe a great debt to the farmer who agreed to allow monitoring on an active farm. The authors would also like to thank Dr. Ronan Dorrepaal and Ms. Emma Jane Wade for advice provided.

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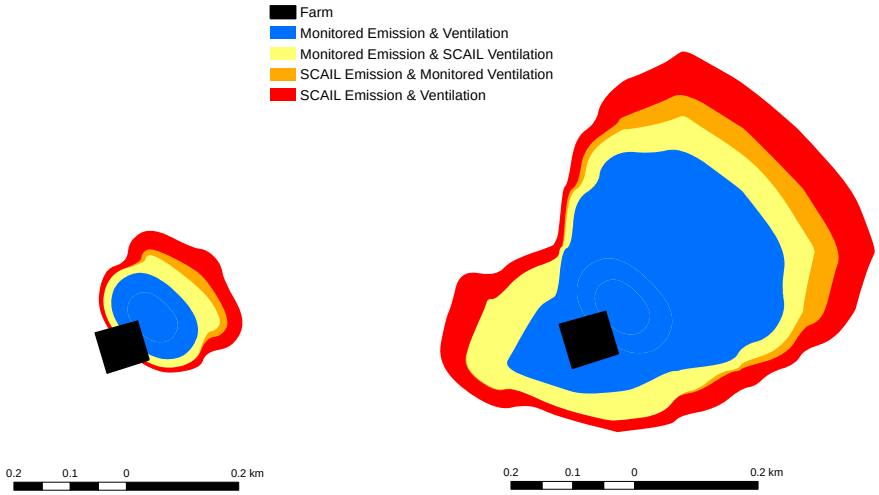
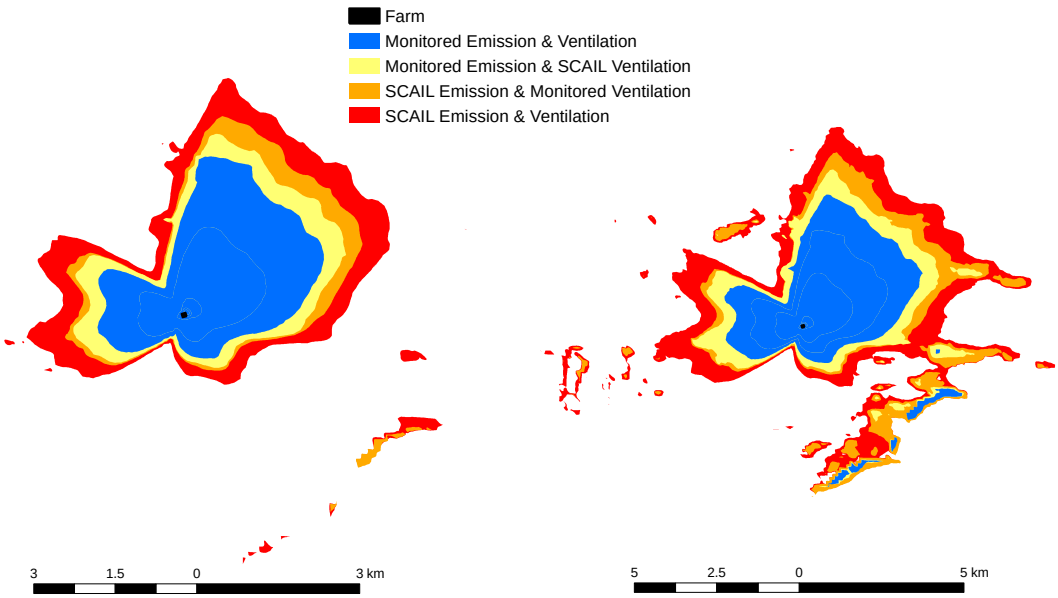
8. Appendixes



Appendix 1. Exceedance of critical levels from contributions of laying hen housing alone for 3 µg NH_3 m^{-3} (Left) and 1 µg NH_3 m^{-3} (Right).



Appendix 2. Where modelled extent of presumed *de minimis* values for dry deposition (0.3 kg N ha^{-1} $year^{-1}$) from laying hen housing occurs when deposited over other (left) and woodland (right) vegetation.