UK Centre for Ecology & Hydrology

# The spatial distribution of ammonia, methane and nitrous oxide emissions from agriculture in the UK 2018

## Annual Report to Defra (Project SCF0107)

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# Executive Summary

- Agricultural emissions of ammonia, methane and nitrous oxide for 2018 were spatially distributed across the UK, and maps produced.
- Holding-level agricultural statistics on livestock numbers and crop areas for 2018 were not available in sufficient time for a full inventory model run. Therefore emission estimates produced for the 2018 inventory were derived by scaling the 2017 emissions based on the changes to 2018 in DA-level livestock numbers and crop areas.
- Non-disclosive agricultural emission maps were produced at a grid resolution of 1 km by 1 km, using detailed agricultural census data, land cover data (Rowland *et al.*, 2017), agricultural practice information (e.g. fertiliser application rates, stocking densities) and emission source strength data from the UK emissions inventories for agriculture 2017 (Misselbrook and Gilhespy 2020 and Brown *et al.* 2020).
- All emission maps correspond to the totals reported by Rothamsted Research North Wyke (RResNW) for 2018.

# 1. Introduction

## 1.1 Background

Emission estimates of ammonia ($NH_3$), methane ($CH_4$) and nitrous oxide ($N_2O$) for the 2018 inventory are based on 2017 outputs from the UK agricultural emission model (jointly developed by Rothamsted Research, ADAS, UK CEH and Cranfield University). The model has been implemented in the C# programming language and is capable of generating UK agricultural emission estimates at a 10 km by 10 km grid resolution. The 10 km gridded estimates produced using the model have been spatially resolved to produce high-resolution 1 km grid emission maps using the redeveloped AENEID model (full details of which can be found in Carnell *et al.* 2018).

The agricultural emission estimates for $NH_3$, $CH_4$ and $N_2O$ are derived annually under Defra project SCF0107 and reported to Ricardo Energy & Environment as part of the UK national inventory submissions (inventories by Misselbrook and Gilhespy 2020 and Brown *et al.* 2020; see Table 1). This report summarises UKCEH's contribution of high-resolution spatial distribution of emissions from agricultural sources to the UK NAEI, and complements the expertise of the wider project consortium in producing UK emission estimates from experimental data, peer-reviewed literature and agricultural management practices, including mitigation options.

Due to licensing restrictions in relation to data protection (GDPR), the detailed 1 km model output can only be shown as "emissions from livestock" and "emissions from fertiliser application to crops and grassland", rather than for individual livestock sectors or crop types.

**Table 1:** UK emissions of ammonia ($NH_3$), methane ($CH_4$) and nitrous oxide ($N_2O$) for 2018, as submitted by RResNW and mapped by CEH (in kt $yr^{-1}$).

| Gas | Source | UK emission (kt) 2018 |
|---|---|---|
| **$NH_3$** | Livestock manure† | 183.9kt $NH_3$ |
| | Fertiliser application | 48.8 kt $NH_3$ |
| | **Total agriculture** | **232.7 kt $NH_3$** |
| **$CH_4$** | Enteric fermentation | 847.0 kt $CH_4$ |
| | Livestock manure | 168.0 kt $CH_4$ |
| | **Total agriculture*** | **1,015.0 kt $CH_4$** |
| **$N_2O$** | Crops & soils# | 39.6 kt $N_2O$ |
| | Direct emissions from livestock manure | 8.0 kt $N_2O$ |
| | **Total agriculture *** | **47.6 kt $N_2O$** |

† Includes emissions from manure-digestate emissions (1.3 kt $NH_3$).

* The GHG maps also include emissions from non-agricultural horses (i.e. all horses present in the UK, rather than only those present on farms that are counted as part of the annual agricultural statistics); N.B. for $NH_3$, non-agricultural horses are reported separately and not included in the agricultural emissions total.

# includes all indirect $N_2O$ emissions, including those related to livestock manures.

## 1.2 Annual work schedule/deliverables

- Task 1: To acquire source data (agricultural survey/census) from the devolved authorities for spatially distributing agricultural ammonia emissions from livestock manures and fertiliser application. This included acquiring data from the cattle tracing system for Great Britain (CTS, via Cranfield University).
- Task 2: To model $NH_3$, $CH_4$ and $N_2O$ emissions from agricultural sources at a 1 km by 1 km grid resolution using the new version of the agricultural emission distribution model for the UK (AENEID). Due to delays in receiving the holding-level agricultural survey data, the 2018 maps have been scaled based on outputs for the year 2017.
- Task 3: To provide a short report describing the methodology and results, highlighting any changes and their consequences.
- Task 4: To streamline the inventory jointly between UKCEH and the consortium partners (Rothamsted Research North Wyke, ADAS, Cranfield University), as part of a continuing improvement process. For this year, this included updating the historic time series of livestock populations and crop areas and developing a method to scale the 2017 maps to the 2018 estimated emission totals.
- Task 5: To submit the spatial datasets to Ricardo Energy & Environment for inclusion in the National Atmospheric Emission Inventory (NAEI) and Greenhouse Gas Inventory (GHGI).

# 2. Methods - Spatial distribution of $NH_3$, $CH_4$ and $N_2O$ emissions from agricultural sources

For the 2018 inventory cycle, a different methodology had to be developed, as holding level agricultural census/survey data were not available in sufficient time for a complete model run this year. This meant that model outputs for the year 2017 were rescaled, as follows: Livestock emission totals for 2018 were estimated to reflect changes in livestock populations from 2017 (agricultural management practices remain unchanged and are assumed to be the same as 2017). The distribution of livestock emissions was based on 2017 individual source maps (e.g. grazing, manure management, housing, storage) for each sector and was scaled to 2018 emissions totals for each UK devolved administration (i.e. England, Wales, Scotland, Northern Ireland). Fertiliser emissions were estimated based on changes in crop areas, which translated through to fertiliser use, assuming the same application rates as 2017. Fertiliser emissions were distributed based on 2017 individual source maps (e.g. direct fertiliser emissions, crop residues etc.) for arable and grassland emissions separately and were scaled to 2018 emission totals for each DA.

- 31 individual UK emission layers (individual sector/source combinations) were used to distribute agricultural $NH_3$ emissions and each layer was scaled to preserve 2018 DA totals.
- 16 individual UK emission layers (individual sector/source combinations) were used to distribute agricultural $CH_4$ emissions and each layer was scaled to preserve 2018 DA totals.
- 41 individual UK emission layers (individual sector/source combinations) were used to distribute agricultural $N_2O$ emissions and each layer was scaled to preserve 2018 DA totals.

Emissions from 'non-agricultural' horses (i.e. horses that are not kept on agricultural holdings) are **not included** in the ammonia emissions maps shown in this report and are mapped and reported to the NAEI separately. Emissions from these horses are however, **included** in the $CH_4$ and $N_2O$ emission maps, for reasons of compliance with the different sets of emission inventory guidelines for air pollutants and GHGs, respectively.

For information on how the outputs for 2017 (and earlier years) were derived please refer to Carnell *et al.* (2019).

# 3. Results

## 3.1 Spatially distributed emissions of $NH_3$, $CH_4$ and $N_2O$ for 2018

All UK maps were produced on the Ordnance Survey GB Grid at a resolution of 1 km x 1 km. The units for all GIS datasets submitted are kg ammonia ($NH_3$), methane ($CH_4$) and nitrous oxide ($N_2O$), respectively, per grid square. All spatial datasets were submitted to RResNW (Defra Contract SCF0107) and to Ricardo (for use in the National Atmospheric Emission Inventory (NAEI, see http://naei.beis.gov.uk/). Figures 1, 2 and 3 show the 2018 maps resulting from the spatial modelling of agricultural emissions (excluding non-agricultural horses) for $NH_3$, $CH_4$ and $N_2O$, respectively (units: kg $ha^{-1}$ $year^{-1}$).

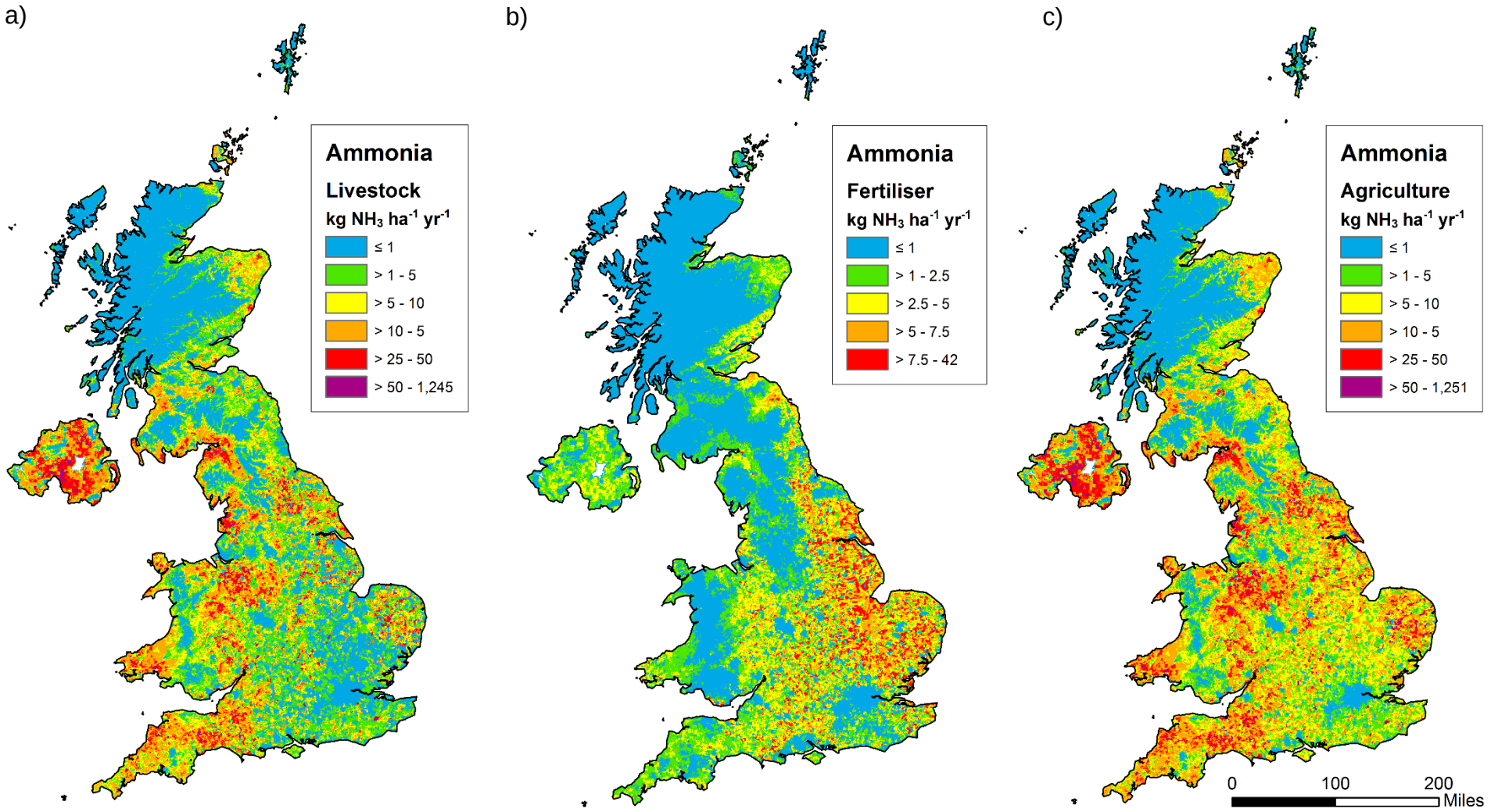


Figure 1: UK ammonia emissions from a) livestock manures, b) fertilisers and c) total agriculture (c = a + b) for 2018 (Units: kg $NH_3$ $ha^{-1}$ $year^{-1}$).

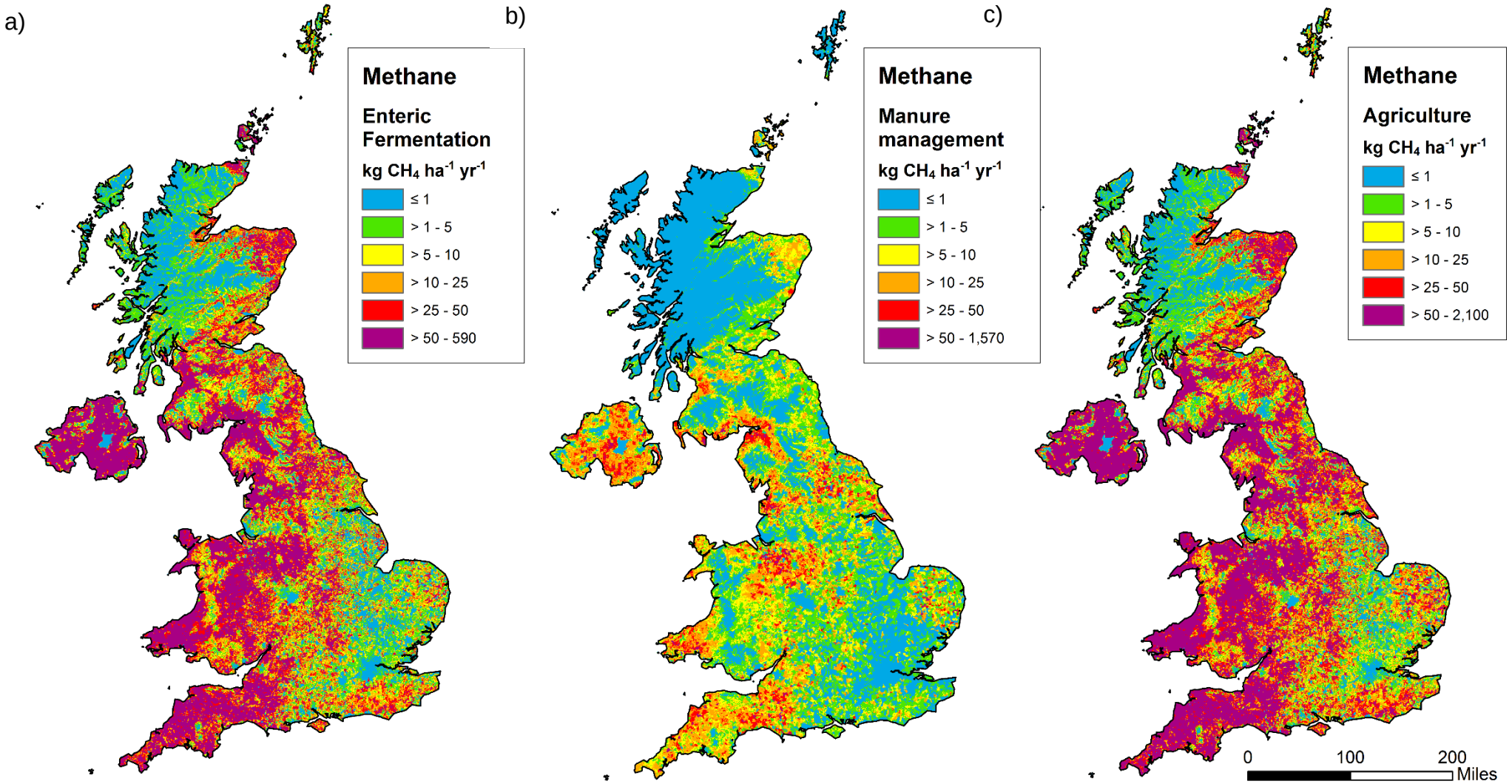


Figure 2: UK methane emissions from a) enteric fermentation, b) livestock manure management and c) total livestock (c = a + b) for 2018 (Units: kg $CH_4$ $ha^{-1}$ $year^{-1}$).

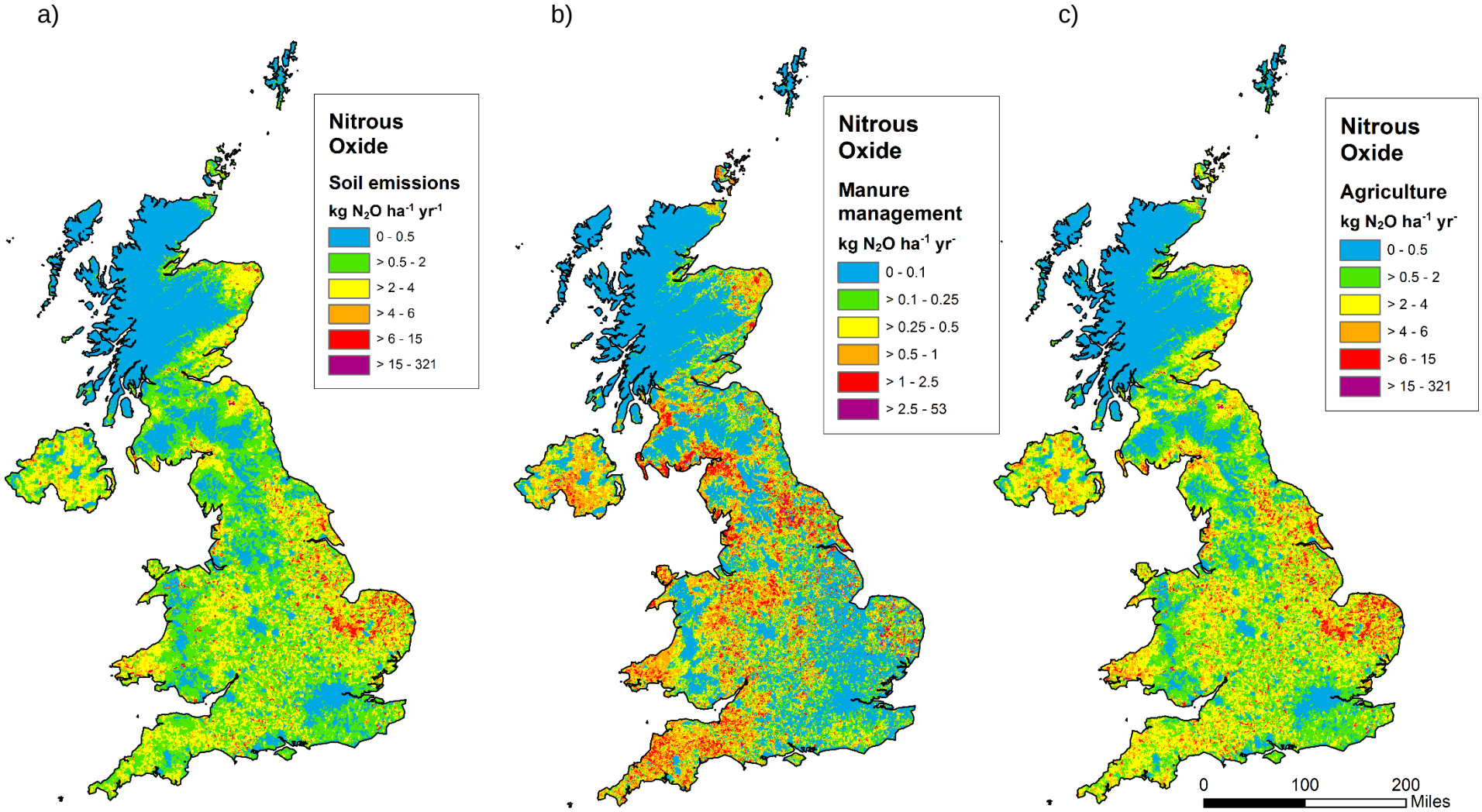


Figure 3: UK nitrous oxide emissions from a) soils, b) livestock manure management and c) total agriculture (c = a + b) for 2018 (Units: kg $N_2O$ $ha^{-1}$ $year^{-1}$).

## 3.2 Major changes and Consequences

### 3.2.1 Changes in emissions from agricultural $NH_3$ sources

Overall, estimated $NH_3$ emissions from UK agricultural sources have decreased by 0.9 kt $NH_3$ between the reported 2017 and 2018 inventories, with 233.5 kt $NH_3$ and 232.7 kt $NH_3$ emitted, respectively (Table 2). No changes to methodology or assumptions regarding management practices and emission factors have been made this year and all changes between 2017 and 2018 were driven by the changes in livestock numbers and crop areas (which translated through to fertiliser use, assuming the same application rates as 2017).

Livestock emissions are estimated to have decreased by 0.4 kt $NH_3$ (~0.3 % increase), with fertiliser emissions decreasing by 0.5 kt $NH_3$ (1 % decrease). This decrease in emissions is associated with a decrease in total fertiliser N use by ~2% from 2017 to 2018.

The minor estimated decrease in livestock emissions between 2017 and 2018 is associated at UK level with a 0.5% reduction in dairy cow numbers, 1.3% reduction in all other cattle, 3% reduction in sheep and increases of 0.9 and 3.6% in pig and poultry numbers.

**Table 2:** Differences between reported ammonia emissions from UK agriculture in 2017 (adapted from Misselbrook and Gilhespy 2020) and the scaled 2018 inventory estimates. Totals may not add up exactly due to rounding.

| | Revised 2017 emissions (kt $NH_3$) | Revised 2018 emissions (kt $NH_3$) | Annual difference |
|---|---|---|---|
| *All cattle* | *115.8* | 114.8 | -1% |
| *All sheep* | *9.6* | 9.3 | -3% |
| *All pigs* | *18.6* | 18.7 | 1% |
| *All poultry* | *37.7* | 38.4 | 2% |
| *Horses, Goats and Deer* | *1.4* | 1.4 | -2% |
| *Application of digestate* | *1.3* | 1.3 | +2% |
| *Application of fertilisers* | *44.9* | *44.4* | -1% |
| *Sewage sludge* | *4.3* | *4.3* | 0% |
| Livestock total | 183.1 | 183.9 | 0% |
| N fertiliser total | 49.2 | 48.8 | -1% |
| **Total agriculture** | **233.5.3** | **232.7** | **0%** |

### 3.2.2 Changes in emissions from agricultural $CH_4$ sources

Total agricultural $CH_4$ emissions from UK agricultural sources have decreased by 12.4 kt $CH_4$ between the published 2017 and 2018 inventories, with 1,027.4 kt $CH_4$ and 1,015.0 kt $CH_4$ emitted, respectively. As with the $NH_3$ emissions (Section 3.2.1), no methodological changes have been made and any changes to emissions are a reflection of changes to activity data.

Enteric emissions are estimated to have decreased marginally by 11.4 kt $CH_4$ (~1 % decrease) and emissions associated with livestock manures by 1.0 kt $CH_4$ (1% decrease), as a result of small changes in livestock numbers as detailed in Section 3.2.1.

**Table 3:** Differences between reported $CH_4$ emissions from UK agriculture in 2017 (adapted from Brown *et al.* 2019) and 2018 inventory estimates. Totals may not add up exactly due to rounding.

| Sector | Grouping | Reported 2017 emissions (kt $CH_4$) | Reported 2018 emissions (kt $CH_4$) | Annual difference (%) |
|---|---|---|---|---|
| All cattle | Enteric emissions | 670.8 | 663.9 | -1% |
| Sheep | Enteric emissions | 161.7 | 157.3 | -3% |
| Pigs | Enteric emissions | 7.5 | 7.5 | 1% |
| Horses, Goats & Deer | Enteric emissions | 18.3 | 18.2 | 0% |
| All cattle | Livestock manure | 133.5 | 132.4 | -1% |
| Sheep | Livestock manure | 4.3 | 4.2 | -3% |
| Pigs | Livestock manure | 25.8 | 26.1 | 1% |
| Poultry | Livestock manure | 3.9 | 3.9 | 1% |
| Horses, Goats & Deer | Livestock manure | 1.5 | 1.5 | -1% |
| Total Enteric emissions | | 858.3 | 847.0 | -1% |
| Total Livestock manure | | 169.1 | 168.0 | -1% |
| **Total Agriculture** | | **1027.4** | **1015.0** | **-1%** |

### 3.2.3 Changes in emissions from agricultural $N_2O$ sources

Total agricultural $N_2O$ emissions from UK agricultural sources have decreased by 0.3 kt $N_2O$ between the published 2017 and 2018 inventories, with 47.9 kt $N_2O$ and 47.6 kt $N_2O$ emitted, respectively. As with the $NH_3$ emissions (Section 3.2.1), no methodological changes have been made and any changes to emissions are a reflection of changes to activity data.

There was a slight decrease (0.04 kt $N_2O$) in $N_2O$ emissions from manure management between 2017 and 2018, but almost unchanged. The minor decrease (-1 %) in nitrous oxide emissions from soils between 2017 and 2018 is largely due to changes in fertiliser use outlined above.

**Table 4:** Differences between reported $N_2O$ emissions from UK agriculture in 2017 (adapted from Brown *et al.* 2019) and 2018 inventory estimates. Totals may not add up exactly due to rounding.

| Sector | Grouping | Reported 2017 emissions (kt $N_2O$) | Reported 2018 emissions (kt $N_2O$) | Method differences |
|---|---|---|---|---|
| *All cattle* | *Manure management* | 5.6 | 5.5 | -1% |
| *All sheep* | *Manure management* | 0.1 | 0.1 | -2% |
| *All pigs* | *Manure management* | 0.9 | 0.9 | 1% |
| *All poultry* | *Manure management* | 0.9 | 0.9 | 1% |
| *Horses, Goats & Deer* | *Manure management* | 0.6 | 0.6 | -1% |
| *All cattle* | *Soil emissions** | 6.1 | 6.1 | *-1%* |
| *All sheep* | *Soil emissions** | 1.4 | 1.4 | *-3%* |
| *All pigs* | *Soil emissions** | 0.8 | 0.8 | *0%* |
| *All poultry* | *Soil emissions** | 1.2 | 1.2 | *2%* |
| *Horses, Goats & Deer* | *Soil emissions** | 0.5 | 0.5 | *-1%* |
| *Application of fertilisers & crop residues* | *Soil emissions** | 23.5 | 23.2 | *-1%* |
| *Sewage sludge, histosols and mineralisation* | *Soil emissions** | 6.4 | 6.4 | *0%* |
| Total direct manure management emissions | | 8.0 | 8.0 | *0%* |
| Total soil emissions | | 39.9 | 39.6 | *-1%* |
| **Total agricultural emissions** | | **47.9** | **47.6** | *-1%* |

# 4. Conclusions

New high-resolution ammonia, methane and nitrous oxide emission maps were derived for the UK (Defra project SCF0107), and submitted for inclusion in the 2018 version of the NAEI and GHGI for agriculture in the UK. Agricultural emissions were derived using 2017 model outputs from the agricultural emission inventory model and the high-resolution spatial distribution model developed under Defra project AC0102. The 2018 maps have been submitted at a 1 km grid resolution (non-disclosive). Due to a delay with the availability of holding level input data to the modelling, the approach applied for 2018 differs from the previous years, with modelling based on detailed scaling of the 2017 model outputs.

# 5. Acknowledgements

The authors are grateful to Defra, who are funding this work under project SCF0107, as a contribution to the National Ammonia Emissions Inventory (NAEI) and Greenhouse Gas Inventory (GHGI), and the Devolved Authorities of the UK for providing agricultural census/survey data.

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