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# Respiratory hospital admission risk near large composting facilities

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ABSTRACT

*Background:* Large-scale composting can release bioaerosols in elevated quantities, but there are few studies of health effects on nearby communities.
*Methods:* A cross-sectional ecological small area design was used to examine risk of respiratory hospital admissions within 2500 m of all 148 English large-scale composting facilities in 2008–10. Statistical analyses used a random intercept Poisson regression model at Census Output Area (COA) level (mean population 310). Models were adjusted for age, sex, deprivation and tobacco sales.
*Results:* Analysing 34,963 respiratory hospital admissions in 4656 COAs within 250–2500 m of a site, there were no significant trends using pre-defined distance bands of >250–750 m, >750–1500 m and >1500–2500m. Using a continuous measure of distance, there was a small non-statistically significant ($p = 0.054$) association with total respiratory admissions corresponding to a 1.5% (95% CI: 0.0–2.9%) decrease in risk if moving from 251 m to 501 m. There were no significant associations for subgroups of respiratory infections, asthma or chronic obstructive pulmonary disease.
*Conclusion:* This national study does not provide evidence for increased risks of respiratory hospital admissions in those living beyond 250 m of an outdoor composting area perimeter. Further work using better measures of exposure and exploring associations with symptoms and disease prevalence, especially in vulnerable groups, is recommended to support regulatory approaches.


## 1. Introduction

As a result of the 1999 European Union Landfill Directive (1999/31/EC) requiring diversion of waste from landfill, more waste in member states is now being processed at composting facilities, with significant growth in the composting industry (DEFRA, 2009; European Commission, 2012). Composting facilities deal with the biodegradable components of waste and the process relies on the breakdown of the waste by microorganisms (Swan et al., 2003). During the composting process, these microorganisms can become airborne, particularly when the compost is disturbed (Taha et al., 2006), and contribute to the atmospheric loading of bioaerosol. Bioaerosols can consist of bacteria, fungi, pollen and constituents, fragments and by-products of cells (Douwes et al., 2003) that vary in size from 0.02–100 μm (Dowd and Maier, 2000). Bioaerosols with an aerodynamic diameter of less than 10 μm are of particular concern in relation to respiratory health because they can be inhaled; some are small enough to penetrate deep into the lung and to the alveolar sac which might trigger negative health effects (Douwes et al., 2003; Ivens et al., 1999). However, quantitative evidence on both exposure and response to bioaerosols from waste composting is limited (Pearson et al., 2015) and there are few studies looking at health effects of waste composting (Giusti 2009; Pearson et al., 2015; Searl, 2008; Wéry, 2014). Occupational health studies of compost site workers have mainly focussed on respiratory

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impacts (Pearson et al., 2015), with some studies showing reduction in lung function (Bünger et al., 2007; Sigsgaard et al., 1994); respiratory symptoms (Bünger et al., 2000; Hambach et al., 2012) and symptoms consistent with allergic rhinoconjunctivitis (Bünger et al., 2007; Hambach et al., 2012; van Kampen et al., 2012); and increased chronic bronchitis (Bünger et al., 2007). Community studies have reported increases in respiratory symptoms and throat and eye irritation near sites (Pearson et al., 2015). No community studies have looked at healthcare usage.

Current UK guidance takes a precautionary approach and states that the contribution from biowaste processing to atmospheric bioaerosol concentration at the nearest 'sensitive receptor', for example a dwelling or workplace, or 250 m from the site, whichever is closer, should not exceed acceptable levels (Environment Agency, 2010). The acceptable levels are currently defined as 300, 500 and 1000 Colony Forming Units per cubic metre (CFU/m$^3$) above upwind concentrations for gram-negative bacteria, *Aspergillus fumigatus* and total bacteria respectively (Environment Agency, 2010) as measured by the standardised sampling protocol (AfOR, 2009). In Germany, a minimum distance of 300 m or 500 m for enclosed and open-windrow facilities resepectively, is enforced for facilities processing 3000 kg or more, although acceptable limits of bioaerosols are not provided (BUNR, 2002). To the authors' knowledge there are no existing guidelines for community levels of bioaerosols outside the UK, but there are occupational guidelines in Germany, where a regulatory occupational limit of 50,000 CFU/m$^3$ of mesophilic fungi is set for breathable air in the workplace (BAUA, 2013) and in the Netherlands recommendations of an occupational exposure limit for endotoxin of 90 Endotoxin Units per cubic metre (EU/m$^3$) (DECOS, 2010).

The aim of this national study was to examine risk of respiratory hospital admissions in areas near all large composting sites in England with an open composting element, with particular reference to areas just outside current Environment Agency permitting guidelines of 250 m from site.

## 2. Materials and methods

### 2.1. Site selection

Large scale composting facilities given permits by the Environment Agency (EA) and operating in England between 2008 and 2010 were identified (Fig. 1). A permit is usually required when composting sites store or treat in excess of 60–80 tons of compost at any one time, depending on retention time (Environment Agency, 2014). The EA record when the permit was obtained, the type of facility, the site address and British National Grid coordinates. We assumed that once a permit had been obtained the facility began operating and did not cease to operate during the period of the study. Large scale composting can be performed indoors or outdoors, and approximately 80% of sites in the UK include open windrow composting (i.e. composting is performed outdoors and the biodegradable waste is formed into long piles called windrows). Only sites with an outdoor composting component (open windrow facilities or in-vessel facilities with outdoor maturation or storage areas) were included, as bioaerosol emissions from composting processes performed outdoors are not filtered or controlled.

### 2.2. Exposure data

Site locations were verified using the addresses and grid references provided by the EA. The perimeter of outdoor composting areas were digitised using Google$^{TM}$ Earth (version 7), imported into a Geographical Information System (ArcGIS version 10.0, ESRI Inc.) and distance bands from the edge of the digitised outdoor composting areas were added. The distance bands used in statistical analyses were 0–250 m, >250–750 m, >750–1500 m and >1500–2500 m from the outdoor composting area perimeters, informed by current published literature (see Table 1 for details). Distance as a continuous measure was also examined.

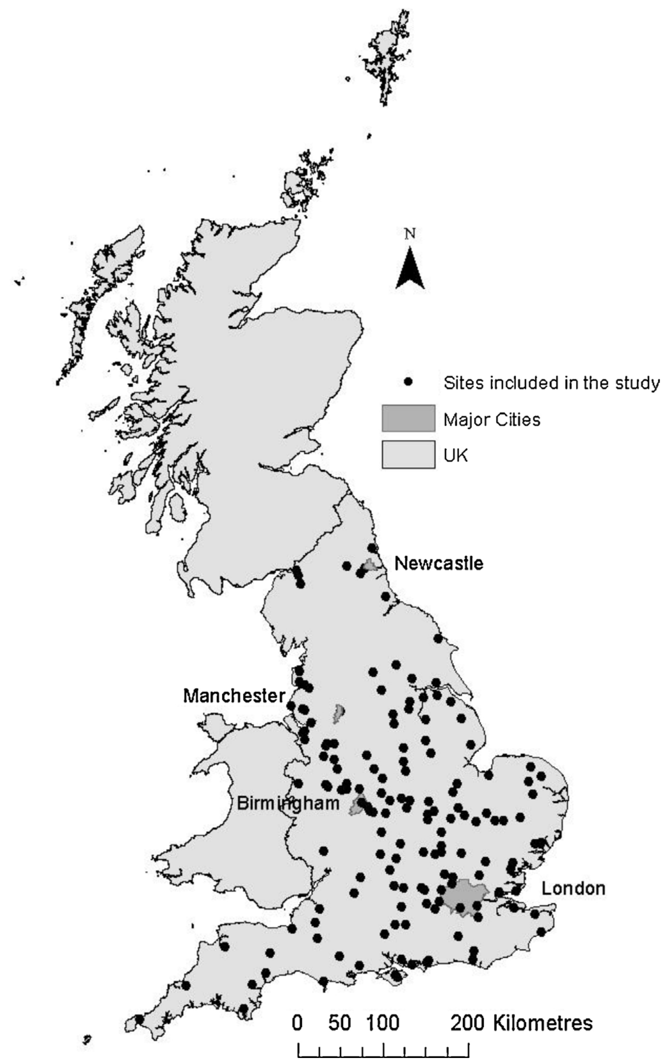


**Fig. 1.** Locations of large scale composting facilities in England with an outdoor composting component operating in 2008–10.

### 2.3. Outcome data

Postcoded emergency and non-emergency hospital admissions by age and sex between 2008–10 were obtained from Hospital Episode Statistics (HES) data held by the UK Small Area Health Statistics Unit (SAHSU), provided by the Health and Social Care Information Centre (HSCIC). Admissions with a primary diagnosis for the admission (i.e. first episode of care) of (i) respiratory disease (coded to International Classification of Disease version 10 (ICD10), chapter J), (ii) respiratory infections (ICD10 J00-22), (iii) asthma (ICD10 J45-46), and (iv) chronic obstructive pulmonary disease (COPD) (ICD10 J40- 44) were selected for those with a postcode of residence within 2500 m of a composting site. It was not possible to analyse admissions coded to diseases relating to organic dusts (ICD10 J66-67) due to very small numbers (n = 17 admissions, corresponding to 14 individuals). There were only 30 respiratory- related admissions (relating to 22 individuals) in the 0–250 m distance band so this band was consequently excluded as results would have

**Table 1**
Distance bands added to each site with justification.

| Distance Band (m) | | Justification |
|---|---|---|
| 1 | 0–250 | Current distance set by the Environment Agency whereby bioaerosols released from composting facilities are at a maximum, but generally expected to return to a level below the acceptable level above background (Environment Agency, 2010) |
| 2 | >250–750 | Distance where studies have occasionally reported bioaerosol concentrations above the acceptable levels, above background, set by the Environment Agency (Pankhurst et al., 2011; Williams et al., 2013) |
| 3 | >750–1500 | Distance where bioaerosols have been detected, but did not exceed the current acceptable levels set by the Environment Agency (Reinthaler et al., 1997; Williams et al., 2013) |
| 4 | >1500–2500 | Control area—assumed no anthropogenic contribution above background |

been unstable due to small numbers. Repeat hospital admissions during the study period in the same individuals, as well as hospital admissions occurring before the site permitting date (see Fig. 2) were also excluded.

### 2.4. Denominator data

Area-level population estimates were obtained using Office for National Statistics (ONS) annual mid-year population estimates at Census Output Area (COA) level. COAs are the smallest geographical unit at which population estimates are available by age and sex categories (mean population 310 in study area COAs).

### 2.5. Confounder data

Carstairs index 2001, an area-level deprivation score was obtained from ONS. Carstairs provides a composite measure of deprivation derived from area-level information on unemployment, car ownership, household overcrowding (>1 person per room) and social class (Carstairs and Morris, 1989); scores were categorised into quintiles for analysis. Area-level tobacco sales data (pounds spent per week per adult aged 16+ years on tobacco sales within a COA) was used as a proxy for smoking; this is a commercially available data set provided by CACI (2014) which was available for 2014. Tobacco sales data were missing for 74 COAs and therefore these COAs were excluded from the adjusted analysis.

### 2.6. Harmonising small area geography

Data came in three different geographical resolutions: population and confounder data at COA level; hospital admissions at residential postcode level (on average 17 households per postcode in Great Britain); and distance bands around sites. Data were harmonised to COA level, as population and confounder data were available at this geography. The postcode centroid was used to assign admissions to COAs. The population-weighted COA centroid was used to assign a distance band to each COA as some COAs stretched across more than one distance band (see Fig. 3 for an example). Population-weighted centroids provide a better proxy of exposure for COA population than geometric centroids as they take into account where the majority of the population live within that COA (see technical summary in Appendix A).

### 2.7. Statistical analysis

A random intercept Poisson regression model was used with COA as the unit of analysis. This model allows for overdispersion in the data due to small counts in some areas. A hierarchical structure was assumed, given different sites and potential for clustering in hospital admissions by site (Hox, 2010). The statistical model equation is provided in Appendix B, Eq. (B.1). Analyses were conducted for all respiratory, respiratory infections, asthma and COPD admissions, comparing each distance band with the reference band >1500–2500 m from outdoor composting area perimeters. The basic model was adjusted for age and sex; additional adjustments

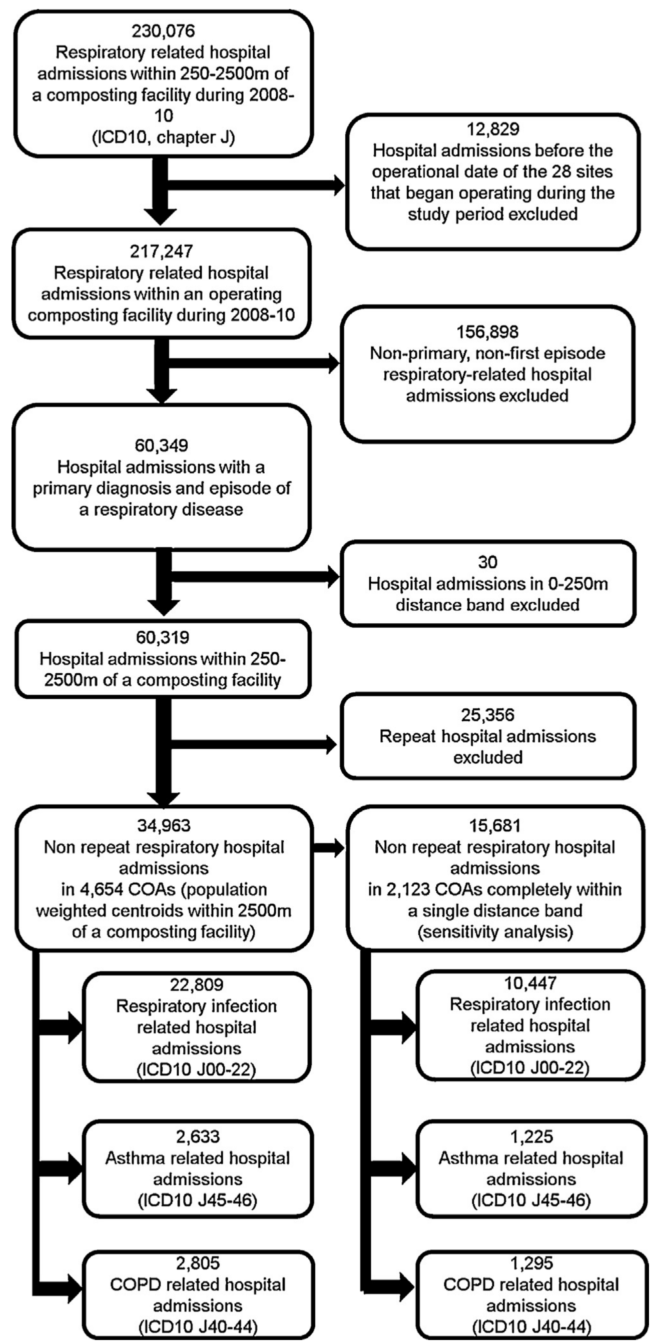


**Fig. 2.** Hospital admissions data cleaning. Only first episodes of primary respiratory-related hospital admissions were included during 2008–10 after the site had begun operating.

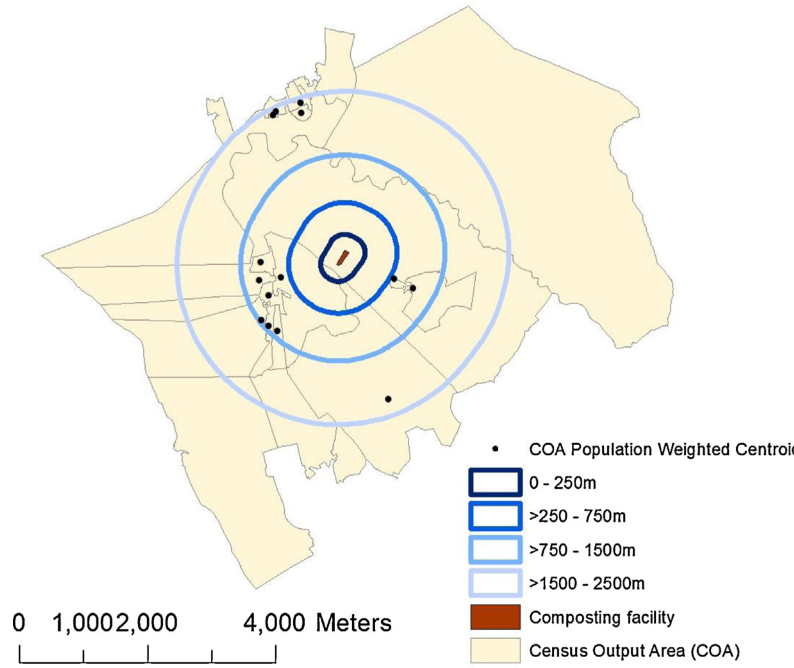


**Fig. 3.** An example of a composting facility with COAs spanning over multiple distance bands, showing population weighted centroids.

were made for area-level deprivation and tobacco sales. A continuous measure of distance using the COA population-weighted centroid from site was also calculated (using log-transformed distance for normality).

A sensitivity analysis was conducted including only the COAs completely within a single distance band to explore potential exposure misclassification resulting from using population weighted centroids to assign a COA population to a distance band.

## 3. Results

A total of 148 composting sites were included in the study, 117 were open windrow sites, and 31 were in-vessel sites with an outdoor maturation or storage component (Appendix C).

There were 4656 COAs where the population weighted-centroid was located within >250–2500 m of the 148 sites included in this study. Of these COAs, 54.40% (n = 2533) were distributed over more than one distance band.

There were a total of 34,963 (non-repeat) person-admissions for respiratory illness within >250–2500 m of a composting facility during 2008–10 (Fig. 2). There were mean (SD) of 8.90 (6.02), 7.69 (5.13) and 7.38 (5.24) admissions per COA respectively for bands >250–750 m, >750–1500 m and >1500–2500 m from site boundaries. Older individuals and those living in more deprived COAs were over-represented in respiratory hospital admissions compared with the population for those areas (Table 2).

Unadjusted analyses suggested a small increased risk of admissions for all respiratory disease and COPD, but not respiratory infections nor asthma, for those living nearer a composting site whether assessed by distance band (with significant *p*-values for trend) or log-transformed distance (Table 3). After adjustment for age, sex, deprivation and tobacco sales, relative risks (RR) of respiratory and COPD admissions were reduced in each distance band and those for COPD lost statistical significance. In adjusted models for respiratory admissions, the RR was 1.01 (95% CI 0.95–1.06) for COAs >250–750 m from site boundaries and 1.03 (1.01–1.05) >750–1500 m compared with the reference band (>1500–2500 m), with a non-significant *p*-value for trend. Using log-transformed distance from site a small borderline significant (p = 0.054) decreasing risk for respiratory admissions with increasing distance from site was observed, equivalent to a 1.5% (CI: 0.0–2.9%) decrease in risk if moving from the innermost edge of the 250 m band (251 m) to the start of the next distance band (501 m) from site. No significant associations were seen with this log-transformed distance for asthma, COPD or respiratory infection admissions.

When restricting analyses to the 2123 (45.6%) of COAs whose boundaries did not cross distance bands, there was no evidence of an association between any outcome and different distance bands (Table 3).

## 4. Discussion

To our knowledge this is the first study to investigate associations between residential proximity to a composting facility with an open-air composting component and respiratory-related hospital admissions. We did not find a clear indication of increased risk of admission for populations living nearer (within >250–1500 m) to facilities in England compared to those living further away (1500–2500 m). While in the main analyses we observed small increases in risk of respiratory admission with increasing proximity to site that were borderline statistically significant after adjustment, these were not seen in a sensitivity analysis using just under half the areas with a theoretically lower risk of exposure misclassification.

There are few other studies of health effects in communities living near a composting site (Aatamila et al., 2011; Browne et al., 2001; Herr et al., 2003a,b; Kramer et al. 1989; Liu et al., 2011), and these provide limited evidence of increased exposure levels to bioaerosols at distances greater than 200 m to 300 m downwind of a composting site (Pearson et al., 2015). Three questionnaire-based community health studies reported increases in respiratory symptoms in those living nearer to composting sites (Aatamila et al., 2011; Herr et al., 2003a,b). Aatamila et al. (2011) compared residents living within 1500 m to those living within 3000–5000 m, Herr et al. (2003a) looked at residents in three distance bands, 150–200 m, >200–400 m and >400-500 m, and Herr et al. (2003b)

**Table 2**
Descriptive statistics for the non-repeat respiratory-related hospital admissions and population in 2008–10 by distance band.

| Distance Band | | | | | |
|---|---|---|---|---|---|
| | | 1 (0–250 m) | 2 (>250–750 m) | 3 (>750–1500 m) | 4 (>1500–2500 m) |
| Number of COAs[a] | All COAs in the study area | 4 | 172 | 1114 | 3370 |
| | Completely within a single distance band (sensitivity analysis) | 1 | 26 | 393 | 1704 |
| Hospital Admissions | | | | | |
| Number of hospital admissions | All respiratory | 22 | 1.527 | 8.596 | 24.840 |
| | Respiratory infections only | 17 | 999 | 5.559 | 16.234 |
| | Asthma only | 0 | 129 | 645 | 1859 |
| | COPD only | 2 | 135 | 705 | 1963 |
| Number of hospital admissions by age group (%)[b] | 0–19 years (%) | 6 (27.27) | 557 (36.48) | 2977 (34.63) | 8478 (34.13) |
| | 20–39 years (%) | 4 (18.18) | 194 (12.70) | 1115 (12.97) | 3404 (13.70) |
| | 40–59 years (%) | 5 (22.73) | 212 (13.88) | 1239 (14.41) | 3542 (14.26) |
| | > = 60 years (%) | 7 (31.82) | 564 (36.94) | 3265 (37.98) | 9416 (37.91) |
| Sex[b] | Male (%) | 63.64 | 49.6 | 50.9 | 50.4 |
| Carstairs deprivation quintile (1 = least deprived) at COA level[b,c] | 1 (%) | 31.82 | 15.39 | 1.97 | 17.37 |
| | 2 (%) | 50.00 | 13.03 | 19.80 | 18.57 |
| | 3 (%) | 18.18 | 14.73 | 18.29 | 21.40 |
| | 4 (%) | 0.00 | 22.53 | 21.93 | 20.62 |
| | 5 (%) | 0.00 | 34.32 | 23.01 | 22.04 |
| Population | | | | | |
| Population | Total | 3745 | 172,048 | 1,060,069 | 3,225,041 |
| Number of people by age group (%)[d] | 0–19 years (%) | 906 (24.19) | 42789 (25.79) | 257998 (24.88) | 779550 (24.93) |
| | 20–39 years (%) | 987 (26.36) | 44008 (26.52) | 257245 (24.80) | 788504 (25.21) |
| | 40–59 years (%) | 1087 (29.03) | 44157 (26.61) | 286577 (27.63) | 851539 (27.23) |
| | > = 60 years (%) | 765 (20.43) | 34983 (21.08) | 235308 (22.69) | 707932 (22.64) |
| Sex | Male (%) | 49.45 | 49.45 | 48.85 | 48.87 |
| Carstairs deprivation quintile (1 = least deprived) at COA level[c] | 1 (%) | 25.00 | 20.93 | 21.81 | 21.57 |
| | 2 (%) | 50.00 | 15.12 | 22.26 | 21.07 |
| | 3 (%) | 0.00 | 16.86 | 19.30 | 22.76 |
| | 4 (%) | 0.00 | 17.44 | 18.94 | 18.40 |
| | 5 (%) | 25.00 | 19.65 | 17.68 | 16.20 |
| COA tobacco sales (£/person 16+ years) | Mean (Inter-quartile range) | 6.59 (5.13–8.06) | 8.01 (5.08–11.02) | 7.18 (4.87–9.32) | 7.00 (4.83–8.78) |

[a] Population weighted centroid denotes which distance band the COA is in for COAs which overlap distance bands (Fig. 3).
[b] For all respiratory-related hospital admissions.
[c] Quintiles for Great Britain.
[d] Average over 2008–2010.

**Table 3**
Random intercept Poisson regression model results considering all respiratory-related hospital admissions, respiratory infections, asthma hospital admissions and COPD hospital admissions. 'RR' denotes relative risk and 'CI' denotes Confidence Interval.

| Distance Band (m) | Unadjusted models (n at COA level = 4656) RR (95% CI) | Adjusted for deprivation and smoking proxy confounders (n at COA level = 4580)[a] RR (95% CI) | Sensitivity Analysis on COAS completely within a distance band. Adjusted for deprivation and smoking proxy confounders (n at COA level = 2123)[a] RR (95% CI) |
|---|---|---|---|
| All respiratory-related | | | |
| >250–750 m vs. >1500–2500 m | 1.05 (0.99–1.11) | 1.01 (0.95–1.06) | 0.99 (0.90–1.00) |
| >750–1500 m vs. >1500–2500 m | 1.02 (1.00–1.05) | 1.03 (1.01–1.05) | 0.97 (0.54–1.15) |
| Reference (>1500–2500 m) | 1.00 | 1.00 | 1.00 |
| P for trend | p = 0.01 | p = 0.10 | P = 0.41 |
| Log-transformed distance | 0.97 (0.94–1.00) | 0.98 (0.96–1.00)[b] | 1.08 (0.94–1.24) |
| Respiratory infections | | | |
| >250–750 m vs. >1500–2500 m | 1.01 (0.94–1.08) | 1.02 (0.93–1.07) | 1.03 (0.87–1.22) |
| >750–1500 m vs. >1500–2500 m | 0.98 (0.95–1.01) | 0.97 (0.94–1.01) | 1.00 (0.95–1.05) |
| Reference (>1500–2500 m) | 1.00 | 1.00 | 1.00 |
| P for trend | p = 0.48 | p = 0.42 | p = 0.76 |
| Log-transformed distance | 0.99 (0.96–1.03) | 0.99 (0.95–1.06) | 0.97 (0.91–1.04) |
| Asthma | | | |
| >250–750 m vs. >1500–2500 m | 1.13 (0.94–1.36) | 1.10 (0.91–1.32) | 0.99 (0.85–1.14) |
| >750–1500 m vs. >1500–2500 m | 1.02 (0.92–1.11) | 1.01 (0.91–1.10) | 0.89 (0.48–1.28) |
| Reference (>1500–2500 m) | 1.00 | 1.00 | 1.00 |
| P for trend | p = 0.22 | p = 0.43 | p = 0.57 |
| Log-transformed distance | 0.99 (0.94–1.05) | 0.97 (0.86–1.07) | 1.09 (0.89–1.32) |
| COPD | | | |
| >250–750 m vs. >1500–2500 m | 1.14 (1.00–1.29) | 1.05 (0.99–1.19) | 0.97 (0.93–1.02) |
| >750–1500 m vs. >1500–2500 m | 1.03 (0.97–1.10) | 1.02 (0.96–1.09) | 0.94 (0.82–1.07) |
| Reference (>1500–2500 m) | 1.00 | 1.00 | 1.00 |
| P for trend | 0.04 | 0.32 | 0.20 |
| Log-transformed distance | 0.94 (0.87–1.01) p = 0.08 | 0.97 (0.89–1.03) p = 0.34 | 1.04 (0.98–1.10) p = 0.13 |

[a] Not all confounders were available for all COAs due to differences in 2001 and 2011 Census geographies.
[b] This represents a 2% lower risk for an e- fold (2.71) increase in metres further away from the composting facility, therefore, for example a ((501/251)/2.71) × 2%) = 1.5% lower risk if moving from 251 m to 501 m).

examined residents living within 150–1500 m of a composting facility. There was limited evidence of increased exposure levels at distances greater than 200–300 m in these studies. A fourth study using a symptom diary study did not find significant associations between allergy and asthma symptoms and *A. fumigatus* spore counts in residents living 540 m downwind of a composting site (Browne et al., 2001). Liu et al. (2011), however, completed a lab-based study and found elevated inflammatory markers in human cell cultures when exposed to endotoxin samples taken on-site and up to 600 m downwind of a facility.

Similar to most of the community studies, we used distance as a proxy for bioaerosol exposure. There were not enough people living within 250 m, where measurements show that concentrations of bioaerosol are most likely to exceed the EA's acceptable levels (Deacon et al., 2009; Pankhurst et al., 2011; Pearson et al., 2015; Williams et al., 2013) nor respiratory admissions to reliably investigate respiratory admission risk within the EA 250 m precautionary area exclusion zone. Population characteristics were also different from those in other distance bands, with no COAs classified as deprived (Table 2) raising the likelihood of bias. Our study is a cross-sectional small area (ecological) study without information on individual level exposure and our results, therefore, do not provide quantitative evidence to support or disprove the recommended threshold levels or the 250 m distance band stipulated in the Environment Agency's position statement. We were unable to account for wind direction or buoyancy which has been found to affect peak levels and the frequency of high levels of bioaerosols, and therefore mean COA concentrations of bioaerosols (Herr et al., 2003a; Pankhurst et al., 2011).

There are no established methods to measure or model long-term exposure to bioaerosols from composting sites. Bioaerosols comprise a heterogeneous mixture and components, which may have different dispersion patterns that have not been conclusively established, but are most likely to be of public health concern in a general population living near composting sites. We chose not to assume a predominant wind direction as annual mean direction varies considerably and may be affected to local topography (Lapworth and McGregor, 2008). Similarly we did not account for variations in seasonality, as this study was designed to look at spatial and not temporal variability in respiratory admissions. While a handful of studies have reported that there is some seasonal variation in bioaerosol concentrations with elevations in the summer and winter months (Nielsen et al., 1997; Recer et al., 2001; Schlosser et al., 2009), the evidence base is limited and the relationship between bioaerosol emissions from composting facilities and season is not well understood. Future work is needed to improve exposure estimates. Dispersion models have the potential to estimate bioaerosol exposure temporally and spatially. However dispersion modelling in this field has been limited to date, mainly due to the difficulties in representing emissions in the dispersion model, and a lack of measured data in which to calibrate and validate dispersion models. Further work on improving our confidence in dispersion model outputs is required before dispersion modelling can be routinely used.

### 4.1. Other strengths and limitations of the study

The study included all composting facilities with an outdoor composting component in England, thereby minimising selection bias. Outcome data were objectively collected and independently coded hospital admissions for admissions to National Health Service (NHS) hospitals of which there were a total of 43,291,060

(35.44% (15,341,558) of which emergency admissions) in England in 2008–10 (HSCIC, 2013). These data are quality checked with high coverage rates (HSCIC, 2014). There were 2,326,310 (5.4%) of HES inpatient records in 2008–10 in England that did not have a valid postcode and therefore could not be assigned to a spatial location. Use of objectively collected data is advantageous as it avoids response bias associated with health questionnaires, a significant limitation of previous health studies (Pearson et al., 2015).

Geographical location of sites was carefully determined and verified using Google™ Earth and distance bands were calculated from the perimeter of the outdoor composting areas rather than site address (a point). The exact location of population at risk was difficult to determine as the highest spatial resolution at which age and sex distribution of the population is available in England is the COA level, but we attempted to minimise geographical misclassification by use of the population-weighted centroid for COAs. We also conducted a sensitivity analysis of COAs that were wholly within our pre-determined distance bands from outdoor composting area perimeters.

While outdoor composting area perimeter is of regulatory and therefore public health interest in terms of protection against health risks, active areas within composting sites may change over time and the outdoor composting area perimeter may not be a good proxy for distance from areas with active release of bioaerosols.

We used a cross-sectional small area (ecological) study design, which can be useful in initial assessments and generation of hypotheses; a similar study design was used to assess the risk of adverse birth outcomes in areas near to landfill sites in England (Elliott et al., 2001), where there were uncertainties over exposures and exposure pathways. However, results apply to areas and may not relate to individuals living in those areas with different exposures and susceptibilities. A different study design would be required to examine exposure and health risks at an individual level.

The very small increases in risk seen in our main analyses could be a result of residual confounding (factors associated with living near a composting site as well as with respiratory disease that were not fully adjusted for). While we adjusted for important confounders such as age, sex, area-level deprivation and tobacco sales as a smoking proxy, we did not have information on individual level smoking or co-morbidities. We had information on composting sites operating in 2008–10 and chose a similar timeframe for hospital admissions as we considered short-term and seasonal effects were likely to be most relevant. It was not possible to account for migration in and out of the study area, although this would have been minimised with the relatively short timeframe used.

We did not consider other potential sources of bioaerosols that may contribute to exposure. For example, agricultural activities are known to release bioaerosols in elevated quantities (O'Connor et al., 2013). As composting sites are typically located in rural areas, bioaerosol exposure from composting and intensive agriculture needs to be assessed in future studies. Moreover, other sources of pollution that may cause respiratory health symptoms (for example particulate emissions from diesel car emissions) were not considered.

Hospital admissions represent a severe end of the spectrum of potential health effects of bioaerosol exposures. The community and occupational studies to date are relatively small scale and it is unlikely that severe impacts would have been reliably demonstrated if infrequent. However, there was an opportunity to explore this in this national study with ~35,000 respiratory hospital admissions. Previous community studies have reported minor respiratory health problems (such as coughs, bronchitis etc.) which may not necessarily warrant hospital admission in residents living near composting facilities (Aatamila et al., 2011; Herr et al. 2003a,b; Pearson et al., 2015). The use of primary care data would have allowed us to better investigate more subtle health effects, but these data are currently not available in England at a national level.

## 5. Conclusions

We conducted a national-scale cross-sectional small area study. Results did not show any consistent increased risk in respiratory, respiratory infections, asthma or COPD hospital admissions in those living beyond 250 m of outdoor composting site perimeters in England. While this argues against large increased risks of severe respiratory disease related to large-scale composting in the general population given the current regulatory approach, our study design would not have detected impacts on susceptible individuals, including the immunocompromised. We were not able to investigate risks nearer than 250 m to an outdoor composting area perimeter as the current regulations mean that few people live in this zone.

Recommendations for follow-on research to provide further evidence to inform regulatory approaches include improvements in exposure estimates (for example by using dispersion models or biomarkers of exposure if available), use of individual-level health outcome data relating to symptoms and disease prevalence where available, and consideration of seasonal impacts as bioaerosols concentrations are likely to be lower in the winter (Nielsen et al., 1997)

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Average expenditure on tobacco for 2014 at small area level were provided by CACI© Copyright 1996–2014 CACI Limited. Data were provided to be used solely for academic, personal and/or non-commercial purposes.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijheh.2016.03.004.

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